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**Department Animal Breeding, Nutrition and Laboratory Animal Science**

Effect of nutrition on swine back fat and reproduction in Israeli farms

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**Terms and abbreviations:**

BCS- Body scondition scoring

BF- back fat

BW – Body Weight (Kg)

CP- Crude Protein

E2- Estrogen

EFA- Essential fatty acid

EFS- Electronic feeding system

FA- Fatty acids

FOI - Farrowing Oestrus Interval

Fi- feed intake

FR (farrowing rate)

LH- Luternizing hormone

ME- Metabolized energy

P4- **progesterone**

PBA- piglets born alive

PPMF – pigs produced per mated female

TB (total piglet born)

WOI- Weaning to Oestrus interval

WMI- Weaning to mating interval

WSI- Weaning to service interval

**Abstract:**

Backfat has been verified to be an indicator of the metabolic state of the sow in the body of research in the long established swine growing region of Europe. Accordingly back fat measurement have become an important tool in assessing future reproductive performance of sows undergoing a breeding cycle. This criteria has yet to be utilized or validated in the newly emerging pig farming industry in Israel, which is characterized by unique climatic, regulatory and cultural conditions. Currently, the primary tool for assessing insemination timing and body condition is based on visual scoring.

This study reviewed the worldwide literature and examined the country specific connection between nutrition, as reflected in back fat levels, and reproductive efficiency in Israel. The back fat levels of 60 Large White x Landrace sows and gilts in three Israeli swine breeding farms were recorded over the reproductive cycle at insemination, farrowing and weaning. Sows were weighed at farrowing and at weaning. The litter size, PBA and total weaned piglets per sow per reproductive cycle were recorded as well to evaluate their reproductive performance. The husbandry conditions and human factor were assessed, including proper feeding, protection from environmental changes, size and composition of in group (age) and the keeping systems.

Results showed that, contrary to our expectations, the negative correlation between back fat loss during lactation to WOI (Weaning Oestrus Interval) was neither consistent nor powerful in all groups and swine breeding farms, indicating lack of robustness of this criteria for the variant conditions under which sows are grown in the emerging Israeli swine industry. In contrast, the back fat at weaning was strongly and negatively correlated with the WOI in all farms and groups. Visual body scoring, in contrast, was not consistently negatively correlated with WOI in all groups and was less powerfully correlated than back fat levels at weaning in all grous and farms.

Our results indicate a direct connection between back fat levels and return of estrus and fertility. These results showed that the back fat ultrasound measurement method commonly used in the pig farming industry in Europe provides a much more accurate assessment of future reproductive success and body scoring than the currently used methods in Israel.

**Introduction:**

The primary aim of this study was to determine the correlation of back fat level in sows with reproductive efficiency in three separate commercial swine herds in Israel. The correlation visual body scoring of body condition, with reproductive efficiency and back fat measurements in these swine herds was also assessed in order to determine the extent to which visual body scoring was correlated with the back fat level. The reproductive efficiency is described as the amount of piglets weaned per sow per year.

Maintaining optimal body condition of sows is a prerequisite for achieving adequate fat and meat production levels in pig herds. Better understanding the role different factors play in sow reproductive efficiency is dependent, and selection of the proper criteria to asses them under specific conditions such as those present in the Israeli swine industry, is required to reduce swine rearing costs and increase profit, improve swine welfare, litter size and farrowing rate, and expand the scope of the swine industry to new regions in the world.

· In this thesis I will first provide an overview of the parameters according to which sow reproductive efficiency is assessed. I will then review the various factors impacting these parameters, grouped according to four categories; Husbandry and Management, Innate (including genotype), Nutrition, and Environmental (Soede & Kemp, 2013); their role in reproductive efficiency and their impact as a limiting facto of it as expressed in change in body condition and back fat level.

I will then address the unique conditions and practices under which the swine farming industry operates in Israel, in which the swine industry is still developing and extremely limited due to historical, cultural, climate (semiarid conditions) conditions and a regulatory environment informed by religious law (Jewish and Muslim) against consumption of swine flesh. Briefly, the small Israeli swine farming industry contains no more than 120,000 swine of which 15000 are breeding sows (Israeli Ministry of Agriculture & Rural Development). It is primarily located in the northern part of Israel which closest approached the Mediterranean climate of parts of Southern Europe (though still more warm and arid), though an experimental farm used for growing pigs for research and medical purposes, which was included in this study is located in Kibbuz Lahav, in the southern, desert region of the country. The only breeds grown in Israel are a crossbreed of Landrace and Large white, which are the local breeds (Lean genotype).

The reason for this is an adverse regulatory environment which includes a religious law inspired prohibition on the importation of living swine which poses a problem to restocking with other breeds and improving the genetic variability of existing swine herds.

I will then describe the swine breeding farms in which this study took place the, study herds, the methods used to assess the backfat and reproductive efficiency parameters of the study herds, the results of the study and their significance.

**Goals:**

The primary goal of this study is to determine the correlation between back fat level in the unique Israeli environment and the reproductive efficiency of sows grown in this environment. Specific goals include:

1. Do backfat levels measured by the researcher predict reproductive efficiency as well as body score condition (BCS) used in in the Israeli swine industry?
2. How do the local semiarid conditions and the means used to alleviate them impact reproductive efficiency?
3. Do the husbandry management practices in the different farms investigated such as pen size, keeping, feeding method have an impact on reproductive performance compatible with findings from long established swine industries in temperate climate conditions.

**Review of literature**

**Reproductive efficiency terms and backfat**

**Backfat:**

Backfat is composed of lipids (fatty acids), water and collagen. The concentration of the FA (fatty acids) in the Backfat reflects the nutritional quality, as defined by the energy content, of the swine feeding regime. The measurement of back fat level is a more objective and precise method to assess the actual BCS of sow than visually (Charette et al 1996) as it reflects the total fat content of the sow (Mullan and Williams 1990), which is in turn a reflection of the Fi (Feed intake) and energy content of the feed. It can therefore be used as a tool to asses whether the feeding technique is adequate. Aside from reflecting the nutritional state, backfat measurement can also be used to predict a number of reproductive performances traits as puberty attainment, TB (total piglet born per litter) and FR(farrowing rate) and, in welfare, for assessing overfed and underfed sows (Barnett et al 2001). The amount of backfat is regulated by nutrition, and the physiological state of the sow. lactation results in mobilization of fat and protein reserves in the backfat to meet the nutritional demands of lactation (Shields et al, 1985). If mobilization of backfat reserves is too high the result will be a lower litter size and a higher incident of anestrus (Clowes et al, 2003).

A study of correlation between back fat and reproductive traits (Maes et al 2004) carried out in 730 gilts divided into 3 groups indicated that the body condition score can be calculated based on back fat and body weight using the following formula to predict the total lipid qty :

Li(lipid) kg= 0.381\*bwt (kg) + 0.042 backfat (mm) – 31.099 with R2= 90%,

In sow showing estrus in 10 D the qty of live piglets/cycle was calculated by a regression equation= 11.92 + 2.17\* (% ∆back fat (mm) during lactation) + 0.36\* (parity group)

The visual body condition score comparing to P2 (back fat measurement) overall correlation was moderate –0.48 which is slightly higher found in other studies (Esbenshade 1986- correlation coefficient =0.3) (Maes 2004)

∆in back fat:

in herd A+C where an extra feed was given there was a + correlation, while in herd B was a (-) correlation:

this proves that in the 2nd half of gestation there is an increase in energy requirement ≈ fetus growth (Aherne & Kirkwood 1985)

During lactation – back fat levels decreased (most pronounced in herd B ≈-20.3%)

Weaning – the highest ∆back fat levels

**Association between back fat levels during lactation and reproductive efficiency:**

Qty pigs weaned/ sow and lactation back fat loss – shows a positive association, since more E is needed of milk production in larger litter sizes (Aherne et al 1999)

Lactating sows with a higher back fat loss tend to have a decrease in reproductive efficiency the results were not significant enough to state a direct connection (P>0.05) this is probably because changes in back fat during lactation were too subtle to have an effect of reproductive performance (Esbenshade 1986)

 ***Backfat Hormones***

Backfat is a significant source of hormones related to reproduction performance such as leptin, IGF-1 and P4 which are the metabolic hormones responsible for puberty, estrus and pregnancy maintenance (P4 especially for the latter).

*Leptin***:**

Leptin is a protein hormone which plays an important role in puberty onset (Qian et al, 1999) prior to an increase of LH secretion (Barb et al, 2001) and the serum [leptin] has a positive correlation with back fat level (mm) (Rensis et al, 2005). Furthermore, Leptin serum and milk concentration in the lactating sow has a positive correlation with backfat thickness and energy feeding level during gestation (Estienne 2003).

Activation of a catabolic process (lactation) by change in weight or nutritional status causes a change in Leptin secretion (Barb et al 20001a).Leptin level in the blood is correlated with energy balance level. In other words a negative energy balance is reflected in a lower leptin concentration in the blood. This results in a negative effect on LH secretion which results in a negative effect on reproduction as well an increases Fi and weight gain (Whisnant & Harrell 2002)

During lactation there is a positive correlation between increase feed intake and [leptin] and a greater LH pulse frequency prior to weaning and a shorter FOI (farrowing Oestrusinterval ) (Koketsu et al 1998)

*IGF-1:*

Plays an important role in puberty onset in gilts. Its expression is positively correlated with back fat thickness (Te Pas et al, 2004) and with early onset of puberty (in under 153 days) (Patterson et al 2010)

During the early lactation period, IGF-1 has a positive effect on LH pulse frequency and a shorter WOI (Whitley et al 1998)

*P4- progesterone:*

P4 has a role in maintaining pregnancy – its levels are high during the pregnancy and drop before farrowing (Barb et al, 2002). Its levels are influenced by feeding regime during pregnancy, which inhibits the LH pulse and decreases dramatically towards farrowing. A high feed regime reduces the progesterone level in gilts and results in a higher pregnancy rate (HELSINKI, 2005),

In gilts there is a strong correlation between P4 levels in the plasma and in the back fat (1:200 ratio) (Hillbrand & Elsaesser 1983)

**WOI – Weaning to Oestrus Interval:**

WOI is the interval between the last day of weaning and the first day in which the sow displays signs of standing heat. This is an important parameter for evaluating reproductive productivity.

