

**Morphological traits as early indicators of male broiler breeder fertility**

**By**

**Dolan Russell Oosterberg**

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**Supervisor: Prof. E. Van Marle Köster**

**Co-Supervisor: Dr. C. D. Le Roux**

## Declaration

I, Dolan Russell Oosterberg, do hereby declare that the research presented in this dissertation, was executed by myself, and apart from the normal guidance from my supervisor, I have received no assistance.

Neither the substance, nor any part of this dissertation has been submitted in the past, or is to be submitted for a degree at this University or any other University.

This dissertation is presented in partial fulfilment of the requirements for the degree MSc (Agric) in Animal Production.

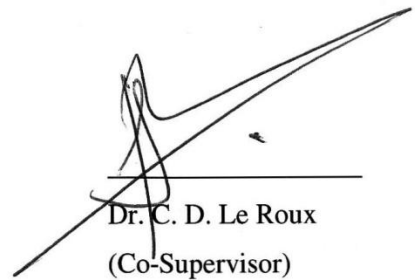
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Mr. D. R. Oosterberg  
(Candidate)



Prof. E. Van Marle Köster  
(Supervisor)



Dr. C. D. Le Roux  
(Co-Supervisor)

10-01-2013

Date

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## Abstract

The broiler industry is a primary supplier of white meat and a popular protein source in human diets. The poultry industry aims to produce a broiler chick with high liveability, high growth and high feed conversion efficiency; therefore high growth performance has been emphasized in the parent stock. Fertility of the broiler breeders is one of the most important aspects in broiler production. Standard hatchery practice for fertility determination is 18-day candling, but a more suitable indicator would be a 12-day breakout. The aim of this study was to evaluate routine farm data and to identify additional measurements as early indicators of male broiler breeder fertility. The results showed that neither the routine nor the additional male body weight measurements significantly contributed to either 18- or 12- day fertility ( $P > 0.0001$ ). Female weight, however, contributed significantly to 18-day fertility ( $P > 0.0001$ ). Shank length only showed a significant effect ( $P > 0.005$ ) on 18-day fertility. Routine body condition score and routine vent score both contributed significantly to 18-day fertility ( $P > 0.0001$ ). Additional vent score was shown to have a significant effect on 12-day fertility at  $P > 0.005$ ; similarly additional body condition score also had a significant effect on 12-day fertility, but at  $P > 0.05$ . The limitations in this study, including the small sample size may have contributed to the lack of significance found in the measurements used. The results indicate that further studies under controlled conditions may be useful in identifying shank length as an early indicator of male broiler breeder fertility.

## **TABLE OF CONTENTS**

|                                                                                  |            |
|----------------------------------------------------------------------------------|------------|
| <b>DECLARATION</b>                                                               | <b>i</b>   |
| <b>ACKNOWLEDGEMENTS</b>                                                          | <b>ii</b>  |
| <b>ABSTRACT</b>                                                                  | <b>iii</b> |
| <b>LIST OF TABLES</b>                                                            | <b>vi</b>  |
| <b>LIST OF FIGURES</b>                                                           | <b>vii</b> |
| <b>LIST OF ABBREVIATIONS</b>                                                     | <b>ix</b>  |
| <br>                                                                             |            |
| <b>CHAPTER 1: INTRODUCTION</b>                                                   | <b>1</b>   |
| 1.1 Background of the broiler industry                                           | 1          |
| 1.2 Structure of the broiler breeding industry                                   | 4          |
| 1.3 Aim of this study                                                            | 6          |
| <br>                                                                             |            |
| <b>CHAPER 2: LITERATURE REVIEW</b>                                               | <b>8</b>   |
| 2.1.1 Inheritance of reproductive traits                                         | 8          |
| 2.1.2 Male versus Female Fertility                                               | 11         |
| 2.1.3 Nutritional Factors                                                        | 14         |
| 2.1.4 Environmental Factors                                                      | 15         |
| 2.2 Morphological traits and fertility                                           | 18         |
| 2.3 Future considerations for broiler breeder production                         | 19         |
| <br>                                                                             |            |
| <b>CHAPTER 3: MATERIALS AND METHODS</b>                                          | <b>21</b>  |
| 3.1 Materials                                                                    | 21         |
| 3.1.1 Origin and background of routine farm data collected                       | 21         |
| 3.1.2 Composition of the routine farm data                                       | 22         |
| 3.1.3 Objective and subjective measurements related to broiler breeder fertility | 22         |
| 3.2 Methods                                                                      | 27         |
| 3.2.1 Additional data collection                                                 | 27         |
| 3.2.2 Fertility measurements                                                     | 30         |
| 3.3 Data analysis                                                                | 32         |

|                                                   |           |
|---------------------------------------------------|-----------|
| 3.3.1 Data cleaning and compilation               | 33        |
| 3.4 Models for data interpretation                | 34        |
| 3.4.1 Routine farm data analysis                  | 34        |
| 3.4.2 Additional data analysis                    | 34        |
| <br>                                              |           |
| <b>CHAPTER 4: RESULTS</b>                         | <b>37</b> |
| 4.1 Results                                       | 37        |
| 4.1 Descriptive statistics                        | 37        |
| 4.1.1 Routine farm data                           | 37        |
| 4.1.2 Additional data                             | 37        |
| 4.2.1 Trends of all traits analysed in this study | 38        |
| 4.3 Model results                                 | 41        |
| 4.3.1 Test model                                  | 41        |
| 4.3.2 Model statistical results                   | 41        |
| <br>                                              |           |
| <b>CHAPTER 5: DISCUSSION</b>                      | <b>52</b> |
| <br>                                              |           |
| <b>CHAPTER 6: CONCLUSION</b>                      | <b>57</b> |
| <br>                                              |           |
| <b>REFERENCES</b>                                 | <b>59</b> |
| <br>                                              |           |
| <b>APPENDIX A</b>                                 | <b>73</b> |
| <b>APPENDIX B</b>                                 | <b>75</b> |
| <b>APPENDIX C</b>                                 | <b>89</b> |
| <b>APPENDIX D</b>                                 | <b>84</b> |

## **LIST OF TABLES**

### **CHAPTER 2: LITERATURE REVIEW**

|                                                                                      |          |
|--------------------------------------------------------------------------------------|----------|
| <b>Table 2.1 Heritability estimates for traits of economic importance in poultry</b> | <b>9</b> |
|--------------------------------------------------------------------------------------|----------|

### **CHAPTER 3: MATERIALS AND METHODS**

|                                                                                                      |           |
|------------------------------------------------------------------------------------------------------|-----------|
| <b>Table 3.1 Summary of farms included in the study</b>                                              | <b>21</b> |
| <b>Table 3.2 Summary of standard traits recorded routinely on all farms</b>                          | <b>22</b> |
| <b>Table 3.3 Description of measurements routinely recorded on-farm</b>                              | <b>23</b> |
| <b>Table 3.4 Hatchery capacities within the company</b>                                              | <b>27</b> |
| <b>Table 3.5 Age intervals for additional data collection</b>                                        | <b>28</b> |
| <b>Table 3.6 Summary of traits measured routinely on-farm and their use in the respective models</b> | <b>33</b> |
| <b>Table 3.7 Summary of additional measurements recorded and their use in the respective models</b>  | <b>33</b> |

### **CHAPTER 4: RESULTS**

|                                                                                                 |           |
|-------------------------------------------------------------------------------------------------|-----------|
| <b>Table 4.1 Summary of descriptive statistics of routine farm data used for analysis</b>       | <b>37</b> |
| <b>Table 4.2 Summary of descriptive statistics of additional measurements recorded</b>          | <b>38</b> |
| <b>Table 4.3 Results of model I for 18-day fertility and routine farm measurements</b>          | <b>41</b> |
| <b>Table 4.4 Results of model II for 18-day fertility and the additional measurements</b>       | <b>43</b> |
| <b>Table 4.5 Results of model III for the additional farm measurements and 12-day fertility</b> | <b>45</b> |
| <b>Table 4.6 Results of model IV for the 12-day fertility and the routine farm measurements</b> | <b>47</b> |
| <b>Table 4.7 Results of Model Ia for 18-day fertility and the routine farm measurements</b>     | <b>49</b> |
| <b>Table 4.8 Results of model IVa for 12-day fertility and the routine farm measurements</b>    | <b>50</b> |

## LIST OF FIGURES

### CHAPTER 1: INTRODUCTION

|                                                                                                                                                                                                       |   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|
| Figure 1.1 Comparison of animal protein prices in 2010<br>( <a href="http://www.sapoultry.co.za/pdf%20avi/tuesday/BO%20REPORT.pdf">http://www.sapoultry.co.za/pdf%20avi/tuesday/BO%20REPORT.pdf</a> ) | 1 |
| Figure 1.2 Per capita consumption of animal protein in 2010<br>( <a href="http://www.daff.gov.za/docs/statsinfo/Ab2012.pdf">http://www.daff.gov.za/docs/statsinfo/Ab2012.pdf</a> )                    | 2 |
| Figure 1.3 Structure of the South African broiler industry<br>( <a href="http://www.sapoultry.co.za/industry_profile.php">http://www.sapoultry.co.za/industry_profile.php</a> )                       | 5 |

### CHAPTER 3: MATERIALS AND METHODS

|                                                                                                                                                                                                                                                          |    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 3.1 Vent score of five                                                                                                                                                                                                                            | 24 |
| Figure 3.2 Vent score of one                                                                                                                                                                                                                             | 25 |
| Figure 3.3 House manager condition scoring a male broiler                                                                                                                                                                                                | 26 |
| Figure 3.4 Chart of body condition scoring ( <a href="http://www.cobb-vantress.com">http://www.cobb-vantress.com</a> )                                                                                                                                   | 27 |
| Figure 3.5 Schematic diagram of male shank ( <a href="http://web2.uconn.edu/poultry/4-H%20Poultry/index.html">http://web2.uconn.edu/poultry/4-H%20Poultry/index.html</a> (University of Connecticut Poultry 4-H Website))                                | 29 |
| Figure 3.6 Shank length as measured on farm                                                                                                                                                                                                              | 30 |
| Figure 3.7 Example of mass candling<br>( <a href="http://www.thepoultrysite.com/articles/1603/investigating-hatchery-practice-assessing-fertility">http://www.thepoultrysite.com/articles/1603/investigating-hatchery-practice-assessing-fertility</a> ) | 31 |
| Figure 3.8 Example of fertile and infertile eggs at 12-days<br>( <a href="http://www.ca.uky.edu/smallflocks/faq.html">http://www.ca.uky.edu/smallflocks/faq.html</a> )                                                                                   | 32 |

### CHAPTER 4: RESULTS

|                                                                                             |    |
|---------------------------------------------------------------------------------------------|----|
| Figure 4.1 Comparison of additional male body weights (AMW) between Ross and Cobb           | 38 |
| Figure 4.2 Comparison of additional vent scores (AVS) between Ross and Cobb                 | 39 |
| Figure 4.3 Comparison of additional body condition scores (ABCS) between Ross and Cobb      | 40 |
| Figure 4.4 Comparison of additional shank lengths (ASL) between Ross and Cobb               | 40 |
| Figure 4.5 Comparison of 12-day fertility values ( $F_{12}$ ) between Ross and Cobb         | 40 |
| Figure 4.6 Comparison of routine vent scores (RVS) and 18-day fertility values ( $F_{18}$ ) | 42 |

|                                                                                                                             |           |
|-----------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>Figure 4.7 Comparison of routine body condition scores (RBCS) and 18-day fertility values (F<sub>18</sub>)</b>           | <b>42</b> |
| <b>Figure 4.8 Comparison of additional vent scores (AVS) and 18-day fertility values (F<sub>18</sub>)</b>                   | <b>43</b> |
| <b>Figure 4.9 Comparison of routine vent scores (RVS) and additional vent scores (AVS)</b>                                  | <b>44</b> |
| <b>Figure 4.10 Comparison of additional shank lengths (ASL) and 18-day fertility values (F<sub>18</sub>)</b>                | <b>45</b> |
| <b>Figure 4.11 Comparison of additional shank lengths (ASL) and 12-day fertility values (F<sub>12</sub>)</b>                | <b>46</b> |
| <b>Figure 4.12 Comparison of additional body condition scores (ABCS) and 12-day fertility values (F<sub>12</sub>)</b>       | <b>47</b> |
| <b>Figure 4.13 Comparison of the routine farm body condition scores (RBCS) and 12-day fertility values (F<sub>12</sub>)</b> | <b>48</b> |
| <b>Figure 4.14 Comparison between the two body condition score measurements (RBCS and ABCS)</b>                             | <b>48</b> |
| <b>Figure 4.15 Comparison of routine female weights (RFW) and 18-day fertility values (F<sub>18</sub>)</b>                  | <b>49</b> |
| <b>Figure 4.16 Comparison of routine female weights (RFW) and 12-day fertility values (F<sub>12</sub>)</b>                  | <b>50</b> |

## LIST OF ABBREVIATIONS

|                       |                                                     |
|-----------------------|-----------------------------------------------------|
| <b>AFMA</b>           | Animal Feed Manufacturers Association               |
| <b>AI</b>             | Artificial Insemination                             |
| <b>ABCS</b>           | Additional body condition score measurement         |
| <b>AMW</b>            | Additional male weight measurement                  |
| <b>ASL</b>            | Additional shank length measurement                 |
| <b>AVS</b>            | Additional vent score Measurement                   |
| <b>CP</b>             | Crude Protein                                       |
| <b>DAFF</b>           | Department of Agriculture, Forestry & Fisheries     |
| <b>F<sub>12</sub></b> | 12-day fertility value as expressed as a percentage |
| <b>F<sub>18</sub></b> | 18-day fertility value as expressed as a percentage |
| <b>FSH</b>            | Follicle Stimulating Hormone                        |
| <b>g</b>              | gram/s                                              |
| <b>Kcal</b>           | Kilocalorie/s                                       |
| <b>Kg</b>             | Kilogram/s                                          |
| <b>LH</b>             | Luteinizing Hormone                                 |
| <b>MAS</b>            | Marker Assisted Selection                           |
| <b>ME</b>             | Metabolizable Energy                                |
| <b>mm</b>             | Millimetre/s                                        |
| <b>ppm</b>            | Parts per Million                                   |
| <b>QTL</b>            | Quantitative Trait Loci                             |
| <b>R</b>              | South African Rands                                 |
| <b>RBCS</b>           | Routine body condition score measurement            |
| <b>RFIM</b>           | Routine feed intake of male's measurement           |
| <b>RFW</b>            | Routine female weight measurement                   |
| <b>RMW</b>            | Routine male weight measurement                     |
| <b>RVS</b>            | Routine vent score measurement                      |
| <b>SAPA</b>           | South African Poultry Association                   |
| <b>Std. Dev.</b>      | Standard Deviation                                  |
| <b>SQI</b>            | Semen Quality Index                                 |
| <b>%</b>              | Percentage                                          |

## Chapter 1

### Introduction

#### 1.1 Background of the broiler industry

The broiler industry has developed rapidly over the years to become one of the primary suppliers of white meat to the human population, and is fast becoming the most popular protein source in human diets. This is mainly due to its low relative cost when compared to pork or beef; and it is believed to be healthier than red meat (Husted, 2005). Figure 1.1 shows a comparison of the average cost of poultry meat versus beef and pork products. Broiler meat may be processed in various ways and provides for versatile and tasty meals for the modern consumer. Chicken meat is also regarded as a low fat alternative to red meat and rich in certain B vitamins and selenium which are not prevalent in red meat (Farrell, 2008; Fisinin, *et al.*, 2008).

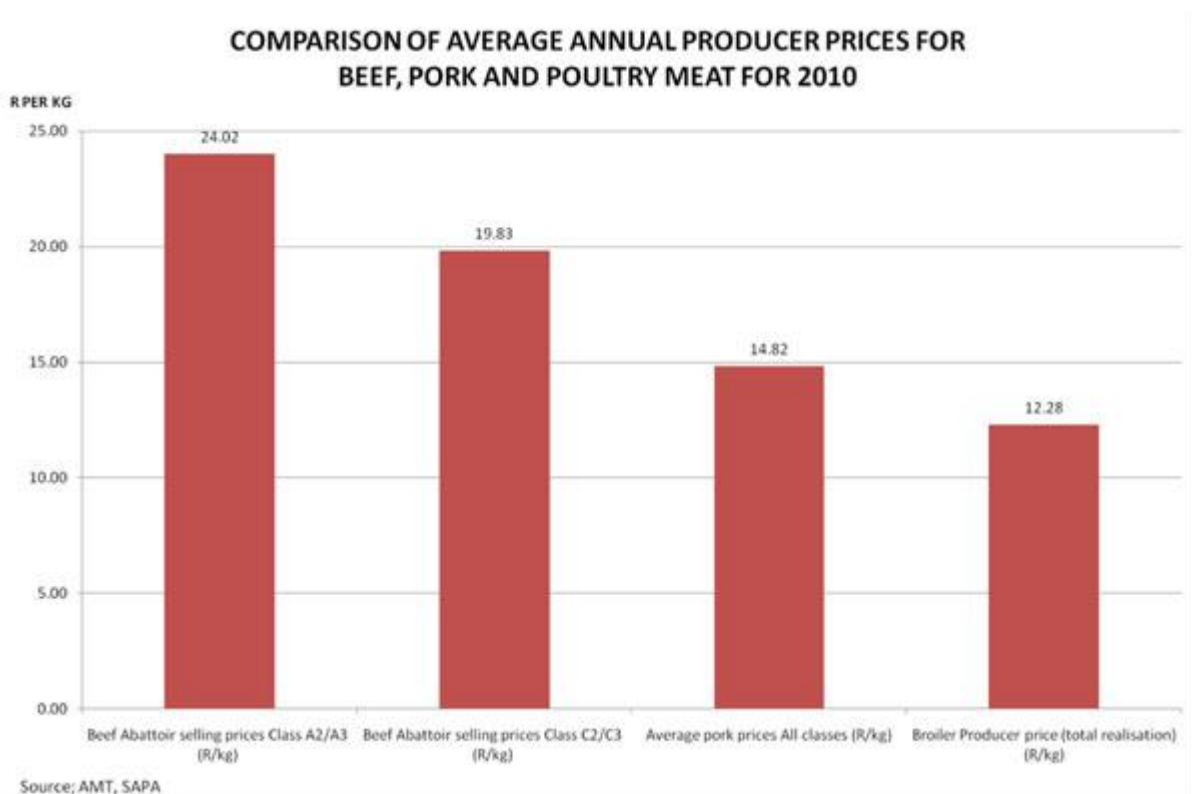


**Figure 1.1 Comparison of animal protein prices in 2010**  
(<http://www.sapoultry.co.za/pdf%20avi/tuesday/BO%20REPORT.pdf>)

From a production point of view, broilers have the advantage of a short generation interval, with an average of 35 days when compared to pigs and ruminants and therefore the poultry industry has the potential for high throughput and meeting the high demand for broiler meat. In the 1970's beef was the primary meat

source consumed in South Africa, but with the changes in relative accessibility and cost, poultry now has highest per capita consumption. Current statistics provided by the Department of Agriculture, Forestry and Fisheries (<http://www.daff.gov.za/docs/statsinfo/Ab2012.pdf>) indicated that the average per capita consumption of poultry was 34.91 kilograms per person. In comparison per capita consumption in 2011 for beef, pork and, mutton and goat were 17.07, 4.6, and 2.9 kilograms per annum respectively (<http://www.daff.gov.za/docs/statsinfo/Ab2012.pdf>). Globally South Africa was ranked 13<sup>th</sup> on the list for per capita consumption of poultry, with Hong Kong having the highest per capita consumption at 67.2 kilograms per person (<http://www.allcountries.org>). This further emphasized the importance of poultry as a protein source and a major component of the human diet. Other factors that influenced this shift were the health benefits of eating poultry, income level of consumer and the versatility of the final product (Husted, 2005; Farrell, 2008; Fisinin *et al.*, 2008). In Figure 1.2 the per capita consumption of animal protein in 2010 in South Africa is shown.

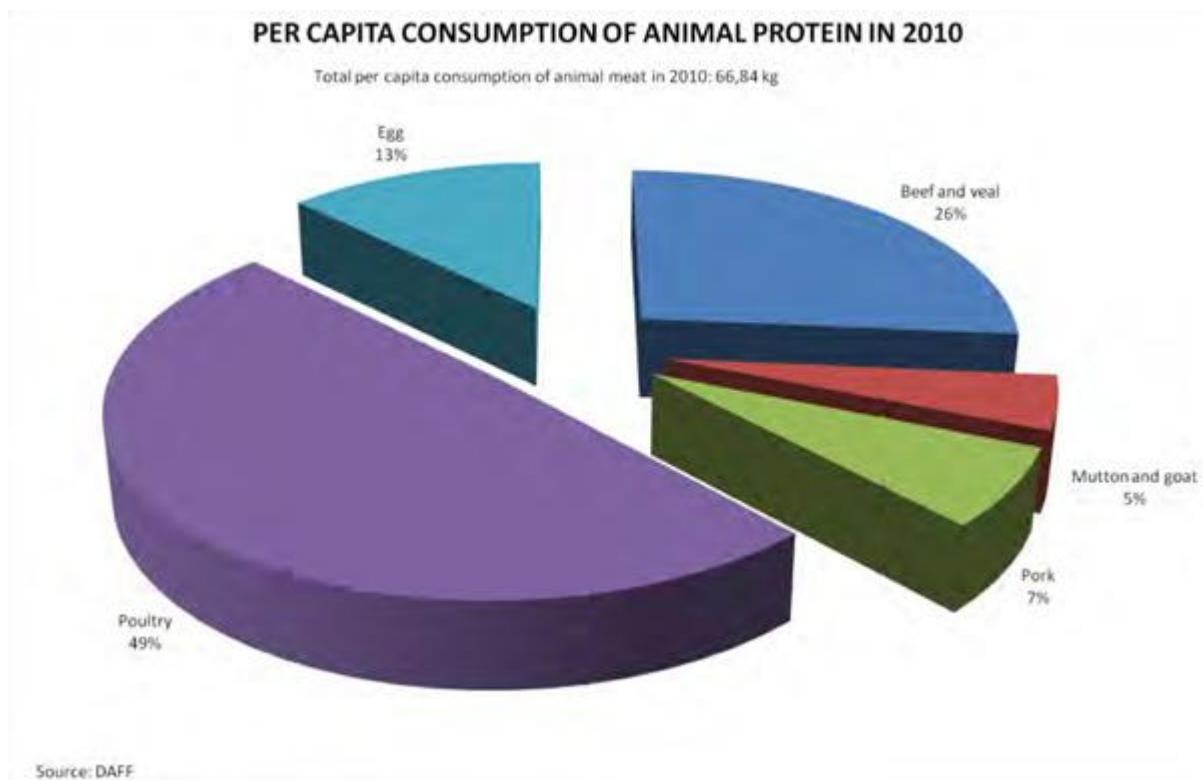


**Figure 1.2 Per capita consumption of animal protein in 2010**  
(<http://www.daff.gov.za/docs/statsinfo/Ab2012.pdf>)

South Africa's broiler meat production was estimated to be approximately 1 766 000 tons per annum with the gross value of R25 068 789 billion in 2011, making it one of the most important contributors to the value of agricultural production in South Africa (<http://www.daff.gov.za/docs/statsinfo/Ab2012.pdf>). Total

consumption has increased to 1 740 293 tonnes, which was 27% greater than beef, pork and mutton combined. In South Africa, commercial producers slaughtered an estimated 978.9 million broilers during 2011. The broiler organization of SAPA stated that more poultry products were consumed than all other animal products combined in their 2010 annual report, where 62.2% of the locally produced animal protein consumed in South Africa was from poultry. In 2011 imports of poultry products amounted to 350 202 million tons which were mainly from Brazil. Large-scale broiler producers contribute about 70% of the total poultry meat production, with the remaining 30% consisting of mature chicken slaughter (end-of-lay hens and breeders), small-scale and “backyard” poultry production, ducks, geese, turkeys and other specialised white-meat products ([http://www.daff.gov.za/docs/statsinfo/Trends\\_2010.pdf](http://www.daff.gov.za/docs/statsinfo/Trends_2010.pdf)). The poultry sector in South Africa used approximately 72% of the production output of the feed industry, and 15 -25% of total maize production. In South Africa, the poultry industry is dominant sector in agriculture, comprising 23% of total agriculture. Maize is the major ingredient of broiler meal, constituting 70% - 75% of the diet, with sunflower, soya, fishmeal and other ingredients making up the remainder ([http://www.nwpg.gov.za/transport/NWFTD/nw/industries/poultry\\_production/index\\_xml.html](http://www.nwpg.gov.za/transport/NWFTD/nw/industries/poultry_production/index_xml.html)). Production results from 2009 indicate that 4 019 million tonnes of maize were used for animal consumption, with poultry consuming approximately 2.4 million tonnes of that ([http://www.daff.gov.za/docs/statsinfo/Trends\\_2010.pdf](http://www.daff.gov.za/docs/statsinfo/Trends_2010.pdf)). Maize is a vital component of most animal’s diets and if the price of maize is high, the production costs will also be high for the producers, which may lead to the cost of the final product being higher. Less feed is used to feed poultry relative to beef cattle, per animal, thus the costs of production and final costs will be lower for poultry and hence more favourable for the consumer.

Over the past three decades the production of broiler meat has grown from a small scale business to one of the largest agricultural industries in the country. Consumer patterns have also changed from having the occasional roasted chicken to including broiler meat on a regular basis in the weekly diet. This is due to the ease and variety of preparation, as well as poultry being a healthier alternative to red meat and more affordable source of protein. Data provided by The South African Poultry Association (SAPA) and the Animal Feed Manufacturers Association (AFMA) indicated that the broiler industry in South Africa increased in output by sixty eight percent over the past ten years. Several factors contributed to the increase and fast development of the broiler industry, including the intense genetic selection on the birds by the parent breeding companies (Reddy, 1996; Eitan & Soller, 2002; Havenstein *et al.*, 2003); producing birds with lower residual feed intake and greater feed conversion efficiencies. Smaller framed broiler breeders require less feed, but with the benefit of higher egg production and a decrease in ages at sexual maturity. Modern broilers are now ready for slaughter at 32 days compared to 101 days four decades ago (Pollock, 1999; Flock *et al.*, 2005). The amount of feed consumed has decreased to give a feed conversion ratio much lower and more efficient than before (4.42 compared to the current ratio of 1.47). Both feed and housing technology

have also been improved upon. It is estimated that up to 85% of the improvement in broiler production was as a result of genetic improvement and the remaining 10 to 15% of this advance was due to improved housing and management practices.

## 1.2 Structure of the broiler breeding industry

The broiler breeder industry consists of a complex structure with all breeding stock owned by approximately ten companies worldwide (Szwaczkowski, 2003). Genetic selection is primarily based on pedigree selection where separate male and female lines are selected based on improvements in traits of economic importance (Reddy, 1996; Arthur & Albers, 2003; Thiruvankadan *et al.*, 2011). In the 1950's there were many primary breeders owning various lines of breeding stock in the Western countries, this decreased to about 20 in the early 1980's. Currently there are three groups of primary breeders that dominate the broiler breeding market worldwide namely Aviagen which includes Ross, Arbor Acres and Indian River breeds, Tyson (Cobb-Vantress and Avian) and Hubbard-ISA (Hubbard and Shaver) (Flock & Preisinger, 2002; Thiruvankadan *et al.*, 2011).

The poultry breeding companies developed ways of protecting their intellectual property investment in the few breeds available by selection of specific lines and development of hybrids, making use of crossbreeding, line breeding and inbreeding systems. This allows the companies to sell the specific line developed for the market demand, making these companies the sole suppliers of genetic material (Hoffmann, 2005). In South Africa there are two main breeds of broiler breeder stock namely Ross and Cobb. The grandparent stock imported from specific companies is based on line selection for specific traits; one line may be selected for superior growth rates, while another may have been selected for superior feed conversion efficiency. These lines would then be crossed to generate the Ross or Cobb parent stocks or broiler breeders, which produce the broilers for the South African market. In Figure 1.3 an outline of the structure in the broiler breeding industry in South Africa is shown.

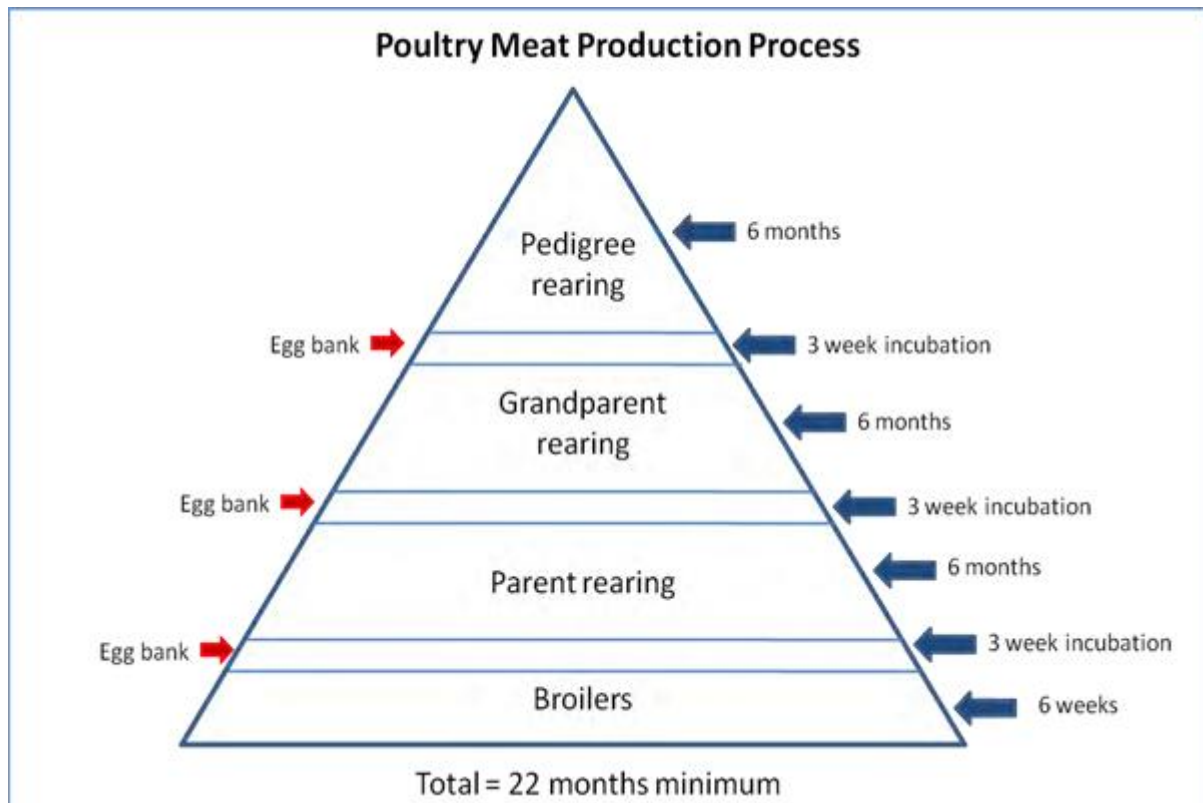


**Figure 1.3 Structure of the South African broiler industry**  
([http://www.sapoultry.co.za/industry\\_profile.php](http://www.sapoultry.co.za/industry_profile.php))

Of all the aspects important to broiler production, fertility of the broiler breeders is one of the most important, and it is affected by many external factors such as nutrition, genetics, management and environmental factors (Abudabos, 2010; Chung, 2010; Moyle *et al.*, 2010; Alsobayel & Albadry, 2012). The ultimate goal of the poultry industry is to produce a broiler chick that has high liveability, high growth and high feed conversion efficiency; therefore the modern parent stock has been bred with the genetic potential for high growth performance. This has certain limitations due to the negative association between growth and reproductive traits (Emmerson, 1997; Barbato, 1999; McGary *et al.*, 2002; Reddish, 2004; Decuyper *et al.*, 2010; Richards *et al.*, 2010; Meijerhof, 2011). The mating strategies applied to the great grandparent and grandparent stocks are to improve both reproduction and growth, but the emphasis is towards the growth of the broiler, which is the final product. This is controlled by the use of line breeding where specific lines are bred purely for one specific trait, whether it is superior growth or superior fertility. The multipliers are hybrids of these lines and their fertility is already genetically 'fixed'. The producer of the day-old chick needs to manage the available genetics to optimize fertility and production (Decuyper *et al.*, 2003). It is therefore essential to understand the rearing and overall management of broiler breeders, males in particular.