WOI is influenced by a number of factors including Lactation length (Poleze 2006), lactation weight loss (Thaker and Bilkei 2005), parity number andlitter size (Eliasson 2000), season (Pruneir 1996), nutrition (Whittemore 1996) and genetics (Rydhmer 2000).

A normal WOI is usually under 7 days. According to Kostesu et al (Koketsu et al , 2005) sows in which the WOI exceeds 7 days display a lower reproductive performance. Sows which present a high lactation weight loss display a longer WOI and a lower conception rate in the next cycle (Eliasson 2000)

**Parameters effecting reproductive efficiency**

**Husbandry and farm management parameters:**

***Light intensity and length:***

Lighting has a direct effect on swine physiological and mental state (), has and also plays a role in regulation of melatonin secretion (Love et al, 1993), Melatonin is of particular importance in maintaining a desirable reproductive cycle, as it affects hormonal levels such as P4 (progesterone) and LH (luteinizing hormone) which are essential for a cycling sow.Melatonin is produced by the pineal gland during dark hours. A high concentration has a negative effect on LH and GnRH release resulting in a lower farrowing rate (Love et al 1993)

***Gas level***

The maximum levels of gas in swine housing in Israel is defined as follows:

 NH3- 10 ppm; CO2- 3000 ppm; H2S- 2.5 ppm

Gas concentrations above these limits in the swine housing have a negative effect on its health and reproduction, including delayed puberty in gilts (Malayer et al,1987)

***Housing systems:***

There are a two main approaches to swine housing systems. The first is the free range (all in all out) in which the social composition of the herd is fixed and the members of the group are kept in a relatively spacious yard exposed to environmental conditions. When swine are kept outdoors common practice in developed swine industry is to detect ovulation is by assaying for the P4 metabolite excreted in feces (Razdan 2004). In Israel however, Estrus detection is carried out based solely on visual physiological and behavioral signs of estrus (Sterning , 1995, Elasson, 2000). Such signs include interaction between sows within the group and with the teaser boar, (Sterning et al, 1990).

The second approach is the group housing system in the group is kept in a penned perimeter, not exposed to climate changes or direct sunlight, and where the social composition of the group undergoes managed change depending on the husbandry preferences of the operation, meant to minimize the WOI (Weaning to Oestrus interval) of serviced sows. The stress associated with group housing performed during Artificial Insemination (AI) and gestation (Kongsted 2004) is associated with the return to estrus during lactation time (Byrnat, Petherick 1983) and the mixing of gestating gilts and sows that have yet to return to estrus (during lactation) creates social stress caused by aggressive behavior of the sows towards the gilts. This has the effect of increasing the rate of estrus return in the sows and the reducing the WOI (Weaning to Oestrus interval) by 4-5 days (Sterning et al 1990), although this practice reduces the total number of weaned piglets/litter in the early estrus sows (McGlone, 2004) The stress of the gilts in the WSI (weaning to service interval) of the sows can be ablated by providing deep litter (straw bedding) with individual feeding in feeding stalls.

When newly weaned sows are moved to a breeding area containing other sows the adaptation period to the group and dominance expressing behavior lasts only a day or two. On the other hand, when gilts are moved to a breeding area containing sows the dominance expressing behavior and conflict can last up to a month. The extended space required to avoid prolonged fighting under those conditions can lead to suppression of estrus signs.

The need to balance the goal of returning lactating sows to estrus rapidly (via mixing with gestating gilt population) with preventing return to estrus of gestating gilts under the stressful conditions of this mixed population requires early detection of estrus signs in both populations, as well as knowledge and skill in applying techniques aimed at minimizing risk factors (see below under stress section)

*Typical Failures in group housing systems*

It is crucial that sows who have a negative energy balance during their lactation period reach a positive energy balance before AI and during the first 3 weeks of pregnancy in order to carry to term.

 Achieving this target is dependent on sufficient feed intake – as food deprivation of even 1 day out of a 13 day feeding period has been shown to result in delayed embryo development and a lower P4 concentration (Razdan et al 2004). Furthermore, sows which spent less time feeding had a lower farrowing rate and litter size (Kongsted et al, 2006)

A solution for this is an ad libitum (non restricted) diet of fermentable non starch polysaccharides which increases the back fat and body weight during gestation. However, since the diet is fermentable non starch it has no negative effect on the Feed Intake (Fi) of the lactation and reproductive performance (Van der Peet-Schwering 2004). Performance and individual feed intake characteristics of group-housed sows fed a non-starch polysaccharides diet ad libitum during gestation over three parities (litters brought to term).

**Parity (litter cycle #) in relation to farm management:**

The parity (litter cycle # carried to term by the sow) effects the diet and other management variables appropriate for the sow population and individual.

1st parity (gilts)- have a feed intake level that is lower by 20% than other parities. Therefore, they require a higher concentration of nutrients including a 1.3% lysine diet (48.8 g/day) (0.2% higher than later parities) in their lactation diet in order to counterbalance their lower intake and minimize nitrogen loss (Touchette 1998).

Multiparous sows with a parity greater than 5 have a shorter WOI when grown in free range housing (Hultén 1995);

**Heat management**

Since pigs are not capable of either sweating or shivering, they are particularly sensitive to high and low temperature conditions (Ingram 1965). Any change in temperature leads to a decreased feed intake, milk production and as a result a lower piglet weaned per litter (Vidal et al 1991). Means of minimizing heat stress include:

i.) **Sprinklers**

Using water to moisten the skin is one way to release heat stress, thus reducing sow weight loss by 2/3 and improving litter weight gain, leading to improved reproductive traits (McGlone et al 1988)

ii.) **Appropriate shelter from sun exposure**

Shelters to prevent exposure to the sun are used in order to prevent heat stress, especially during farrowing (McGlone, 1987)

iii.) **Adjusting diet:**

Diets are adjusted to a high fat feed intake in order to increase energy density in order to compensate for lower feed intake (Schoenherr et al, 1989 a,b).

iv.) **Hormonal approach:**

Gonadotropins (PG600) and progestens (Regumate) are also used in order to deal with heat stress. PG600 is injected at weaning in order to stimulate follicular growth and reduce occurrence of anestrus. Regumate, on the other hand, is used in cycling gilts of estrus synchronization of lactating sow estrus synchronization by eCG.

· **Stress**

Chronic stress results in elevated cortisol levels in the blood which disturbs proper ovulation by reduced P4 (progesterone) and E2 (Estrogen) (Pedersen et al 1993)

During pregnancy, the most sensitive days are the first 2-4 weeks. since the maternal recognition occurs around day 11-16, and so grouping should be done within the first 2 post farrowing (Kirkwood et al, 2005.).

Gilts should be housed separately from older sows in group housing systems with floor feeding, due to their submissive behavior in relation to the older sows in mixed groups. When housed in EFS (electronic feeding system) housing they have been observed only approaching the feeding station once a day, due to competition and dominance by older sows (Csermely et al, 1989, Var Schwering 2003). This lower feeding incidence of Gilts housed together with sows has been shown to result in lower back fat gain. (Soede, et al 2006).)

Aggressiveness is an additional problem in mixed grouping (Turner et al 2001.) which results in a lower Fi, and an increase in return to estrus rate. When unfamiliar sows of similar ages are mixed together this results in fights for dominance which last for 1-2 days (Spoolder, et al,1996, Moore et al, 1993) . However,if new gilts are introduced into a large dynamic sow groups, integration time is a minimum of one month (Spoolder et al, 1998a.). Straw bedding has been found to have a positive effect in reducing aggressive and stereotypic behavior as a "thermal and physical comfort during sleeping and rest periods” ( Barnett et al, 2001)

The aggressiveness resulting from joining gilts to a group of sows can be reduced by permitting gilts a restricted contact with the group for 5 days before the introduction to the group. This provides the gilts a familiarity with the new group and exposure to the sows. Another approach is to expose breeding gilts in a 3 weekly interval to sows in a large outdoor run. This has been shown to result in less aggressive interactions, and submissive behavior of gilts when engaging with a dominant sow (.Van Putten et al 1997)

An additional method to reduce aggression and stress after mixing is to add a boar to the sow and gilt mix. In addition to reducing aggression, this has also been found to increases the litter size.( Kirkwood and Zanella, 2005.)

**Innate variables:**

**Genotype:**

The field of sow breeding recognizes 2 basic genotypes categories:

The Industrial (H) genotype requires a higher protein level but lower DE (Digestible energy) intake. It is characterized by later puberty onset.

The lean (L) genotype, in contrast, requires a high DE (digestible energy), mineral and vitamins but lower protein level. It is favored for its more rapid growth, heavier weight at puberty and younger age of insemination compared to the industrial genotype. Examples of the lean genotype include the Landrance, Large-White, Pietrain and various crossed breeds deriving from them which are common in Israel.

During lactation the voluntary Fi of the lean genotype is lower than that of the industrial genotype, resulting in greater body weight loss during lactation as opposed to higher weight gain during gestation.

The industrial genotype have a higher backfat thickness and bodyweight in comparison to the lean genotype, but in each farrowing the gap between them narrows, as the lean genotpe grows in both parameters while the industrial genotype stays relatively constant. During the pregnancy the average Fi is equal – in average 3.5 kg/d, which leads to greater weight gain in gestation in the lean genotype.

**Parity**

Parity 1 sows (gilts) have a lower reproductive performance than later parity sows. Reproductive performance (litter size and PBA) increases until peaking at parity 3-5 before declining as parity is associated with growth of the sow and the development of the reproductive system (Engblom et al 2007). Reproductive performance in the 1st litter sow will predict its productivity in life (Engblom et al 2007)

In 1st and 2nd parity the litters are most homogenous and small (Quesnel et al, 2008) while peaking in the 3rd, followed by a small decrease in the 4th and 5th parity (Knecht, 2015)

Lactation feed intake increases with parity ( Young et al, 2004), making back fat loss highest at the lower parities, particularly the first where feed intake is 20% smaller than parity 3 (Young et al, 2004)

Inaddition to litter size the sow’s body weight also increases between parity 1-3 (i.e. maternal growth) – there is an increase in protein and AA requirement all through gestation, the sow body weight stabilizes after the 4th parity.

**Second litter syndrome:**

Second parity sows may have suboptimal farrowing rate and litter size, due to high weight losses during first lactation. Sows with low reproductive performance in their second parity also tend to show a lower performance in later parities and are subject to greater risks of early culling. To overcome this reduced second parity reproductive performance, feed intake during first lactation needs to be improved. post-weaning management strategies can also influence second parity performance. Improved recovery prior to insemination can be achieved by

i.) prevention by early intervention (gilt management), at lactation – **nutritional approach:** ad libitum water and gradual increase of Fi.

ii.) Longer WOI by skipping a breeding cycle for catabolism to recover by using Altrenogest treatment (Leeuwen 2011) for < 8 days if follicle development in compromised or longer (<2 weeks post weaning).

iii.) Compensation in the next pregnancy – by + bwt recovery in first 1st month of pregnancy by increasing Fi (Hoving 2012)

**Environmental factors**

**Seasonality and photoperiod:**

In seasonal breeders, such as the European wild sow, the changing photoperiod regulates the reproduction mechanism, through variations in melatonin secretion by the pineal gland. The melatonin profile of domestic sow is also influencing by season and Peltoniemi et al. (Peltoniemi, 1999) concluded that the photoperiod is the primary environmental factor influencing Sow’s lower reproductive performance in summer. In other temperate climates and in climatic chambers, the combined effects of the ambient temperature and photoperiod contribute to the reproductive performance of the sow (Prunier et al., 1996). The characteristics of tropical humid climate differ from temperate climates, particularly in regards to low changes in photoperiod and high variations in ambient temperature and relative humidity between seasons (Berbigier, 1988). However, knowledge about the effect of Arid and Semi-Arid climatic conditions on melatonin secretion have yet to be investigated in relation to swine reproduction.

**Temperature**

High temperatures and long photoperiod exposure causes reduced gonadotropin release which damages ovarian growth and resulting in low testosterone. Low parity sows are especially sensitive to warm outdoor climate

 **Nutrition**

 Amino acids (AA)**:**

AA are a limiting nutritional factor and the requirement for lysine (Samuel et al 2010), threonine (Levesque et al, 2011), isoleucine and tryptophan (Moehn et al, 2012) increases dramatically following the transition from the early (maternal and maintenance) to the late (fetal growth) phase of the Gestation. The requirements change (and generally decrease over parities (table 1)

**AA requirements during gestation**

|  |  |  |
| --- | --- | --- |
|  | Early gestation | Late gestation |
| Parity | 1st | 2nd | 3rd | 1st | 2nd | 3rd |
| Lysine gr/day | 0.83 | 0.6 |   | 1 | 0.84 | 0.54 |
| Threonine gr/day  |   | 0.32 |   |   | 0.62 | 0.51 |
| Tryptophan gr/day  |   | 0.08 |   |   | 0.12 |   |
| Isoleucine gr/ day |   |   | 0.15 |   |   | 0.4 |
| Fi- corn soybean meal (Kg/day) | 1.8 | 2.2  | 2.4  | 2.4 | 2.7  | 2.8  |

***Table 1-AA requirements in different parities in early and late gestation (***Srichana 2006, ***Levesque 2010, Levesque 2011, Samuel 2010, Samuel 2008, Moehn 2011).***

**Feedstuff and AA:**

Feedstuff composition is aimed at achieving high true illeal digestibility. Corn has a high Lysine and Threonine availability (Stein 2001) but barley has higher threonine availability than corn (Levesque 2011). Soybean meal, with 48% CP (crude protein) is high in lysine and threonine, and combining it with corn is ideal for 1st parity gilt for which the limiting AA is lysine, unlike older sows in which the limiting AA is threonine.

A high AA diet generally contains protein feedstuff such as soybean/ canola meal. A low AA diet. Alow AA diet generally contains barley with miniral and vitamin supplements. In the last month of gestation gilts generally receive an additional 0.6 kg/day of corn and soybean meal, 2nd parity sows receive an additional 0.5 kg/day, and older sows receive 0.4kg/day. Gilts in the early stage of gestation (D0-D77) also receive and additional 250 gr CP/ day and 400 gr CP/ day in D98-D114 (Arc, 1981)

**Mineral and vitamin requirements:**

Deficiency in trace elements and vitamins can results in undesirable outcomes in the progeny. Such deficiencies include:

**Zn deficiency –**decreases birth weight and litter size when lacking in pregnant sows

**Manganese deficiency –** low levels of sexual hormones

**Iodine deficiency –** during gestation results in goiter, a mild deficiency leads to longer pregnancy time and leads to farrowing of weak piglets. **Prevention by adding 0.17 mg/kg feed of iodine**

**Ca + P balance deficiency-** may be caused by excretion in lactation. Ca deficiency may lead to decreased milk production**.**

**Vitamins supplements for lactating sows:**

Vitamin A- about 7000 IU / day/sow, is increased by high nitrate/nitrite. Deficiency during gestation produces dead piglets (Fekete , 2008).

Vitamin E supplement at 5.3 g/day/sow, **> 4000 IU/kg air dry feed** deficiency results in MMA syndrome (Fekete , 2008)

**EFA (essential fatty acids)-**

Linoleic acid- >0.1% in air fry feed.

Riboflavin – 16 mg/sow

**Energy balance and feeding regime during gestation:**

There is a reduction in energy balance during the transition between early and late gestation. , i.e. lipid loss in general occurs at late gestation and back fat loss in particular in 2nd and 1st parities (Samuel 2007, Mcmillan 2003, Noblet , 1985). During the late period of 2nd and 1st parity gestations, there is an increase of heat production and a negative energy balance (Samuel 2007), but multiparous (>2nd parity) sows tend to retain a positive energy balance (Ramonet 2000). Maintainence of a feed restricted regime during gestation for gilts is important in order to reduce the weight and back fat gain during gestation as it has been established that excessive gain during gestation leads to reduced feed intake and greater back fat loss during lactation, and a resulting increase in the WOI (Weaning to Oestrus Interval) (Whittemore 1996)

NutriLower protein and DE (digestible energy) %

digestible lysine g/kg but if at end of pregnancy ≈ average litter weight, if low à increase to 16 g/kg

· Weaning:

Depending on days of lactation:

if 28 days – NE = 14,500 kcal/day + digestible lysine 55 g /day

if 21 days: NE= 12900 kcal/day + digestible lysine 49 g/days

**Energy balance and feeding regime during lactation:**

There is a distinct connection between reduced feed intake during lactation and extended weaning to oestrous interval and anoestrus (king and Dunkin 1986) as well as decrease in pregnancy rate (Kirkwood 1990) Gilts with a low energy and protein intake will also undergo an elongated period until showing oestrus by the high negative nitrogen balance (king 1987)

**Flushing**

In order to increase the rate of conception, the gilts/sows are flushed with a high energy diet feed mix preparatory to AI.

**Feeding levels:**

The goals when designing a feeding regime is to prepare sows for proper BCS (Body condition scoring) before farrowing, maximizing farrowing carried to term and litter size, while meeting daily nutrition requirements. Overfeeding gestating sows may result in impaired mammary development, and reduced Fi during lactation. Low feed intake during lactation at parity 1 results in poor reproductive performance at parity 2

Feeding levels – 2.3-2.5 kg/day of gestation diet with a caloric content of 3.1 Mcal ME (metabolizable energy)/kg or 2.18-2.35 kg diet/day with a caloric content of 3.3 Mcal ME/kg if corn soy diet is used (Levesque et al. 2011).

Excessive feed intake has an effect at Day 0-2 post AI and at day 75-90 of gestation in gilts- overfeeding risks fat deposition in mammary gland and reduced milk production (Hurley, 2006 ).

Feeding levels should result in a proper ratio of back fat / body weight– by week 7 post mating, it is possible to asses if this goal has been met. If not – a daily increase of 0.9 kg/day until day 100 of gestation is required. 2.5% mixed animal fat added to the feed 3 weeks before farrowing and during the 28th days of lactation increased the PBA (Pigs born alive) and total weaned piglets (Fekete & Makai 1989).