For the general determination of fertility in a flock, hatchability is the typical measurement used. This is due to the fact that if either of the parents is subfertile then the egg laid will not hatch. Standard hatchery practice for fertility determination is an 18-day candling. This is where clear eggs are removed and classified as infertile. This is not a true determination of fertility as some of the supposed infertile eggs could be early, middle or late embryonic deaths. A more suitable indicator would be a 12-day breakout to determine fertility. Indirect methods of determination of fertility in males have been described in the literature. McGary *et al.* (2003) indicated that morphological traits such as keel length, posterior pelvic width and length, comb length and width, and wattle length, width and area are correlated with fluctuating asymmetry of bilateral traits associated with fertility, such as the skeletal changes and delivery of semen. This indicates that these morphological traits may be used as measurement tools in the industry to determine the fertility of males. This is a fairly advantageous technique as these measurements can be included in standard management programs, and do not require the culling of birds as in other invasive techniques. The use of morphological traits, such as body weight, leg conformation, and secondary sex characteristics as indicators of male fertility in broiler breeders has been studied (McGary *et al.*, 2002). It was found that morphological characteristics, instead of body weight alone, were linked to a male's ability to mate efficiently.

### 1.3 Aim of this study

A broiler breeding and production company in South Africa contracted the Department of Animal and Wildlife Sciences of the University of Pretoria to conduct a research project on the identification and use of morphological traits as early indicators of male broiler breeder fertility to improve the management of the males and thus achieve better fertility. Morphological traits are those traits which pertain to the physical appearance of the animal and are generally easy to monitor in terms of development, and measurement of these traits is usually non-invasive and easily measured on live birds. It has been noted that there is a decrease in the fertility of the male broiler breeders at the end of their production cycle. Certain factors or conditions determine if the decline is rapid or if it is a gradual decline, or even if the potential level of fertility is reached in various phases. For these morphological traits to be useful they should be measureable in the beginning of the production cycle and be able to predict, or give an indication of fertility later in the cycle. Enabling management to modify accordingly and results of improved fertility seen before the end of the cycle. Producers of the parent stock, such as Ross and Cobb breeders, have a keen interest in the outcome of this study as it may improve their selection criteria.

The aim of this study was to evaluate existing data, with a number of production parameters measured routinely on-farm and to identify additional measurements that may be used as early indicators of male broiler breeder fertility. To achieve this aim two objectives were set. Firstly, the analysis of farm data, consisting of production parameters which were routinely recorded (weight, body condition score and feed

intake) collected over a period of two years. Secondly, an additional morphological trait of shank length was recorded during the same two year period on the same farms as those in the on-farm data collection; and analysed for comparison and association with routine farm production data. Male body weights, body condition score and vent score were also recorded as part of the additional measurements, this was to minimize the differences seen when these measurements are recorded by different individuals. The determination of fertility was done by using 12-day candling and breakout at 30, 35, 40, 50 and 60 weeks of age. These intervals were assumed to be the critical stages during the production cycle.

Hypothesis: Morphological traits can serve as early indicators of male broiler breeder fertility in breeder flocks.

## Chapter 2

### Literature review

#### Introduction

The main aim of the broiler breeder industry is to produce a healthy day old broiler chick with the ability to grow and reach a market weight of approximately 2kg within 35 days. Broilers are characterized by high growth rates and lean tissue deposition. The breeding objectives in the broiler industry are complex as both growth and reproductive traits need to be included in the selection program. In the broiler breeder grandparents, fertility is included, with the desired growth traits for the end product. However, the interaction between nutritional and reproductive traits is complex and continually changing with the introduction of new genetic lines (Renema *et al.*, 2006). Due to the unfavourable association between reproduction and growth in general, it has been quite a challenge to improve fertility in broiler breeders (Emmerson, 1997; Barbato, 1999; McGary *et al.*, 2002; Reddish, 2004; Decuypere *et al.*, 2010; Richards *et al.*, 2010; Meijerhof, 2011). The emphasis placed on high growth rates has been shown to result in poor reproductive efficiency (Rauw *et al.*, 1998; Bramwell, 2008b), especially in males (McGary *et al.*, 2002).

In this chapter literature was reviewed with regard to some of the factors that may influence male broiler breeder fertility, including external environment, genetics and nutrition.

#### 2.1.1 Inheritance of reproductive traits

Heritability estimates for traits of economic importance in poultry vary from low (0.1) for fitness traits to moderate and high (0.6) for growth traits (Nicholas, 1987; Le Bihan-Duval *et al.*, 1998; Kabir *et al.*, 2007; Momoh & Nwosu, 2008; Grosso *et al.*, 2010). Traits associated with female broiler breeder fertility, such as egg weight and age at first egg, have moderate heritabilities; while hatchability has a very low estimate of 0.1, as it is influenced by a number of environmental factors, such as egg handling, storage time, shell thickness and temperature (Kirk *et al.*, 1980; Bennett, 1992; Lapao *et al.*, 1999; Wiggins, 2008; Yassin *et al.*, 2008; Yoho *et al.*, 2008; Abudabos, 2010). Hatchability is however the trait most commonly used as the measure for fertility, as it is an easy trait to measure with little effect on production, but it is difficult to select for. In Table 2.1 heritability estimates of traits important for both broiler breeder fertility and production as reported in literature are shown.

**Table 2.1 Heritability estimates for traits of economic importance in poultry**

| <b>Trait</b>                            | <b>Heritability</b> | <b>Reference</b>                                                                                                                       |
|-----------------------------------------|---------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| <b>Fitness traits</b>                   |                     |                                                                                                                                        |
| Viability                               | 0.05-0.1            | Nicholas, 1987; Bourdon, 2000                                                                                                          |
| Mortality                               | 0.02-0.0893         | Robertson & Lerner, 1949; Shalev & Pasternak, 1983; Gavora, 1990                                                                       |
| Mortality due to reproductive disorders | 0.0264              | Robertson & Lerner, 1949                                                                                                               |
| Fertility                               | 0.05-0.2            | Shalev & Pasternak, 1983; Nicholas, 1987; Beaumont <i>et al.</i> , 1997; Leeson & Summers, 2000; Caverio & Schmutz, 2009; Wolc, 2009   |
| <b>Male reproductive traits</b>         |                     |                                                                                                                                        |
| Semen index                             | 0.15                | Al-Samarai <i>et al.</i> , 2009                                                                                                        |
| Mass motility                           | 0.29-0.87           | Kabir <i>et al.</i> , 2006; Al-Samarai <i>et al.</i> , 2009                                                                            |
| Individual motility                     | 0.28                | Al-Samarai <i>et al.</i> , 2009                                                                                                        |
| Dead spermatozoa                        | 0.22                | Al-Samarai <i>et al.</i> , 2009                                                                                                        |
| Abnormal spermatozoa                    | 0.24-0.42           | Kabir <i>et al.</i> , 2007; Al-Samarai <i>et al.</i> , 2009                                                                            |
| Ejaculate volume                        | 0.26-0.45           | Ansah <i>et al.</i> , 1985; Kabir <i>et al.</i> , 2007; Al-Samarai <i>et al.</i> , 2009                                                |
| Semen colour                            | 0.55                | Kabir <i>et al.</i> , 2006                                                                                                             |
| Sperm concentration                     | 0.37-0.73           | Ansah <i>et al.</i> , 1985; Kabir <i>et al.</i> , 2007                                                                                 |
| Sperm binding capacity                  | 0.38                | Barbato, 1999                                                                                                                          |
| <b>Egg related traits</b>               |                     |                                                                                                                                        |
| Hatchability                            | 0.05-0.27           | Nicholas, 1987; Pollock, 1999; Bourdon, 2000; Caverio & Schmutz, 2009                                                                  |
| Age at first egg                        | 0.44                | Lubritz & Smith, 1996                                                                                                                  |
| Egg weight                              | 0.52-0.91           | Nicholas, 1987; Ming <i>et al.</i> , 1995; Lubritz & Smith, 1996                                                                       |
| Egg size                                | 0.45                | Bourdon, 2000                                                                                                                          |
| Incubation time of egg                  | 0.49                | Suarez, 1997                                                                                                                           |
| <b>Growth related traits</b>            |                     |                                                                                                                                        |
| Feed conversion ratio                   | 0.2-0.4             | Pym & Nicholls, 1979; Pollock, 1999; Leeson & Summers, 2000; Momoh & Nwosu, 2008                                                       |
| Mature body weight                      | 0.21-0.71           | Nicholas, 1987; Chambers, 1990; Le-Bihan Duval, 1998; Bourdon, 2000; Pakdel, 2002; Whitehead <i>et al.</i> , 2003; Momoh & Nwosu, 2008 |
| Breast width                            | 0.25                | Bourdon, 2000                                                                                                                          |
| Breast meat yield                       | 0.52-0.65           | Le-Bihan Duval, 1998; Grosso, 2010                                                                                                     |
| Breast muscle percentage                | 0.73                | Zerehdaran <i>et al.</i> , 2004                                                                                                        |
| Abdominal fat percentage                | 0.71                | Zerehdaran <i>et al.</i> , 2004                                                                                                        |
| Abdominal fat yield                     | 0.63                | Le-Bihan Duval, 1998                                                                                                                   |
| Weight gain                             | 0.37                | Pym & Nicholls, 1979                                                                                                                   |
| <b>Conformation traits</b>              |                     |                                                                                                                                        |
| Shank length                            | 0.56-0.6            | Abdellatif, 1988; Campo <i>et al.</i> , 2005; Singh <i>et al.</i> , 2008                                                               |
| Fluctuating asymmetry                   | 0.1                 | Campo <i>et al.</i> , 2005                                                                                                             |

Selection for improved broiler production efficiency has a negative impact on subsequent reproductive efficiency in broiler breeders (Rauw *et al.*, 1998; Decuypere *et al.*, 2003; Bramwell, 2008b). Reproductive efficiency has been shown to be poorer with regard to reproductive capacity, which includes mating ability, fertility and semen specific characteristics (Rauw *et al.*, 1998; Barbato, 1999). In research on turkeys, intense long term selection for increased muscle mass resulted in impaired natural mating ability, as the males were

too heavy and damaged the females when mounting (Kjaer & Mench, 2003). This was overcome by the use of artificial insemination (AI), while still allowing for selection on growth to occur (Whitehead *et al.*, 2003).

Several reviews have indicated a negative genetic correlation between growth rate and components of semen quality (McGary *et al.*, 2002; Bilezikci *et al.*, 2005; Thiruvengadam *et al.*, 2011). There is however potential to apply positive correlated responses, where one of the two correlated traits is difficult to measure. There is a positive genetic correlation (0.75) between fertility and sperm binding capacity; where the greater the binding capacity of the sperm to the perivitelline membrane, results in a higher production of fertile eggs (Barbato, 1999). A positive phenotypic correlation was also found between fertility and semen quality by Baczynski (2008). As mentioned above fertility has a relatively low heritability of 0.1, and is expressed as a threshold trait, completely expressed (fertile) or not at all (infertile) (McDaniel and Craig, 1962; Barbato, 1999). Subfertility seems to be unevenly distributed among populations, with both male- and female- based phenotypes contributing to the problem (Robertson & Lerner, 1949; Wolc *et al.*, 2009). Subfertility was shown to be highly correlated (0.75), both phenotypically and genotypically, to sperm binding to *in vivo* or *in vitro* perivitelline membranes (Barbato, 1999). The culling of subfertile males identified on the basis of poor *in vitro* sperm binding should have a beneficial effect on the population. Secondary sexual characteristics in male broiler breeders have also been shown to have a direct relationship with fertility (McGary *et al.*, 2002); whereby male broiler breeders within specific strains with larger combs were likely to have higher fertility. Similarly wattle characteristics were shown to have a negative correlation (0.68) with sperm mobility, but a positive correlation of 0.55 was found between comb width and sperm concentration (Baczynski, 2008).

It has been suggested that major genes influenced sub fertility (Hocking & Duff, 1989; Brillard, 2004; Tona *et al.*, 2004; Wolc *et al.*, 2009; Sharifi *et al.*, 2010; King'ori, 2011). Molecular genetic studies in recent years have provided quantitative trait loci (QTL). QTLs are sections found on the chromosomes that affect traits, and may be useful in marker assisted selection (MAS). QTL's in the chicken genome have been segregated into five main categories of traits, namely; egg, growth, disease resistance, metabolic traits and behavioural traits. Of these five, the growth traits have substantially more QTL's. Studies to determine the QTL's that affect growth and feed efficiency traits, have returned variable results, where up to 22 different QTL's have been found that affect body weight (Thiruvengadam *et al.*, 2011).

The selection performed in broiler breeders has also led to changes in the skeletal structure of males, which affects semen transfer. Males have twice the risk of females in terms of skeletal disorders; this is mainly due to the initial rapid growth early in life and then the weight gain later in life (Thiruvengadam *et al.*, 2011). Research by McGary *et al.* (2003) has shown that morphological traits are correlated with fluctuating asymmetry of bilateral traits associated with fertility, and Campo *et al.* (2005) estimated that the heritability of fluctuating asymmetry is moderate, allowing indirect selection to occur on fertility. The bilateral traits that

were investigated included keel length, posterior pelvic width and length, comb length and width, and wattle length, width and area. Shank length was one of the morphological traits that were measured in the study by Deeb & Lamont (2002), and a heritability of 0.6 was reported. A high genetic correlation between shank length and body weight in males of 0.3-0.91 has been reported (Wolanski *et al.*, 2004; Kabir *et al.*, 2006; Wolanski *et al.*, 2006), and these morphological traits could therefore be used in selection for fertility in males. There is also a strong positive correlation of 0.25 between male body weight and the incidence of leg disorders (Riddell, 1992; Julian, 1998; Bradshaw *et al.*, 2002). A positive relationship with testes weight and comb area has been reported by Tyler & Gous. (2008) and can thus also be considered as an objective, non-invasive technique to determine fertility in male broiler breeders. Regardless of the method of selection, broiler growth has improved while the reproductive ability of the breeders has simultaneously decreased (Decuypere *et al.*, 2003; Brillard, 2004; Bramwell, 2005). Brillard (2004) suggested that alternative strains with slower growth rates should be considered, as well as focussing more on the use of artificial insemination.

### 2.1.2 Male versus Female Fertility

A main contention point in determining fertility in broiler breeders is if the cause of the infertility can be attributed to the males or the females. Both genetic and non-genetic factors from both the male and female affect egg fertilization and embryo development in breeder parents. Fertility of an individual egg is a function of the genotype of the embryo, to which both parents contribute and therefore, both paternal and maternal effects should be accounted for simultaneously when analysing fertility (Wolc *et al.*, 2009). Most of the research to date in broiler breeder fertility has been done on males (Liberona, 2007). Most of the studies have been conducted using AI, and the difference between AI and natural mating has not been accounted for (McGary *et al.*, 2002). The reduction of fertility observed in naturally mating flocks may be associated with increased body weight of the males toward the end of the production cycle (Hocking & Duff, 1989; Wolanski *et al.*, 2004; Chung, 2010). This is attributed to unsuccessful matings between the male and female, because of the size of the males.

Male factors affecting fertility may include sperm metabolism, semen concentration, sperm motility, and the percentage of abnormal or dead sperm cells (Wolc *et al.*, 2009). Behavioural factors include the male's ability to successfully and successively mate with the hens (Bilcik *et al.*, 2005). A large number of studies have been conducted with regards to semen evaluation and spermatozoa penetration of the perivitelline membrane, as indicators of male fertility, as well as external factors influencing these traits (Ansah *et al.*, 1985; Bramwell *et al.*, 1996b; Barbato, 1999; Donoghue *et al.*, 1999; Froman *et al.*, 1999; Hazary *et al.*, 2001; Parker *et al.*, 2002; Bowling *et al.*, 2003; Bilcik *et al.*, 2005; Gumulka & Kapkowska, 2005; Barna *et al.*, 2007; Al-Samrai *et al.*, 2009). An overall lack of association was found by Bilcik *et al.*

(2005) between mating behaviour, morphological traits, sperm quality and fertility. This suggested a multifactorial nature of fertility of males in natural mating systems (Bilcik *et al.*, 2005). It was reported by Barbato (1999) that subfertile females exhibited less than 50% sperm binding capacity when compared to fertile females. A decrease in a broiler breeder flock's fertility can mostly be attributed to individual males with extreme sub fertility (McGary *et al.*, 2002; Barna *et al.*, 2007). Research has shown that semen characteristics, more specifically sperm motility (Froman *et al.*, 1999), have a greater influence on fertility than when compared to the female reproductive system. In more recent work Froman (2006) indicated that male broiler breeder fertility can be improved by selection on sperm motility.

The negative effects of age on fertility and reproduction are poorly understood (Gumulka & Kapkowska, 2005). In a study to determine the effect of both male and female age on the number of spermatozoa that penetrate the perivitelline membrane, as an indication of fertility, the older males had a higher average penetration and fertility compared to the younger males (Bramwell *et al.*, 1996b). A study by Gumulka & Kapkowska (2005) to determine the effect of broiler breeder's age on fertility and sperm penetration of the perivitelline membrane showed that the decrease in fertility as the flock ages was more obvious in the females than in the males, it suggested that this was due to the decreased efficiency of the sperm storage tubules. A study concerning the age-related decline in fertility by Barna *et al.* (2007), demonstrated that sperm penetration of the perivitelline membrane still decreased regardless of male number, which indicated that the female reproductive tract and other female effects may have a greater effect on the decrease in fertility in the later stages of the cycle, than what was previously believed. A general rule is that fertility usually increases from 65-75% at the beginning of the production cycle and peaks at 95-98% at 35-37 weeks of age, and then between 40-45 weeks, fertility begins to decline. One possible reason for this decline in fertility is that after 40 weeks the female needs more frequent matings to maintain the high fertility while at the same age the male mating activity is decreasing (Wilson *et al.*, 2002).

A possible solution to this age related decline in fertility of female broiler breeders, while using AI is to decrease the time interval between inseminations, or to increase the sperm concentration (Bramwell, 2008a). It was discovered through AI, spermatozoa penetration was affected by the age of the females and not the age of the males. Sperm mobility is used as an indicator of semen quality (Bowling *et al.*, 2003), and poor semen quality has a direct effect on fertility. As such most breeder managers would opt for the use of AI. This is a very accurate method, but it must be justified as it is time consuming and costly (Bearden *et al.*, 2004). Studies indicate that AI will not become a major practice in the broiler industry as it has in the turkey industry, and as such the broiler breeder industry will continue to rely on natural mating systems. This is due to the cost in terms of monetary value and time versus the advantages of AI. This emphasizes the need for management practices to be improved upon to manage the negative correlation between body weight and

reproductive performance in broiler breeders (Emmerson, 1997; Barbato, 1999; McGary *et al.*, 2002; Reddish, 2004; Aziz, 2009; Decuypere *et al.*, 2010; Richards *et al.*, 2010; Meijerhof, 2011).

In order to manage fertility in male broiler breeders optimally, the analysis of sperm characteristics and the culling of inferior males need to be included in the current management programs (Donoghue, 1999). It would also be beneficial to analyse males during the rearing phase, as this is where all gonadal development occurs, and very little can be done from a physiological point of view during the production phase. It is therefore essential to understand the rearing and overall management of the males. Males are smaller and less uniform than females at one day of age; they have been dubbed and doted which adds to the already great stress (Liberona, 2007). It is recommended by all the major breeders that males are checked regularly to maintain uniformity in terms of body weight, weight gain and feed intake as this will have an effect on overall fertility (Liberona, 2007).

During the life of the male broiler breeders there are three main periods of sexual development, which are critical in terms of fertility. The first two periods occur during the rearing phase of the cycle, whereas the third period occurs during the production phase of the cycle. The first period is from hatch to 14 weeks of age, this is where testicular growth is slow, multiplication of the Sertoli cells occurs during this period and optimum sperm cell number is determined by this. The second period is from 14 to 24 weeks, and this is where there is rapid testicular growth and semen production begins. The last phase is from 25 weeks onwards, which is during the production phase of the cycle. Testicular growth should be completed by 30 weeks and remain constant until at least 40 weeks, and then will decrease gradually from then onwards (Liberona, 2007). It can be seen from these three stages that the most critical would be the first, if there is no proper testicular development and inadequate Sertoli cell multiplication, there will not be sufficient sperm production, and thus a lowered fertility. Vizcarra *et al.* (2001) noted that the theoretical maximum number of sperm was directly linked to the number of Sertoli cells. These Sertoli cells are stimulated by Follicle Stimulating Hormone (FSH). Sertoli cell development is completed by 10 weeks of age and thus maximum sperm production in male broiler breeders is determined around the same time (Vizcarra *et al.*, 2001). It can then be hypothesized that increasing FSH concentrations at rearing may increase maximum sperm production and increase overall fertility. Problems during any of these phases, such as poor management or disease will influence and greatly reduce fertility.

It can safely be assumed that if an egg has been laid, the potential fertility is there (Liberona, 2007). Female factors include egg quality, behavioural and physiological factors such as prevalence of sperm storage tubules (Cavero & Schmutz, 2009). Management factors will influence the hatchability of the fertile egg. The main cause of infertility in female broiler breeders according to Liberona (2007) is overfeeding, which leads to obesity. Fertility is also known to be reduced in broiler breeder hens with high body weights

(Rauw *et al.*, 1998). Visual traits, such as back feathering in female broiler breeders, have been applied by Moyle *et al.* (2010) as an indication of mating activity to female broiler breeders, where less feathering was due to higher mating activity. The study indicated that this was not true, and feather loss cannot be attributed to mating activity alone, and may have even acted as a deterrent to the males (Moyle *et al.*, 2010). Literature has shown that high body weights and fat deposition are negatively correlated with fertility in broiler breeders (Wilson, 2002; Romero-Sanchez, 2005; Chung, 2010).

### 2.1.3 Nutritional Factors

Nutritional influences on male broiler breeder fertility were not included in the aim of this study, although numerous studies have been conducted over the years (Robey *et al.*, 1988; Fontana *et al.*, 1990; Bramwell *et al.*, 1996; Walsh & Brake, 1996; Millman *et al.*, 2000; Surai, 2002; Tona *et al.*, 2004; Tolcamp *et al.*, 2005; Liberona, 2007; Renema *et al.*, 2007b; Romero-Sanchez *et al.*, 2007; Pishnamazi *et al.*, 2008; De Jong & Guemene, 2009; Romero *et al.*, 2009; Richards *et al.*, 2010) clearly indicating that nutrition has a large and varied effect on broiler breeders in general, and specifically fertility. In order for optimum production, formulation of the diet must integrate information about the bird, the feed, and the environment into an accurate theory that can then be used in a model where it would then be possible to determine the most economical method of feeding broilers under a wide range of economic conditions (Gous, 1998).

Broiler breeder diets are usually high in protein and energy; the diets are tailored to be nutrient dense to counteract the effects of feed restrictions (Brake, 2003). In a study by Romero-Sanchez *et al.* (2007) the effect of cumulative nutrition on fertility and other physiological traits, such as body weight, shank length and comb height, were studied by feeding two diets, it was shown that the high plane of nutrition increased body weight, shank length, and comb height during the rearing period, whereas the low plane of nutrition showed improved fertility during late production. A cumulative nutrient intake during the rearing period of 29 580 kcal of Metabolizable Energy (ME) and 1 470 g of Crude Protein (CP) was shown to be sufficient for later male reproductive performance (Brake, 2003). CP has one of the greatest effects on fertility during the rearing period as this is where most of the protein is needed for growth and development (Brake, 2003). Studies have shown that if there was a decrease in dietary energy intake, there would be a negative effect on sperm concentration and total live sperm, but there was no effect on ejaculate volume or percentage dead sperm per ejaculate (Bramwell *et al.*, 1996a). After a 16 week trial of dietary energy treatment, it was shown that there is a significant linear and proportional effect of the diet on testes weight. The majority of the results of nutritional trials suggest that nutritional strategies may be used to counteract the negative correlation between fertility and growth traits (Brake, 2003).

Nutrition and feeding of the female broiler breeder should be based on reproductive physiology of the birds; and factors that influence their growth (Renema *et al.*, 2006). Inadequate nutrition during rearing, regardless of the weight of the female will lead to poor fertility later on in the cycle (Brake, 2003). Effective ovary management is seen as an integral part of a successful breeder management program, with regards to the female broiler breeder.

#### **2.1.4 Environmental Factors**

Environmental factors would include any external factors that have an effect on the male broiler breeder, and in turn affect fertility. Such factors would include lighting regime, housing situation, stocking density, mating ratio and other management practices. The reproductive efficiency of broiler breeders is increasingly dependent on very specific feed restriction and lighting programs to optimise reproduction (Renema *et al.*, 2006).

Light intensity and duration affects broiler breeder fertility, and selection for increased photoperiodic drive in males should improve the photoperiodic drive in the females, and thus improve female reproductive performance (Eitan & Soller, 1996). It was found by Lewis *et al.* (2008) that birds performed better in a transfer from eight hours light to 16 hours of light, as opposed to the control of a constant 16 hours of light. The birds with the increased light showed improved growth and feed conversion efficiency. This result has mainly been attributed to the decrease in nocturnal feeding when shifting to longer light lengths. Moyle *et al.*, (2012) also showed that males that were older at the time of light stimulation had a higher fertility than younger males; these younger males also exhibited a lower mating frequency than the older males. It was demonstrated by Vizcarra *et al.* (2001) that there is a designated point for establishing the regulation of gonadotropin secretion, which is partially complete in the first few weeks of life. It is also suggested that circulating levels of FSH are related to testicular size, and to the theoretical level of reproduction. As such, it can be inferred that management conditions can alter the circadian rhythms, which in turns alters FSH levels and reproductive capacity. Circadian rhythms relate to the body's natural response to different periods of light and dark. Even though in most broiler breeder production units, the light is controlled artificially, there will always be the underlying natural rhythm, but it can be mostly controlled by the lighting regimes in place. A study conducted by Lewis *et al.* (2005) in determining the effects of photoperiods on plasma FSH and Luteinizing Hormone (LH) concentrations, concluded that plasma FSH and LH concentrations are of little value to the broiler breeder industry in terms of determining the degree of photorefractoriness, age at sexual maturity or subsequent egg production. Male broiler breeders subjected to photoperiod changes in the later stages of the production cycle showed little or no change with regard to reproductive status.

The male broiler breeder's fertility naturally decreases as the cycle progresses. The onset of photorefractoriness in male broiler breeders was earlier than the standard photoperiod length, when the photoperiod length was increased at 40 weeks of age (Tyler *et al.*, 2011). A study to determine the effects of body weight and lighting regime on broiler breeder production showed that sexual maturity of the broiler breeders under standard lighting conditions were at a younger age than those that were subjected to a non-incremental lighting regime. It was concluded that either broiler breeders require an increment in photoperiod to stimulate rapid gonadal development or that broiler breeders exhibit juvenile photorefractoriness that takes longer to be dissipated when birds are not given a period of short days (Gous & Cherry, 2004).

In more recent years there has been a progressive shift in chicken production to warmer geographic areas (Daghir *et al.*, 2009; Dickson-Hoyle & Reenber, 2009; Gillespie & Flanders, 2009). Most broiler breeder flocks are now housed in open-sided houses, where light cannot be controlled completely, although rearing does occur in closed houses where the lighting conditions can be controlled. The benefit of making use of closed houses in rearing is that the crucial stages of development can be influenced more easily with regards to sexual development and maturation. Earlier than accepted sexual maturity of broiler breeders that have been stimulated by external photoperiods will result in smaller eggs. In males, early sexual maturity is generally followed by a rapid decrease in reproductive performance (Mathur, 2003; Lewis *et al.*, 2005; Lewis *et al.*, 2006).

A study making use of a dwarf strain of broiler breeders, by Lubritz & Smith (1996) concluded that there should be a favourable response in dwarf breeds when selected for reproductive performance. This could be beneficial in broiler breeder production, as smaller animals need smaller housing and have lower feed requirements (Lubritz & Smith, 1996; Charpentier, 2009; Pym, 2010). The dwarf strain may also have a lowered incidence of heat stress, but this is counteracted by the lower body weight which in turn leads to reduced egg numbers and egg weights (Mathur, 2003). Thiruvankadan *et al.* (2011) confirmed previous research on the benefits of including the dwarf gene into selection programs

Heat stress is termed a period of time whereby an animal is unable to maintain internal physiological temperature balance due to the external environment. Heat stress will have an effect on fertility in both males and females (McDaniel *et al.*, 1995). Sperm from heat stressed males showed a lower penetration of the perivitelline membrane than sperm from normal males (McDaniel *et al.*, 1995). Egg production in general will be decreased in heat stressed females (McDaniel *et al.*, 1995). Semen volume, spermatocrit and percentage dead sperm do not seem to be affected by higher ambient temperatures. It was noted that males under heat stress conditions would contribute more to the overall infertility than females would (McDaniel *et al.*, 1995) that male fertility is more affected by heat stress than females. A further study by McDaniel *et al.*

(2004) on males was to determine the effect of heat stress and whether the addition of ascorbic acid to the diet had any effect. It has been shown that during periods of mild and extreme heat stress that the percentage of dead sperm in the ejaculate increases, but will return to normal during the recovery period. There was also a linear decrease in sperm mobility during heat stress, which also increased again during the recovery period. The addition of ascorbic acid to the diet did not improve semen characteristics of heat stressed or non-heat stressed males. High levels of ascorbic acid (1000 parts per million (ppm)) were seen to lower fertility during heat stress. A comparison between heat stressed male broiler breeders and a control group based on seminal plasma function, showed that the seminal plasma from heat stressed males had decreased fertilizing ability. Furthermore, combining the control with the heat stressed group's seminal plasma did not improve fertilizing ability (Karaca *et al.*, 2002).

Male-male competition and morphological traits such as body weight, comb, wattle, and tarsus and spur size, as indicators of reproductive success in broiler breeders were investigated by Bilcik & Estevez (2004). The results showed that male competition did have an effect on mating efficiency, but not on efficacy. Males with the highest mating activity did not necessarily sire the most offspring. It was also found that none of the morphological traits they examined would be useful as indicators of male reproductive potential, which could possibly be explained by the small number of males in the trial (Bilcik & Estevez 2004). Further work conducted by Bilcik *et al.* (2005) in the determination of male-male competition, sperm quality and morphological characteristics, the results showed that males with higher body weights had higher mating frequencies, but without cloacal contact, than those of lower weights. It was also shown that males with smaller combs had more mating attempts, whether successful or not. After analysis of the sperm of the males it was determined that males with higher sperm concentrations also had lower fertility (Bilcik *et al.*, 2005). These researchers were unable to find strong significant associations between the morphological traits examined and fertility and sperm quality.

The mating ratio, or the number of males to females, is an important parameter for maximizing fertility. Parent stock breeders recommend about eight or nine males to 100 females at 20 to 30 weeks of age with a reduction to about six or seven males to 100 females at the end of the production cycle. It was reported by Hazary *et al.* (2001) that when there is a ratio greater than one male to ten females, the fertility may be adversely affected by male aggression and competition for mating and territory, this was further emphasized by Chotesangasa (2001) whereby an experiment comparing differing mating ratios was conducted. Higher mating ratios had lower levels of fertility due to male-male interactions. The correct mating ratio is dependent on the strain and condition of the broiler breeders (Wilson, 2002). In a flock where males are more aggressive, fewer males would be needed, similarly for body condition where if the males are in a better condition, they will be able to mate effectively and efficiently (Wilson, 2002). Higher fertility is

seen when there are fewer males to females, either as a response of the females to fewer males, or a decrease in aggression between the males, and more mating activity (Bilcik *et al.*, 2005).

Spiking is considered as a possible short term solution in older flocks where there is a lower fertility. Spiking is where young broiler breeder males are introduced into an older flock to compensate for the decline in fertility that usually occurs after 45 weeks of age (Chung, 2010; <http://www.cobb-vantress.com>). This decline in fertility can be due to a decrease in mating interest (35-40 weeks of age), a reduction in sperm quality (55 weeks), lower mating efficiency (poor management leading to males in poor physical condition), or excess male mortality resulting in a reduced male to female ratio (<http://www.cobb-vantress.com>). Spiking will not, however, solve the infertility issue as those sub fertile birds are still present (Barna *et al.*, 2007). Alternatively the decline in fertility can be addressed by practicing intra-spiking. This is where males from other houses on the same site are moved between houses. It is also beneficial in terms of the age as all males are the same age whereas new males brought in might be of different ages (Casanovas, 2000). Intra-spiking is the exchanging 25-30% of original males between houses from the same farm, without importing any young males, to create a similar stimulus to mating activity as the one created by spiking. Like spiking, intra-spiking gives better results when done earlier in life (<45 weeks). Intra-spiking is inexpensive, easy-to-practice and has a minimal biosecurity risk. It has also been seen when infertile males are removed, they tend to have a high incidence of musculo-skeletal lesions (Hocking & Duff, 1989). There may also be a decrease in the libido of the older males if spiking is practiced (Duncan *et al.*, 1990). It can then be hypothesized that if male body weight is controlled by feed restrictions, there would be a lowered incidence of lesions and a raised level of fertility (Casanovas, 2000).