**Feedstuff:**

Feed at lactation time must have a high energy (ME) and protein level (AA-lysine) in order to ensure a proper production of milk- An important effect of a high energy and high AA (lysine) level in the feed is its positive effect on LH release (Zak et al 1997, Jones and Stanly 1999). High energy and protein (lysine) intake in 1st parity sows ensures a better follicle quality after weaning (Clowes 2003) as well restricting feed intake results in a lower ovulation rate (Zak 1997).

**Energy intake – high E intake ≈ high feed intake**

When reduced feed is implemented, supplementing the diet with high fat level>5% will compensate for the low Fi. This results in a high fat milk production instead as utilization of the feed as an energy source. Using high dietary fat during lactation will improve litter weaning weight but will reduce the number of LH peaks in early lactation (Soede 1995).

Feeding level before farrowing should be a minimum of 1.8 kg /day, and sows should not be deprived from feed until just before the farrowing day in order to avoid oral ulcers.

· **Oxidative stress:**

Oxidative stress is a state linked with pregnancy complications in highly prolific sows and is very common in lean genotype breeds.

Oxidative stress is a frequent disorder during the gestational period (Jauniaux 2006).It is caused by the increased metabolic burden on sow at late gestation and lactation periods which in turn causes an elevated systemic oxidative stress via a low availability of antioxidants at those periods. Reproductive performance changes during gestation and lactation are usually a predisposing factor for a clinical presentation of oxidative stress (Mateo et al 2009, Kim et al 2009).

Profiling of the antioxidant concentrations at beginning vs the end of gestation, and at beginning vs end of lactation in sows fed with according to theNRC requirements and assaying blood at gestation days 30,60,90,110 and lactation days 3,5,10,18 revealed that Isolation and analysis of lymphocytes via an HPLC system and UV reveled substantial damage to lymphocyte DNA from mid gestation onwards, deteriorating towards farrowing and only recovering at the end of the lactation period. No significant differences between the productive periods most likely by high rate of basal DNA damage. The plasma levels of retinol (carotenoids) and α- tocopherol decreased from day 30 of gestation with the lowest level at end of gestation only increasing back to the beginning gestation level at end of lactation (day 18) (Ronchi et al 2011).

Gestation is characterized by placental production of reactive O2 species (Casanueva and Viteri, 2003) a high free radical level results in lipid and protein oxidation (Serdar 2003) which may damage the fetus ( Prater 2008). This implies a high metabolic demand during gestation, rising as farrowing approaches, in which the [α-tocopherol] was the lowest which contradicts with the fact that the highest supply of it in gestational diet feeding. This may be by a rapid transfer of α-tocopherol between the sow and piglet.

The use of antioxidant agents in feed is supposed to suppress free radical formation such as fat soluble antioxidant carotenoids and tochopherol as well as leutin present in the feed provided in gestational and lactation diets. (Zhao et al, 2006).

Vitamin E serves as an antioxidant and its concentration is directly correlated with feeding of gestational demands according to the Vitamin E diet composition (Pinelli Saavedra 2003).However, during gestation a high energy demand and increased O2 levels favor a high production of reactive O2 species (Reyes 2006).

The elevated oxidative DNA damage begins during gestation and lasts during the lactation and weaning period. This may be a result of a high metabolic demand during gestation which causes an adverse effect on the placenta (Mueller et al 2005) which is normally an antioxidant enzyme source, but results in high level production of O2 radicals induced by the placenta.

Gestation diets therefore contains a high content of antioxidants and supplement of alpha- tocopherol. During oxidative stress the blood concentration of tocopherol and retinol decreases towards the end of gestation, requiring supplements of Vitamin E,C and Se that fulfill both an antioxidant function and are beneficial for the sow immune response (Wuryastuti 1993) .

· **Feed toxins and reproduction failure:**

Alfatoxins produced by molds which usually appear in feed grains stored in high moisture level- inducing an abnormal estrus signs resulting in anestrus and conception failure in post weaning sows and abortion in pregnant sow

**General information regarding Israel:**

**Pens:**

Under Israel animal welfare regulations, the restraint time for sows is compatible with EU regulation, limited for after farrowing and during lactation and for a **maximum period of two weeks**.

**Free range keeping-**

Starting on the 14th day after farrowing, lactating sows are kept loose in a yard. The rationale for this is that restraint is as a tool to prevent piglets being crushed by the sow and crushing is mainly concentrated in the first 1-3 days after farrowing, primarily under conditions in which piglets cannot find a sufficiently warm resting area. The increased risk of crushing in a cold environmental situation may stem from weakening of the piglets by the cool temperatures in the pen; furthermore, piglet which spend almost all their time at the sow’s teat for warmth are more likely to be crushed.

**Temperature**

Specific provisions for piglets: minimal temperature of 25°C in the resting area of the piglets in the farrowing pen during the entire lactation period. The rationale is to reduce the propensity of piglets to seek the sow as a source of heat, and in so doing reduce the risk of crushing by the sow.

**Materials and methods:**

**Study herds:**

This study was carried out in 3 swine farms in Israel. The toal number of sows investigated was 75 ,divided into the following groups:.

In each farm I chose 25 sows in total: 15 gilts (primiparous farrowing) and 10 sows (multiparous). Data was collected from AI through farrowing to a follow up of the sows until the next Insemination cycle.

**Housing conditions:**

**Farm 1 (unnamed)-**

A small scale farm holding no more than 250 swines located in the northern galilee portion of Israel, near the Israeli-Arab village of Evlayim. Gilts and sows were kept together in groups ranging between 15-20 sows per pen, with no attempt at differentiation based on age or body weight. The housing was partially ventilated in order to minimize the accumulation of ammonia, CO2 H2S, etc and partially for protection from climatic conditions. There was no limitation or control over the Fi consumption of the sows.

**Farm 2 (Mania):**

A larger scale farm housing 1500 swine, also located in the northern galilee portion of Israel, near the Israeli-Arab village of Evlayim. Gilts and sows were kept in different buildings, each building divided into different floors which housed a different stage in the reproductive cycle. These floors included:

**Early Gestation phase**- 1st month of gestation

**Mid gestation phase**- day 30-90

**Late gestation phase**- day 90-110/115

**Farrowing crates**- providing the farrowing sows a controlled stress free environment with straw flooring

**Lactation stage 1** – first 10 days

**Lactation stage 2**- days 10-28

10-15 sows of similar age (to reduce stress caused by mixing new sows/gilts) were grown in each pen. Feeding facilities were constructed to ensure free access to feed by sows/gilts so that all have an similar feed intake with minimal aggression.

**Lighting and T** (C0)-

During the gestation and mid-late lactation period the sows were grown at 25-27 C0 and 150 lux for 16 hours/day

Forrowing swines were kept in pens whose area was a minimum of 1 meter with a min temperature of 25 Co, and a heating lamp providing additional heating to the piglets.

Sows at 1 week post weaning were kept at a minimum of 24Co

**Farm 3: (requested to remain anonymous)**

A large scale experimental farm located in southern Negev area of Israel (desert climate).

Holds about a thousand swine of which 300 are multiparous sows and 200 are gilts. Sows and gilts are housed in different housing according to reproductive state (lactation, gestation, growers, ect.) in such a manner that each house (divided into sections) supplies the ideal conditions for each stage of production- space for each sow, Temperature, water and feed supply regulated by a computer system (ESF- electronic feed system).

In this farm the husbandry practices are by far the best of the 3 farms. The sows are provided with a relatively free range keeping complying with the EU regulations and recommendations during gestation and close to farrowing time to reduce stress which may lead to abortions and other unwanted complications.

**The housing systems:**

· *gestation* – free range keeping, concrete slotted flooring with hay bedding to reduce incidence of lameness – gilts kept together in same groups composition from 1st selection, while sows have mixed cycles. Temperature and humidity (20 C0) are controlled by use of fans and sprinklers.

· Pre- farrowing (5 days prior to farrowing time) – 3 days post *farrowing*:

A quiet stress free environment with minimum human intervention. Daylight imitating illumination. Water intake is increased to 25 Liters/day until day 3 post farrowing.

*· Lactation period -*

Sufficient area with straw bedding for resting, heating lamp for piglets. From day 7 onwards - semi free range keeping in yard for sows.

· AI- a minimum of 1.4 meters/sow in the AI crate where sows are transferred after detecting estrus

*Grouping system:*

- Sows: divided into 2 according to BCS- thin and ideal

-Gilts- separate group

Each group received a teasing boar/

Insemination was performed twice in case of normal estrus and three times in case of a long estrus.

Grouping was according to age and avoided introduction of new individuals before farrowing and in the first 60 days of gestation, so as to reduce stress and aggression.

· *Experimental cooling system via mattress under over HCT (high critical temperature):*

The HCT mattress cooling system was used in an experimental building in which lactating sows are kept, due to the high losses to malignant hyperthermia in the summer preceding this study, an aired mattress was placed in which water was supplied, via the fanning system. The temperature was thereby regulated to a level in which the milk production, average backfat and Body weight loss was kept to a minimum, and kept the feed intake level from decreasing.

**2.)** **Measurement of P2 (backfat):**

**P2 – backfat measurement:**

Backfat was measured by means of an ultrasonic probe- the most precise and accurate method (Magowan and Mccan 2006). an abdominal transducer ultrasound was placed at the P2 position and operated in the ‘A’ mode, 6-8 cm away from midline of the body at the last rib, measured at the 2 ends of the rib (6-8 cm gap) and calculating an average.

Backfat was measured via– last rib 65 mm from the center line of the back.

Backfat was measured in gilts and sows at the day of insemination (day 0), day of farrowing (day 110-114) , beginning of lactation ( Day 0), day of weaning (Day 28) and at 5-7 day post weaning (Day 0 of insemination).