## 2.2 Morphological traits and fertility

A number of studies have shown that morphological traits have some correlations or associations with fertility (Barbato, 1999; McGary *et al.*, 2003; Wolanski *et al.*, 2004; Bilcik *et al.*, 2005). Shank length is typically recorded from the top of the hock to the base of the foot pad. If the foot pad is swollen and cracked a more accurate measurement would be from the hock joint to the crevice on the side of the foot pad (Galal, 2007; Renema *et al.*, 2007b). Shank length measurement in poultry has a high heritability of 0.7 (Deeb & Lamont, 2002). Shanks that are considered long in relation to their weight are a major source of leg problems in heavier birds. Therefore broilers have been successfully selected for proportionally shorter shanks for many generations. Direct selection to reduce shank length in broilers has dramatically altered the percentage shank length, despite the high genetic correlation with body weight (Chambers, 1990). A positive correlation between both body length and shank length with adult body weight in the local chickens of Tanzania was reported by Msoffe *et al.* (2001). In a study on Rhode Island Red and Rhode Island White chickens to determine heritabilities and interrelationships of certain traits Kabir *et al.* (2006) found that shank length and

body weight were highly correlated (0.645) at a young age in the birds. The correlation was still positive as the birds matured (0.582), but it was not as high.

Cobb parent stock studies have shown that testes size is directly related to fertility, as it relates to sperm producing capability (<http://www.cobb-vantress.com>). Reference is also made by the parent companies that body weight is also directly related to testes size, and in turn to fertility. Comb size has been related to testes size, only up until sexual maturity at 35 weeks of age. Shank length has not been correlated with testes development, but with mating ability (Casanovas, 2008). A study by Wolanski *et al.* (2006) focused on chick quality and early growth traits in broiler breeders where shank length, body weight, chick length and hock colour were included. The study showed that specifically shank length and chick body length correlated more with body weight at 14 days of age than at hatch, which lead the researchers to conclude that it is valuable to assess the chick more accurately at hatch to have improved broiler breeder production and fertility (Wolanski *et al.*, 2006).

### **2.3 Future considerations for broiler breeder production**

A current method of determining fertility is the egg breakout technique (Wilson *et al.*, 2004). This method is used to determine the amount of eggs that will be needed to supply growers with day old broiler chicks. It also acts as a diagnostic tool for investigating why flocks are not hatching as predicted (Wilson *et al.*, 2004). A technique which may become useful in the future is the sperm penetration assay; this is a technique that was developed to determine quantitatively sperm-egg binding and sperm penetration of the perivitelline layer (Bramwell *et al.*, 2004). The correlation between this in vitro assay and infertility across all broiler breeder lines is between 0.75 and 0.85 (Szwaczkowski, 2003). Thus this method could become particularly useful in determining fertility/infertility. As mentioned earlier this method has been used successfully in heat stress trials where the higher sperm penetration resulted in higher fertility. A new technology for use in artificial insemination of hens is the use of the OptiBreed Sperm Quality Index. If semen quality is known before use, then the dosage used in AI could be less, if the diluents used are adequate. This would allow for the maximum number of inseminations per ejaculate to occur (Parker *et al.*, 2002). The Sperm Quality Index (SQI) is an overall measure of semen quality and relies on the number of deflections of light due to the movement of sperm in a capillary tube (Parker *et al.*, 2002). A major disadvantage of SQI is that it can only be used accurately after 28 weeks of age as this is when the values become static and are therefore more accurate predictors of fertility (Parker *et al.*, 2002). Another method of semen analysis is the Osborne index. This is a technique used when multiple traits are objectively selected for, and are valued in accordance with their relative economic importance, heritability and correlations with the other traits. It provides a relative index of the traits to allow for optimal results when selecting for multiple traits (Kabir *et al.*, 2007).

Many production companies have shifted their focus to chick quality, as it is essential to have a healthy day old broiler breeder chick in order to optimize its productive life through management, nutrition and other factors (Decuyper *et al.*, 2006). Certain factors, such as egg holding time and temperature and others will affect the hatchability of broiler breeders. If a broiler breeder chick is not healthy at day one, it cannot be expected to perform optimally later in life.

## **Conclusion**

In conclusion, there is sufficient evidence from literature that fertility problems associated with male broiler breeders requires attention. In this study morphological traits of males will be analysed during the production cycle of a number of broiler breeder flocks within a broiler breeder company, and compared to routine farm data as well as hatchability data to determine potential morphological traits as early indicators of male broiler breeder fertility.

## Chapter 3

### Materials and Methods

The data used in this study was provided by one of the major broiler breeder companies in South Africa. Data analysis in this study consisted of the routine measurements on-farm and additional morphological traits measured. The data was collected over a period of 14 months, from seven broiler breeder production farms.

#### 3.1 Materials

##### 3.1.1 Origin and background of routine farm data collected

The data originated from seven farms in the Gauteng region. The management practices on the different farms were fairly similar, and were based on standard guidelines provided by Ross and Cobb. Standard guidelines were introduced in 2007, and as such all practices after this date are more uniform and consistent between farms compared to previous years. Housing types differ between the rearing and breeding farms, where light-tight type environmentally controlled housing is used in rearing, while breeding farms make use of naturally ventilated and fan assisted housing. Temperature is monitored on a daily basis using minimum/maximum thermometers. Light intensity and daylight length are strictly controlled, with different programs followed for rearing and breeding. General housing and management guidelines are shown in appendix A. Table 3.1 provides a summary of the farms included in this study, as well as the breeds on those farms. Farm I experienced a disease outbreak towards the end of the production cycle and data for this farm was thus incomplete, and as such was removed from the study, leaving six farms for the final analysis.

**Table 3.1 Summary of farms included in the study**

| Farm | Breed    | Notes    |
|------|----------|----------|
| A    | Cobb PS  |          |
| D    | Ross 308 |          |
| E    | Ross 308 |          |
| F    | Cobb PS  |          |
| G    | Cobb PS  |          |
| H    | Cobb PS  |          |
| I    | Ross 308 | Excluded |

On the broiler breeder farms the average production cycle commences with the males and females being introduced at 20 weeks of age. The sexes were kept separate at the rearing farms up to 20 weeks of age. Males were introduced from the rearing farm first to adapt to the feeder and drinker systems, regardless

of which male feeding system is in place. The average capacity of the houses within the group varies between 1000 and 6000 birds, with 10% being males, and an average stocking density of 5.5 birds per m<sup>2</sup>. The initial mating ratio is 10 females to one male and this is decreased as the cycle progressed to about seven females for every male by week 55. Mating ratio will vary from farm to farm and depend on mortalities, culls and other production data such as fertility and egg production.

Feeding was managed via a controlled feed intake program based on the parent breeder company guidelines and nutrient specifications. The general dietary guidelines recommended by the Ross and Cobb parent stock companies for broiler breeders were attached as Appendix B. Female broiler breeders were fed with the use of track feeders and males were fed with either pan or trough feeders.

### 3.1.2 Composition of the routine farm data

The routine farm data consisted of seven major categories, with various traits measured in these categories. Most traits described were recorded on all of the farms, except vent scoring, which was only recorded on six of the farms. These measurements were included in the daily practices of the farm and consist of feed intake, mortalities, body weight, egg production, culls and fertility. Table 3.2 shows a summary of the standard measurements recorded routinely on the farms used in this study.

**Table 3.2 Summary of standard traits recorded routinely on all farms**

| Category of traits | Trait measured                | Number of farms |
|--------------------|-------------------------------|-----------------|
| Weights:           | Male weight (g)               | 7               |
|                    | Female weight (g)             | 7               |
| Feed intake:       | Male feed intake (g)          | 7               |
|                    | Female feed intake            | 7               |
| Mortalities:       | Male mortalities              | 7               |
|                    | Female mortalities            | 7               |
| Culls:             | Male culls                    | 7               |
|                    | Female culls                  | 7               |
| Egg production:    | Total egg production          | 7               |
|                    | Total eggs set                | 7               |
|                    | Number of fertile eggs        | 7               |
|                    | Number of first grade chicks  | 7               |
|                    | Number of second grade chicks | 7               |
| Subjective scores: | Body condition score          | 7               |
|                    | Vent score                    | 6               |

### 3.1.3 Objective and subjective measurements related to broiler breeder fertility

Various measurements are employed on the farms as management techniques to monitor the growth and production of the birds. In Table 3.3 is a brief description of some of the measurements included in this study.

**Table 3.3 Description of measurements routinely recorded on farm**

| Trait/measurement    | Description                                                                             | Unit of measurement | Repeat | Comment                             |
|----------------------|-----------------------------------------------------------------------------------------|---------------------|--------|-------------------------------------|
| Body weight          | 100 birds per house are weighed                                                         | g                   | Weekly | Both males and females are weighed. |
| Vent score           | Scoring of vent of males for sexual activity                                            | Score of 1 to 5     | Weekly | Subjective measurement.             |
| Body condition score | Scoring of fleshing of males for 'fitness', to determine change in condition over time. | Score of 1 to 5     | Weekly | Subjective measurement.             |

Body weight is a measurement that is routinely done on a weekly basis on all the farms. The weekly measurements were recorded by the same individual every time on a particular farm. Both male and female data was recorded and compared to the breed standards. The scales used were either electronic or manual. On average 100 birds per house were weighed and scored. Birds were cordoned off in pens in various places in the houses, and weighed. Body weight was recorded in grams (g). Usually once all the birds have been weighed an average body weight and coefficient of variation were calculated, which is a measure of flock uniformity. Uniformity of a flock gives an indication of how the distribution of a specific trait is spread over a normal curve. This was mainly done with body weight. A uniform flock for body weight would be where 80% of the flock are within 10% of the flock mean (Leeson & Summers, 2006).

Vent scoring was only done on the males and although it is a subjective measurement, it is a useful indicator of sexual activity. Vent scoring is where the vent was examined and given a score between one and five. A vent score of five indicated a red vent, with apparent moisture and little feather cover. A vent score of one, on the other hand, was indicative of a white vent, which was dry and possibly flakey with the surrounding feathers fully re-grown. A vent score of five was ideal, as it showed the male had a high level of sexual activity, whereas a vent score of one usually meant the male was not active (personal communication, Mr. K. Bezuidenhoudt, [hennops@gmail.com](mailto:hennops@gmail.com)). Figures 3.1 and 3.2 show the two extremes of vent scoring. Vent scoring was done at the same time as weighing with the same males used.



**Figure 3.1 Vent score of five**



**Figure 3.2 Vent score of one**

Body condition score was also done on a scale of one to five and was an indication of the amount of fleshing on the breast of the bird. A condition score of five indicated an over fat bird with a well-rounded breast resembling the letter ‘U’, and a condition score of one showed a skinny bird with very little flesh covering, similar to a ‘V’ shape. Condition score optimum is between a two and a three. Body condition scoring is also a subjective method and was done by the same individual to minimize variation and error. Figure 3.3 shows a practical example of a worker condition scoring a bird, while Figure 3.4 shows a simplified chart of the body condition score scale.



**Figure 3.3 House manager condition scoring a male broiler**

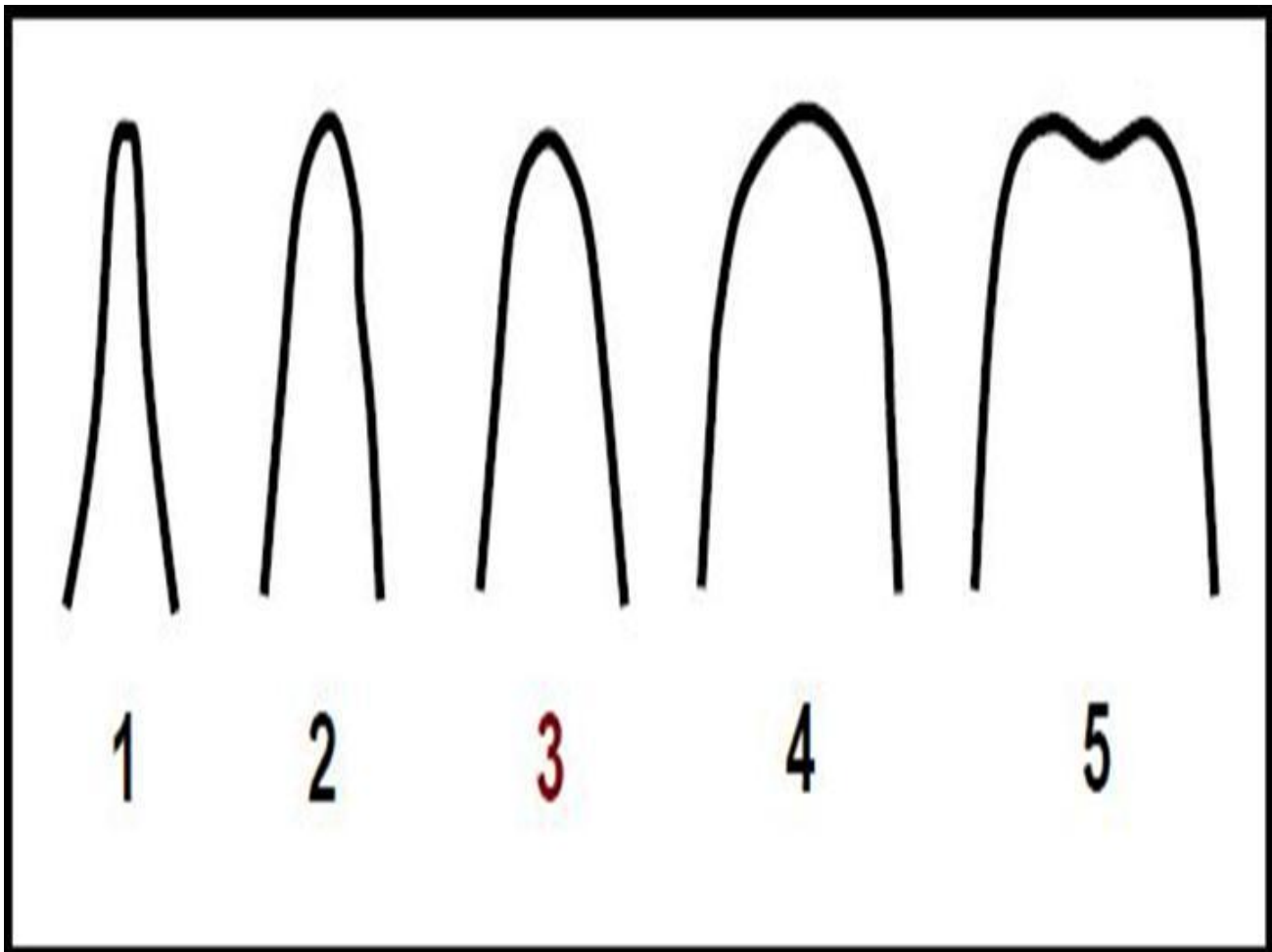


Figure 3.4 Chart of body condition scoring (<http://www.cobb-vantress.com>)

For all the farms, corresponding data for the hatcheries were also collected, including hatchability and fertility. Table 3.4 shows a summary of the hatchery capacities.

**Table 3.4 Hatchery capacities within the company**

| Hatchery | Total number of setters | Total capacity of setters | Total number of hatchers | Total capacity of hatchers |
|----------|-------------------------|---------------------------|--------------------------|----------------------------|
| HA       | 16                      | 1 843 200                 | 16                       | 307 200                    |
| HB       | 20                      | 1 848 744                 | 20                       | 308 124                    |
| HC       | 36                      | 2 076 300                 | 18                       | 345 600                    |

## 3.2 Methods

### 3.2.1 Additional data collection

Seven broiler breeder flocks were followed through their 40 week production cycle and additional morphological traits thought to be of importance to male broiler breeder fertility were measured and recorded

at specific time intervals throughout the production cycle. The times of collection varied slightly due to biosecurity reasons. It is standard biosecurity practice to have a minimum of 72 hours between visiting different farms, as to prevent cross contamination. Thus where one farm was visited in week 21, another would have to be visited during week 22. Corresponding hatchery data was also collected at specific intervals. Table 3.5 shows the intervals at which the additional measurements were recorded, and at which interval corresponding hatchery data was collected.

**Table 3.5 Age intervals for additional data collection**

| Age (in weeks) | Data Collected       |
|----------------|----------------------|
| 21             | On farm              |
| 25             | On farm              |
| 30             | On farm and hatchery |
| 35             | On farm              |
| 40             | On farm and hatchery |
| 50             | On farm and hatchery |
| 60             | On farm and hatchery |

Body weight of the males was recorded following the same procedures to the routine farm recording. Body weight was recorded in grams (g). Birds were cordoned off in pens. 50 males were weighed at each visit, body condition score and vent scoring was done on the same 50 males. It should be noted that both body condition score and vent score are not considered new measurements in this study as they are also recorded as part of the routine on-farm practices. They were included as part of the additional measurements due to the subjective nature of their scoring and as such one individual would measure these scores on all farms in this study. The aim of this was to minimize the variation between farms by eliminating the differences observed between different individuals measuring on different farms.

The additional measurement of shank length was recorded on all farms. Shank length is defined as an estimate of frame size in broiler breeders. This measurement is recorded with the use of a linear calliper. Typical measurements are taken from the top of the hock (at a joint angle of 90 degrees) to the base of the foot pad. This is similar to the method used in most studies found in literature. For accuracy of measurement, the shank bone was felt for and the measurement recorded from that point. This is due to the fact that as the birds age, the foot pad may become swollen or enlarged and thus distort the shank length measurement if the foot pad is included in that measurement. Figure 3.5 is a schematic diagram of a typical shank in male broiler breeders.

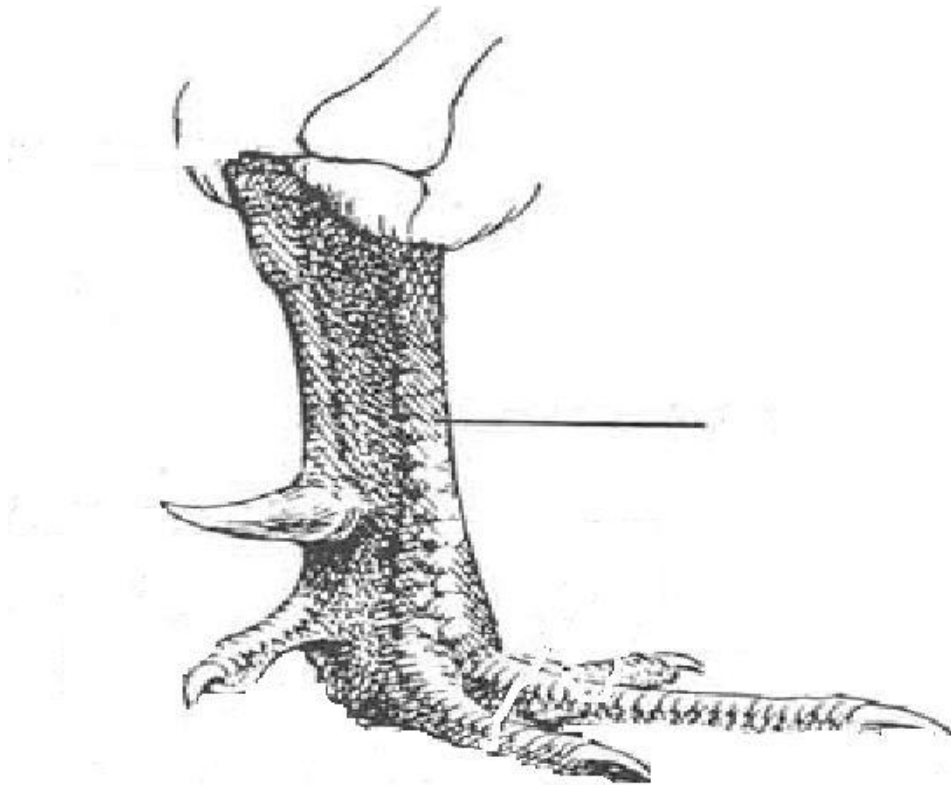


**Figure 3.5 Schematic diagram of male shank** (<http://web2.uconn.edu/poultry/4-H%20Poultry/index.html>) (University of Connecticut Poultry 4-H Website))

All shank length measurements were taken on the right leg, and recorded in centimetres (cm). An initial test to determine whether the left or right leg would be more accurate was conducted. It was determined that both legs were of the same length, but the right leg was continuously measured to maintain uniformity of measurements. Figure 3.6 depicts a photograph of the actual measurement of the shank on one of the test farms.



**Figure 3.6 Shank length as measured on farm**

### **3.2.2 Fertility measurements**

Fertility was calculated using a 12-day candling and breakout procedure at the hatchery. A 12-day breakout is preferred over the standard 18-day candling, as it is seen as a more accurate determination of fertility. A visit was arranged 12-days after the farm visit. This factors in the assumption that the eggs used in the breakout are the eggs produced on the same day as the farm visit 12-days earlier. Mass candling was the method used for candling; this is where the whole tray of eggs is placed on a table with a light from the bottom. Figure 3.7 shows an example of mass candling. All the light eggs are considered clear and will be removed for breakout. The objective of candling is to determine which eggs are clear or not. All the clear eggs are removed. These are then broken open to determine whether they were infertile or if it is early embryonic deaths. The numbers of each, as well as mistakes and cracks are recorded. Fertility is then determined by the number of eggs set, less the number of infertile eggs, as a percentage of total eggs set on that tray. It should be noted that 18-day fertility measurement is based only on a candling procedure, while

12-day fertility makes use of a candling and breakout procedure. Both 18- and 12-day fertility results were collected for analysis.

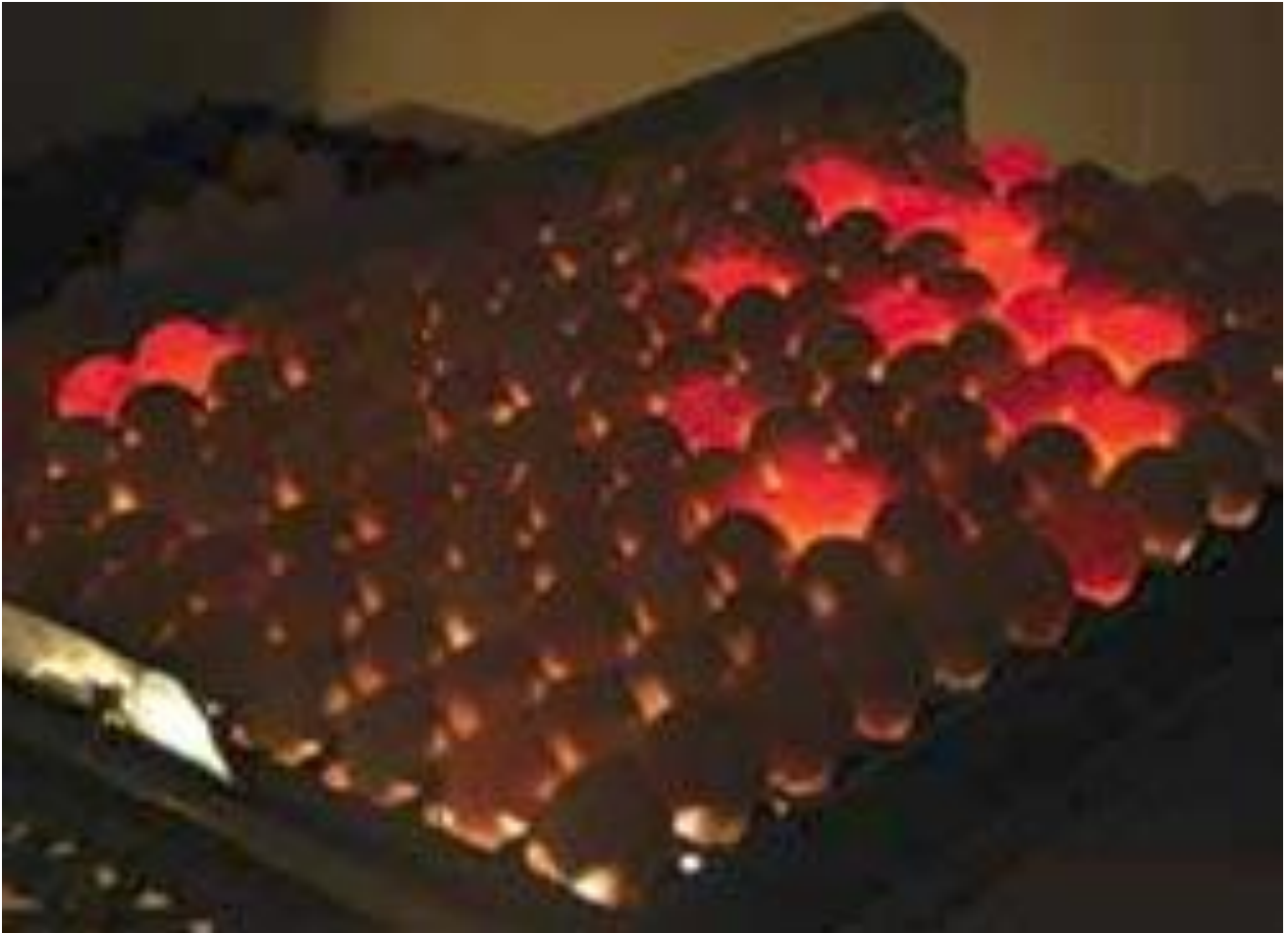


**Figure 3.7 Example of mass candling** (<http://www.thepoultrysite.com/articles/1603/investigating-hatchery-practice-assessing-fertility>)

Figure 3.8 shows an example of both a fertile egg and an infertile egg before incubation. The infertile eggs show no development and the blastocyst is a small solid white spot on the yolk. The fertile egg on the other hand shows some development of the germinal disk, called a blastoderm. This can be seen as a white spot on the yolk with an irregular shaped halo around it.

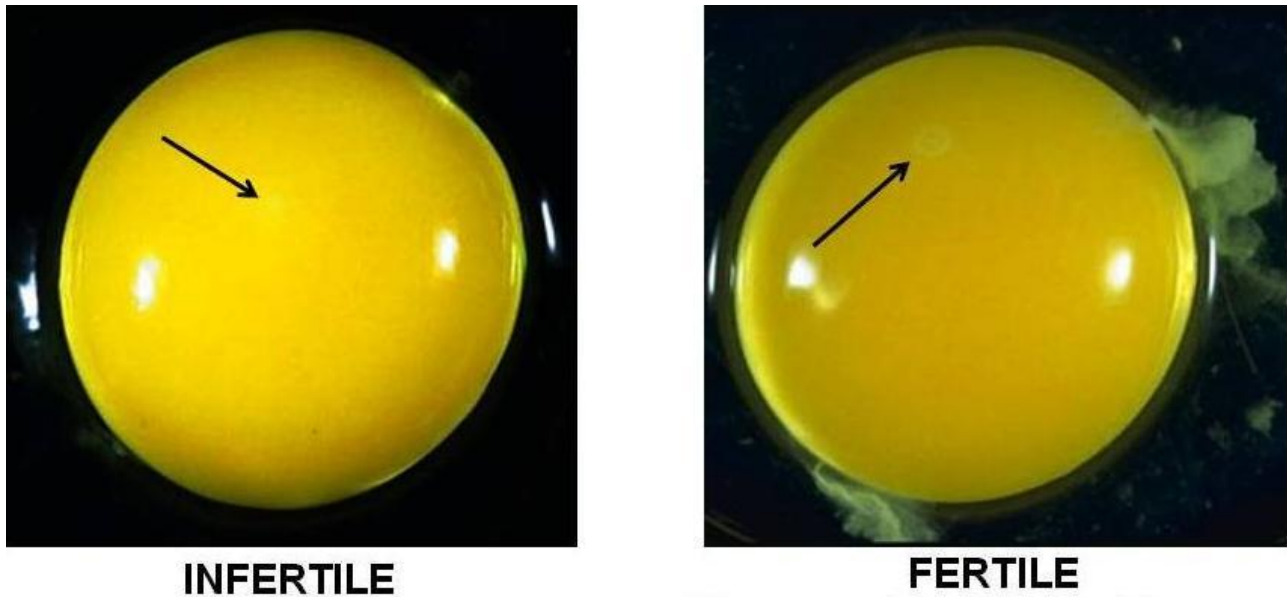


**Figure 3.8 Example of infertile (left) and fertile (right) eggs**  
(<http://www.ca.uky.edu/smallflocks/faq.html>)

### 3.3 Data analysis

A standard breeder farm may contain many sites, and each site may have a number of houses ranging from two to 10. For the purposes of this study a ‘site’ was seen as a separate entity and labelled as a ‘farm’. Four data sets were available for analysis. The first data set was the routine farm measurements. These measurements were routinely collected on the farms, either daily as for feed intake or weekly for variables such as male and female weights; also included in this were the routine morphological traits, these were recorded weekly and included the vent and breast scores of the males. Both breast and vent scoring have set guidelines on measurement, but are subjective measurements that rely on an individual’s interpretation of those guidelines. The second data set was compiled from the hatcheries. This included the fertility as calculated on an 18-day candling as well as the total number of eggs set. The third data set was that of the additional measurements considered to be of importance, which included shank length. Similar to the routine farm measurements male body weight, vent score and breast condition score were also collected, so as to minimize the variation seen between farms when different individuals record these measurements. These measurements were recorded at specific intervals thought to be of importance during the production cycle of the birds. The last data set was the additional hatchery measurements, which included the fertility based on a 12-day candling and breakout.

### 3.3.1 Data cleaning and compilation

Data was edited for potential errors, such as incorrect and missing values, as well as any outliers that would have distorted the results. The four data sets were then combined into one larger complete data set where each trait was compared with the others. To do this, a format of production weeks was developed, where each trait was grouped based on the time the measurement was recorded in relation to the age of the flock. For example feed intake was measured on a daily basis, whereas weight was only recorded once a week, thus all data recorded within a particular week was grouped together. All farms were made uniform such that each farm's data began with 21 weeks and ended at 61 weeks. One farm in particular experienced disease outbreak towards the end of the production cycle and data for this farm was thus incomplete, and as such was removed from the study, leaving six farms for the final analysis. Appendix C provides an example of each of the data sources, as well as the final compilation into a production week summary. Tables 3.6 and 3.7 provide summaries of the origin of the traits measured and their use in the respective models.

**Table 3.6 Summary of traits measured routinely on-farm and their use in the respective models**

| Traits measured on-farm                 | 18-day fertility |          | 12-day fertility |           |
|-----------------------------------------|------------------|----------|------------------|-----------|
|                                         | Model I          | Model Ia | Model IV         | Model IVa |
| Routine male weights (RMW) (g)          | X                | X        | X                | X         |
| Routine feed intake of males (RFIM) (g) | X                | X        | X                | X         |
| Routine body condition score (RBCS)     | X                | X        | X                | X         |
| Routine vent scores (RVS)               | X                | X        | X                | X         |
| Routine female weights (RFW) (g)        | X                | X        | X                | X         |

**Table 3.7 Summary of additional measurements recorded and their use in the respective models**

| Additional traits measured  | 18-day fertility | 12-day fertility |
|-----------------------------|------------------|------------------|
|                             | Model II         | Model III        |
| Shank length (ASL) (cm)     | X                | X                |
| Male body weight (AMW) (g)  | X                | X                |
| Vent score (AVS)            | X                | X                |
| Body condition score (ABCS) | X                | X                |

### **3.4 Models for data interpretation**

The hypothesis was to determine which traits significantly explained the variation within the fertility measurement. Four models were run where fertility was compared to routine farm measurements or additional measurements, each time with the two fertility measurements of 12-days and 18-days.

An initial test model was run to determine whether using the farm as a whole, or individual houses within a farm was more accurate. This model was run twice, once each with each of the fertility values as the dependant variable.