Sow backfat thickness at 10th rib, 6.5 cm from one side of the backbone was measured at the beginning of gestation ,end of gestation, after farrowing (d 0 of lactation), and at weaning (d 28 of lactation) by using an di-medical imaging ultrasound (Loveland, CO). Changes in backfat thickness of sows and gilts during lactation were measured by calculating the difference between backfat thicknesses at d 0 of lactation and backfat thickness at weaning.

**Sow parity categories**

Sows were classified into 6 groups according to their parity and farm

Farm 1

10 gilts (parity 1)

10 sows (parity 2 and above)

Farm 2

10 gilts (parity 1)

10 sows (parity 2 and above)

Farm 3

10 gilts (parity 1)

10 sows (parity 2 and above)

**3.)** **Conception rate after first AI and time period from farrowing to re-conception: (FOI= farrow to Oestrus interval)**

All three farms performed the AI twice within in a 12 hours difference between day 0 of estrus to day 4. Farm 3 performed an additional AI in cases of long estrus. The timing of the backfat measurements were based on the records of the farms of the sow’s reproductive phase and insemination. Statistical analysis was carried out with the SAS GLM software and correlation procedure, the regression equation was used to predict maternal weight gain needed for 0, 3, 6 and 9 mm backfat gain.

At day 30 from AI- pregnancy success/ failure was assessed according to heat sign expression (as returns) by the sows and ultrasound was performed by the farms to confirm pregnancy.

**4.)**  **Conception rate% - CR**

Is defined as the number of gilts and sows not returning to estrus after insemination / number of sows and gilts inseminated per cycle.

**5.)** **Farrowing rate%- FR**

Is defined as number of pregnancies carried to term/# of conceptions**. The FR is dependent on three factors: the quality of the sow, the semen and the AI breeder**

**6.)** **WOI= weaning to estrus interval:**

Is calculated as follows:

 WOI= date of weaning –date of estrus onset

**7.)** **PBA:**

Is defined as number of piglets born alive/ litter**,** I.e. if the litter is 20 piglets but only 16 are viable then PBA **= 0.8%**

**8.)** **Piglets weaned per year per sow:**

Is defined as number of piglets weaned per sow per sow (over 3 reproductive cycles)

Piglets weaned per year per sow=piglets weaned in litter 1+ litter 2 + litter 3

**9.) Statistical analysis**

The correlation of these performance factors to the backfat measurements were analyzed using linear regression models**.**

Correlation between back fat (mm) and visual body condition score was assessed using Pearson correlation.

**10.)** **Feed composition – nutritional aspects:**

The various farms utilized different feeding mixtures and provided different feed intakes to their sows as described in tables 2-4 below.

· **Farm 1**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Pregnancy day 0-70** | **Pregnancy day 71-105** | **Lactation phase** |
| **ME kcal/kg** | 3100 | 3000 | 3400 |
| **Crude Protein%** | 14 | 18 | 20 |
| **Lys%** | 0.62 | 0.62 | 0.69 |
| **Fiber %** | 6 | 6 | 4.5 |
| **Fat%** | 7 | 6.5 | 11.5 |
| **Ca %** | 0.8 | 0.8 | 1 |

 ***Table 2a –nutritional feed composition for a sow during 1 reproductive cycle in farm 1***

**Feeding regime according to production stage:**

|  |  |  |
| --- | --- | --- |
| **Day:** | **Feeding mixture** | **Feed intake (kg/day)** |
| 1st trimester | Pregnant 1 | 2.2 |
| Mid pregnancy - 1 day pre-farrowing | Pregnant 2 | 2.8 |
| Farrowing day |   | Mainly liquid |
| **Farrowing – day 0** |   |   |
| Day 1 | Lactating | Restricted |
| Day 2-day 7 | Lactating | 0.5-2 |
| Day 7-day 28 | Lactating | 2-5 |
| **End of lactation – day 0** |   |   |
| 0-7 days | Premix + Vitamin A,D,E | 2.1-2.5 |
| Day 10-30 |   | 2.8 |

***Table 2b- Feed intake ration and restriction in farm 1:*** *Amount (in Kg/day) of feed intake for sows at various phases of their reproductive cycle. Lactation and pregnancyfeeding mixtures are as decribed in table 2a. Premix composition confidential.*

· **Farm 2 – Mania farm**

**Farm 2 feeding mix**

|  |  |  |
| --- | --- | --- |
|  | **Pregnant** | **Lactating** |
| **Dry matter %** | 88.43 | 88.78 |
| **Metabolized Energy** **kcal/kg** | 2880 | 3091 |
| **Crude Protein%** | 15.45 | 17.62 |
| **Lys%** | 0.62 | 0.69 |
| **Fibre %** | 5.58 | 4.62 |
| **Fat%** | 1.96 | 3.32 |
| **Ca %** | 0.7 | 0.91 |
| **Maiz %** | 12 | 13 |
| **Barley %** | 40 | 41 |
| **Soymeal 48%** | 6.5 | 15 |
| **Sunflower meal 36 %** | 3.3 | 2.36 |
| **Wheat bran – Israeli %** | 15 |   |
| **Premix %** | 3 | 4 |
| **Total qty kg** | 3000 | 3000 |

***Table 3a- Nutritional feed composition for a sows during 1 reproductive cycle in farm 2***

**Farm 2 feeding regime according to reproduction stage:**

|  |  |  |
| --- | --- | --- |
| **Day:** | **Feeding mixture** | **Qty (kg/day)** |
| 1st trimester | Pregnant | 2.1 |
| Mid pregnancy - 1 day pre-farrowing | Pregnant | 2.6 |
| Farrowing day |   | Mainly liquid |
| **Farrowing – day 0** |   |   |
| Day 1 | Lactating | Restricted |
| Day 2-day 7 | Lactating | 0.5-2 (gradual) |
| Day 7-day 28 | Lactating | 2+0.5kg/day/piglet born |
| **End of lactation – day 0** |   |   |
| 0-7 days | Premix | 3 |
| Day 10-30 |   | 3 |

**Table 3b- Feed intake ration and restriction.** *Lactation and pregnancy feeding mixtures are as decribed in table 2a. Premix composition confidential.*

**Farm 3:**

**Farm 3 feeding mix**

|  |  |  |
| --- | --- | --- |
|  | **Gestation** | **Lactation** |
| Dry matter% | 87 | 87 |
| Metabolized Energy (kcal/kg) | 3000 | 3150 |
| Crude Protein% | 14.5 | 17 |
| Crude fat% | 8 | 5.4 |
| CF% | 8 | 5.5 |
| P% | 0.55 | 0.6 |
| Ca% | 0.9 | 0.9 |
| Ash% | 7.28 | 7.16 |
| Na% | 0.17 | 0.15 |
| Fe% | 366 | 372 |
| Lys% | 0.85 | 0.55 |
| Meth% | 0.28 | 0.3 |
| Mg% | 0.26 | 0.22 |
| Vitamin A% | 15 | 15 |
| Vitamin E% | 100 | 50 |
| Threonine % | 0.5 | 0.55 |

 **Table 4a-- Nutritional feed composition for a sow during reproductive cycle in farm 3**

 **Farm 3 feeding program:**

|  |  |  |
| --- | --- | --- |
| **Age:** | **Feed intake (kg/day)** | Frequency of feeding  |
|  **Gilts:**     | 165-200 days | 2-2.2 | Once a day |
| 200-218 days | 2.7 | Twice/day |
| Day 218-223 | 3-3.2 | Twice/day |
| AI- day 80 of gestation | 2.4-2.5 | Twice/day |
| Day 80 gestation –farrowing | 2.8-3 | Twice/day |
| **Sows:**     | End weaning- AI | 3.5-3 | From day 3 à 3 kg /day |
| AI- 30 day gestation | 2.8-3 | Twice/day |
| Gestation D 30-80 | 2.5 | Twice/day |
| D 80- farrowing | 3 |   |
| **Lactation:**D 0-2D 2-7D 7-28 |  12-44-12  |  Increasing qty every 3 days by 2 kg |

***Table 4b- Feed intake ration and restriction on farm 3***

**11.)** **Nutrition requirements during gestation and objectives of different farms in Israel**

The metabolized energy calculated for each farm was determined as described by Noblet et al (Noblet et al, 1993) = 0.07 kcal/ (kg\* BW0.75\*min standing) which translates to a min 17.8% ME. In gilts have a higher need for fat consumption than sows as gilts and also require more protein intake during gestation.

In each farm the feed intake provided during gestation is determined by the body state objective of the target sow/gilt:

**Farm 1:**

The objective of Farm 1 was to reach a back fat level (as assessed by visual body condition scoring) of a minimum of 19 mm in gilts and >20 mm in sows

**Farm 2:**

The objective of farm 2 is a back fat level of > 18 mm for gilts, reaching body weight goal as early possible, while maintaining a high litter size.

For sows – the objective is to to minimize body weight loss at lactation, back fat > 21 mm

**Farm 3:**

The objective of farm 3 were to ensure Gilts reached target body weight at min 240 days old, while aiming for an ideal sow profile as thin, not overly muscular with a back fat of 15-17 mm at farrowing.