#### **3.4.1 Routine farm data analysis**

Routine farm data was analysed by using the SAS program (SAS Institute Inc., Cary, NC, USA. 2009). The data was first normalized by removing outliers and other anomalies, for example negative values for age and other missing data. Statistical parameters estimated were mean, standard deviation for the traits recorded. The statistical model used for the routine farm data took into account all data collected from the farms, including the hatchery and scoring data.

#### **3.4.2 Additional data analysis**

The additional data collected was analysed similarly to the routine farm data by using SAS (SAS Institute Inc., Cary, NC, USA. 2009). Production parameters along with the statistical inferences were calculated. The statistical models used would include; all measurements recorded and the corresponding hatchery data, thus there would be four sets of data namely; the routine farm measurements, the hatchery data corresponding to the routine farm data, the additional measurements recorded, and the hatchery data corresponding to the additional measurements. In order to incorporate all four of the data sources into the analysis four basic models were constructed, with further refinement of two of the models.

The basic model was using measurements to predict a fertility value. The four main models used to analyse the data are explained below:

- I. 18-day fertility predicted by routine farm measurements
- II. 18-day fertility predicted by additional measurements
- III. 12-day fertility predicted by additional measurements
- IV. 12-day fertility predicted by routine farm measurements

These four models were constructed as follows, to incorporate all the data sets.

Model I: 18-day fertility predicted by routine farm measurements

$$\text{So, } F_{18} = \text{RBCS} + \text{RVS} + \text{RMW} + \text{RFIM}$$

Where,  $F_{18}$  = 18-day fertility measurement

RBCS = Routine body condition score measurement

RVS = Routine vent score measurement

RMW = Routine male weight measurement

RFIM = Routine feed intake of the males measurement

Model II: 18-day fertility predicted by additional measurements

$$\text{So, } F_{18} = \text{ABCS} + \text{AVS} + \text{AMW} + \text{ASL}$$

Where,  $F_{18}$  = 18-day fertility measurement

ABCS = Additional body condition score measurement

AVS = Additional vent score measurement

AMW = Additional male weight measurement

ASL = Additional shank length measurement

Model III: 12-day fertility predicted by additional measurements

$$\text{So, } F_{12} = \text{ABCS} + \text{AVS} + \text{AMW} + \text{ASL}$$

Where,  $F_{12}$  = 12-day fertility measurement

ABCS = Additional body condition score measurement

AVS = Additional vent score measurement

AMW = Additional male weight measurement

ASL = Additional shank length measurement

Model IV: 12-day fertility predicted by routine farm measurements

$$\text{So, } F_{12} = \text{RBCS} + \text{RVS} + \text{RMW} + \text{RFIM}$$

Where,  $F_{12}$  = 12-day fertility measurement

RBCS = Routine body condition score measurement

RVS = Routine vent score measurement

RMW = Routine male weight measurement

RFIM = Routine feed intake of the males measurement

After analysing the results of the four models it was noted that the male weight is dependent on feed intake, and using both traits in the models may have masked the contribution of male weight to fertility. As

such the RFIM was replaced with Routine Female Weight (RFW), and models one and four were re-run with the modifications.

Model Ia: 18-day fertility predicted by routine farm measurements

$$\text{So, } F_{18} = \text{RBCS} + \text{RVS} + \text{RMW} + \text{RFW}$$

Where,  $F_{18}$  = 18-day fertility measurement

RBCS = Routine body condition score measurement

RVS = Routine vent score measurement

RMW = Routine male weight measurement

RFW = Routine female weight measurement

Model IVa: 12-day fertility predicted by routine farm measurements

$$\text{So, } F_{12} = \text{RBCS} + \text{RVS} + \text{RMW} + \text{RFW}$$

Where,  $F_{12}$  = 12-day fertility measurement

RBCS = Routine body condition score measurement

RVS = Routine vent score measurement

RMW = Routine male weight measurement

RFW = Routine female weight measurement

In total six models were used to analyse the traits measured and the results of these are presented in the following chapter.

## Chapter 4

### 4.1 Results

#### 4.1 Descriptive Statistics

##### 4.1.1 Routine farm data

The routine farm data was analysed by using SAS (SAS Institute Inc., Cary, NC, USA. 2009). Table 4.1 provides a summary of the descriptive statistics of the routine farm measurements and the corresponding hatchery data. These traits were measured continuously from the start of the production cycle to the end, as part of routine management practices. Some traits were measured daily, such as feed intake, whereas others were measured weekly, such as body weights. 50 males were weighed weekly and the average of their measurements was recorded in grams (g), and as such an average of the average was used in the models. Therefore there are a relatively low number of observations available for analysis, and differ for each model, ranging from 504 in model I to 42 in model IV. Vent score was not recorded as a standard measurement on all of the farms included in this study. The fertility measurement used was based on an 18-day candling and then converted to a percentage ( $F_{18}$ ).

**Table 4.1 Summary of descriptive statistics of routine farm data used for analysis**

| Trait    | Number of Observations | Mean    | Median | Std. Dev. | Min. | Max.   |
|----------|------------------------|---------|--------|-----------|------|--------|
| RFW      | 1112                   | 3587.63 | 3627.5 | 396.28    | 2384 | 4465.8 |
| RMW      | 1166                   | 4624.56 | 4690   | 605.26    | 2474 | 5768.4 |
| RFIM     | 8084                   | 169.83  | 171.17 | 18.91     | 120  | 210    |
| $F_{18}$ | 2022                   | 91.15   | 92.98  | 5.05      | 64   | 99.13  |
| RVS      | 610                    | 2.60    | 2.60   | 0.50      | 1.04 | 3.94   |
| RBCS     | 934                    | 2.91    | 3      | 0.65      | 1    | 5      |

RFW = Routine female weight (g); RMW = Routine male weight (g); RFIM = Routine feed intake of the males (g);  $F_{18}$  = 18-day fertility value (%); RVS = Routine vent score; RBCS = Routine body condition score

##### 4.1.2 Additional data

The additional data was analysed similarly to the routine farm data by using SAS (SAS Institute Inc., Cary, NC, USA. 2009). Table 4.2 shows a summary of the descriptive statistics of the additional measurements included in the analysis. All additional measurements were recorded at specific time intervals during the production cycle, as mentioned above. Only shank length and the 12-day fertility value were considered as additional measurements, as the male body weights, vent score, and body condition score are

already recorded in routine farm management practices. These measurements were included in the additional measurements to minimize the variation between farms, due to the subjective nature of the scores. The fertility value for the additional measurements was calculated based on a 12-day candling and breakout, and subsequently converted to a percentage ( $F_{12}$ ).

**Table 4.2 Summary of descriptive statistics of additional measurements recorded**

| Variable | N    | Mean    | Median | Std. Dev. | Minimum | Maximum |
|----------|------|---------|--------|-----------|---------|---------|
| AMW      | 5799 | 4659.46 | 4740   | 734.87    | 2480    | 6200    |
| ASL      | 5799 | 11.73   | 11.8   | 0.86      | 9.1     | 14.6    |
| ABCS     | 5799 | 2.48    | 2      | 0.64      | 1       | 4       |
| AVS      | 5799 | 2.17    | 2      | 0.96      | 1       | 4       |
| $F_{12}$ | 66   | 95.70   | 96     | 2.16      | 90.67   | 99.18   |

AMW = Additional male weight (g); ASL = Additional shank length (cm); ABCS = Additional body condition score; AVS = Additional vent score;  $F_{12}$  = 12-day fertility value (%)

#### 4.2.1 Trends of all traits analysed in this study

Standard trends were constructed for each of the traits analysed. This was first, to validate the normality of the data, and secondly, to compare these trends to standard production trends as seen in the industry. The results of this, as shown in Figures 4.1 to 4.5 shows the comparison between Ross and Cobb breeds for 12-day fertility trends, and the morphological traits of interest, such as male body weight, shank length, vent score, and body condition score. In these graphs there is a marked difference between the two genotypes (Ross and Cobb) available from the data.

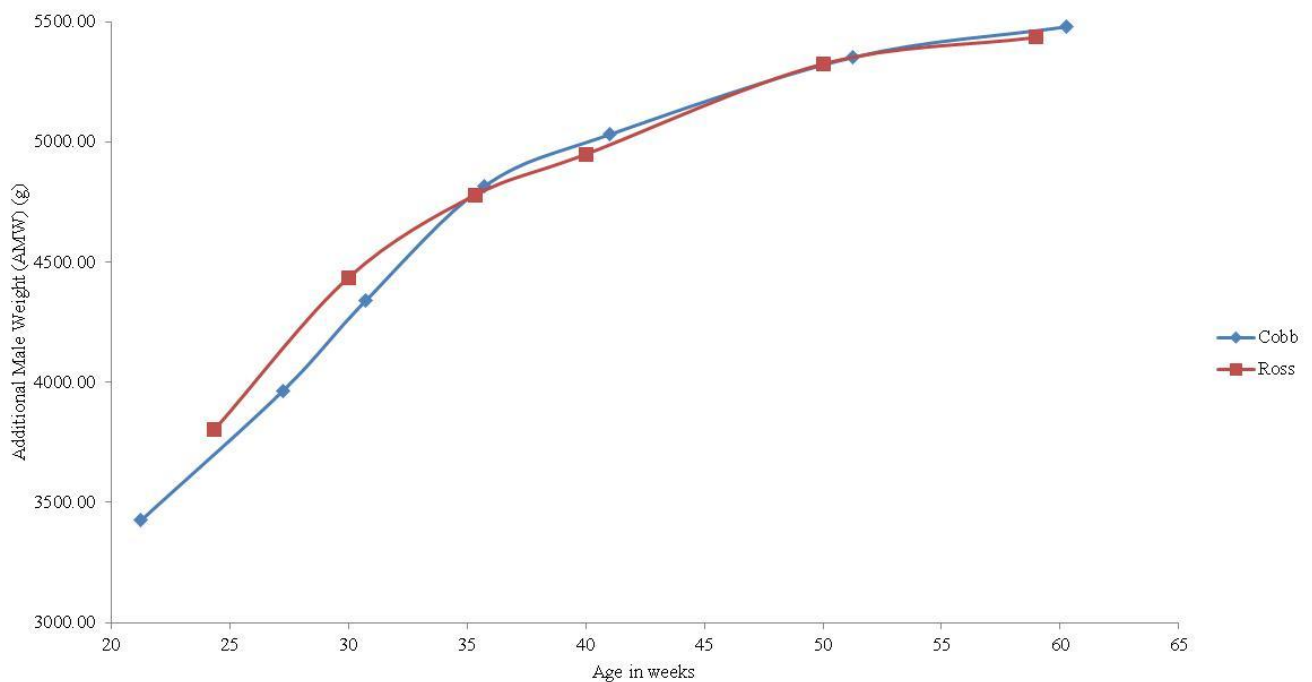


**Figure 4.1 Comparison of additional male body weights (AMW) between Ross and Cobb**

In Figure 4.2 Cobb birds tended to have a high vent score than the Ross birds over the 40 week production cycle.

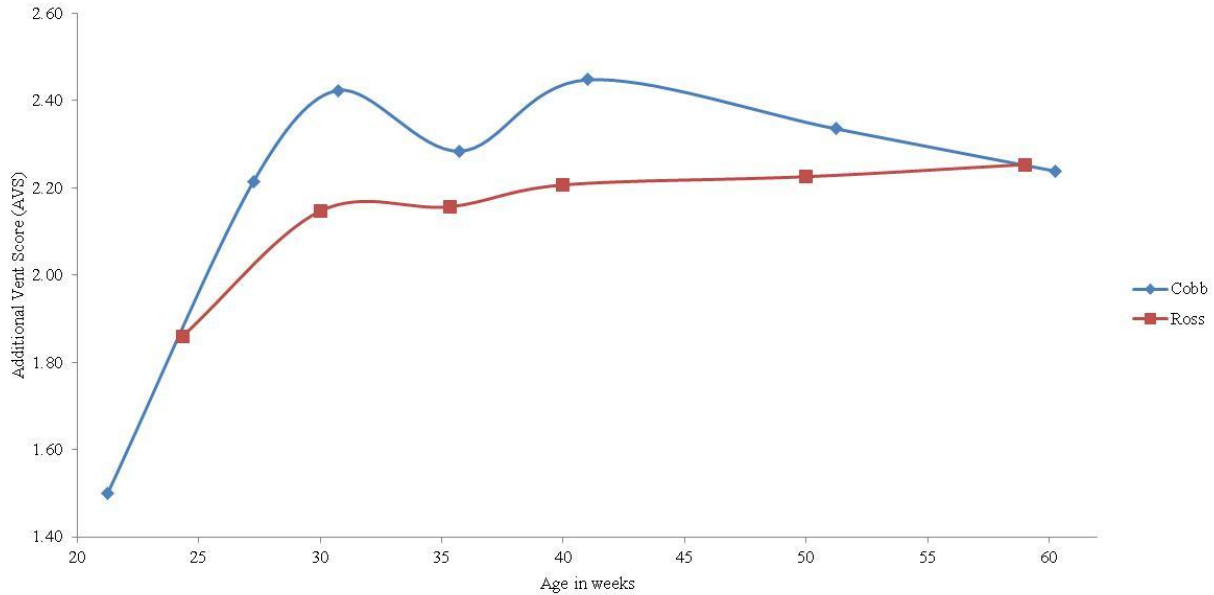


**Figure 4.2 Comparison of additional vent scores (AVS) between Ross and Cobb**

The average body condition score, as shown in Figure 4.3, of the Cobb flocks was higher than Ross over the 40 week production cycle.

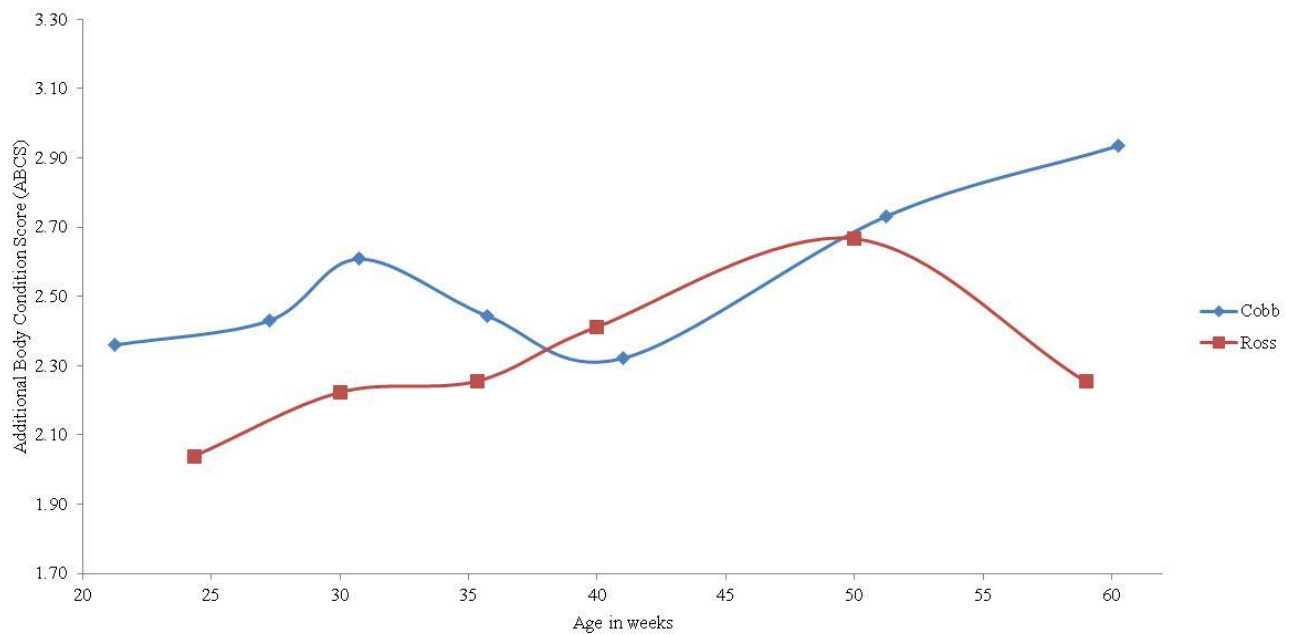


**Figure 4.3 Comparison of additional body condition scores (ABCS) between Ross and Cobb**

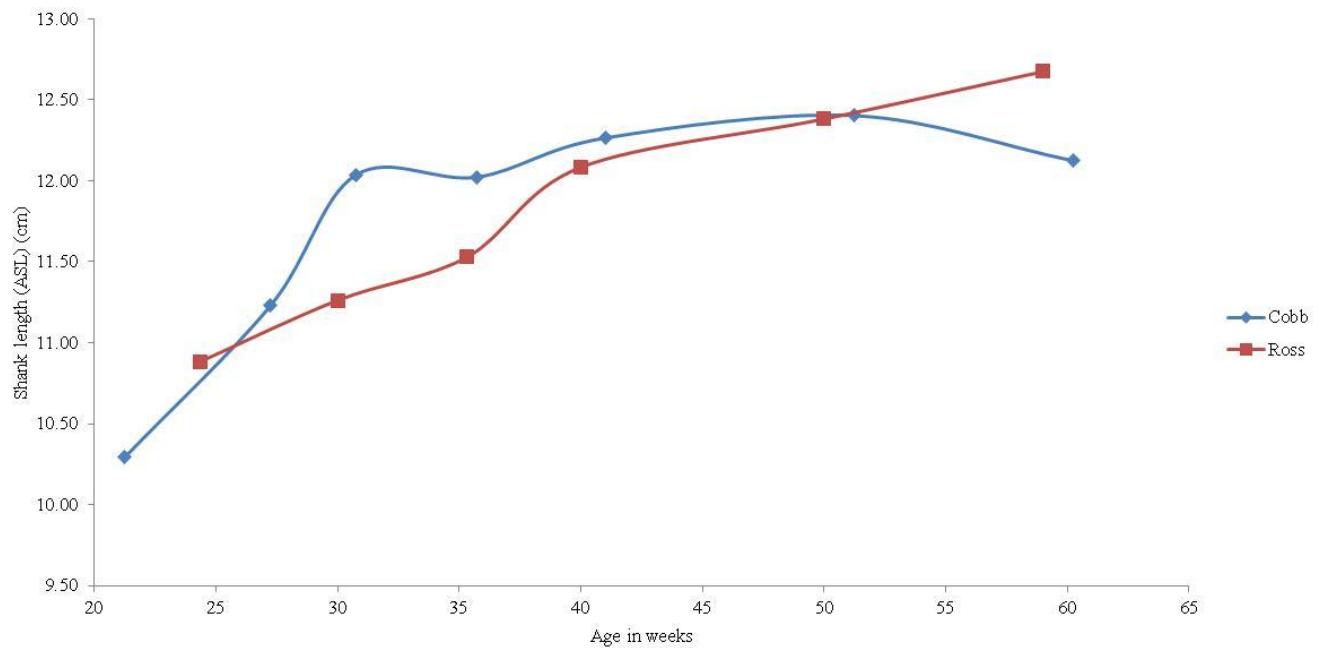


**Figure 4.4 Comparison of additional shank lengths (ASL) between Ross and Cobb**

The average 12-day fertility values for Cobb were higher than Ross over the 40 week production cycle, but both genotypes followed the expected trend for 12-day fertility, where there is a decrease in fertility towards the end of the production cycle, as shown in Figure 4.5.

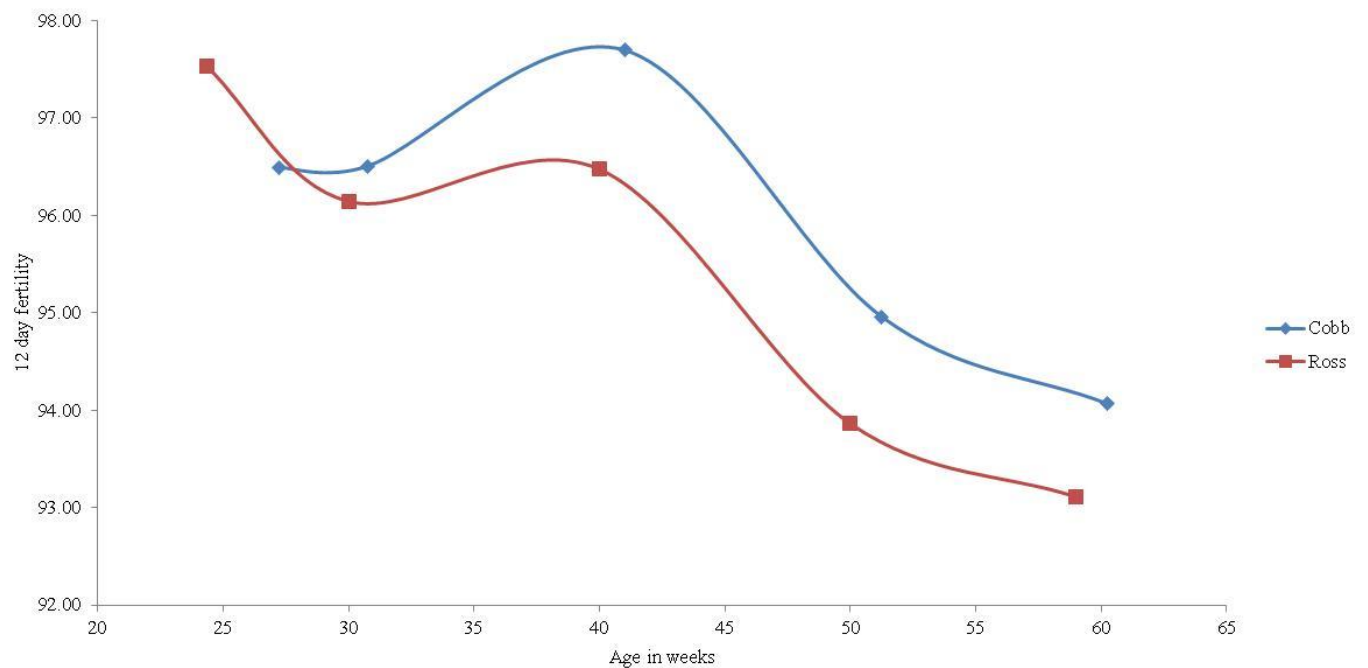


**Figure 4.5 Comparison of 12-day fertility values ( $F_{12}$ ) between Ross and Cobb**

## 4.3 Model results

### 4.3.1 Test model

A Tukey test was run ( $P > 0.05$ ) to determine whether there were significant differences between houses on the same farms and no differences were observed. Results did indicate that there was a significant difference between farms. It is of importance to note that the significant differences between the farms could be attributed to the two different breeds used. The results, as shown in appendix D, indicated that the differences between houses on the same farm were not significant and therefore these could be combined and only farms were then compared to each other in the following analyses.

### 4.3.2 Model statistical results

Plots of fertility over time showed that the relationship between the two was not linear, thus WEEKS, WEEKS<sup>2</sup>, and WEEKS<sup>3</sup> were included in the models to accommodate the non-linear elements of the relationship. All three of the traits were shown to significantly contribute to the average fertility ( $F_{18}$  and  $F_{12}$ ).

The first model was based on the routine farm measurements and the routine fertility value, as defined previously on page 33. The results of this model as shown in Table 4.3 indicated that farm, vent score (RVS) and breast score (RBCS) all contributed to the variation in the 18-day fertility value ( $P > 0.0001$ ). Specific differences between individual farms are shown in Appendix D. Only where there is a complete set of data for every trait during a specific production week, can the data be used in analysis, resulting in a lower number of observations. The average 18-day fertility value expressed as a percentage ( $F_{18}$ ) in this model was 91.09. The average fertility value was calculated from the number of observations available for analysis in this model.

**Table 4.3 Results of model I for 18-day fertility and routine farm measurements**

| Source             | DF | Type III SS | Mean Square | F Value | Pr > F |
|--------------------|----|-------------|-------------|---------|--------|
| Farm               | 18 | 1660.82     | 92.27       | 11.28   | <.0001 |
| WEEKS              | 1  | 390.16      | 390.16      | 47.69   | <.0001 |
| WEEKS <sup>2</sup> | 1  | 389.89      | 389.89      | 47.65   | <.0001 |
| WEEKS <sup>3</sup> | 1  | 326.05      | 326.05      | 39.85   | <.0001 |
| RMW                | 1  | 22.25       | 22.25       | 2.72    | 0.0998 |
| RFIM               | 1  | 3.90        | 3.90        | 0.48    | 0.4905 |
| RVS                | 1  | 301.83      | 301.83      | 36.89   | <.0001 |
| RBCS               | 1  | 195.08      | 195.08      | 23.84   | <.0001 |

RMW = Routine male weight (g); RFIM = Routine feed intake of the males (g); RVS = Routine vent score; RBCS = Routine body condition score

In model I, vent score (RVS) was shown to significantly contribute to 18-day fertility ( $P > 0.0001$ ); Figure 4.6 shows a comparison between these two traits over the production cycle.

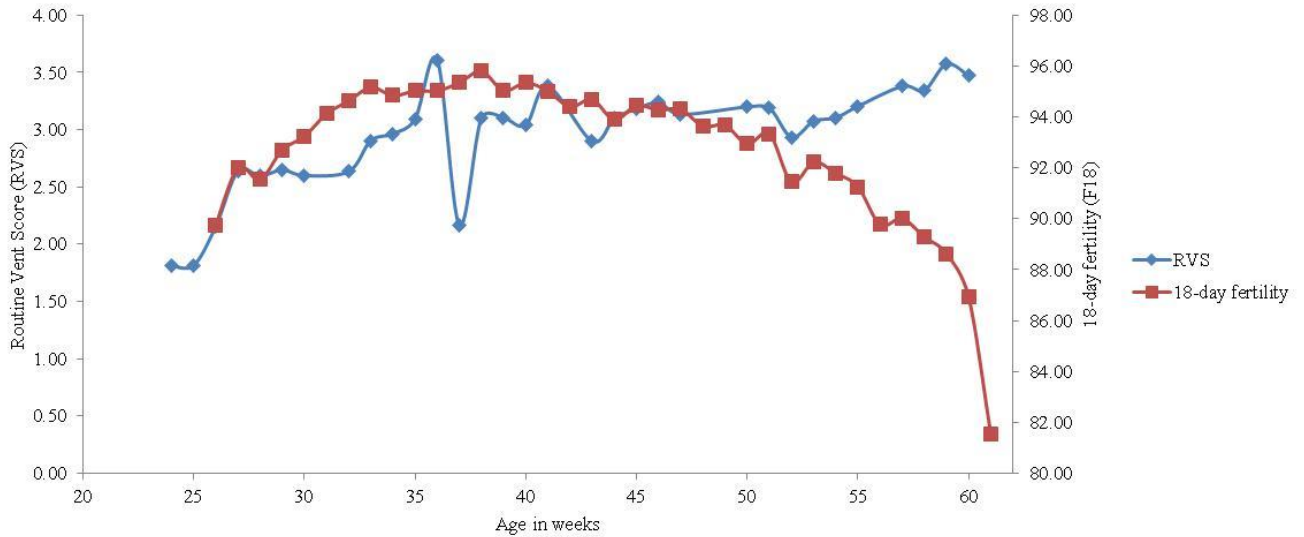


**Figure 4.6 Comparison of routine vent scores (RVS) and 18-day fertility values ( $F_{18}$ )**

Similarly RBCS was shown to have a significant influence on 18-day fertility ( $P > 0.0001$ ) and this comparison is shown in Figure 4.7.

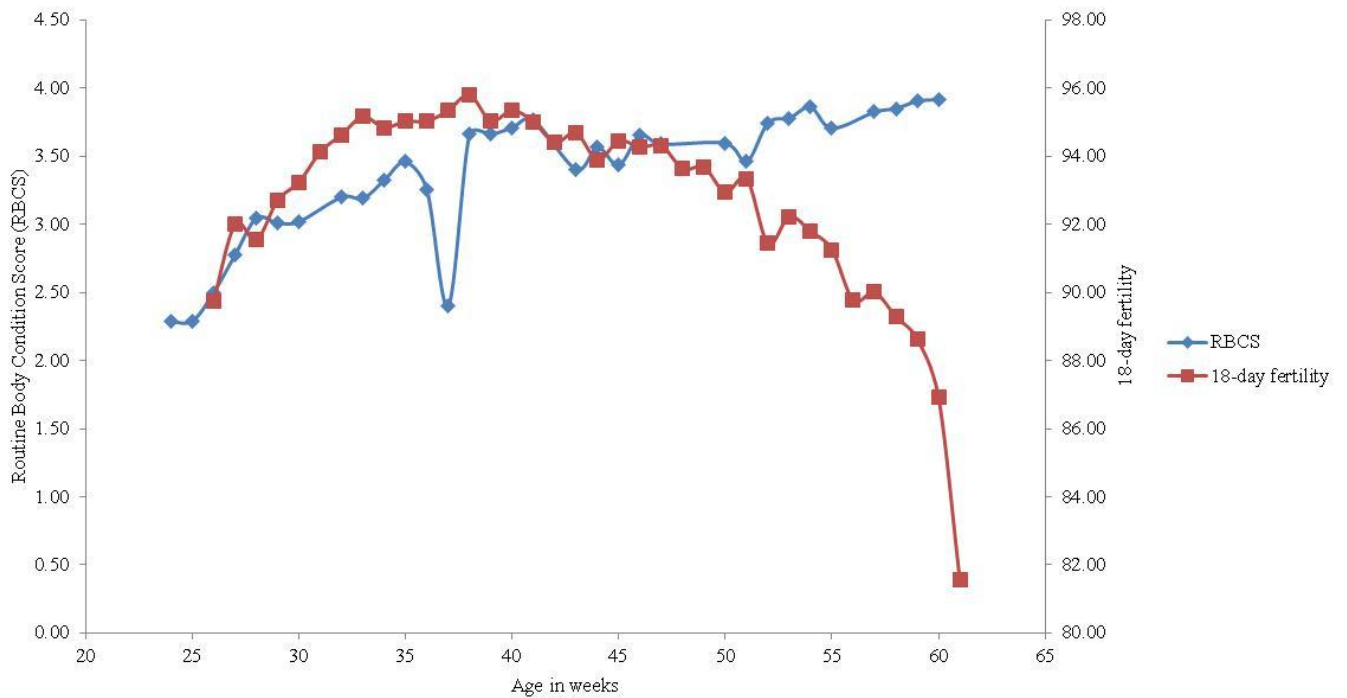


**Figure 4.7 Comparison of routine body condition scores (RBCS) and 18-day fertility values ( $F_{18}$ )**

Model II was to determine whether any of the additional measurements recorded had any significant influence on the 18-day fertility value ( $P > 0.0001$ ). The results of this model as shown in Table 4.4 indicated that only farm contributed to the variation in the 18-day fertility value ( $P > 0.0001$ ). The results of the Tukey test ( $P > 0.05$ ) showed that there was no significant difference between houses on the same farm, or between different farms, as can be seen in Appendix D. The discrepancy indicated between the results of the model and the Tukey tests indicate that there are other factors influencing the farms, which were not accounted for in this model. The 18-day fertility value, expressed as a percentage, in this model was 92.1.

**Table 4.4 Results of model II for 18-day fertility and the additional measurements**

| Source             | DF | Type III SS | Mean Square | F Value | Pr > F |
|--------------------|----|-------------|-------------|---------|--------|
| Farm               | 14 | 322.64      | 23.05       | 3.88    | 0.0001 |
| WEEKS              | 1  | 65.99       | 65.99       | 11.12   | 0.0015 |
| WEEKS <sup>2</sup> | 1  | 78.57       | 78.57       | 13.24   | 0.0006 |
| WEEKS <sup>3</sup> | 1  | 74.46       | 74.46       | 12.55   | 0.0008 |
| AMW                | 1  | 16.80       | 16.80       | 2.83    | 0.0978 |
| AVS                | 1  | 3.48        | 3.48        | 0.59    | 0.4469 |
| ABCS               | 1  | 3.48        | 3.48        | 0.59    | 0.4467 |
| ASL                | 1  | 37.08       | 37.08       | 6.25    | 0.0153 |

AMW = Additional male weight (g); AVS = Additional vent score; ABCS = Additional body condition score; ASL = Additional shank length (cm)

Figure 4.8 shows a comparison of the additional vent score (AVS) and 18-day fertility.