**Nutritional approach towards insemination- flushing:**

In order to increase the rate of conception, the gilts/sows on each farm were flushed with a high energy diet preparatory to AI. Below are the parameters of the flushing in each farm (table 5)

|  |  |  |
| --- | --- | --- |
|  | **Feed intake** | **additives** |
| **Farm1** | 3 kg/ day (instead of 2.8 kg/day) | + Vitamin A,D,E |
| **Farm 2** | 3-3.6 kg/day (instead of 3 kg/day) | + high lysine % |
| **Farm 3** | Sugar 250 g/day + non supplemented starter feed 500 g/day- to improve estrus signs (in addition to 4-12 kg/day) ME – 43 MJ from day of weaning for 4 days |  |

***Table 5: Flushing feed regime in farms 1-3.***

· **Genotype:**

Genetic improvement is limited in Israel. Since I is illegal to import new living breeds and mixing them with the local genome to produce better traits, the main improvement is done by importing sperm from Europe.

In order to improve prolificacy, reproductive qualities while maintaining lean genotype traits and to expend the genetic genome, farms in Israel use imported semen from EU and mix it with local breeds, siring a more diverse offspring.

Farm 1 imports only large white and Landrace (from which the Israeli stock is derived) Semen, mostly from France.

Farm 2 imports high high quality large white semen from Belgium.

Farm 3, however, –semen imports include Landrace X large white- **Gallia**, IX pietrain (higher muscle %), **Naima sow** – better milk quantity and quality, and more teats/sow to produce a high litter average, more robust pigs. Semen is screened to exclude the gene responsible for malignant hyperthermia, prevent siring of over the upper range of fetuses (14-16), and exclude boar weight over 1000 kg.

·

***12.) Heat stroke prevention: a serious metabolic issue in Israel:***

Heat stroke is condition triggered by improper thermoregulation in response to extreme high heat and warm climate. Israel, a Mediterranean country with arid and warm climate, especially in the southern parts (during the whole year), is characterized by high temperatures specifically at summer when the average temperature is 27-37 C (under the best circumstances). In addition to high incidents of heat strokes followed by death and economic loss to the swine industry, this environment increases in the ammonia emission and urine contamination over body. It has been previously established that swine under heat stress, convert the feed into energy instead of gaining weight and display a decreased daily feed intake from an average of 3500 g/day to 2500 g/day.

In addition to incorporation of fans and ventilation to housing facilities, and adding Viriniamycin – stafac to the feed mix in farm 1 and 2 and as is done, when necessary, in the EU, farm 3 has developed a novel Cooling mattress system to maintain a temperature below the required threshold.

**Results**

Exlusion of samples from study population

Of the 75 sows and gilts entered into the study, 15 were excluded in the course of the study due to death or not carrying pregnancies to term.

In farm 1 – 5 gilts were excluded – 3 gave birth to stillborn piglets (victims of a parvo virus infection) and 2 died of PRRS (porcine respiratory reproductive syndrome)

In farm 2 – 3 gilts suffered from a spay leg and were culled, and 2 sows aborted in the 1st trimester

In the 3rd farm – 5 sows of 2nd parity were exposed to a high temperature resulting in second litter syndrome – culled out of economic considerations.

**Back fat(P2) measurements:**

**Farm 1:**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample (Gilts, Parity 1) | Gestation Day 0 | Lactation Day 0 | Lactation- Day 28 | Change in backfat (mm)- gestation | Change in backfat (%)- gestation | Change in backfat (mm)- lactation | Change in backfat (%)- lactation | Interval between farrowing to re conception- days | WOI (Weaning to Oestrus Interval) - days |
| 1 | 16.1 | 18.2 | 15.9 | 2.1 | 13.04% | -2.3 | -12.64% | 78 | 50 |
| 2 | 16.8 | 20.2 | 17 | 3.4 | 20.24% | -3.2 | -15.84% | 56 | 28 |
| 3 | 15.9 | 18.8 | 15 | 2.9 | 18.24% | -3.8 | -20.21% | 75 | 47 |
| 4 | 16 | 18.1 | 15.3 | 2.1 | 13.13% | -2.8 | -15.47% | 52 | 24 |
| 5 | 15.4 | 17.2 | 14.4 | 1.8 | 11.69% | -2.8 | -16.28% | 55 | 27 |
| 6 | 15.9 | 17 | 14.7 | 1.1 | 6.92% | -2.3 | -13.53% | 57 | 29 |
| 7 | 16.7 | 19.3 | 15.3 | 2.6 | 15.57% | -4 | -20.73% | 78 | 50 |
| 8 | 17 | 20.5 | 17.5 | 3.5 | 20.59% | -3 | -14.63% | 56 | 28 |
| 9 | 18.3 | 21.1 | 18.1 | 2.8 | 15.30% | -3 | -14.22% | 34 | 6 |
| 10 | 18.8 | 21.9 | 18.2 | 3.1 | 16.49% | -3.7 | -16.89% | 35 | 7 |
| Average | 16.69 | 19.23 | 16.14 | 2.54 | 15.12% | -3.09 | -16.04% | 57.6 | 29.6 |

***Table 6a – back fat levels at pregnancy and loss at lactation in relation to reproductive parameters in Gilts.***

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample (Sows) | Day 0 | Day 0 | Day 28 | Change in backfat (mm)- gestation | Change in backfat (%)- gestation | Change in backfat (mm) | Change in backfat (%)- lactation | Parity | Interval between farrowing to re conception | WOI (Weaning to Oestrus Interval) - days |
| 1 | 16.56 | 18.2 | 16 | 1.64 | 9.90% | -2.2 | -12.09% | 2 | 35 | 7 |
| 2 | 16.3 | 18.9 | 16.1 | 2.6 | 15.95% | -2.8 | -14.81% | 5 | 77 | 49 |
| 3 | 16.2 | 17.9 | 14.4 | 1.7 | 10.49% | -3.5 | -19.55% | 4 | 57 | 29 |
| 4 | 17 | 20.5 | 16.9 | 3.5 | 20.59% | -3.6 | -17.56% | 2 | 76 | 48 |
| 5 | 17.7 | 21 | 17.9 | 3.3 | 18.64% | -3.1 | -14.76% | 2 | 55 | 27 |
| 6 | 18.3 | 20.3 | 19 | 2 | 10.93% | -1.3 | -6.40% | 3 | 59 | 31 |
| 7 | 18.5 | 20.6 | 18.6 | 2.1 | 11.35% | -2 | -9.71% | 3 | 37 | 9 |
| 8 | 18.8 | 21 | 19 | 2.2 | 11.70% | -2 | -9.52% | 3 | 56 | 28 |
| 9 | 19 | 21.9 | 19.3 | 2.9 | 15.26% | -2.6 | -11.87% | 5 | 38 | 10 |
| 10 | 16.56 | 18.2 | 16 | 1.64 | 9.90% | -2.2 | -12.09% | 2 | 37 | 9 |
| Average | 17.49 | 19.85 | 17.32 | 2.36 | 13.47% | -2.53 | -12.84% |   | 52.7 | 24.7 |

***Table 6b – back fat levels at pregnancy and loss at lactation in relation to parity and reproductive parameters in sows***

**Farm 2 (Mania):**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample (Gilts, Parity 1) | Day 0 | Day 0 | Day 28 | Change in backfat (mm)- gestation | Change in backfat (%)- gestation | Change in backfat (mm) | Change in backfat (%)- lactation | Interval between farrowing to re conception | WOI (Weaning to Oestrus Interval) - days |
| 1 | 18.98 | 22.3 | 19.3 | 3.32 | 17.49% | -3 | -13.45% | 37 | 9 |
| 2 | 19.1 | 22 | 19 | 2.9 | 15.18% | -3 | -13.64% | 33 | 5 |
| 3 | 18.3 | 21.3 | 18 | 3 | 16.39% | -3.3 | -15.49% | 55 | 27 |
| 4 | 18.3 | 21.4 | 18.3 | 3.1 | 16.94% | -3.1 | -14.49% | 34 | 6 |
| 5 | 19 | 22.7 | 19.2 | 3.7 | 19.47% | -3.5 | -15.42% | 35 | 7 |
| 6 | 17.8 | 19.7 | 18 | 1.9 | 10.67% | -1.7 | -8.63% | 36 | 8 |
| 7 | 16.9 | 19.3 | 16.1 | 2.4 | 14.20% | -3.2 | -16.58% | 56 | 28 |
| 8 | 16.8 | 19.2 | 17 | 2.4 | 14.29% | -2.2 | -11.46% | 57 | 29 |
| 9 | 17 | 20 | 16.4 | 3 | 17.65% | -3.6 | -18.00% | 56 | 28 |
| 10 | 17.9 | 20.8 | 17.3 | 2.9 | 16.20% | -3.5 | -16.83% | 36 | 8 |
| Average | 18.01 | 20.87 | 17.86 | 2.86 | 15.85% | -3.01 | -14.40% | 43.5 | 15.5 |

***Table 7a- back fat levels at pregnancy and loss at lactation in relation to reproductive parameters in farm 2- gilts***

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample (Sows) | Day 0 | Day 0 | Day 28 | Change in backfat (mm)- gestation | Change in backfat (%)- gestation | Change in backfat (mm) | Change in backfat (%)- lactation | Parity | Interval between farrowing to re conception | WOI (Weaning to Oestrus Interval) - days |
| 1 | 19.2 | 23 | 21 | 3.8 | 19.79% | -2 | -8.70% | 3 | 33 | 5 |
| 2 | 19.7 | 24 | 21 | 4.3 | 21.83% | -3 | -12.50% | 2 | 38 | 10 |
| 3 | 18.9 | 22 | 19 | 3.1 | 16.40% | -3 | -13.64% | 4 | 36 | 8 |
| 4 | 20 | 24 | 21 | 4 | 20.00% | -3 | -12.50% | 2 | 35 | 7 |
| 5 | 19.1 | 22 | 19.5 | 2.9 | 15.18% | -2.5 | -11.36% | 5 | 33 | 5 |
| 6 | 19.5 | 22.3 | 19.9 | 2.8 | 14.36% | -2.4 | -10.76% | 4 | 37 | 9 |
| 7 | 18.2 | 21 | 18.9 | 2.8 | 15.38% | -2.1 | -10.00% | 2 | 35 | 7 |
| 8 | 18.5 | 21.2 | 19 | 2.7 | 14.59% | -2.2 | -10.38% | 5 | 34 | 6 |
| 9 | 17.9 | 20.9 | 18 | 3 | 16.76% | -2.9 | -13.88% | 3 | 56 | 28 |
|   | 18.1 | 20.5 | 19 | 2.4 | 13.26% | -1.5 | -7.32% | 4 | 76 | 48 |
| Average | 18.91 | 22.09 | 19.63 | 3.18 | 16.76% | -2.46 | -11.10% |   | 41.3 | 13.3 |