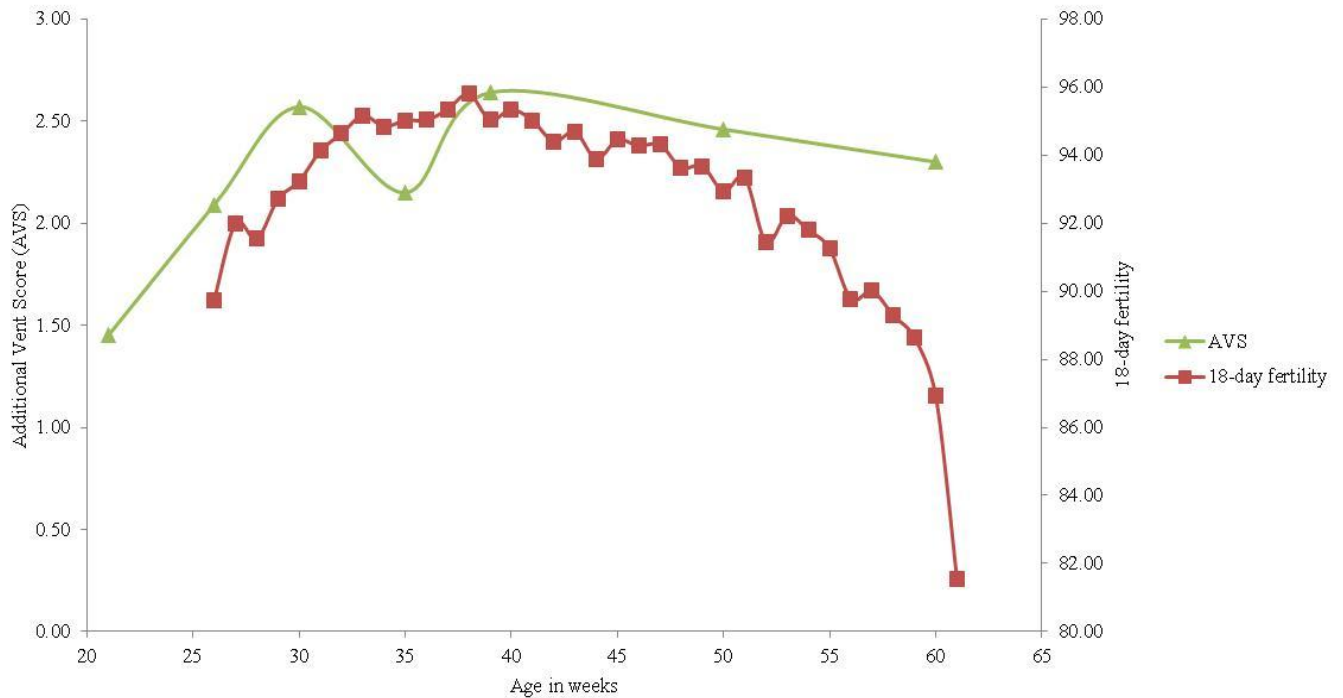


**Figure 4.8 Comparison of additional vent scores (AVS) and 18-day fertility values ( $F_{18}$ )**

Additional vent score (AVS) did not have a significant influence on 18-day fertility, whereas the routine vent score (RVS) was significant ( $P > 0.0001$ ). This difference could be attributed to the subjectivity of the score and is shown in figure 4.9. A similar conclusion can be drawn regarding the differences between the two body condition scores (RBCS and ABCS).

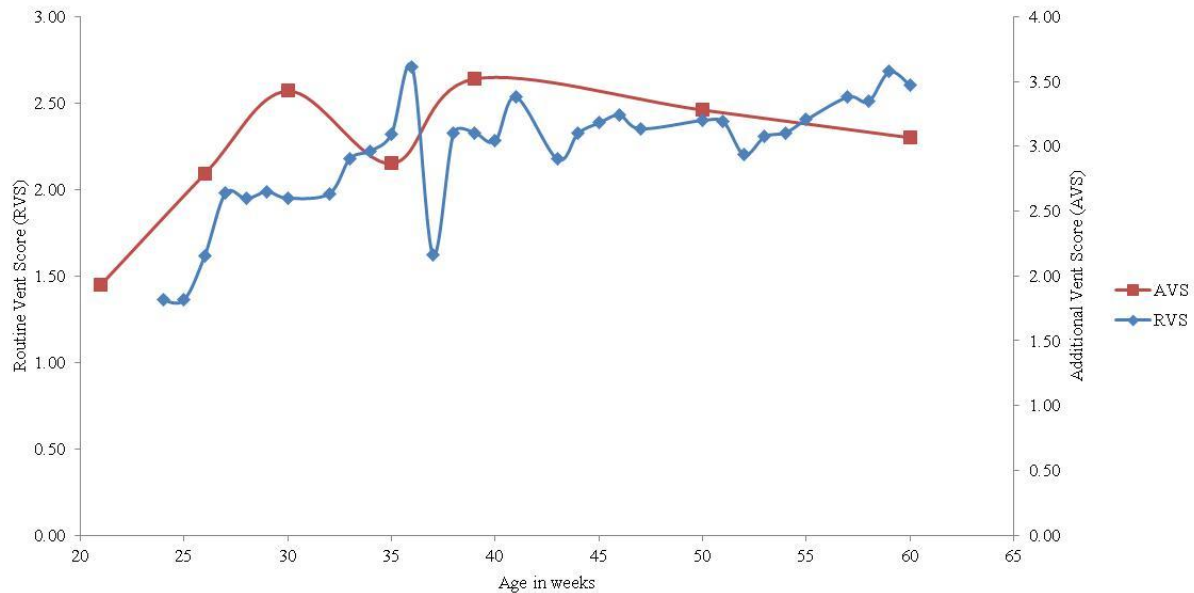


**Figure 4.9 Comparison of routine vent scores (RVS) and additional vent scores (AVS)**

Shank length was one of the main morphological traits measured in this study in an attempt to determine if it would be a useful indicator of fertility. The results of model II however indicate that shank length did not significantly contribute to 18-day fertility ( $P > 0.0001$ ), but may have a greater contribution if the confidence interval was relaxed ( $P > 0.005$ ). Figure 4.10 shows a comparison of the shank length measurements and the 18-day fertility values.

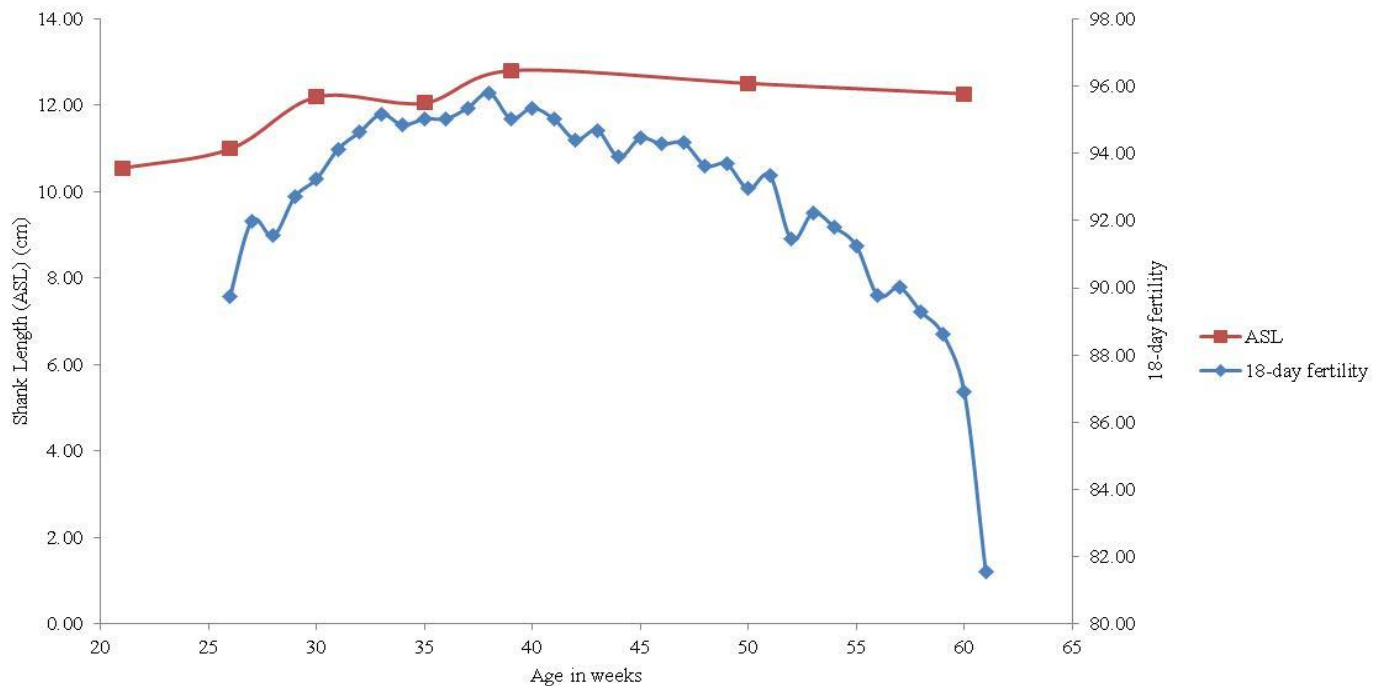


**Figure 4.10 Comparison of additional shank lengths (ASL) and 18-day fertility values ( $F_{18}$ )**

Model III was to determine whether any of the additional measurements recorded, had a significant influence on the 12-day fertility values. The results of this model as shown in Table 4.5 indicated that none of the traits contributed to the variation in the 12-day fertility value ( $P > 0.0001$ ). The average 12-day fertility value over the 40 week production cycle, expressed as a percentage ( $F_{12}$ ) in this model was 95.6. The results of the Tukey test, as seen in Appendix D indicate that there was no significant difference ( $P > 0.05$ ) between farms or houses on the same farm, further emphasizing the benefit of using a single individual to record the measurements for the subjective scores, and improve the uniformity of the farm management practices.

**Table 4.5 Results of model III for the additional farm measurements and 12-day fertility**

| Source             | DF | Type III SS | Mean Square | F Value | Pr > F |
|--------------------|----|-------------|-------------|---------|--------|
| Farm               | 14 | 98.17       | 7.01        | 3.18    | 0.0029 |
| WEEKS              | 1  | 38.19       | 38.19       | 17.31   | 0.0002 |
| WEEKS <sup>2</sup> | 1  | 38.62       | 38.62       | 17.51   | 0.0002 |
| WEEKS <sup>3</sup> | 1  | 36.15       | 36.15       | 16.38   | 0.0003 |
| AMW                | 1  | 4.60        | 4.60        | 2.08    | 0.158  |
| AVS                | 1  | 20.78       | 20.78       | 9.42    | 0.0042 |
| ABCS               | 1  | 10.76       | 10.76       | 4.88    | 0.034  |
| ASL                | 1  | 0.03        | 0.03        | 0.01    | 0.9103 |

AMW = Additional male weight (g); AVS = Additional vent score; ABCS = Additional body condition score; ASL = Additional shank length (cm)

Figure 4.11 shows a comparison of the shank length with 12-day fertility values, there was no significant contribution of shank length to this fertility value ( $P > 0.0001$ ).

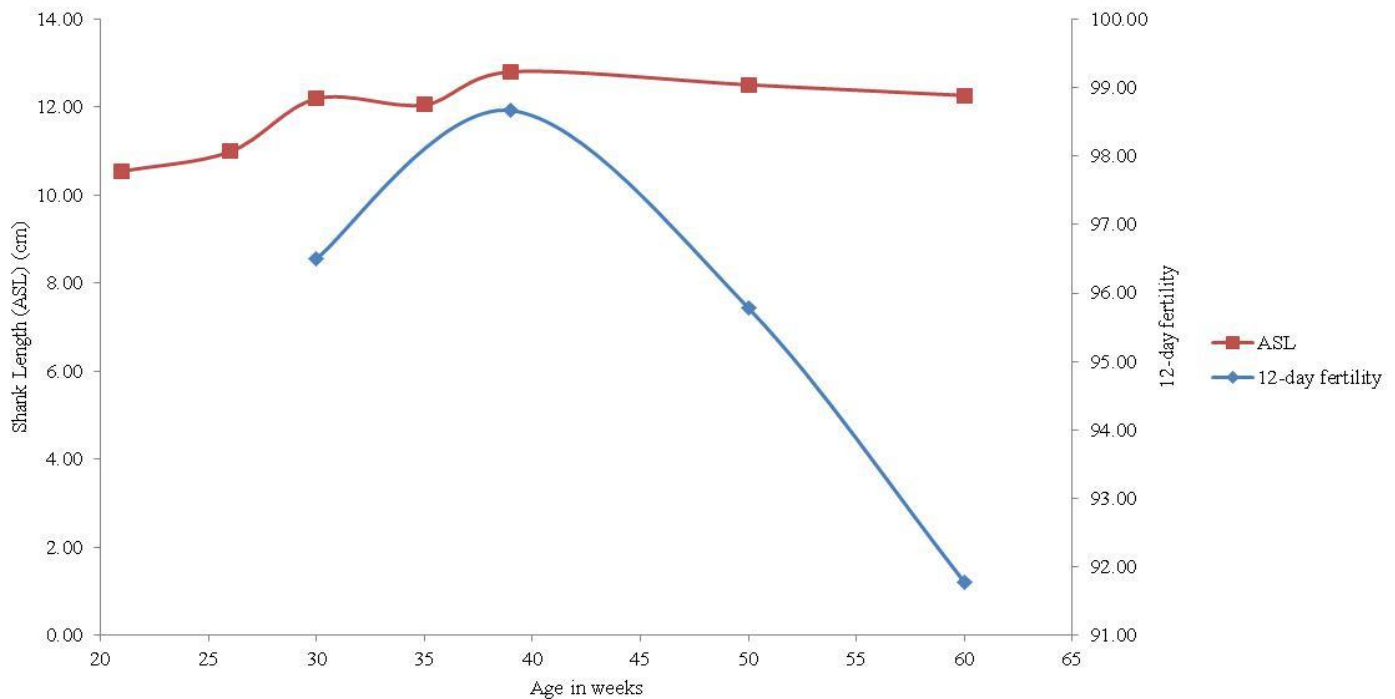


**Figure 4.11 Comparison of additional shank lengths (ASL) and 12-day fertility values ( $F_{12}$ )**

Similar to the previous model ABCS did not have a significant contribution to fertility ( $P > 0.0001$ ); but both vent score (AVS) and body condition score (ABCS) may have a significant contribution to 12-day fertility if the confidence interval were to be relaxed ( $P > 0.005$ ). Figure 4.12 shows a comparison of ABCS with 12-day fertility values.

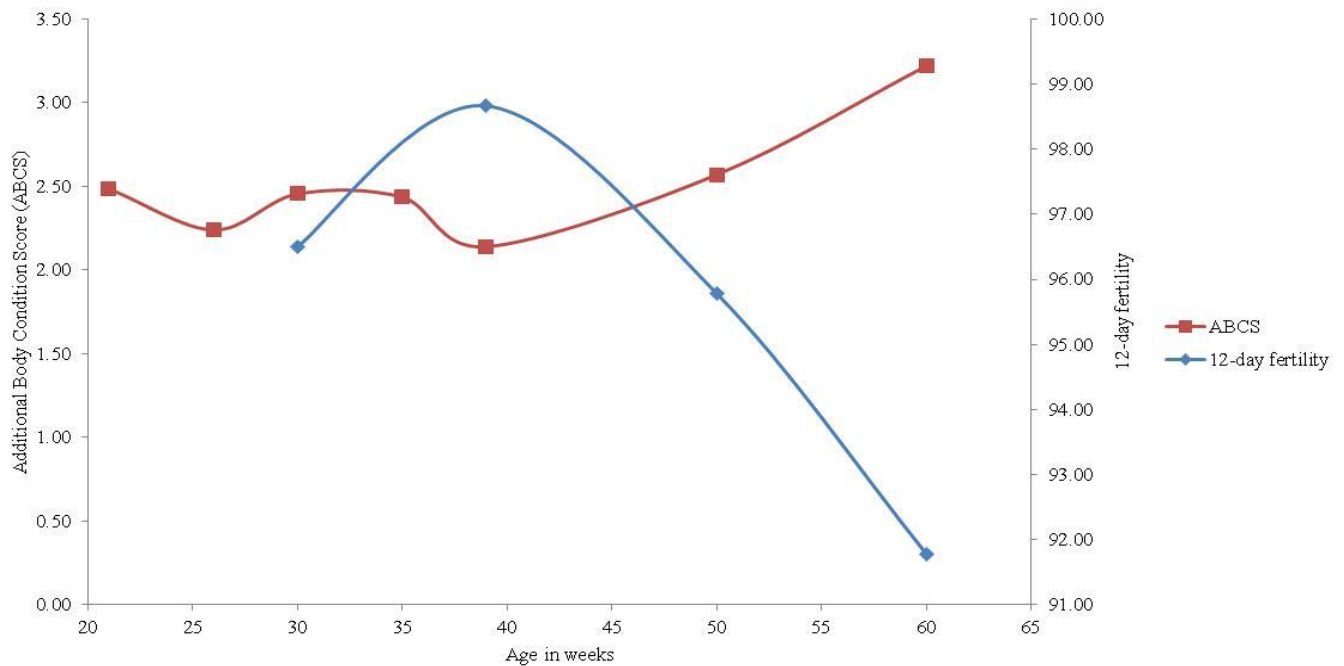


**Figure 4.12 Comparison of additional body condition scores (ABCS) and 12-day fertility values ( $F_{12}$ )**

The fourth model was run to determine whether any of the routine farm measurements recorded had an influence on the 12-day fertility value. The results of this model as shown in Table 4.6 indicated that none of the traits used contributed to the variation in the 12-day fertility value ( $P > 0.0001$ ). The average 12-day fertility value for the 40 week production cycle, expressed as a percentage, in this model was 95.29. The results of the Tukey test ( $P > 0.05$ ) as shown in Appendix D indicate that there were not significant differences between houses on the same farm, or between different farms.

**Table 4.6 Results of model IV for the 12-day fertility and the routine farm measurements**

| Source             | DF | Type III SS | Mean Square | F Value | Pr > F |
|--------------------|----|-------------|-------------|---------|--------|
| Farm               | 11 | 27.72       | 2.52        | 0.89    | 0.5652 |
| WEEKS              | 1  | 6.58        | 6.58        | 2.32    | 0.1415 |
| WEEKS <sup>2</sup> | 1  | 7.07        | 7.07        | 2.49    | 0.1284 |
| WEEKS <sup>3</sup> | 1  | 6.60        | 6.60        | 2.32    | 0.1411 |
| RMW                | 1  | 0.07        | 0.07        | 0.03    | 0.8735 |
| RFIM               | 1  | 0.05        | 0.05        | 0.02    | 0.894  |
| RVS                | 1  | 3.90        | 3.90        | 1.37    | 0.2531 |
| RBCS               | 1  | 8.18        | 8.18        | 2.88    | 0.1032 |

RMW = Routine male weight (g); RFIM = Routine feed intake of the males (g); RVS = Routine vent score; RBCS = Routine body condition score

Neither of the body condition scores (RBCS or ABCS) contributed significantly to 12-day fertility values ( $P > 0.0001$ ). This is similar to the differences seen in vent scores and could be attributed to the subjectivity of the score and is shown in figures 4.13 and 4.14.

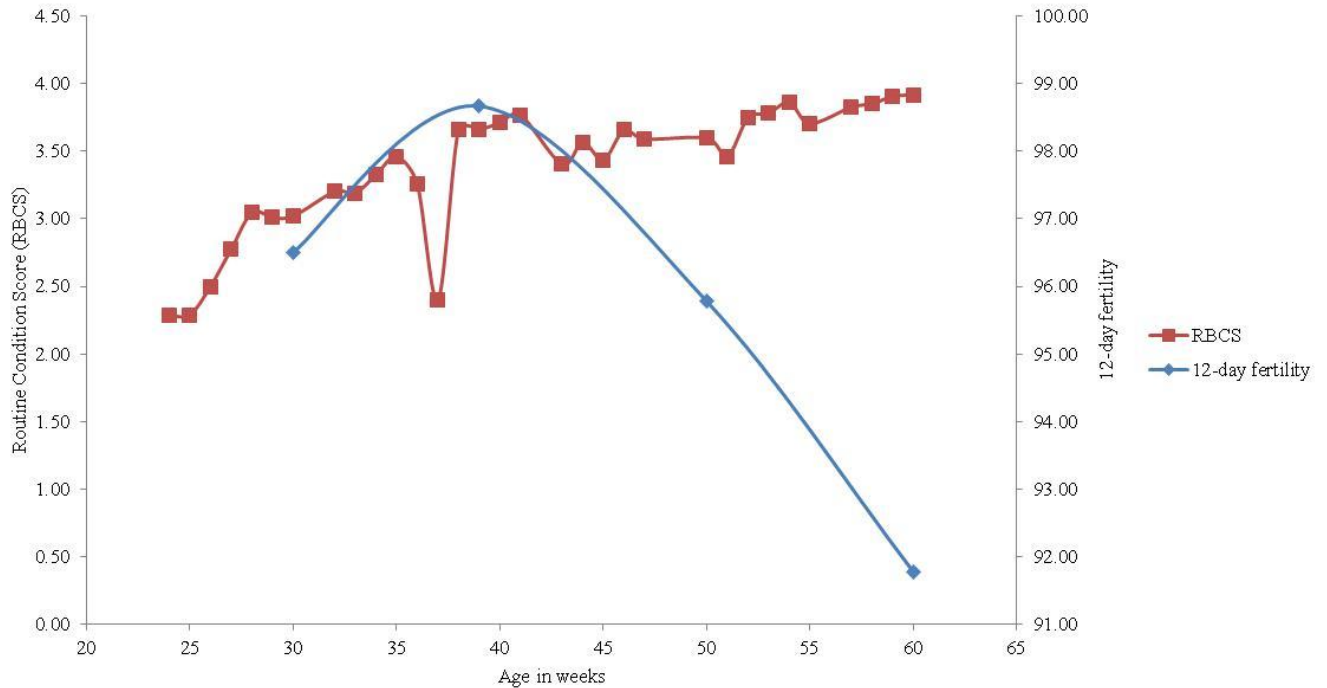


**Figure 4.13 Comparison of the routine farm body condition scores (RBCS) and 12-day fertility values ( $F_{12}$ )**

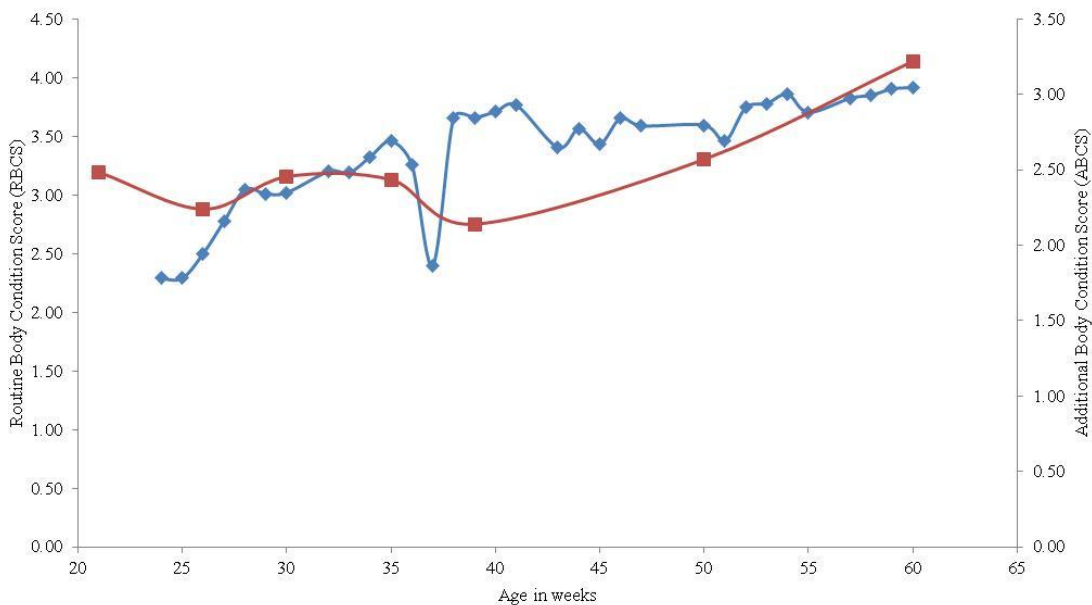


**Figure 4.14 Comparison between the two body condition score measurements (RBCS and ABCS)**

The first two models were adjusted to included female weight. The first modified model including female weight was to determine if the routine farm measurements had any influence on the 18-day fertility values. The results of this model as shown in Table 4.7 indicated that farm, vent score (RVS), body condition score (RBCS), and now the female weight (RFW) contributed to the variation in the 18-day fertility value ( $P > 0.0001$ ). This is similar to the original model, where RVS and RBCS contribute towards 18-day fertility, but RMW does not. The average fertility as a percentage ( $F_{18}$ ) in this model was 91.09. Figure 4.15 shows a comparison between the female weights and the 18-day fertility values.

**Table 4.7 Results of Model Ia for 18-day fertility and the routine farm measurements**

| Source             | DF | Type III SS | Mean Square | F Value | Pr > F |
|--------------------|----|-------------|-------------|---------|--------|
| Farm               | 5  | 1011.57     | 202.32      | 28.21   | <.0001 |
| WEEKS              | 1  | 272.99      | 272.99      | 38.07   | <.0001 |
| WEEKS <sup>2</sup> | 1  | 307.88      | 307.88      | 42.94   | <.0001 |
| WEEKS <sup>3</sup> | 1  | 264.41      | 264.41      | 36.87   | <.0001 |
| RMW                | 1  | 0.64        | 0.64        | 0.09    | 0.7648 |
| RVS                | 1  | 181.63      | 181.63      | 25.33   | <.0001 |
| RBCS               | 1  | 148.66      | 148.66      | 20.73   | <.0001 |
| RFW                | 1  | 498.81      | 498.81      | 69.56   | <.0001 |

RMW = Routine male weight (g); RVS = Routine vent score; RBCS = Routine body condition score; RFW = Routine female weight (g)

The results of the Tukey test ( $P > 0.05$ ), as shown in Appendix D, indicate that there were no significant differences between houses on the same farm, but there were significant differences between farms. Furthermore, the differences between farms could be attributed to the different breeds housed on those farms.

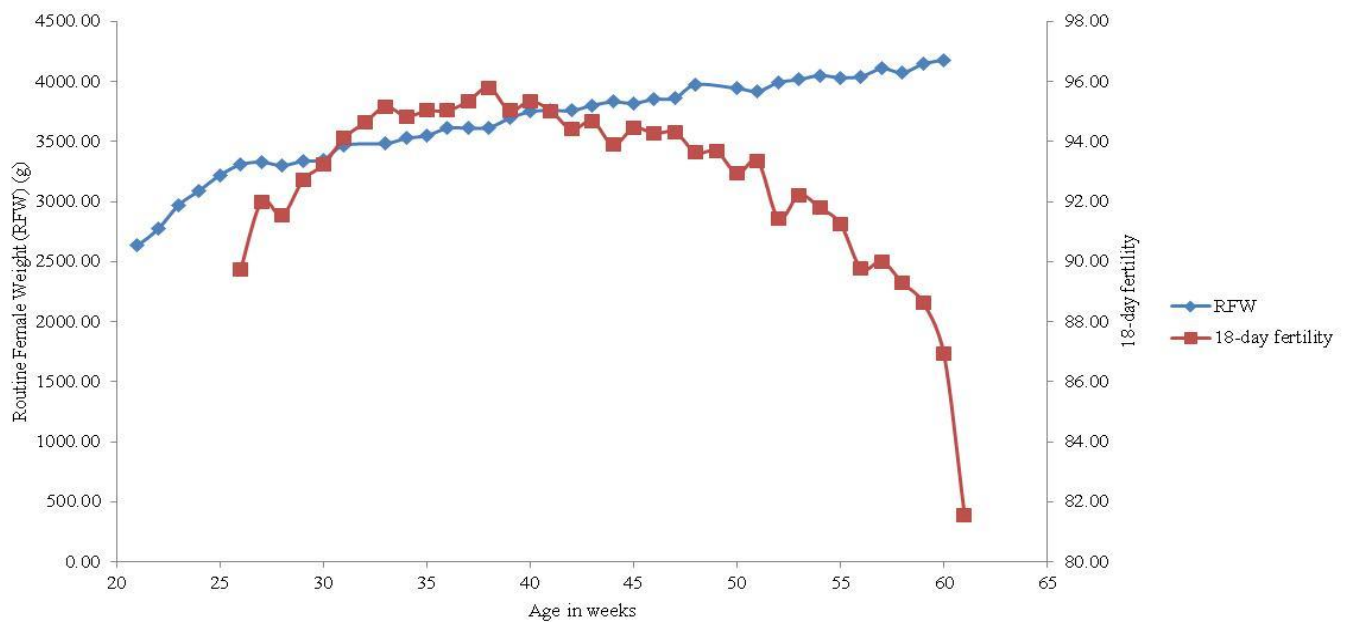


**Figure 4.15 Comparison of routine female weights (RFW) and 18-day fertility values ( $F_{18}$ )**

The second modified model was run where the routine farm measurements, including the new trait of female weight (RFW), had any significant influence on the 12-day fertility value. The results of this model as shown in Table 4.8 indicated that none of the variables contributed to the variation in the 12-day fertility value, including the female weight ( $P > 0.0001$ ). This is similar to the original model, where none of the traits contributed towards the 12-day fertility value. The average fertility value ( $F_{12}$ ) in this model was 95.29. Figure 4.16 shows a comparison between female weight (RFW) and 12-day fertility, and female weight did not show a significant relationship with 12-day fertility.

**Table 4.8 Results of model IVa for 12-day fertility and the routine farm measurements**

| Source             | DF | Type III SS | Mean Square | F Value | Pr > F |
|--------------------|----|-------------|-------------|---------|--------|
| Farm               | 4  | 24.12       | 6.03        | 2.38    | 0.0737 |
| WEEKS              | 1  | 17.33       | 17.33       | 6.85    | 0.0138 |
| WEEKS <sup>2</sup> | 1  | 16.45       | 16.45       | 6.5     | 0.0161 |
| WEEKS <sup>3</sup> | 1  | 14.68       | 14.68       | 5.8     | 0.0224 |
| RMW                | 1  | 0.31        | 0.31        | 0.12    | 0.7305 |
| RVS                | 1  | 1.30        | 1.30        | 0.51    | 0.4796 |
| RBCS               | 1  | 5.72        | 5.72        | 2.26    | 0.1432 |
| RFW                | 1  | 2.25        | 2.25        | 0.89    | 0.3535 |

RMW = Routine male weight (g); RVS = Routine vent score; RBCS = Routine body condition score; RFW = Routine female weight (g)

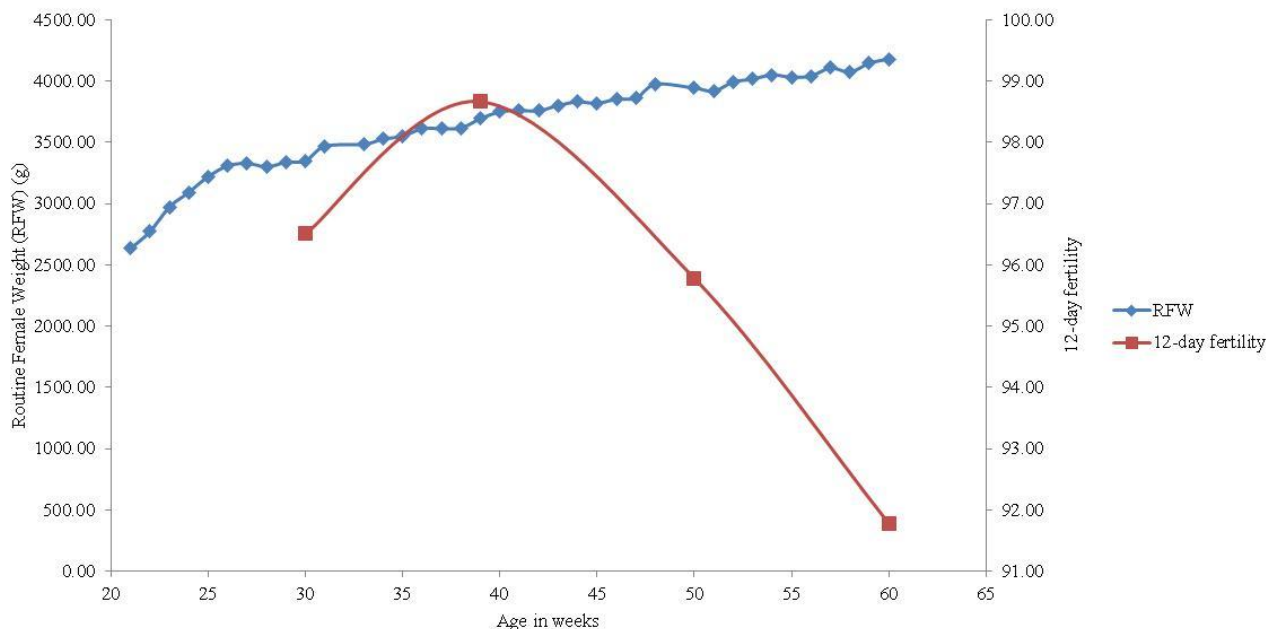


**Figure 4.16 Comparison of routine female weights (RFW) and 12-day fertility values ( $F_{12}$ )**

All models had  $R^2$  values greater than 0.60, whereby at least 60% of the variation in all of the models can be explained by all the traits used in the models. The models run were based on a P value of  $> 0.0001$ . It

can be seen from these results that if the confidence interval was relaxed, more traits may be shown to have a significant influence on fertility values.

The results of the Tukey test ( $P > 0.05$ ) as shown in Appendix D indicate that there is a statistically significant difference between farms, but not between houses on the same farm. From the appendix it can be seen more clearly that the significant difference between farms as shown in the models can be seen as differences between the two breeds used. It should be noted that not all farms that housed different breeds showed statistically significant differences ( $P > 0.05$ ); this could mainly be due to the uniformity of the management practices on the different farms.

## Chapter 5

### Discussion

The aim of this study was to identify morphological traits as potential indicators in determining male broiler breeder fertility. Many studies have shown that morphological traits have some correlations or associations with fertility (Barbato, 1999; McGary *et al.*, 2003; Wolanski *et al.*, 2004; Bilecik *et al.*, 2005). The morphological traits analysed in this study include shank length, body weight and body condition score. Shank length was tested using three different models to determine if there was a significant influence on either 18- or 12- day fertility values ( $P > 0.0001$ ) and the results indicated that with a relaxed confidence interval ( $P > 0.005$ ) shank length significantly influenced 18-day fertility, and shank length may be a useful measurement in broiler breeder fertility management. The shank length increased from 9.1 centimetres (cm) at 20 weeks of age to 14.6cm at 60 weeks of age. These figures are similar to those found in literature, where reported shank length averages were between 9.5cm and 14.5cm from 20 weeks to 63 weeks of age (McGovern, 2002; Wolanski *et al.*, 2004; Romero-Sanchez *et al.*, 2005). However, it should be noted that the shank lengths recorded by McGovern (2002) were measured from the hock to the junction between the second and third digit while flexed. Some studies have recorded shank lengths by measuring the shank bone once it has been removed from a culled male (Tyler, *et al.*, 2009). This method may be more accurate but was not feasible in this study as measurements were recorded on a commercial farm. Most studies have based their shank length measurements on the same method used in this study, but it is not clear in these studies if allowances were included for the size of the foot pad. It is assumed that if a measurement is recorded from the base of the foot pad, it will include the thickness of the pad and the measurement will not be a true reflection of the shank length. In this study, the shank length measurement was recorded at the bottom of the shank, where the bone could be felt, to reduce the influence of the fat pad. It was noted in this study, as well as in literature (Wolanski *et al.*, 2004; Renema *et al.*, 2007a), that males with a higher body weight tended to have longer shank lengths. The average shank length of the males did not differ significantly between houses on the same farm. Where the Tukey tests indicated differences between farms, it was shown that these differences were due to a difference between the two genotypes Ross and Cobb. These breed differences however, were not observed on the same farm, and therefore cannot be confirmed as solely being due to differences in the two genotypes. This study was conducted on commercial production units and a structured trial with Ross and Cobb would be required for confirmation.

Shank length measurement in poultry has a high heritability of 0.7 (Deeb & Lamont, 2002), and is also positively correlated with body weight (Chambers, 1990; Msoffe *et al.*, 2001; Kabir *et al.*, 2006). Research by McGary *et al.* (2003) has shown that morphological traits are correlated with fluctuating asymmetry of bilateral traits associated with fertility, and Campo *et al.* (2005) estimated that the heritability of fluctuating

asymmetry is moderate, allowing indirect selection to occur on fertility. The bilateral traits included keel length, posterior pelvic width and length, comb length and width, and wattle length, width and area. There is a high genetic correlation between shank length and body weight in males of 0.30-0.91 (Wolanski *et al.*, 2004; Kabir *et al.*, 2006; Wolanski *et al.*, 2006). From this study shank length shows potential as an indicator trait in male broiler breeder fertility.

A major focus in the broiler breeder industry is to study nutritional solutions with regards to the decline in fertility. Feed intake of the males was included in some of the models, but it had no significant influence on fertility ( $P > 0.0001$ ). Body weight however, can be seen as a direct result of feed intake, and as such feed intake was removed from the analysis.

Male and female body weights were traits that were measured in this study, and it was shown that only female body weight had a significant influence on 18-day fertility. Male weight was recorded on the farm as part of standard production, but it was also recorded as an additional measurement in this study. The average male weight as measured routinely on-farm (RMW) was 4.62kg compared to 4.66kg as part of the additional measurements (AMW). A difference was observed between the two measurements and differences could be expected due to different individuals that recorded the different measurements over time and that the birds weighed at one interval were not the same as those measured at the next interval. From a practical point of view it was not possible to mark specific birds for measurement, but rather a representative sample was used as an indication of the weight of all the males in the house. The results of this study showed neither the routine nor the additional male body weight measurements (RMW and AMW) significantly contributed to either 18- or 12- day fertility ( $P > 0.0001$ ). In two of the models where female weight (RFW) was included, it was shown that female weight significantly contributed to 18-day fertility, but not to 12-day fertility. Similar to shank length, if the confidence interval were relaxed to  $P > 0.05$ , the male weights would have a greater influence on both 18- and 12- day fertility. Literature has confirmed that both male and female weights influence fertility, and thus body weight should remain as a management tool for fertility.

There is intensive selection for growth traits to maximize broiler potential, but this has a negative impact on reproductive traits in general, and more specifically fertility in the broiler breeders (McGary *et al.*, 2002; Decuypere *et al.*, 2003; Reddish, 2004; Bramwell, 2008b; Decuypere *et al.*, 2010; Richards *et al.*, 2010; Meijerhof, 2011). The reduction of fertility observed in naturally mating flocks may be associated with increased body weight of the males toward the end of the production cycle (Hocking & Duff, 1989; Wolanski *et al.*, 2004; Chung, 2012). Reproductive efficiency in leaner males has been shown to be poorer with regard to reproductive capacity, which includes mating ability, fertility and semen specific characteristics (Rauw *et al.*, 1998; Barbato, 1999).

Body condition is closely related to body weight and is used as a measure of fleshing or size and shape of the breast of the males. It commonly used as a feeding management tool on the farms used in this study. A greater fleshing on the breast of the male results in a high body condition score and this is interpreted as over feeding, or reduced activity of the males, and feed is adjusted accordingly. Body condition scoring is a subjective measurement as it relies on an individual's interpretation of the fleshing of the bird. Similar to male body weight, body condition score was recorded both with the routine farm measurements (RBCS) as well as part of the additional measurements (ABCS). Average routine farm body condition score was 2.90, whereas the additional measurement gave a value of 2.48, the slight difference seen here can be attributed to the subjective nature of the score, as well as the fact that different birds were measured each time. The routine farm body condition score significantly contributed to 18-day fertility values ( $P > 0.0001$ ). At a more relaxed confidence interval ( $P > 0.005$ ), both the routine farm and additional body condition scores contributed to both 18- and 12- day fertility. In this study heavier males also had high body condition scores. This result is supported by literature, where males that have a lower body weight are generally thinner and have a low condition score (McGovern, 2002; Reddish & Lilburn, 2004; Wolanski *et al.*, 2004; Romero-Sanchez *et al.*, 2007). Frame size of the birds will influence the relation between body weights and condition score. Flocks with large frames may be on target weight as indicated by breeder company standards but condition scores may be low. This indicates need for more feed allowance, to improve the condition of the birds to maintain mating activity (personal communication C. Le Roux, [cdlroux@mweb.co.za](mailto:cdlroux@mweb.co.za)). This confirms that body condition score should be included as a male management tool.

The intensity of the redness of the vent is a useful management tool in the assessment of male activity within a flock. Males performing at optimum rates will have a deep red vent colour, resulting in a high vent score. The main objective of this measurement is to monitor and maintain a high vent score, which is an indication of high mating activity in male broiler breeders, throughout the production cycle. Males with a pale vent, or a low vent score, are most likely not mating. It is recommended to remove those particular birds from the flock to improve overall fertility (Aviagen Breeder management Guide, 2006). Vent scoring was used in this study, but as with body condition score it is a subjective measurement and is prone to bias. It may still be used as an indirect indicator of fertility, by monitoring mating activity. It is a fairly easy measurement to record and is already included in management practices on some farms. In this study it was shown that the routine farm vent scoring (RVS) had a significant influence on 18-day fertility values, but not on 12-day values ( $P > 0.0001$ ). The additional vent scoring (AVS) was shown to have no significant influence on either of the fertility values ( $P > 0.0001$ ), possibly due to the low number of observations. However, it may be able to contribute to the 12-day fertility values if the confidence interval were relaxed to  $P > 0.05$ .

Fertility measurements recorded at the hatcheries is based on an 18-day candling. This is not a true determination of fertility as it does not account for early embryonic deaths. True fertility is determined by performing a breakout of freshly laid eggs, a breakout on eggs after three days of incubation or by a 12-day candling and breakout. A breakout is usually only performed if there is seen to be a major issue with either hatchery or farm performance. The Cobb hatchery guide ([http://www.cobb-vantress.com/contactus/brochures/Hatchery\\_Guide\\_2008.pdf](http://www.cobb-vantress.com/contactus/brochures/Hatchery_Guide_2008.pdf)) supports the 18-day candling method as it fits into the standard management practices, and only recommends a 12-day candling if major problems are seen in fertility and hatchability. The fertility measurement of a 12-day candling and breakout was included in the additional measurements as a potentially more accurate measure than the 18-day candling. At 18-days, when compared to 12-days, it is difficult to distinguish between early embryonic deaths and infertile eggs at 18-days, and thus is more easily distinguishable at 12-days. This is supported in literature where some hatcheries use a 12-day breakout routinely, whereas others may use it in times of flock problems (Mauldin, 1993). The Aviagen hatchery management guide (Tullet, 2009) suggests that a breakout done earlier than 12-days does not show any underlying problems with fertility. This is because not enough embryonic development has occurred yet. Although breakouts closer to hatching tend to yield more results, it is difficult to determine the underlying cause of eggs that failed to hatch. A further advantage of performing a 12-day candling and breakout is that fewer fertile eggs are destroyed than when compared to a breakout performed at an earlier date. An analysis by Wilson (1993) suggests that three breakouts are critical to monitoring problem flock fertility performance, namely one breakout as soon as possible after the eggs have been laid, the second at around 12-days and the last one to be conducted on the eggs that did not hatch. This may yield results, but it is a costly exercise as many of the eggs will be destroyed in the process, resulting in lower numbers of eggs available for hatching.

In this study, significant farm differences were seen only when comparing 18-day fertility values and not with 12-day fertility values ( $P > 0.0001$ ). These differences were seen between the different breeds used, and may be partially attributed to genotype. The lack of significant differences found between farms in the 12-day fertility values could be due to the improved accuracy of the measurement over the 18-day one, which is most likely due to other external factors that would affect embryo survival; such as egg handling and storage conditions, as well as egg quality.

## **Limitations**

This study was based on routine data recorded on nine broiler breeder farm, and additional data over a two year period. The study therefore had to be conducted within certain limitations. With regard to the routine farm data, it should be noted that it was already in an averaged format, and as such the models that include these routine farm measurements would be analysing the average of the average for the traits, this

might explain the lack of significant influence of these traits on fertility. In the additional measurements, 50 birds weighed and the data was averaged and used as such in the models. If more birds were measured at more frequent intervals, a more accurate and comparable result would be seen. The intervals at which measurements were recorded were thought to be critical within the production cycle of the broiler breeders. However, biosecurity had to be taken into account, where different farms could only be visited after a period of absence from other farms; this was to minimize any possible cross-contamination or transfer of diseases from one farm to another. This study was conducted within routine farm management and not under experimental conditions and therefore there was potential for greater variation. It should be noted that a common factor in the results was the farm influence which was attributed to the two different breeds used, namely Ross and Cobb. There are numerous genetic differences between the two breeds, which may explain some of the variation between farms, but management would also have a large contribution towards this difference. It was seen in the results that farm may have contributed significantly to the variation in fertility ( $P > 0.0001$ ), but with further analysis by making use of the Tukey test that there were no differences between houses on the same farm, nor any differences between farms ( $P > 0.05$ ). This would imply that the farm differences seen in the model are created by other management factors and external environment that are not accounted for in the current models. The data sets had inherent limitations with regards to the relatively low number of observations and using subjective traits based on scores. With relaxed confidence intervals, traits such as shank length could show significance, and merits further research under experimentally controlled conditions.

In conclusion, shank length holds the most potential as an early indicator of male broiler breeder fertility. It is however, a time-consuming measurement and does not seem feasible to implement it into current commercial broiler breeder management practices. Literature, practical observation and results have found potential for further study of the various measurements used in this study.

## Chapter 6

### Conclusion

The broiler industry is well established and a primary supplier of protein in human diets. Of all the aspects important to broiler production, fertility of the broiler breeders is one of the most important, and it is affected by many external factors. The aim of this study was to evaluate existing data, with a number of production parameters measured on-farm and to identify additional measurements that may be used as early indicators of male broiler breeder fertility. This data consisted of production parameters (weight, body condition score, vent score and feed intake) and an additional morphological trait of shank length. The determination of fertility was done by using 12-day candling and breakout at 30, 35, 40, 50 and 60 weeks of age. These intervals are thought to be the critical stages during the production cycle.

Shank length was tested using three different models at a confidence level of  $P > 0.0001$  and from the results it was seen that if the confidence interval were to be relaxed to  $P > 0.005$ , shank length may significantly influence 18-day fertility. This suggests that shank length may be a useful measure in broiler breeder fertility management. Female body weights had a significant influence on 18-day fertility ( $P > 0.0001$ ), while the results of this study showed that neither the routine nor the additional male body weight measurements (RMW and AMW) significantly contributed to either 18- or 12- day fertility. In two of the models where female weight (RFW) was included, it was shown that female weight significantly contributed to 18-day fertility, but not to 12-day fertility. Contrary to the results in this study, literature has shown that both male and female weights influence fertility. Similar to male body weight, body condition score was recorded both routinely (RBCS) and as part of the additional measurements (ABCS). If a more relaxed confidence interval was used, both routine and additional body condition scores would contribute to both 18- and 12- day fertility values. Due to its association with body weight, body condition score may be a likely alternative for monitoring male broiler breeder reproductive performance. Vent scoring as with body condition score is a subjective measurement and is prone to bias, but still useful as an indirect indicator of fertility, by monitoring mating activity. It is a fairly easy measurement to record and is already included in management practices on some farms. In this study the routine vent scoring (RVS) contributed to the 18-day fertility.

The results of this study indicated that there was a significant difference between the farms with regards to 18-day fertility values ( $P > 0.0001$ ), and is partially attributed to the breed differences. These significant differences were not seen between farms when comparing 12-day fertility values ( $P > 0.0001$ ). Instances where the models have indicated that there were significant influences on fertility by the farm ( $P > 0.0001$ ), but not when farms were compared by the Tukey test ( $P > 0.05$ ), shows that there are other factors

that are included in the farm, that will affect fertility, but have not been identified in this study. These factors may include hatchery conditions and egg handling, as well as egg quality. Thus, it is essential to make use of a true determination of fertility, while taking all other factors into account, such as 12-day candling and breakout.

Literature has proven the merits of the various measurements used in this study. The results from this study could not always be supported by those found in literature and could be due to the limited sample size in this study. The intervals at which measurements were recorded were thought to be critical within the production cycle of the broiler breeders. However, biosecurity had to be taken into account, where different farms could only be visited after a period of absence from other farms; this was to minimize any possible cross-contamination or transfer of diseases from one farm to another. As mentioned before, both body condition score and vent score are subjective measures, and until such time as there is a more accurate and objective method for determining these scores, there will continue to be variation between farms, and limited comparisons can be drawn from them. Although shank length holds the most potential as an indicator for fertility, it is a time-consuming measurement and does not seem feasible to implement it into current commercial broiler breeder management practices. The general lack of correlation between the measurements used in this study and the fertility values has been attributed to small sample size and other factors. It should also be considered that the lack of significance found may be due to the uniformity of the management practices found on all of the farms, and as such variation between the farms is minimal. The results observed however, merit further investigation under experimentally controlled conditions and innovative thought for more objective methods when measuring vent score and body condition score.

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## Appendix A

### A.1 Housing Guidelines

**Table A.1.1 Broiler breeder rearing housing standards per house within the company**

| Farm | Number males | House length | House width | Feed track length | Number nipples | Number bells | Closed sided | Number Fans |         | Lights             |                      | Square meter | Feed space cm per male | Birds per bell |
|------|--------------|--------------|-------------|-------------------|----------------|--------------|--------------|-------------|---------|--------------------|----------------------|--------------|------------------------|----------------|
|      |              |              |             |                   |                |              |              | 50 inch     | 36 inch | Number See-morelux | Number Incan-descent |              |                        |                |
| RA   | 4771         | 60           | 13          | 468               | 1140           | 0            | Yes          | 4           | 1       | 60                 | 0                    | 780.0        | 19.6                   |                |
| RB   | 2300         | 54           | 12          | 335               | 0              | 77           | Yes          | 4           | 0       | 75                 | 0                    | 648.0        | 29.1                   |                |
| RC   | 2141         | 25           | 14.4        | 288               | 0              | 51           | Yes          | 2           | 2       | 0                  | 22                   | 360.0        | 26.9                   | 42.0           |

**Table A.1.2 Broiler breeder production housing standards per house within the company**

| Farm | House length (m) | House width (m) | Open sided | Closed | Number Fans |         | Lights               |                          |                     |
|------|------------------|-----------------|------------|--------|-------------|---------|----------------------|--------------------------|---------------------|
|      |                  |                 |            |        | 50 inch     | 36 inch | Number Barry Seemore | Number Fluorescent tubes | Number Incandescent |
| A    | 99               | 12              | yes        |        | 0           | 0       | 99                   | 198                      | 6                   |
| B    | 99               | 12              | yes        |        | 0           | 0       | 99                   | 198                      | 6                   |
| D    | 95.5             | 12              | no         | yes    | 4           | 2       | 96                   | 192                      | 6                   |
| E    | 30               | 7               | yes        |        | 0           | 0       | 25                   | 50                       | 0                   |
| F    | 45.85            | 13.4            | yes        |        | 0           | 0       | 35                   | 70                       | 0                   |
| G    | 85.3             | 12.1            | yes        |        | 0           | 0       | 79                   | 158                      | 0                   |
| H    | 92               | 13.6            | yes        |        |             |         |                      |                          |                     |

**Table A.1.3 Male broiler breeder feed and water guidelines per house within the company**

| Farm | Feed track length (m) | Number nipples | Number bells | Male feeder length (m) | Number of pans for males | Males per pan | Birds per nipple | Birds per bell |
|------|-----------------------|----------------|--------------|------------------------|--------------------------|---------------|------------------|----------------|
| A    | 397.32                | 751            | 0            | 60                     | 0                        |               | 8.1              |                |
| B    | 404.24                | 710            | 0            | 60                     | 0                        |               | 8.5              |                |
| D    | 544.36                | 719            | 0            | 63                     | 0                        |               | 9.2              |                |
| E    | 64.6                  | 0              | 18           | 12                     | 0                        |               |                  | 61.1           |
| F    | 189.12                | 488            | 0            | 27                     | 0                        |               | 5.9              |                |
| G    | 449.5                 | 788            | 0            | 60.1                   | 0                        |               | 7.3              |                |
| H    | 398                   |                | 78           |                        | 67                       | 7.5           |                  | 70.5           |

**Table A.1.4 Broiler breeder stocking densities per house within the company**

| Farm | Number males | Mating ratio (F:M) | Square meter | Total per meter | cm <sup>2</sup> per male |
|------|--------------|--------------------|--------------|-----------------|--------------------------|
| A    | 550          | 10                 | 1188.0       | 5.1             | 21.8                     |
| B    | 550          | 10                 | 1188.0       | 5.1             | 21.8                     |
| D    | 600          | 10                 | 1146.0       | 5.8             | 21.0                     |
| E    | 100          | 10                 | 210.0        | 5.2             | 24.0                     |
| F    | 260          | 10                 | 614.4        | 4.7             | 20.8                     |
| G    | 525          | 10                 | 1032.1       | 5.6             | 22.9                     |
| H    | 500          | 10                 | 1251.2       | 4.4             | 0.0                      |

## Appendix B

### B.1. Nutrient Specifications

**Table B.1.1 Ross 708 and 308 Nutrient Specifications**

|                                    |      |                         |                         |
|------------------------------------|------|-------------------------|-------------------------|
| Crude Protein                      | %    | 12-14                   |                         |
| Energy per kg                      | Kcal | 2600-2800               |                         |
|                                    | MJ   | 10.9-11.7               |                         |
| <b>Amino Acids</b>                 |      | <b>Total</b>            | <b>Digestible</b>       |
| Lysine                             | %    | 0.45-0.55               | 0.40-0.49               |
| Methionine & Cystine               | %    | 0.38-0.46               | 0.34-0.41               |
| Methionine                         | %    | 0.16-0.22               | 0.15-0.20               |
| Threonine                          | %    | 0.36-0.46               | 0.32-0.40               |
| Valine                             | %    | 0.48-0.58               | 0.42-0.50               |
| Isoleucine                         | %    | 0.40-0.51               | 0.35-0.45               |
| Arginine                           | %    | 0.61-0.72               | 0.55-0.65               |
| Tryptophan                         | %    | 0.10-0.17               | 0.09-0.15               |
| <b>Minerals</b>                    |      |                         |                         |
| Calcium                            | %    | 0.8-1.2                 |                         |
| Available Phosphorus               | %    | 0.3-0.4                 |                         |
| Magnesium                          | %    | 0.05-0.1                |                         |
| Sodium                             | %    | 0.16-0.23               |                         |
| Chloride                           | %    | 0.16-0.23               |                         |
| Potassium                          | %    | 0.40-0.75               |                         |
| <b>Added Trace Minerals Per Kg</b> |      |                         |                         |
| Copper                             | mg   | 10                      |                         |
| Iodine                             | mg   | 2                       |                         |
| Iron                               | mg   | 50                      |                         |
| Manganese                          | mg   | 120                     |                         |
| Zinc                               | mg   | 100                     |                         |
| Selenium                           | mg   | 0.3                     |                         |
| <b>Added Vitamins per Kg</b>       |      | <b>Wheat based feed</b> | <b>Maize based feed</b> |
| Vitamin A                          | IU   | 12000                   | 11000                   |
| Vitamin D3                         | IU   | 3500                    | 3500                    |
| Vitamin E                          | mg   | 100                     | 100                     |
| Vitamin K (Menadione)              | mg   | 5                       | 5                       |
| Thiamin (B1)                       | mg   | 3                       | 3                       |
| Riboflavin (B2)                    | mg   | 12                      | 12                      |
| Nicotinic Acid                     | mg   | 50                      | 55                      |
| Pantothenic Acid                   | mg   | 13                      | 15                      |
| Pyridoxine (B6)                    | mg   | 5                       | 4                       |
| Biotin                             | mg   | 0.30                    | 0.25                    |
| Folic Acid                         | mg   | 2                       | 2                       |
| Vitamin B12                        | mg   | 0.03                    | 0.03                    |
| <b>Minimum Specification</b>       |      |                         |                         |
| Choline per kg                     |      | 1000                    |                         |
| Linoleic Acid                      | %    | 0.80-1.20               |                         |

**Table B.1.2.1 Cobb 500 Fast Feather recommended digestible amino acid levels based on amino acid/lysine ratios**

| <b>Phase</b>       | <b>Pre-Starter/Starter</b> | <b>Grower/Pre-Breeder</b> | <b>Breeder</b> | <b>Male</b> |
|--------------------|----------------------------|---------------------------|----------------|-------------|
| <b>Age (Days)</b>  | <b>0-28</b>                | <b>29-154</b>             | <b>155+</b>    | <b>155+</b> |
| <b>Age (Weeks)</b> | <b>0-4</b>                 | <b>5-22</b>               | <b>23+</b>     | <b>23+</b>  |
| Lysine             | 100                        | 100                       | 100            | 100         |
| Methionine         | 44                         | 45                        | 47             | 50          |
| M + C              | 75                         | 85                        | 86             | 90          |
| Tryptophan         | 22                         | 25                        | 25             | 29          |
| Threonine          | 70                         | 83                        | 75             | 93          |
| Arginine           | 105                        | 100                       | 90             | 100         |
| Valine             | 67                         | 75                        | 80             | 75          |
| Isoleucine         | 70                         | 83                        | 76             | 83          |
| Leucine            | 118                        | 130                       | 112            | 120         |
| Histidine          | 32                         | 33                        | 34             | 35          |
| Phenylalanine      | 65                         | 65                        | 66             | 65          |
| P + T              | 115                        | 120                       | 120            | 120         |

**Table B.1.2.2 Cobb 500 Fast Feather recommended nutrient levels (%per 1000 kcal/kg metabolizable energy)**

| Phase                | Pre-Starter |       | Starter |       | Grower |       | Pre-Breeder |       | Breeder 1 |       | Breeder 2 |       | Male  |       |
|----------------------|-------------|-------|---------|-------|--------|-------|-------------|-------|-----------|-------|-----------|-------|-------|-------|
| Age (Days)           | 0-14        |       | 0-28    |       | 29-126 |       | 127-154     |       | 155-280   |       | 281+      |       | 155+  |       |
| Age (Weeks)          | 0-2         |       | 0-4     |       | 5-18   |       | 19-22       |       | 23-40     |       | 41+       |       | 23+   |       |
| Crude Protein        | 6.974       |       | 6.630   |       | 5.600  |       | 5.590       |       | 5.590     |       | 5.240     |       | 4.717 |       |
| Calcium              | 0.349       |       | 0.358   |       | 0.383  |       | 0.524       |       | 1.048     |       | 1.119     |       | 0.326 |       |
| Available Phosphorus | 0.157       |       | 0.160   |       | 0.156  |       | 0.157       |       | 0.157     |       | 0.139     |       | 0.163 |       |
| Sodium               | 0.067       |       | 0.067   |       | 0.075  |       | 0.066       |       | 0.066     |       | 0.066     |       | 0.069 |       |
| Chloride             | 0.067       |       | 0.067   |       | 0.075  |       | 0.066       |       | 0.066     |       | 0.066     |       | 0.069 |       |
| Potassium            | 0.209       |       | 0.215   |       | 0.232  |       | 0.227       |       | 0.227     |       | 0.209     |       | 0.218 |       |
| Linoleic Acid        | 0.436       |       | 0.436   |       | 0.430  |       | 0.419       |       | 0.454     |       | 0.349     |       | -     |       |
| Amino Acid           | Dig.        | Total | Dig.    | Total | Dig.   | Total | Dig.        | Total | Dig.      | Total | Dig.      | Total | Dig.  | Total |
| Lysine               | 0.391       | 0.436 | 0.322   | 0.359 | 0.190  | 0.230 | 0.220       | 0.260 | 0.230     | 0.262 | 0.225     | 0.255 | 0.152 | 0.175 |
| Methionine           | 0.172       | 0.192 | 0.142   | 0.158 | 0.086  | 0.104 | 0.099       | 0.117 | 0.108     | 0.123 | 0.106     | 0.120 | 0.076 | 0.088 |
| M + C                | 0.293       | 0.327 | 0.242   | 0.269 | 0.162  | 0.196 | 0.187       | 0.221 | 0.198     | 0.225 | 0.194     | 0.219 | 0.137 | 0.158 |
| Tryptophan           | 0.086       | 0.096 | 0.071   | 0.079 | 0.048  | 0.058 | 0.055       | 0.065 | 0.058     | 0.066 | 0.056     | 0.064 | 0.044 | 0.051 |
| Threonine            | 0.273       | 0.306 | 0.225   | 0.251 | 0.158  | 0.191 | 0.183       | 0.216 | 0.173     | 0.199 | 0.169     | 0.194 | 0.141 | 0.165 |
| Arginine             | 0.411       | 0.458 | 0.338   | 0.377 | 0.190  | 0.230 | 0.220       | 0.260 | 0.207     | 0.236 | 0.203     | 0.230 | 0.152 | 0.175 |
| Valine               | 0.262       | 0.292 | 0.216   | 0.241 | 0.143  | 0.173 | 0.165       | 0.195 | 0.184     | 0.210 | 0.180     | 0.204 | 0.114 | 0.131 |
| Isoleucine           | 0.273       | 0.306 | 0.225   | 0.251 | 0.158  | 0.191 | 0.183       | 0.216 | 0.175     | 0.199 | 0.171     | 0.194 | 0.126 | 0.145 |
| Leucine              | 0.461       | 0.515 | 0.380   | 0.424 | 0.247  | 0.299 | 0.286       | 0.338 | 0.258     | 0.293 | 0.252     | 0.286 | 0.182 | 0.210 |
| Histidine            | 0.125       | 0.140 | 0.103   | 0.115 | 0.063  | 0.076 | 0.073       | 0.086 | 0.078     | 0.089 | 0.077     | 0.087 | 0.053 | 0.061 |
| Phenylalanine        | 0.254       | 0.283 | 0.209   | 0.233 | 0.124  | 0.150 | 0.143       | 0.169 | 0.152     | 0.173 | 0.149     | 0.168 | 0.099 | 0.114 |
| P + T                | 0.450       | 0.501 | 0.370   | 0.413 | 0.228  | 0.276 | 0.264       | 0.312 | 0.276     | 0.314 | 0.270     | 0.306 | 0.182 | 0.210 |

**Table B.1.2.3 Cobb 500 Fast Feather recommended supplementary levels of vitamins and trace elements per metric ton basis**

| <b>Phase</b>         | <b>Unit</b> | <b>Pre-Starter/Starter</b> | <b>Grower</b> | <b>Pre-Breeder/Breeder</b> |
|----------------------|-------------|----------------------------|---------------|----------------------------|
| <b>Age (Days)</b>    |             | <b>0-28</b>                | <b>29-126</b> | <b>127+</b>                |
| <b>Age (Weeks)</b>   |             | <b>0-4</b>                 | <b>5-18</b>   | <b>19+</b>                 |
| Vit. A (Maize Diets) | MIU         | 10                         | 10            | 12                         |
| Vit. A (Wheat Diets) | MIU         | 11                         | 11            | 13                         |
| Vit. D3              | MIU         | 3                          | 3             | 3                          |
| Vit. E               | KIU         | 75-80                      | 45-50         | 50-100                     |
| Vit. K               | g           | 3                          | 3             | 6                          |
| Thiamine             | g           | 2                          | 2             | 2.5-3.5                    |
| Riboflavin           | g           | 5-8                        | 5-7           | 10-16                      |
| Pantothenic Acid     | g           | 8-12                       | 8-10          | 25                         |
| Niacin               | g           | 20-40                      | 20-35         | 40                         |
| Pyridoxine           | g           | 3                          | 3             | 6                          |
| Folic Acid           | g           | 1.5                        | 1             | 4                          |
| Vit. B12             | mg          | 25                         | 20            | 35-40                      |
| Biotin (Maize Diets) | mg          | 250                        | 250           | 300                        |
| Biotin (Wheat Diets) | mg          | 300                        | 300           | 375                        |
| Vit. C               | g           | 25                         | 25            | 50                         |
| Choline              | g           | 300-350                    | 200-300       | 250-450                    |
| Manganese            | g           | 100                        | 100           | 120                        |
| Zinc                 | g           | 100                        | 120           | 110                        |
| Iron                 | g           | 20-50                      | 20-50         | 40-55                      |
| Copper               | g           | 10-15                      | 10-15         | 10-15                      |
| Iodine               | g           | 1.5                        | 0.5           | 2                          |
| Selenium             | g           | 0.3                        | 0.3           | 0.3                        |

## Appendix C

### C.1 Examples of data sources used for analysis

Only data used for the statistical analysis is shown below.