***Table 7b – back fat levels at pregnancy and loss at lactation in relation to parity and reproductive parameters in farm 2- sows.***

**Farm 3:**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample (Gilts, Parity 1) | Day 0 | Day 0 | Day 28 | Change in backfat (mm)- gestation | Change in backfat (%)- gestation | Change in backfat (mm) | Change in backfat (%)- lactation | Interval between farrowing to re conception | WOI (Weaning to Oestrus Interval) - days |
| 1 | 15 | 16.8 | 14.8 | 1.8 | 12.00% | -2 | -11.90% | 25 | 4 |
| 2 | 15.3 | 17.2 | 16 | 1.9 | 12.42% | -1.2 | -6.98% | 32 | 11 |
| 3 | 14.9 | 17 | 14 | 2.1 | 14.09% | -3 | -17.65% | 45 | 24 |
| 4 | 13 | 15 | 11.8 | 2 | 15.38% | -3.2 | -21.33% | 53 | 32 |
| 5 | 15 | 18.3 | 16.5 | 3.3 | 22.00% | -1.8 | -9.84% | 42 | 21 |
| 6 | 14.9 | 17.4 | 15.4 | 2.5 | 16.78% | -2 | -11.49% | 26 | 5 |
| 7 | 16 | 19 | 17.5 | 3 | 18.75% | -1.5 | -7.89% | 25 | 4 |
| 8 | 16.8 | 19.2 | 17 | 2.4 | 14.29% | -2.2 | -11.46% | 33 | 12 |
| 9 | 15 | 17.9 | 15 | 2.9 | 19.33% | -2.9 | -16.20% | 34 | 13 |
| 10 | 16.5 | 19 | 16.7 | 2.5 | 15.15% | -2.3 | -12.11% | 36 | 15 |
| Average | 15.24 | 17.68 | 15.47 | 2.44 | 16.02% | -2.21 | -12.69% | 35.1 | 14.1 |

***Table 8a- back fat levels at pregnancy and loss at lactation in relation to reproductive parameters in farm 3- gilts***

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample (Sows) | Day 0 | Day 0 | Day 28 | Change in backfat (mm)- gestation | Change in backfat (%)- gestation | Change in backfat (mm) | Change in backfat (%)- lactation | Parity | Interval between farrowing to re conception | WOI (Weaning to Oestrus Interval) - days |
| 1 | 18 | 20 | 18.8 | 2 | 11.11% | -1.2 | -6.00% | 3 | 25 | 4 |
| 2 | 19 | 22 | 19.9 | 3 | 15.79% | -2.1 | -9.55% | 2 | 24 | 3 |
| 3 | 18.3 | 21.3 | 19.6 | 3 | 16.39% | -1.7 | -7.98% | 3 | 26 | 5 |
| 4 | 17 | 19 | 17.2 | 2 | 11.76% | -1.8 | -9.47% | 4 | 34 | 13 |
| 5 | 18.2 | 20.5 | 18 | 2.3 | 12.64% | -2.5 | -12.20% | 2 | 33 | 12 |
| 6 | 15 | 17 | 15.3 | 2 | 13.33% | -1.7 | -10.00% | 2 | 47 | 26 |
| 7 | 16.9 | 19.2 | 17.9 | 2.3 | 13.61% | -1.3 | -6.77% | 4 | 35 | 14 |
| 8 | 18.5 | 21.2 | 19 | 2.7 | 14.59% | -2.2 | -10.38% | 5 | 34 | 13 |
| 9 | 17.7 | 19.7 | 18.4 | 2 | 11.30% | -1.3 | -6.60% | 3 | 36 | 15 |
| 10 | 18.8 | 20.5 | 19.2 | 1.7 | 9.04% | -1.3 | -6.34% | 3 | 34 | 13 |
| Average | 17.74 | 20.04 | 18.33 | 2.30 | 12.96% | -1.71 | -8.53% |   | 32.8 | 11.8 |

***Table 8b – back fat levels at pregnancy and loss at lactation in relation to parity and reproductive parameters in farm 3- sows.***

· **Reproductive performance:**

Litter size, PBA and total piglets weaned was calculated for each gilt and sow in each farm (tables 9-12 below).

PBA was defined as:

 #viable piglets/litter

Total piglets weaned was defined as:

#weaned piglets/litter

**Farm 1**

|  |  |  |
| --- | --- | --- |
|  | Gilts | sows |
| sample | litter size | PBA | total weaned | litter size | PBA  | total weaned  |
| 1 | 9 | 0.777778 | 0.56 | 14 | 0.79 | 0.64 |
| 2 | 10 | 0.6 | 0.50 | 16 | 0.69 | 0.50 |
| 3 | 11 | 0.64 | 0.45 | 17 | 0.65 | 0.59 |
| 4 | 12 | 0.58 | 0.42 | 15 | 0.67 | 0.53 |
| 5 | 8 | 0.75 | 0.63 | 16 | 0.56 | 0.44 |
| 6 | 11 | 0.73 | 0.55 | 14 | 0.64 | 0.57 |
| 7 | 7 | 0.86 | 0.71 | 13 | 0.62 | 0.54 |
| 8 | 6 | 1.00 | 0.67 | 12 | 1.00 | 0.67 |
| 9 | 8 | 0.75 | 0.63 | 10 | 0.90 | 0.70 |
| 10 | 9 | 0.78 | 0.67 | 13 | 0.69 | 0.54 |
| average | 9.1 | 0.745967 | 0.576984 | 14 | 0.719999 | 0.571694 |

***Table 9 – litter size, PBA and total weaned data for farm 1.*** *PBA = piglets born alive / litter size. total weaned = number weaned piglets/ litter size*

**Farm 2**

|  |  |  |
| --- | --- | --- |
|  | Gilts | sows |
| sample | litter size | PBA | total weaned | litter size | PBA  | total weaned  |
| 1 | 10 | 0.80 | 0.70 | 14 | 0.93 | 0.86 |
| 2 | 9 | 0.89 | 0.78 | 16 | 0.88 | 0.81 |
| 3 | 8 | 1.00 | 1.00 | 18 | 0.67 | 0.56 |
| 4 | 9 | 0.89 | 0.78 | 15 | 0.73 | 0.67 |
| 5 | 10 | 0.80 | 0.70 | 16 | 0.81 | 0.69 |
| 6 | 11 | 0.91 | 0.82 | 13 | 0.85 | 0.77 |
| 7 | 9 | 1.00 | 0.89 | 17 | 0.82 | 0.71 |
| 8 | 7 | 1.00 | 0.86 | 18 | 0.89 | 0.72 |
| 9 | 8 | 0.88 | 0.75 | 16 | 0.94 | 0.81 |
| 10 | 9 | 0.89 | 0.78 | 12 | 0.92 | 0.83 |
| average | 9 | 0.905076 | 0.804755 | 15.5 | 0.842881 | 0.742253 |

***Table 10– litter size, PBA and total weaned data for farm 2.*** *PBA = piglets born alive / litter size. total weaned = number weaned piglets/ litter size*

**Farm 3**

|  |  |  |
| --- | --- | --- |
|  | Gilts | sows |
| sample | litter size | PBA | total weaned | litter size | PBA  | total weaned  |
| 1 | 8 | 0.88 | 0.75 | 10 | 0.90 | 0.90 |
| 2 | 7 | 0.86 | 0.86 | 12 | 0.83 | 0.75 |
| 3 | 6 | 1.00 | 1.00 | 14 | 0.86 | 0.79 |
| 4 | 6 | 1.00 | 0.83 | 13 | 0.85 | 0.85 |
| 5 | 7 | 1.00 | 0.86 | 11 | 0.91 | 0.82 |
| 6 | 8 | 0.88 | 0.88 | 15 | 0.87 | 0.73 |
| 7 | 5 | 1.00 | 1.00 | 16 | 0.88 | 0.75 |
| 8 | 6 | 0.83 | 0.83 | 16 | 0.81 | 0.69 |
| 9 | 8 | 0.88 | 0.75 | 14 | 0.86 | 0.71 |
| 10 | 9 | 0.78 | 0.67 | 15 | 0.87 | 0.80 |
| average | 7 | 0.909325 | 0.842262 | 13.6 | 0.86237 | 0.778517 |

***Table 11 – litter size, PBA and total weaned data for farm 3.*** *PBA = piglets born alive / litter size. total weaned = number weaned piglets/ litter size*

|  |  |  |
| --- | --- | --- |
|  | Gilts | sows |
| Farm | Average litter size | Average PBA | Average total weaned | Average litter size | Average PBA  | Average total weaned  |
| farm 1 | 9.1 | 0.75 | 0.58 | 14 | 0.72 | 0.57 |
| farm 2 | 9 | 0.91 | 0.8 | 15.5 | 0.84 | 0.74 |
| farm 3 | 7 | 0.91 | 0.84 | 13.6 | 0.86237 | 0.78 |