**Table C.1.1 Example of on-farm data source**

| Farm | STRAINNAME | DAY<br>S | WEIGHT_F<br>(g) | WEIGHT_M<br>(g) | FEEDRATIO_M<br>(g) | TOTALEGGPRODUCTION |
|------|------------|----------|-----------------|-----------------|--------------------|--------------------|
| A    | Cobb PS    | 148      |                 | 3176            | 122.10             |                    |
| A    | Cobb PS    | 149      |                 |                 | 122.18             |                    |
| A    | Cobb PS    | 150      |                 |                 | 125.45             |                    |
| A    | Cobb PS    | 151      |                 |                 | 125.45             |                    |
| A    | Cobb PS    | 152      |                 |                 | 125.45             |                    |
| A    | Cobb PS    | 153      | 2586            | 3541            | 125.45             |                    |
| A    | Cobb PS    | 154      |                 |                 | 125.45             |                    |
| A    | Cobb PS    | 155      |                 |                 | 125.45             |                    |
| A    | Cobb PS    | 156      | 2732            | 3622            | 127.27             |                    |
| A    | Cobb PS    | 157      |                 |                 | 127.27             |                    |
| A    | Cobb PS    | 158      |                 |                 | 127.27             |                    |
| A    | Cobb PS    | 159      |                 |                 | 127.27             |                    |
| A    | Cobb PS    | 160      | 2835            | 3734            | 127.74             |                    |
| A    | Cobb PS    | 161      |                 |                 | 128.21             |                    |
| A    | Cobb PS    | 162      |                 |                 | 128.44             |                    |
| A    | Cobb PS    | 163      | 2948            | 3735            | 128.44             | 3                  |
| A    | Cobb PS    | 164      |                 |                 | 128.44             | 10                 |
| A    | Cobb PS    | 165      |                 |                 | 128.68             | 24                 |
| A    | Cobb PS    | 166      |                 |                 | 130.52             | 26                 |
| A    | Cobb PS    | 167      | 2971            | 3780            | 130.52             |                    |
| A    | Cobb PS    | 168      |                 |                 | 130.52             |                    |
| A    | Cobb PS    | 169      |                 |                 | 130.52             |                    |
| A    | Cobb PS    | 170      | 3030            | 3838            | 129.65             | 223                |
| A    | Cobb PS    | 171      |                 |                 | 129.70             | 311                |
| A    | Cobb PS    | 172      |                 |                 | 131.61             | 387                |
| A    | Cobb PS    | 173      |                 |                 | 132.46             | 521                |
| A    | Cobb PS    | 174      | 3157            | 3847            | 132.46             | 636                |
| A    | Cobb PS    | 175      |                 |                 | 131.59             | 776                |
| A    | Cobb PS    | 176      |                 |                 | 131.65             | 1108               |
| A    | Cobb PS    | 177      | 3242            | 3900            | 131.71             | 1258               |
| A    | Cobb PS    | 178      |                 |                 | 135.34             | 1386               |
| A    | Cobb PS    | 179      |                 |                 | 135.34             | 1762               |
| A    | Cobb PS    | 180      |                 |                 | 135.59             | 1987               |
| A    | Cobb PS    | 181      | 3163            | 3932            | 134.60             | 2040               |
| A    | Cobb PS    | 182      |                 |                 | 134.27             | 2396               |
| A    | Cobb PS    | 183      |                 |                 | 135.08             | 2640               |
| A    | Cobb PS    | 184      | 3309            | 4067            | 139.72             | 2481               |
| A    | Cobb PS    | 185      |                 |                 | 139.72             | 3593               |
| A    | Cobb PS    | 186      |                 |                 | 139.39             | 3463               |

**Table C.1.2 Example of scoring data source**

| FARM | STRAIN  | SCORETYPE        | SCORE |
|------|---------|------------------|-------|
| A    | Cobb PS | Vent Avg Score   | 1.85  |
| A    | Cobb PS | Breast Avg Score | 2.39  |
| A    | Cobb PS | Vent Avg Score   | 1.85  |
| A    | Cobb PS | Breast Avg Score | 2.39  |
| A    | Cobb PS | Vent Avg Score   | 2.05  |
| A    | Cobb PS | Breast Avg Score | 2.50  |
| A    | Cobb PS | Vent Avg Score   | 2.62  |
| A    | Cobb PS | Breast Avg Score | 2.96  |
| A    | Cobb PS | Vent Avg Score   | 2.59  |
| A    | Cobb PS | Breast Avg Score | 3.04  |
| A    | Cobb PS | Vent Avg Score   | 2.70  |
| A    | Cobb PS | Breast Avg Score | 3.02  |
| A    | Cobb PS | Vent Avg Score   | 2.68  |
| A    | Cobb PS | Breast Avg Score | 3.22  |
| A    | Cobb PS | Vent Avg Score   | 2.48  |
| A    | Cobb PS | Breast Avg Score | 3.10  |
| A    | Cobb PS | Vent Avg Score   | 2.56  |
| A    | Cobb PS | Breast Avg Score | 3.23  |
| A    | Cobb PS | Vent Avg Score   | 2.97  |
| A    | Cobb PS | Breast Avg Score | 3.36  |
| A    | Cobb PS | Vent Avg Score   | 3.11  |
| A    | Cobb PS | Breast Avg Score | 3.43  |
| A    | Cobb PS | Vent Avg Score   | 3.17  |
| A    | Cobb PS | Breast Avg Score | 3.47  |
| A    | Cobb PS | Vent Avg Score   | 3.63  |
| A    | Cobb PS | Breast Avg Score | 3.30  |
| A    | Cobb PS | Breast Avg Score | 2.52  |
| A    | Cobb PS | Vent Avg Score   | 2.28  |
| A    | Cobb PS | Vent Avg Score   | 3.13  |
| A    | Cobb PS | Breast Avg Score | 3.67  |
| A    | Cobb PS | Breast Avg Score | 3.67  |
| A    | Cobb PS | Vent Avg Score   | 3.13  |
| A    | Cobb PS | Vent Avg Score   | 3.10  |
| A    | Cobb PS | Breast Avg Score | 3.59  |
| A    | Cobb PS | Vent Avg Score   | 3.38  |
| A    | Cobb PS | Breast Avg Score | 3.69  |
| A    | Cobb PS | Vent Avg Score   | 3.01  |
| A    | Cobb PS | Breast Avg Score | 3.35  |
| F    | Cobb PS | Vent Avg Score   | 3.16  |
| F    | Cobb PS | Breast Avg Score | 3.63  |
| F    | Cobb PS | Vent Avg Score   | 3.16  |
| F    | Cobb PS | Breast Avg Score | 3.41  |
| F    | Cobb PS | Vent Avg Score   | 3.18  |
| F    | Cobb PS | Breast Avg Score | 3.68  |
| F    | Cobb PS | Vent Avg Score   | 3.32  |
| F    | Cobb PS | Breast Avg Score | 3.48  |
| F    | Cobb PS | Vent Avg Score   | 3.24  |
| F    | Cobb PS | Breast Avg Score | 3.55  |
| F    | Cobb PS | Vent Avg Score   | 2.94  |

**Table C.1.3 Example of 18-day hatchery data**

| FARMNAME | STRAINNAME | HATCHERYNAME | TOTALEGGSSET | FERTILE |
|----------|------------|--------------|--------------|---------|
| A        | Cobb PS    | HB           | 1620         | 1430    |
| A        | Cobb PS    | HB           | 9072         | 8273    |
| A        | Cobb PS    | HB           | 5184         | 4769    |
| A        | Cobb PS    | HB           | 12555        | 11333   |
| A        | Cobb PS    | HB           | 15633        | 14326   |
| A        | Cobb PS    | HB           | 4860         | 4591    |
| A        | Cobb PS    | HB           | 17901        | 16512   |
| A        | Cobb PS    | HB           | 11907        | 11094   |
| A        | Cobb PS    | HB           | 972          | 881     |
| A        | Cobb PS    | HB           | 20412        | 18961   |
| A        | Cobb PS    | HA           | 16050        | 14938   |
| A        | Cobb PS    | HB           | 1944         | 1844    |
| A        | Cobb PS    | HA           | 14400        | 13385   |
| A        | Cobb PS    | HA           | 12975        | 12306   |
| A        | Cobb PS    | HA           | 12450        | 11734   |
| A        | Cobb PS    | HB           | 8262         | 7834    |
| A        | Cobb PS    | HA           | 7425         | 7028    |
| A        | Cobb PS    | HB           | 4860         | 4606    |
| A        | Cobb PS    | HA           | 12750        | 12109   |
| A        | Cobb PS    | HA           | 2925         | 2792    |
| A        | Cobb PS    | HA           | 13275        | 12616   |
| A        | Cobb PS    | HA           | 4800         | 4540    |
| A        | Cobb PS    | HA           | 8400         | 7975    |
| A        | Cobb PS    | HA           | 9600         | 9065    |
| A        | Cobb PS    | HA           | 4800         | 4560    |
| A        | Cobb PS    | HB           | 5184         | 4895    |
| A        | Cobb PS    | HA           | 14400        | 13731   |
| A        | Cobb PS    | HA           | 4800         | 4577    |
| A        | Cobb PS    | HA           | 6300         | 5836    |
| A        | Cobb PS    | HA           | 7290         | 6999    |
| A        | Cobb PS    | HA           | 9600         | 9174    |
| A        | Cobb PS    | HA           | 4200         | 3998    |
| A        | Cobb PS    | HA           | 9600         | 9156    |
| A        | Cobb PS    | HA           | 13350        | 12749   |
| A        | Cobb PS    | HA           | 7200         | 6875    |
| A        | Cobb PS    | HA           | 4800         | 4582    |
| A        | Cobb PS    | HA           | 14400        | 13653   |
| A        | Cobb PS    | HA           | 9600         | 9144    |
| A        | Cobb PS    | HA           | 2967         | 2818    |
| A        | Cobb PS    | HA           | 2700         | 2572    |
| A        | Cobb PS    | HA           | 5346         | 5105    |
| A        | Cobb PS    | HA           | 8850         | 8432    |
| A        | Cobb PS    | HA           | 2100         | 1991    |
| A        | Cobb PS    | HA           | 4212         | 4064    |
| A        | Cobb PS    | HA           | 4800         | 4546    |
| A        | Cobb PS    | HA           | 9600         | 9072    |
| A        | Cobb PS    | HA           | 4800         | 4560    |
| A        | Cobb PS    | HA           | 5100         | 4849    |
| A        | Cobb PS    | HA           | 9600         | 9086    |
| A        | Cobb PS    | HA           | 9600         | 8988    |

**Table C.1.4 Example of additional measurements source data**

| FARM | STRAIN  | AGE | WEIGHTM | BCS | SHANK | FAT | SM | VS |
|------|---------|-----|---------|-----|-------|-----|----|----|
| A    | Cobb PS | 21  | 3720    | 2.5 | 10.4  | 0   | 2  | 2  |
| A    | Cobb PS | 21  | 4000    | 3   | 9.7   | 3   | 3  | 1  |
| A    | Cobb PS | 21  | 3240    | 3   | 9.9   | 1   | 3  | 1  |
| A    | Cobb PS | 21  | 3200    | 2.5 | 10.4  | 1   | 2  | 2  |
| A    | Cobb PS | 21  | 3740    | 3   | 10.5  | 2   | 3  | 1  |
| A    | Cobb PS | 26  | 3720    | 2   | 10    | 0   | 3  | 1  |
| A    | Cobb PS | 26  | 3620    | 2   | 10.5  | 1   | 3  | 1  |
| A    | Cobb PS | 26  | 4200    | 3   | 11.1  | 1   | 3  | 3  |
| A    | Cobb PS | 26  | 3740    | 2   | 11    | 1   | 3  | 2  |
| A    | Cobb PS | 26  | 4220    | 2   | 10.6  | 1   | 3  | 1  |
| A    | Cobb PS | 30  | 3700    | 2.5 | 12.5  | 0   | 3  | 2  |
| A    | Cobb PS | 30  | 4360    | 2   | 11.6  | 0   | 3  | 3  |
| A    | Cobb PS | 30  | 4320    | 3   | 12.6  | 1   | 3  | 1  |
| A    | Cobb PS | 30  | 4500    | 3   | 12.2  | 1   | 3  | 1  |
| A    | Cobb PS | 30  | 3680    | 2   | 11.5  | 0   | 3  | 3  |
| A    | Cobb PS | 35  | 5560    | 4   | 11.8  | 0   | 3  | 2  |
| A    | Cobb PS | 35  | 4540    | 2.5 | 13    | 0   | 3  | 3  |
| A    | Cobb PS | 35  | 4720    | 1.5 | 12.3  | 0   | 3  | 1  |
| A    | Cobb PS | 35  | 4860    | 2   | 12.6  | 0   | 3  | 3  |
| A    | Cobb PS | 35  | 4440    | 3   | 11.8  | 1   | 3  | 1  |
| A    | Cobb PS | 40  | 5600    | 2   | 12.8  | 0   | 3  | 3  |
| A    | Cobb PS | 40  | 4260    | 2   | 13    | 0   | 3  | 2  |
| A    | Cobb PS | 40  | 4840    | 2   | 12.8  | 0   | 3  | 4  |
| A    | Cobb PS | 40  | 5240    | 2   | 12.7  | 0   | 3  | 3  |
| A    | Cobb PS | 40  | 4640    | 3   | 12.4  | 0   | 3  | 3  |
| A    | Cobb PS | 50  | 5420    | 3   | 12.2  | 0   | 3  | 2  |
| A    | Cobb PS | 50  | 4900    | 3   | 12.4  | 0   | 3  | 2  |
| A    | Cobb PS | 50  | 5600    | 2   | 12.4  | 0   | 3  | 3  |
| A    | Cobb PS | 50  | 5500    | 2   | 12.6  | 0   | 3  | 1  |
| A    | Cobb PS | 50  | 5100    | 2   | 12.5  | 0   | 3  | 2  |
| A    | Cobb PS | 60  | 5660    | 3   | 12.3  | 0   | 3  | 1  |
| A    | Cobb PS | 60  | 5600    | 4   | 13.1  | 0   | 3  | 2  |
| A    | Cobb PS | 60  | 5540    | 3   | 12.6  | 0   | 3  | 2  |
| A    | Cobb PS | 60  | 5600    | 4   | 12.8  | 0   | 3  | 1  |
| A    | Cobb PS | 60  | 5580    | 4   | 12.6  | 1   | 3  | 1  |

**Table C.1.5 Example of 12-day hatchery data**

| FARM | STRAIN  | AGE | TOTAL | INFERTILE | FERTILITY |
|------|---------|-----|-------|-----------|-----------|
| A    | Cobb PS | 30  | 162   | 7         | 95.68     |
| A    | Cobb PS | 40  | 450   | 7         | 98.44     |
| A    | Cobb PS | 50  | 150   | 8         | 94.67     |
| A    | Cobb PS | 60  | 150   | 18        | 88.00     |

Table C.1.6 Combined data sources to produce production weeks

| FARM | STRAIN  | WEEKS | RFW  | RMW  | RFIM        | SCORE<br>TYPE | SCORE | F <sub>18</sub> | AWM  | ABCS | ASL  | AVS | F <sub>12</sub> |
|------|---------|-------|------|------|-------------|---------------|-------|-----------------|------|------|------|-----|-----------------|
| F    | Cobb PS | 21    |      |      |             |               |       |                 | 3640 | 2.5  | 10.3 | 1   |                 |
| F    | Cobb PS | 21    |      |      |             |               |       |                 | 3260 | 3    | 10.3 | 1   |                 |
| F    | Cobb PS | 21    |      |      |             |               |       |                 | 3880 | 2.5  | 9.4  | 1   |                 |
| F    | Cobb PS | 21    |      |      |             |               |       |                 | 2900 | 2    | 9.1  | 2   |                 |
| F    | Cobb PS | 21    |      |      | 127.4129963 |               |       |                 | 3140 | 2.5  | 10.5 | 1   |                 |
| F    | Cobb PS | 21    |      |      | 127.9069805 |               |       |                 | 2780 | 3    | 10.8 | 2   |                 |
| F    | Cobb PS | 21    |      |      | 127.9069805 |               |       |                 | 3220 | 3    | 10.4 | 1   |                 |
| F    | Cobb PS | 22    |      |      | 129.8449612 |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 22    |      |      | 129.8449612 |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 22    |      |      | 129.8449612 |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 22    | 2732 | 3421 | 129.8449612 |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 22    |      |      | 130.3501987 |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 22    |      |      | 130.3501987 |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 22    | 2824 | 3598 | 132.295723  |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 23    |      |      | 134.2412472 |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 23    |      |      | 134.765625  |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 23    |      |      | 132.8125    |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 23    | 2856 | 3554 | 132.8125    |               |       |                 |      |      |      |     |                 |
| F    | Cobb PS | 23    |      |      | 138.671875  |               |       |                 |      |      |      |     |                 |

## Appendix D

### D.1 Results of Tukey test ( $P > 0.05$ ) analysis of data between houses within a farm and farms

**Table D.1.1 Summary of the results for the Tukey test results based on model I**

Comparisons significant at the 0.05 level are indicated by \*\*\*.

| Farm comparison         | Difference between means | Simultaneous 95% Confidence Limits |      |     |
|-------------------------|--------------------------|------------------------------------|------|-----|
| (Cobb) A 1 - (Ross) E 5 | 3.94                     | 1.12                               | 6.77 | *** |
| (Cobb) A 1 - (Ross) E 6 | 4.08                     | 1.26                               | 6.91 | *** |
| (Cobb) F 6 - (Ross) E 5 | 4.58                     | 1.80                               | 7.37 | *** |
| (Cobb) A 2 - (Ross) E 5 | 4.64                     | 1.81                               | 7.46 | *** |
| (Cobb) F 3 - (Ross) E 5 | 4.64                     | 1.86                               | 7.43 | *** |
| (Cobb) F 4 - (Ross) E 5 | 4.66                     | 1.88                               | 7.45 | *** |
| (Cobb) F 6 - (Ross) E 6 | 4.72                     | 1.94                               | 7.50 | *** |
| (Cobb) A 2 - (Ross) E 6 | 4.78                     | 1.95                               | 7.60 | *** |
| (Cobb) F 3 - (Ross) E 6 | 4.78                     | 2.00                               | 7.57 | *** |
| (Cobb) F 2 - (Ross) E 5 | 4.80                     | 2.02                               | 7.58 | *** |
| (Cobb) F 4 - (Ross) E 6 | 4.80                     | 2.02                               | 7.59 | *** |
| (Cobb) F 1 - (Ross) E 5 | 4.84                     | 2.04                               | 7.65 | *** |
| (Cobb) G 1 - (Ross) E 5 | 4.85                     | 2.10                               | 7.60 | *** |
| (Cobb) F 2 - (Ross) E 6 | 4.94                     | 2.16                               | 7.72 | *** |
| (Cobb) F 1 - (Ross) E 6 | 4.98                     | 2.18                               | 7.78 | *** |
| (Cobb) G 1 - (Ross) E 6 | 4.99                     | 2.24                               | 7.74 | *** |
| (Cobb) G 2 - (Ross) E 5 | 5.04                     | 2.29                               | 7.79 | *** |
| (Cobb) A 1 - (Ross) E 2 | 5.10                     | 2.27                               | 7.92 | *** |
| (Cobb) A 1 - (Ross) D 2 | 5.16                     | 2.45                               | 7.86 | *** |
| (Cobb) G 2 - (Ross) E 6 | 5.18                     | 2.43                               | 7.93 | *** |
| (Cobb) F 5 - (Ross) E 5 | 5.27                     | 2.49                               | 8.06 | *** |
| (Cobb) A 1 - (Ross) E 1 | 5.38                     | 2.59                               | 8.17 | *** |
| (Cobb) F 5 - (Ross) E 6 | 5.41                     | 2.63                               | 8.19 | *** |
| (Cobb) A 1 - (Ross) E 4 | 5.42                     | 2.56                               | 8.28 | *** |
| (Cobb) F 6 - (Ross) E 2 | 5.73                     | 2.95                               | 8.52 | *** |
| (Cobb) A 2 - (Ross) E 2 | 5.79                     | 2.97                               | 8.62 | *** |
| (Cobb) F 6 - (Ross) D 2 | 5.79                     | 3.13                               | 8.46 | *** |
| (Cobb) F 3 - (Ross) E 2 | 5.80                     | 3.01                               | 8.58 | *** |
| (Cobb) F 4 - (Ross) E 2 | 5.82                     | 3.03                               | 8.60 | *** |
| (Cobb) A 2 - (Ross) D 2 | 5.85                     | 3.15                               | 8.56 | *** |
| (Cobb) F 3 - (Ross) D 2 | 5.86                     | 3.19                               | 8.52 | *** |
| (Cobb) F 4 - (Ross) D 2 | 5.88                     | 3.21                               | 8.54 | *** |
| (Cobb) A 1 - (Ross) D 1 | 5.95                     | 3.25                               | 8.66 | *** |
| (Cobb) F 2 - (Ross) E 2 | 5.95                     | 3.17                               | 8.74 | *** |
| (Cobb) F 1 - (Ross) E 2 | 6.00                     | 3.19                               | 8.80 | *** |

|                         |      |      |       |     |
|-------------------------|------|------|-------|-----|
| (Cobb) G 1 - (Ross) E 2 | 6.00 | 3.26 | 8.75  | *** |
| (Cobb) F 2 - (Ross) D 2 | 6.01 | 3.35 | 8.68  | *** |
| (Cobb) F 6 - (Ross) E 1 | 6.02 | 3.27 | 8.77  | *** |
| (Cobb) F 1 - (Ross) D 2 | 6.05 | 3.37 | 8.74  | *** |
| (Cobb) G 1 - (Ross) D 2 | 6.06 | 3.44 | 8.69  | *** |
| (Cobb) F 6 - (Ross) E 4 | 6.06 | 3.24 | 8.88  | *** |
| (Cobb) A 2 - (Ross) E 1 | 6.08 | 3.29 | 8.87  | *** |
| (Cobb) F 3 - (Ross) E 1 | 6.09 | 3.33 | 8.84  | *** |
| (Cobb) F 4 - (Ross) E 1 | 6.11 | 3.36 | 8.86  | *** |
| (Cobb) A 2 - (Ross) E 4 | 6.12 | 3.26 | 8.98  | *** |
| (Cobb) F 3 - (Ross) E 4 | 6.13 | 3.31 | 8.95  | *** |
| (Cobb) F 4 - (Ross) E 4 | 6.15 | 3.33 | 8.97  | *** |
| (Cobb) G 2 - (Ross) E 2 | 6.19 | 3.44 | 8.94  | *** |
| (Cobb) F 2 - (Ross) E 1 | 6.24 | 3.49 | 8.99  | *** |
| (Cobb) G 2 - (Ross) D 2 | 6.25 | 3.63 | 8.88  | *** |
| (Cobb) A 1 - (Ross) E 3 | 6.26 | 3.47 | 9.05  | *** |
| (Cobb) F 2 - (Ross) E 4 | 6.28 | 3.46 | 9.10  | *** |
| (Cobb) F 1 - (Ross) E 1 | 6.28 | 3.51 | 9.05  | *** |
| (Cobb) G 1 - (Ross) E 1 | 6.29 | 3.58 | 9.00  | *** |
| (Cobb) F 1 - (Ross) E 4 | 6.32 | 3.48 | 9.16  | *** |
| (Cobb) G 1 - (Ross) E 4 | 6.33 | 3.55 | 9.12  | *** |
| (Cobb) F 5 - (Ross) E 2 | 6.42 | 3.64 | 9.21  | *** |
| (Cobb) G 2 - (Ross) E 1 | 6.48 | 3.76 | 9.19  | *** |
| (Cobb) F 5 - (Ross) D 2 | 6.48 | 3.82 | 9.15  | *** |
| (Cobb) G 2 - (Ross) E 4 | 6.52 | 3.74 | 9.30  | *** |
| (Cobb) F 6 - (Ross) D 1 | 6.59 | 3.93 | 9.25  | *** |
| (Cobb) A 2 - (Ross) D 1 | 6.65 | 3.94 | 9.35  | *** |
| (Cobb) F 3 - (Ross) D 1 | 6.65 | 3.99 | 9.32  | *** |
| (Cobb) F 4 - (Ross) D 1 | 6.67 | 4.01 | 9.34  | *** |
| (Cobb) F 5 - (Ross) E 1 | 6.71 | 3.96 | 9.46  | *** |
| (Cobb) F 5 - (Ross) E 4 | 6.75 | 3.93 | 9.57  | *** |
| (Cobb) F 2 - (Ross) D 1 | 6.81 | 4.15 | 9.47  | *** |
| (Cobb) F 1 - (Ross) D 1 | 6.85 | 4.17 | 9.53  | *** |
| (Cobb) G 1 - (Ross) D 1 | 6.86 | 4.23 | 9.48  | *** |
| (Cobb) F 6 - (Ross) E 3 | 6.90 | 4.15 | 9.65  | *** |
| (Cobb) A 2 - (Ross) E 3 | 6.96 | 4.17 | 9.75  | *** |
| (Cobb) F 3 - (Ross) E 3 | 6.97 | 4.21 | 9.72  | *** |
| (Cobb) F 4 - (Ross) E 3 | 6.99 | 4.23 | 9.74  | *** |
| (Cobb) G 2 - (Ross) D 1 | 7.05 | 4.42 | 9.67  | *** |
| (Cobb) F 2 - (Ross) E 3 | 7.12 | 4.37 | 9.87  | *** |
| (Cobb) F 1 - (Ross) E 3 | 7.16 | 4.39 | 9.93  | *** |
| (Cobb) G 1 - (Ross) E 3 | 7.17 | 4.46 | 9.88  | *** |
| (Cobb) F 5 - (Ross) D 1 | 7.28 | 4.62 | 9.94  | *** |
| (Cobb) G 2 - (Ross) E 3 | 7.36 | 4.64 | 10.07 | *** |
| (Cobb) F 5 - (Ross) E 3 | 7.59 | 4.84 | 10.34 | *** |

|                         |      |       |      |
|-------------------------|------|-------|------|
| (Cobb) F 3 - (Cobb) A 2 | 0.01 | -2.61 | 2.62 |
| (Cobb) G 1 - (Cobb) F 1 | 0.01 | -2.54 | 2.56 |
| (Cobb) F 4 - (Cobb) F 3 | 0.02 | -2.55 | 2.59 |
| (Cobb) F 4 - (Cobb) A 2 | 0.03 | -2.59 | 2.64 |
| (Ross) E 1 - (Ross) E 4 | 0.04 | -2.94 | 3.03 |
| (Cobb) F 1 - (Cobb) F 2 | 0.04 | -2.55 | 2.63 |
| (Cobb) G 1 - (Cobb) F 2 | 0.05 | -2.48 | 2.58 |
| (Cobb) A 2 - (Cobb) F 6 | 0.06 | -2.56 | 2.67 |
| (Ross) E 2 - (Ross) D 2 | 0.06 | -2.81 | 2.93 |
| (Cobb) F 3 - (Cobb) F 6 | 0.06 | -2.51 | 2.63 |
| (Cobb) F 4 - (Cobb) F 6 | 0.08 | -2.49 | 2.65 |
| (Cobb) H 2 - (Cobb) A 1 | 0.13 | -7.27 | 7.53 |
| (Cobb) F 2 - (Cobb) F 4 | 0.14 | -2.43 | 2.71 |
| (Ross) E 5 - (Ross) E 6 | 0.14 | -2.84 | 3.12 |
| (Cobb) F 2 - (Cobb) F 3 | 0.16 | -2.41 | 2.73 |
| (Cobb) F 2 - (Cobb) A 2 | 0.16 | -2.45 | 2.77 |
| (Cobb) F 1 - (Cobb) F 4 | 0.18 | -2.41 | 2.77 |
| (Cobb) G 1 - (Cobb) F 4 | 0.18 | -2.35 | 2.71 |
| (Cobb) G 2 - (Cobb) G 1 | 0.19 | -2.30 | 2.68 |
| (Cobb) G 2 - (Cobb) F 1 | 0.20 | -2.36 | 2.75 |
| (Cobb) F 1 - (Cobb) F 3 | 0.20 | -2.39 | 2.79 |
| (Cobb) F 1 - (Cobb) A 2 | 0.20 | -2.43 | 2.84 |
| (Cobb) G 1 - (Cobb) F 3 | 0.20 | -2.33 | 2.74 |
| (Cobb) G 1 - (Cobb) A 2 | 0.21 | -2.36 | 2.79 |
| (Cobb) F 2 - (Cobb) F 6 | 0.22 | -2.35 | 2.79 |
| (Ross) D 2 - (Ross) E 1 | 0.23 | -2.61 | 3.07 |
| (Cobb) F 5 - (Cobb) G 2 | 0.23 | -2.30 | 2.76 |
| (Cobb) G 2 - (Cobb) F 2 | 0.24 | -2.29 | 2.77 |
| (Cobb) F 1 - (Cobb) F 6 | 0.26 | -2.33 | 2.85 |
| (Cobb) G 1 - (Cobb) F 6 | 0.27 | -2.26 | 2.80 |
| (Ross) D 2 - (Ross) E 4 | 0.27 | -2.64 | 3.18 |
| (Ross) E 2 - (Ross) E 1 | 0.29 | -2.67 | 3.24 |
| (Ross) D 1 - (Ross) E 3 | 0.31 | -2.53 | 3.15 |
| (Ross) E 2 - (Ross) E 4 | 0.33 | -2.69 | 3.35 |
| (Cobb) G 2 - (Cobb) F 4 | 0.37 | -2.16 | 2.90 |
| (Cobb) G 2 - (Cobb) F 3 | 0.39 | -2.14 | 2.92 |
| (Cobb) G 2 - (Cobb) A 2 | 0.40 | -2.18 | 2.97 |
| (Cobb) F 5 - (Cobb) G 1 | 0.42 | -2.11 | 2.95 |
| (Cobb) F 5 - (Cobb) F 1 | 0.43 | -2.16 | 3.02 |
| (Cobb) G 2 - (Cobb) F 6 | 0.46 | -2.07 | 2.99 |
| (Cobb) F 5 - (Cobb) F 2 | 0.47 | -2.10 | 3.04 |
| (Cobb) F 6 - (Cobb) H 2 | 0.51 | -6.87 | 7.89 |
| (Ross) E 4 - (Ross) D 1 | 0.53 | -2.38 | 3.43 |
| (Cobb) A 2 - (Cobb) H 2 | 0.57 | -6.83 | 7.96 |
| (Ross) E 1 - (Ross) D 1 | 0.57 | -2.27 | 3.41 |

|                         |      |       |       |
|-------------------------|------|-------|-------|
| (Cobb) F 3 - (Cobb) H 2 | 0.57 | -6.81 | 7.95  |
| (Cobb) F 4 - (Cobb) H 2 | 0.59 | -6.79 | 7.97  |
| (Cobb) F 5 - (Cobb) F 4 | 0.61 | -1.96 | 3.18  |
| (Cobb) F 5 - (Cobb) F 3 | 0.63 | -1.94 | 3.20  |
| (Cobb) F 5 - (Cobb) A 2 | 0.63 | -1.98 | 3.25  |
| (Cobb) F 6 - (Cobb) A 1 | 0.64 | -1.98 | 3.25  |
| (Cobb) F 5 - (Cobb) F 6 | 0.69 | -1.88 | 3.26  |
| (Cobb) A 2 - (Cobb) A 1 | 0.70 | -1.96 | 3.35  |
| (Cobb) F 3 - (Cobb) A 1 | 0.70 | -1.91 | 3.32  |
| (Cobb) F 4 - (Cobb) A 1 | 0.72 | -1.89 | 3.34  |
| (Cobb) F 2 - (Cobb) H 2 | 0.73 | -6.65 | 8.11  |
| (Cobb) F 1 - (Cobb) H 2 | 0.77 | -6.62 | 8.16  |
| (Cobb) G 1 - (Cobb) H 2 | 0.78 | -6.59 | 8.15  |
| (Ross) D 2 - (Ross) D 1 | 0.80 | -1.96 | 3.55  |
| (Ross) E 4 - (Ross) E 3 | 0.84 | -2.15 | 3.82  |
| (Ross) E 2 - (Ross) D 1 | 0.86 | -2.02 | 3.73  |
| (Cobb) F 2 - (Cobb) A 1 | 0.86 | -1.76 | 3.47  |
| (Ross) E 1 - (Ross) E 3 | 0.88 | -2.04 | 3.80  |
| (Cobb) F 1 - (Cobb) A 1 | 0.90 | -1.74 | 3.53  |
| (Cobb) G 1 - (Cobb) A 1 | 0.91 | -1.67 | 3.48  |
| (Cobb) G 2 - (Cobb) H 2 | 0.97 | -6.40 | 8.33  |
| (Ross) E 6 - (Ross) E 2 | 1.01 | -1.97 | 4.00  |
| (Ross) E 6 - (Ross) D 2 | 1.07 | -1.80 | 3.94  |
| (Cobb) G 2 - (Cobb) A 1 | 1.10 | -1.48 | 3.67  |
| (Ross) D 2 - (Ross) E 3 | 1.11 | -1.73 | 3.95  |
| (Ross) E 5 - (Ross) E 2 | 1.15 | -1.83 | 4.14  |
| (Ross) E 2 - (Ross) E 3 | 1.17 | -1.79 | 4.12  |
| (Cobb) F 5 - (Cobb) H 2 | 1.20 | -6.18 | 8.58  |
| (Ross) E 5 - (Ross) D 2 | 1.21 | -1.66 | 4.08  |
| (Ross) E 6 - (Ross) E 1 | 1.30 | -1.65 | 4.25  |
| (Cobb) F 5 - (Cobb) A 1 | 1.33 | -1.28 | 3.94  |
| (Ross) E 6 - (Ross) E 4 | 1.34 | -1.67 | 4.36  |
| (Ross) E 5 - (Ross) E 1 | 1.44 | -1.51 | 4.39  |
| (Ross) E 5 - (Ross) E 4 | 1.48 | -1.53 | 4.50  |
| (Ross) E 6 - (Ross) D 1 | 1.87 | -1.00 | 4.74  |
| (Ross) E 5 - (Ross) D 1 | 2.01 | -0.86 | 4.88  |
| (Ross) E 6 - (Ross) E 3 | 2.18 | -0.77 | 5.13  |
| (Ross) E 5 - (Ross) E 3 | 2.32 | -0.63 | 5.27  |
| (Cobb) H 2 - (Ross) E 5 | 4.07 | -3.39 | 11.53 |
| (Cobb) H 2 - (Ross) E 6 | 4.21 | -3.25 | 11.67 |
| (Cobb) H 2 - (Ross) E 2 | 5.23 | -2.23 | 12.68 |
| (Cobb) H 2 - (Ross) D 2 | 5.28 | -2.13 | 12.70 |
| (Cobb) H 2 - (Ross) E 1 | 5.51 | -1.93 | 12.96 |
| (Cobb) H 2 - (Ross) E 4 | 5.55 | -1.92 | 13.03 |
| (Cobb) H 2 - (Ross) D 1 | 6.08 | -1.33 | 13.49 |

|                                                                                |      |       |       |
|--------------------------------------------------------------------------------|------|-------|-------|
| (Cobb) H 2 - (Ross) E 3                                                        | 6.39 | -1.05 | 13.84 |
| Numbers next to Farm (A-H) indicate House number (1-6) on that particular farm |      |       |       |