***Table 12 – average litter size, PBA and total weaned data for farm 3.*** *PBA = piglets born alive / litter size. total weaned = number weaned piglets/ litter size*

|  |  |  |
| --- | --- | --- |
|  | Gilts | Sows |
|  | pearson correlation coefficient between litter size:PBA | pearson correlation litter size:total weaning | pearson correlation litter size: PBA | pearson correlation litter size: total weaning |
| farm1 | -0.88 | -0.88 | -0.7 | -0.68 |
| farm2 | -0.58 | -0.45 | -0.41 | -0.62 |
| farm3 | -0.7 | -0.81 | -0.53 | -0.73 |

***Table 13 –Pearson correlation coefficient between litter sizes, PBA and total weaning in the three farms***

Farm 2, in spite of an equivalent average litter size for gilts (9 Vs 9.1) and a higher average litter size for sows (15.5 Vs 14) was able to achieve a considerably higher PBA (0.91 Vs 0.75 for gilts 0.84 Vs 072 for sows) and total weaned ( 0.8 Vs 0.58 for gilts, 0.74 Vs 0.57 for sows), reflecting its superior husbandry and techniques. Farm 3, aiming at lower litter sizes as part as it’s goals, achieved only slightly superior PBA (0.91 Vs 0.91 for gilts, 0.86 Vs 0.84 for sows) and total weaned (0.84 Vs 0.8 for gilts and 0.78 Vs 0.74 for sows) over Farm 2 (table 13).

Notably, farm 2 also showed a lower correlation between litter size and PBA/total weaned, indicating better husbandry practices capable of aiding sows with large litters.

**Correlation of WOI to back fat at weaning Vs back fat loss during lactation and visual BCS:**

The study has shown a consistent correlation between WOI in sows and gilts in all three farms and their back fat level at the end of the lactation period (table 14). The highest correlation (-0.86) was found in sows in farm 3 and the lowest correlation in sows in farm 1 (-0.17). Back fat at weaning was a far superior measurement method than visual BCS which showed a less powerful correlation than body fat at weaning in every single farm and sow/gilt group (and in two cases a straight rather than inverse correlation). Notably, **changes** to backfat during the lactation period (table 14) did **not** show a consistent or powerful correlation with the WOI, indicating that this measurement is not reliable, in and of itself, for reproductive success.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Pearson correlation coefficient between Back fat levels at lactation day 28 and WOI | Pearson correlation coefficient between visual BCS (Body Conditions Scoring) and WOI | Pearson correlation coefficient between change to backfat during lactation and WOI |
|  | Gilts | Sows | Gilts | Sows | Gilts | Sows |
| Farm1 | -0.63 | -0.17 | -0.4235615 | **0.1071415** | -0.07 | -0.17 |
| Farm2 | -0.76 | -0.44 | -0.6154765 | -0.4044944 | -0.44 | -0.05 |
| Farm3 | -0.64 | -0.86 | **0.3245694** | -0.1755521 | **0.05** | -0.66 |

***Table 14 –Pearson correlation coefficient between back fat content at weaning and loss during lactation to WOI (Weaning to Oestrus interval).***

**Summary**

Of the three farms farm 1 – with the poor husbandry conditions had the least gain of back fat during gestation and the highest loss of back fat loss during weaning, as well as the lowest total backfat at weaning for sows and second lowest for gilts. This is probably because derived from the lack regulation over feed intake on the farm. In addition the nutrition regulation problem, the pens are built in such a way which fails to minimize aggression and stress during the early gestation phase, leading to a high incidence of repeat breeders as well a high incidence of spay leg. Notably, the conception rates in this farm at first AI were far lower than the other farms for both gilts (20% compared to 60% in farm 2 and 80% in farm 3) and sows (40% compared to 80% in farm 2 and 90% in farm 3), indicating an impact of inferior husbandary expertise and techniques (table 15).

Farm 3 in contrast maintained the best husbandry conditions, including free range keeping for lactating sows. Thanks to a highly organized operation almost all heat signs were detected in a timely manner, leading to rapid fertilization by AI in a quiet, stress free house and a very high successful conception rate at first AI. The gestating sows/gilts were then kept in stress free housing until day 60 of gestation, i.e. until implantation when abortion risks were smaller.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | farm1 | farm2 | farm3 |
| Average change in backfat during lactation (%) | Sows | -13.10% | -9.50% | -8.60% |
| Gilts | -16.65% | -10.75% | -13.20% |
| Average weight loss during lactation (%) | sows | -11% | -6.60% | -8.69% |
| Gilts | -21% | -11% | -7.14% |
| Average backfat (mm) at end of lactation | sows | 17.32 | 19.63 | 18.33 |
| Gilts | 16.14 | 17.86 | 15.47 |
| Average Interval between farrowing to re conception- days | sows | 52.7  | 41.3  | 32.8  |
| Gilts | 57.6  | 45.8  | 35.1  |
| Average WOI (Weaning to Oestrus Interval) - days | sows | 24.7 | 13.3 | 11.8 |
| Gilts | 29.6 | 15.5 | 14.1 |
| Conception rate at first AI (%) | sows | 40% | 80% | 90% |
| gilts | 20% | 60% | 80% |
| Litter size | sows | 14 | 15.5 | 13.6 |
| gilts | 9.1 | 9 | 7 |
| PBA (viable piglets/litter size) | sows | 0.719999 | 0.842881 | 0.86237 |
| gilts | 0.745967 | 0.905076 | 0.909325 |
| total weaned # piglets weaned/litter size) | sows | 0.571694 | 0.742253 | 0.778517 |
| gilts | 0.576984 | 0.804755 | 0.842262 |

***Table 15: summary of average backfat and weight at weaning, reproductive parameters and WOI at all farms.***

**Discussion:**

This study set out to investigate the conditions of the swine growing industry in the unique Israeli environment, where BCS is used as the sole measurement to predict reproductive efficiency, and the comparative suitability of backfat measurements to carry out such assessments. The study was carried out in three radically different swine breeding facilities. The first, farm 1, was a small scale operation in whom the workers were local villagers who lacked any professional experience or academic knowledge of the swine breeding. The second, farm 2, was a larger scale operation in which the workers had greater professional experience and stricter operating procedures more compatible with EU regulations.

The third, farm 3, was an experimental farm in which the aim was not to produce the maximum number of piglets for the meat industry but to study the best way to raise healthy, lean pigs for the medical industry. Furthermore, unlike farms number 1 and 2 which were located in northern Israel, which enjoys a Mediterranean climate comparable to that of portions of Southern Europe, Farm 3 was located in the Arid Negev region of southern Israel.

Nonetheless, backfat levels at weaning proved to be immeasurably superior to visual BCS as an indicator of future WOI (Weaning to Oestrus Interval), indicating the robustness of this measurement in predicting the WOI. However, in spite of the extensive literature indicating that a negative energy balance during lactation, as reflected in **change** of backfat levels during lactation, is linked to a long WOI, the results of this study failed to uncover such a correlation, except among sows (but not gilts) in the tightly supervised farm 3 – and even there the backfat level at weaning showed a more powerful correlation with the WOI than the change of backfat levels. Multiple variate analysis on a larger sample population, which is beyond the scope of this study, is required to determine which combination of parameters offers the best predictive value for WOI. However, the inconsistency of the correlation coefficient of the backfat change variable with the WOI between different farms and groupings indicate that it is not sufficiently robust to be employed without swine breeding facility specific research.

As expected, the husbandry practices in farm 1 (including non separation of gilts and sows) resulted in high aggressiveness and competitiveness during feeding, resulting in the highest recorded backfat loss. In farm 3, in contrast, in spite of restricted feeding practices aimed at producing leaner sows and relatively low backfat gains during gestation, back fat loss during lactation was the lowest of the three farms. The superior feeding, stress reducing and estrus detection practices in farm 3, reflected in the less negative energy balance during lactation, resulted in a very low MOI and a high success rate of conception at the first AI. Litter size was found to be strongly negatively correlated with PBA and total weaning, as expected in all three farms, and particularly in farm 1, which lacked the expertise to ablate the negative effects of large litter size on piglet survival. However, practices employed in farm 3 to reduce litter size had only a marginal effect on improving PBA and total weaning, indicating that a point of diminishing returns has been reached.

These findings are compatible with those with findings from long established swine industries in temperate climate conditions such as the EU zone, on the impact of pen size, keeping, and feeding methods on reproductive performance. Accordingly, there is no reason to think that these procedure are not generally applicable to emerging swine industries in arid climates such as Israel.

In addition to the findings described above, this study also encountered a novel, and as far as the author is aware, unique, temperature regulation technique (mattress cooling system) in Farm 3 uniquely developed for swine breeding in arid regions. This system, it’s specific impact on reproductive efficiency under arid conditions and it’s suitability for implementation elsewhere, merits, in this author’s opinion a focused future study.

**Recommendations:**

1. Encourage use of backfat measurement at weaning as parameter for assessing fitness of sow for insemination.
2. Encourage use of backfat measurement at weaning as parameter for assessment of overall husbandary techniques and practice.
3. Carry out larger and multi breeding cycle study enabling assessment of multivariate analysis (including ∆BF during gestation and lactation) to identify robust predictors for reproductive efficiency under variant conditions.
4. Carry out future study of impact and utility of cooling matress technique employed on farm 3 for swine growth and breeding in arid conditions.

**Appendices:**

· **US image of back fat:**

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