**Table D.1.2 Summary of the results for the Tukey test results based on model II**

| Comparisons significant at the 0.05 level are indicated by ***. |                          |                                    |      |
|-----------------------------------------------------------------|--------------------------|------------------------------------|------|
| Farm comparison                                                 | Difference between means | Simultaneous 95% Confidence Limits |      |
| (Cobb) F 2 - (Cobb) F 4                                         | 0.03                     | -4.96                              | 5.01 |
| (Cobb) A 2 - (Cobb) F 6                                         | 0.05                     | -4.93                              | 5.03 |
| (Cobb) F 6 - (Cobb) F 2                                         | 0.09                     | -4.89                              | 5.07 |
| (Cobb) G 2 - (Cobb) G 1                                         | 0.11                     | -4.88                              | 5.09 |
| (Ross) D 1 - (Ross) E 4                                         | 0.11                     | -5.99                              | 6.21 |
| (Cobb) F 6 - (Cobb) F 4                                         | 0.11                     | -4.87                              | 5.09 |
| (Cobb) H 2 - (Cobb) H 3                                         | 0.13                     | -4.86                              | 5.11 |
| (Ross) D 2 - (Ross) E 6                                         | 0.13                     | -5.97                              | 6.23 |
| (Ross) E 5 - (Ross) D 2                                         | 0.14                     | -5.96                              | 6.24 |
| (Cobb) A 2 - (Cobb) F 2                                         | 0.14                     | -4.84                              | 5.12 |
| (Cobb) A 2 - (Cobb) F 4                                         | 0.17                     | -4.82                              | 5.15 |
| (Cobb) G 1 - (Cobb) A 2                                         | 0.22                     | -4.76                              | 5.20 |
| (Cobb) H 1 - (Cobb) H 2                                         | 0.24                     | -4.74                              | 5.22 |
| (Cobb) G 1 - (Cobb) F 6                                         | 0.27                     | -4.71                              | 5.25 |
| (Ross) E 5 - (Ross) E 6                                         | 0.27                     | -5.83                              | 6.37 |
| (Cobb) G 2 - (Cobb) A 2                                         | 0.32                     | -4.66                              | 5.30 |
| (Cobb) G 1 - (Cobb) F 2                                         | 0.36                     | -4.62                              | 5.34 |
| (Cobb) H 1 - (Cobb) H 3                                         | 0.37                     | -4.61                              | 5.35 |
| (Cobb) G 2 - (Cobb) F 6                                         | 0.38                     | -4.61                              | 5.36 |
| (Cobb) G 1 - (Cobb) F 4                                         | 0.38                     | -4.60                              | 5.36 |
| (Cobb) G 2 - (Cobb) F 2                                         | 0.46                     | -4.52                              | 5.44 |
| (Cobb) H 3 - (Cobb) G 2                                         | 0.48                     | -4.50                              | 5.46 |
| (Cobb) G 2 - (Cobb) F 4                                         | 0.49                     | -4.49                              | 5.47 |
| (Cobb) H 3 - (Cobb) G 1                                         | 0.58                     | -4.40                              | 5.56 |
| (Cobb) H 2 - (Cobb) G 2                                         | 0.60                     | -4.38                              | 5.58 |
| (Cobb) H 2 - (Cobb) G 1                                         | 0.71                     | -4.27                              | 5.69 |
| (Cobb) F 4 - (Cobb) A 1                                         | 0.73                     | -4.25                              | 5.72 |
| (Cobb) F 2 - (Cobb) A 1                                         | 0.76                     | -4.22                              | 5.74 |
| (Cobb) H 3 - (Cobb) A 2                                         | 0.80                     | -4.18                              | 5.78 |
| (Cobb) H 1 - (Cobb) G 2                                         | 0.84                     | -4.14                              | 5.83 |
| (Cobb) F 6 - (Cobb) A 1                                         | 0.85                     | -4.14                              | 5.83 |
| (Cobb) H 3 - (Cobb) F 6                                         | 0.85                     | -4.13                              | 5.83 |
| (Cobb) A 2 - (Cobb) A 1                                         | 0.90                     | -4.08                              | 5.88 |
| (Cobb) H 2 - (Cobb) A 2                                         | 0.92                     | -4.06                              | 5.91 |
| (Cobb) H 3 - (Cobb) F 2                                         | 0.94                     | -4.04                              | 5.92 |
| (Cobb) H 1 - (Cobb) G 1                                         | 0.95                     | -4.03                              | 5.93 |
| (Cobb) H 3 - (Cobb) F 4                                         | 0.97                     | -4.02                              | 5.95 |
| (Cobb) H 2 - (Cobb) F 6                                         | 0.98                     | -4.00                              | 5.96 |
| (Cobb) A 1 - (Ross) E 5                                         | 1.02                     | -4.55                              | 6.59 |
| (Cobb) H 2 - (Cobb) F 2                                         | 1.07                     | -3.92                              | 6.05 |

|                         |      |       |      |
|-------------------------|------|-------|------|
| (Cobb) H 2 - (Cobb) F 4 | 1.09 | -3.89 | 6.07 |
| (Cobb) G 1 - (Cobb) A 1 | 1.12 | -3.86 | 6.10 |
| (Ross) E 6 - (Ross) D 1 | 1.15 | -4.96 | 7.25 |
| (Cobb) A 1 - (Ross) D 2 | 1.16 | -4.41 | 6.73 |
| (Cobb) H 1 - (Cobb) A 2 | 1.17 | -3.82 | 6.15 |
| (Cobb) H 1 - (Cobb) F 6 | 1.22 | -3.76 | 6.20 |
| (Cobb) G 2 - (Cobb) A 1 | 1.22 | -3.76 | 6.20 |
| (Ross) E 6 - (Ross) E 4 | 1.26 | -4.84 | 7.36 |
| (Ross) D 2 - (Ross) D 1 | 1.28 | -4.82 | 7.38 |
| (Cobb) A 1 - (Ross) E 6 | 1.29 | -4.28 | 6.86 |
| (Cobb) H 1 - (Cobb) F 2 | 1.31 | -3.67 | 6.29 |
| (Cobb) H 1 - (Cobb) F 4 | 1.33 | -3.65 | 6.31 |
| (Ross) D 2 - (Ross) E 4 | 1.39 | -4.71 | 7.49 |
| (Ross) E 5 - (Ross) D 1 | 1.42 | -4.69 | 7.52 |
| (Ross) E 5 - (Ross) E 4 | 1.53 | -4.57 | 7.63 |
| (Cobb) H 3 - (Cobb) A 1 | 1.70 | -3.28 | 6.68 |
| (Cobb) F 4 - (Ross) E 5 | 1.76 | -3.81 | 7.33 |
| (Cobb) F 2 - (Ross) E 5 | 1.78 | -3.79 | 7.35 |
| (Cobb) H 2 - (Cobb) A 1 | 1.82 | -3.16 | 6.81 |
| (Cobb) F 6 - (Ross) E 5 | 1.87 | -3.70 | 7.44 |
| (Cobb) F 4 - (Ross) D 2 | 1.89 | -3.68 | 7.46 |
| (Cobb) F 2 - (Ross) D 2 | 1.92 | -3.65 | 7.49 |
| (Cobb) A 2 - (Ross) E 5 | 1.92 | -3.65 | 7.49 |
| (Cobb) F 6 - (Ross) D 2 | 2.01 | -3.56 | 7.58 |
| (Cobb) F 4 - (Ross) E 6 | 2.03 | -3.54 | 7.60 |
| (Cobb) F 2 - (Ross) E 6 | 2.05 | -3.52 | 7.62 |
| (Cobb) A 2 - (Ross) D 2 | 2.06 | -3.51 | 7.63 |
| (Cobb) H 1 - (Cobb) A 1 | 2.07 | -2.92 | 7.05 |
| (Cobb) F 6 - (Ross) E 6 | 2.14 | -3.43 | 7.71 |
| (Cobb) G 1 - (Ross) E 5 | 2.14 | -3.43 | 7.71 |
| (Cobb) A 2 - (Ross) E 6 | 2.19 | -3.38 | 7.76 |
| (Cobb) G 2 - (Ross) E 5 | 2.24 | -3.33 | 7.81 |
| (Cobb) G 1 - (Ross) D 2 | 2.28 | -3.29 | 7.85 |
| (Cobb) G 2 - (Ross) D 2 | 2.38 | -3.19 | 7.95 |
| (Cobb) G 1 - (Ross) E 6 | 2.41 | -3.16 | 7.98 |
| (Cobb) A 1 - (Ross) D 1 | 2.44 | -3.13 | 8.01 |
| (Cobb) G 2 - (Ross) E 6 | 2.51 | -3.06 | 8.08 |
| (Cobb) A 1 - (Ross) E 4 | 2.55 | -3.02 | 8.12 |
| (Cobb) H 3 - (Ross) E 5 | 2.72 | -2.85 | 8.29 |
| (Cobb) H 2 - (Ross) E 5 | 2.85 | -2.72 | 8.42 |
| (Cobb) H 3 - (Ross) D 2 | 2.86 | -2.71 | 8.43 |
| (Cobb) H 2 - (Ross) D 2 | 2.98 | -2.59 | 8.55 |
| (Cobb) H 3 - (Ross) E 6 | 2.99 | -2.58 | 8.56 |
| (Cobb) H 1 - (Ross) E 5 | 3.09 | -2.48 | 8.66 |
| (Cobb) H 2 - (Ross) E 6 | 3.12 | -2.45 | 8.69 |

|                         |      |       |       |
|-------------------------|------|-------|-------|
| (Cobb) F 4 - (Ross) D 1 | 3.17 | -2.40 | 8.74  |
| (Cobb) F 2 - (Ross) D 1 | 3.20 | -2.37 | 8.77  |
| (Cobb) H 1 - (Ross) D 2 | 3.23 | -2.34 | 8.79  |
| (Cobb) F 4 - (Ross) E 4 | 3.28 | -2.29 | 8.85  |
| (Cobb) F 6 - (Ross) D 1 | 3.28 | -2.29 | 8.85  |
| (Cobb) F 2 - (Ross) E 4 | 3.31 | -2.26 | 8.88  |
| (Cobb) A 2 - (Ross) D 1 | 3.34 | -2.23 | 8.91  |
| (Cobb) H 1 - (Ross) E 6 | 3.36 | -2.21 | 8.93  |
| (Cobb) F 6 - (Ross) E 4 | 3.40 | -2.17 | 8.97  |
| (Cobb) A 2 - (Ross) E 4 | 3.45 | -2.12 | 9.02  |
| (Cobb) G 1 - (Ross) D 1 | 3.55 | -2.02 | 9.12  |
| (Cobb) G 2 - (Ross) D 1 | 3.66 | -1.91 | 9.23  |
| (Cobb) G 1 - (Ross) E 4 | 3.67 | -1.90 | 9.24  |
| (Cobb) G 2 - (Ross) E 4 | 3.77 | -1.80 | 9.34  |
| (Cobb) H 3 - (Ross) D 1 | 4.14 | -1.43 | 9.71  |
| (Cobb) H 3 - (Ross) E 4 | 4.25 | -1.32 | 9.82  |
| (Cobb) H 2 - (Ross) D 1 | 4.26 | -1.31 | 9.83  |
| (Cobb) H 2 - (Ross) E 4 | 4.37 | -1.20 | 9.94  |
| (Cobb) H 1 - (Ross) D 1 | 4.50 | -1.07 | 10.07 |
| (Cobb) H 1 - (Ross) E 4 | 4.62 | -0.95 | 10.18 |

Numbers next to Farm (A-H) indicate House number (1-6) on that particular farm

**Table D.1.3 Summary of the results for the Tukey test results based on model III**

| <b>Comparisons significant at the 0.05 level are indicated by ***.</b> |                                 |                                           |      |
|------------------------------------------------------------------------|---------------------------------|-------------------------------------------|------|
| <b>Farm comparison</b>                                                 | <b>Difference between means</b> | <b>Simultaneous 95% Confidence Limits</b> |      |
| (Cobb) G 2 - (Cobb) F 4                                                | 0.00                            | -3.83                                     | 3.83 |
| (Ross) E 2 - (Cobb) F 4                                                | 0.06                            | -4.08                                     | 4.20 |
| (Ross) E 2 - (Cobb) G 2                                                | 0.06                            | -4.08                                     | 4.20 |
| (Cobb) F 2 - (Ross) E 2                                                | 0.07                            | -4.36                                     | 4.50 |
| (Ross) D 5 - (Ross) D 6                                                | 0.08                            | -3.75                                     | 3.92 |
| (Ross) E 1 - (Cobb) G 1                                                | 0.11                            | -4.03                                     | 4.25 |
| (Cobb) F 2 - (Cobb) F 4                                                | 0.13                            | -4.01                                     | 4.27 |
| (Cobb) F 2 - (Cobb) G 2                                                | 0.13                            | -4.01                                     | 4.27 |
| (Cobb) G 1 - (Ross) D 5                                                | 0.14                            | -3.70                                     | 3.97 |
| (Cobb) A 2 - (Ross) E 1                                                | 0.15                            | -3.99                                     | 4.29 |
| (Cobb) A 1 - (Cobb) F 2                                                | 0.20                            | -3.94                                     | 4.34 |
| (Cobb) G 1 - (Ross) D 6                                                | 0.22                            | -3.61                                     | 4.05 |
| (Ross) D 6 - (Cobb) F 6                                                | 0.23                            | -3.61                                     | 4.06 |
| (Ross) E 1 - (Ross) D 5                                                | 0.24                            | -3.90                                     | 4.38 |
| (Cobb) A 2 - (Cobb) G 1                                                | 0.26                            | -3.57                                     | 4.09 |
| (Cobb) A 1 - (Ross) E 2                                                | 0.27                            | -3.87                                     | 4.41 |
| (Ross) D 5 - (Cobb) F 6                                                | 0.31                            | -3.52                                     | 4.14 |
| (Cobb) A 1 - (Cobb) F 4                                                | 0.33                            | -3.51                                     | 4.16 |
| (Cobb) A 1 - (Cobb) G 2                                                | 0.33                            | -3.51                                     | 4.16 |
| (Ross) E 1 - (Ross) D 6                                                | 0.33                            | -3.81                                     | 4.47 |
| (Cobb) H 2 - (Cobb) H 1                                                | 0.34                            | -3.80                                     | 4.48 |
| (Cobb) H 3 - (Cobb) A 1                                                | 0.35                            | -3.48                                     | 4.19 |
| (Cobb) A 2 - (Ross) D 5                                                | 0.40                            | -3.44                                     | 4.23 |
| (Cobb) F 4 - (Cobb) A 2                                                | 0.41                            | -3.43                                     | 4.24 |
| (Cobb) G 2 - (Cobb) A 2                                                | 0.41                            | -3.43                                     | 4.24 |
| (Cobb) G 1 - (Cobb) F 6                                                | 0.45                            | -3.39                                     | 4.28 |
| (Ross) E 2 - (Cobb) A 2                                                | 0.46                            | -3.68                                     | 4.60 |
| (Cobb) A 2 - (Ross) D 6                                                | 0.48                            | -3.35                                     | 4.31 |
| (Cobb) F 2 - (Cobb) A 2                                                | 0.53                            | -3.61                                     | 4.67 |
| (Cobb) H 3 - (Cobb) F 2                                                | 0.55                            | -3.59                                     | 4.69 |
| (Ross) E 1 - (Cobb) F 6                                                | 0.55                            | -3.59                                     | 4.69 |
| (Cobb) F 4 - (Ross) E 1                                                | 0.56                            | -3.58                                     | 4.70 |
| (Cobb) G 2 - (Ross) E 1                                                | 0.56                            | -3.58                                     | 4.70 |
| (Ross) E 2 - (Ross) E 1                                                | 0.62                            | -3.81                                     | 5.04 |
| (Cobb) H 3 - (Ross) E 2                                                | 0.62                            | -3.52                                     | 4.76 |
| (Cobb) F 4 - (Cobb) G 1                                                | 0.67                            | -3.17                                     | 4.50 |
| (Cobb) G 2 - (Cobb) G 1                                                | 0.67                            | -3.17                                     | 4.50 |
| (Cobb) H 3 - (Cobb) F 4                                                | 0.68                            | -3.16                                     | 4.51 |
| (Cobb) H 3 - (Cobb) G 2                                                | 0.68                            | -3.16                                     | 4.51 |

|                         |      |       |      |
|-------------------------|------|-------|------|
| (Cobb) F 2 - (Ross) E 1 | 0.69 | -3.74 | 5.11 |
| (Cobb) A 2 - (Cobb) F 6 | 0.71 | -3.13 | 4.54 |
| (Ross) E 2 - (Cobb) G 1 | 0.72 | -3.42 | 4.86 |
| (Cobb) A 1 - (Cobb) A 2 | 0.73 | -3.10 | 4.56 |
| (Cobb) F 2 - (Cobb) G 1 | 0.79 | -3.35 | 4.93 |
| (Cobb) F 4 - (Ross) D 5 | 0.80 | -3.03 | 4.64 |
| (Cobb) G 2 - (Ross) D 5 | 0.80 | -3.03 | 4.64 |
| (Ross) E 2 - (Ross) D 5 | 0.86 | -3.28 | 5.00 |
| (Cobb) A 1 - (Ross) E 1 | 0.88 | -3.26 | 5.02 |
| (Cobb) F 4 - (Ross) D 6 | 0.89 | -2.95 | 4.72 |
| (Cobb) G 2 - (Ross) D 6 | 0.89 | -2.95 | 4.72 |
| (Cobb) F 6 - (Ross) D 4 | 0.91 | -2.93 | 4.74 |
| (Cobb) H 1 - (Cobb) H 3 | 0.93 | -2.91 | 4.76 |
| (Cobb) F 2 - (Ross) D 5 | 0.93 | -3.21 | 5.07 |
| (Ross) E 2 - (Ross) D 6 | 0.94 | -3.20 | 5.08 |
| (Cobb) A 1 - (Cobb) G 1 | 0.99 | -2.84 | 4.82 |
| (Cobb) F 2 - (Ross) D 6 | 1.01 | -3.13 | 5.15 |
| (Cobb) H 3 - (Cobb) A 2 | 1.08 | -2.75 | 4.92 |
| (Cobb) F 4 - (Cobb) F 6 | 1.11 | -2.72 | 4.95 |
| (Cobb) G 2 - (Cobb) F 6 | 1.11 | -2.72 | 4.95 |
| (Cobb) A 1 - (Ross) D 5 | 1.13 | -2.71 | 4.96 |
| (Ross) D 6 - (Ross) D 4 | 1.14 | -2.70 | 4.97 |
| (Ross) E 2 - (Cobb) F 6 | 1.17 | -2.97 | 5.31 |
| (Cobb) A 1 - (Ross) D 6 | 1.21 | -2.62 | 5.04 |
| (Ross) D 5 - (Ross) D 4 | 1.22 | -2.62 | 5.05 |
| (Cobb) H 3 - (Ross) E 1 | 1.24 | -2.90 | 5.38 |
| (Cobb) F 2 - (Cobb) F 6 | 1.24 | -2.90 | 5.38 |
| (Cobb) H 2 - (Cobb) H 3 | 1.27 | -2.87 | 5.41 |
| (Cobb) H 1 - (Cobb) A 1 | 1.28 | -2.56 | 5.11 |
| (Cobb) H 3 - (Cobb) G 1 | 1.34 | -2.49 | 5.18 |
| (Cobb) G 1 - (Ross) D 4 | 1.36 | -2.48 | 5.19 |
| (Cobb) A 1 - (Cobb) F 6 | 1.44 | -2.40 | 5.27 |
| (Ross) E 1 - (Ross) D 4 | 1.46 | -2.68 | 5.60 |
| (Cobb) H 1 - (Cobb) F 2 | 1.48 | -2.67 | 5.62 |
| (Cobb) H 3 - (Ross) D 5 | 1.48 | -2.35 | 5.31 |
| (Cobb) H 1 - (Ross) E 2 | 1.55 | -2.60 | 5.69 |
| (Cobb) H 3 - (Ross) D 6 | 1.56 | -2.27 | 5.40 |
| (Cobb) H 1 - (Cobb) F 4 | 1.60 | -2.23 | 5.44 |
| (Cobb) H 1 - (Cobb) G 2 | 1.60 | -2.23 | 5.44 |
| (Cobb) A 2 - (Ross) D 4 | 1.62 | -2.22 | 5.45 |
| (Cobb) H 2 - (Cobb) A 1 | 1.62 | -2.52 | 5.76 |
| (Cobb) H 3 - (Cobb) F 6 | 1.79 | -2.04 | 5.62 |
| (Cobb) H 2 - (Cobb) F 2 | 1.82 | -2.61 | 6.24 |
| (Cobb) H 2 - (Ross) E 2 | 1.89 | -2.54 | 6.31 |
| (Cobb) H 2 - (Cobb) F 4 | 1.94 | -2.20 | 6.08 |

|                         |      |       |      |
|-------------------------|------|-------|------|
| (Cobb) H 2 - (Cobb) G 2 | 1.94 | -2.20 | 6.08 |
| (Cobb) H 1 - (Cobb) A 2 | 2.01 | -1.83 | 5.84 |
| (Cobb) F 4 - (Ross) D 4 | 2.02 | -1.81 | 5.85 |
| (Cobb) G 2 - (Ross) D 4 | 2.02 | -1.81 | 5.85 |
| (Ross) E 2 - (Ross) D 4 | 2.08 | -2.06 | 6.22 |
| (Cobb) F 2 - (Ross) D 4 | 2.15 | -1.99 | 6.29 |
| (Cobb) H 1 - (Ross) E 1 | 2.16 | -1.98 | 6.30 |
| (Cobb) H 1 - (Cobb) G 1 | 2.27 | -1.57 | 6.10 |
| (Cobb) A 1 - (Ross) D 4 | 2.35 | -1.49 | 6.18 |
| (Cobb) H 2 - (Cobb) A 2 | 2.35 | -1.79 | 6.49 |
| (Cobb) H 1 - (Ross) D 5 | 2.41 | -1.43 | 6.24 |
| (Cobb) H 1 - (Ross) D 6 | 2.49 | -1.35 | 6.32 |
| (Cobb) H 2 - (Ross) E 1 | 2.50 | -1.92 | 6.93 |
| (Cobb) H 2 - (Cobb) G 1 | 2.61 | -1.53 | 6.75 |
| (Cobb) H 3 - (Ross) D 4 | 2.70 | -1.14 | 6.53 |
| (Cobb) H 1 - (Cobb) F 6 | 2.72 | -1.12 | 6.55 |
| (Cobb) H 2 - (Ross) D 5 | 2.75 | -1.39 | 6.89 |
| (Cobb) H 2 - (Ross) D 6 | 2.83 | -1.31 | 6.97 |
| (Cobb) H 2 - (Cobb) F 6 | 3.06 | -1.08 | 7.20 |
| (Cobb) H 1 - (Ross) D 4 | 3.62 | -0.21 | 7.46 |
| (Cobb) H 2 - (Ross) D 4 | 3.96 | -0.18 | 8.10 |

Numbers next to Farm (A-H) indicate House number (1-6) on that particular farm

**Table D.1.4 Summary of the results for the Tukey test results based on model IV**

| Comparisons significant at the 0.05 level are indicated by ***. |                          |                                   |      |
|-----------------------------------------------------------------|--------------------------|-----------------------------------|------|
| Farm comparison                                                 | Difference between means | Simultaneous 95% Confidence Limit |      |
| (Cobb) G 2 - (Cobb) F 4                                         | 0.00                     | -4.32                             | 4.32 |
| (Cobb) A 2 - (Ross) E 5                                         | 0.02                     | -4.64                             | 4.68 |
| (Ross) D 1 - (Ross) E 6                                         | 0.05                     | -4.94                             | 5.03 |
| (Ross) D 2 - (Cobb) F 4                                         | 0.06                     | -4.60                             | 4.72 |
| (Ross) D 2 - (Cobb) G 2                                         | 0.06                     | -4.60                             | 4.72 |
| (Ross) E 6 - (Cobb) G 1                                         | 0.06                     | -4.60                             | 4.72 |
| (Cobb) F 2 - (Ross) D 2                                         | 0.07                     | -4.91                             | 5.05 |
| (Ross) D 1 - (Cobb) G 1                                         | 0.11                     | -4.56                             | 4.77 |
| (Cobb) F 2 - (Cobb) F 4                                         | 0.13                     | -4.53                             | 4.79 |
| (Cobb) F 2 - (Cobb) G 2                                         | 0.13                     | -4.53                             | 4.79 |
| (Ross) E 5 - (Ross) D 1                                         | 0.14                     | -4.85                             | 5.12 |
| (Cobb) A 2 - (Ross) D 1                                         | 0.15                     | -4.51                             | 4.82 |
| (Ross) E 5 - (Ross) E 6                                         | 0.18                     | -4.80                             | 5.17 |
| (Cobb) A 1 - (Cobb) F 2                                         | 0.20                     | -4.46                             | 4.86 |
| (Cobb) A 2 - (Ross) E 6                                         | 0.20                     | -4.46                             | 4.86 |
| (Ross) E 5 - (Cobb) G 1                                         | 0.24                     | -4.42                             | 4.90 |
| (Cobb) A 2 - (Cobb) G 1                                         | 0.26                     | -4.06                             | 4.58 |
| (Cobb) A 1 - (Ross) D 2                                         | 0.27                     | -4.39                             | 4.93 |
| (Cobb) A 1 - (Cobb) F 4                                         | 0.33                     | -3.99                             | 4.64 |
| (Cobb) A 1 - (Cobb) G 2                                         | 0.33                     | -3.99                             | 4.64 |
| (Cobb) F 4 - (Cobb) A 2                                         | 0.41                     | -3.91                             | 4.72 |
| (Cobb) G 2 - (Cobb) A 2                                         | 0.41                     | -3.91                             | 4.72 |
| (Cobb) F 4 - (Ross) E 5                                         | 0.42                     | -4.24                             | 5.08 |
| (Cobb) G 2 - (Ross) E 5                                         | 0.42                     | -4.24                             | 5.08 |
| (Cobb) G 1 - (Cobb) F 6                                         | 0.45                     | -3.87                             | 4.76 |
| (Ross) D 2 - (Cobb) A 2                                         | 0.46                     | -4.20                             | 5.12 |
| (Ross) D 2 - (Ross) E 5                                         | 0.48                     | -4.50                             | 5.46 |
| (Ross) E 6 - (Cobb) F 6                                         | 0.51                     | -4.15                             | 5.17 |
| (Cobb) F 2 - (Cobb) A 2                                         | 0.53                     | -4.13                             | 5.19 |
| (Cobb) F 2 - (Ross) E 5                                         | 0.55                     | -4.43                             | 5.53 |
| (Ross) D 1 - (Cobb) F 6                                         | 0.55                     | -4.11                             | 5.21 |
| (Cobb) F 4 - (Ross) D 1                                         | 0.56                     | -4.10                             | 5.22 |
| (Cobb) G 2 - (Ross) D 1                                         | 0.56                     | -4.10                             | 5.22 |
| (Cobb) F 4 - (Ross) E 6                                         | 0.61                     | -4.06                             | 5.27 |
| (Cobb) G 2 - (Ross) E 6                                         | 0.61                     | -4.06                             | 5.27 |
| (Ross) D 2 - (Ross) D 1                                         | 0.62                     | -4.37                             | 5.60 |
| (Ross) D 2 - (Ross) E 6                                         | 0.66                     | -4.32                             | 5.65 |
| (Cobb) F 4 - (Cobb) G 1                                         | 0.67                     | -3.65                             | 4.98 |
| (Cobb) G 2 - (Cobb) G 1                                         | 0.67                     | -3.65                             | 4.98 |
| (Cobb) F 2 - (Ross) D 1                                         | 0.69                     | -4.30                             | 5.67 |

|                         |      |       |      |
|-------------------------|------|-------|------|
| (Ross) E 5 - (Cobb) F 6 | 0.69 | -3.97 | 5.35 |
| (Cobb) A 2 - (Cobb) F 6 | 0.71 | -3.61 | 5.02 |
| (Ross) D 2 - (Cobb) G 1 | 0.72 | -3.94 | 5.38 |
| (Cobb) A 1 - (Cobb) A 2 | 0.73 | -3.59 | 5.05 |
| (Cobb) F 2 - (Ross) E 6 | 0.73 | -4.25 | 5.72 |
| (Cobb) A 1 - (Ross) E 5 | 0.75 | -3.91 | 5.41 |
| (Cobb) F 2 - (Cobb) G 1 | 0.79 | -3.87 | 5.45 |
| (Cobb) A 1 - (Ross) D 1 | 0.88 | -3.78 | 5.55 |
| (Cobb) A 1 - (Ross) E 6 | 0.93 | -3.73 | 5.59 |
| (Cobb) A 1 - (Cobb) G 1 | 0.99 | -3.33 | 5.31 |
| (Cobb) F 6 - (Ross) E 4 | 1.01 | -3.65 | 5.67 |
| (Cobb) F 4 - (Cobb) F 6 | 1.11 | -3.20 | 5.43 |
| (Cobb) G 2 - (Cobb) F 6 | 1.11 | -3.20 | 5.43 |
| (Ross) D 2 - (Cobb) F 6 | 1.17 | -3.49 | 5.83 |
| (Cobb) F 2 - (Cobb) F 6 | 1.24 | -3.42 | 5.90 |
| (Cobb) A 1 - (Cobb) F 6 | 1.44 | -2.88 | 5.75 |
| (Cobb) G 1 - (Ross) E 4 | 1.45 | -3.21 | 6.12 |
| (Ross) E 6 - (Ross) E 4 | 1.51 | -3.47 | 6.50 |
| (Ross) D 1 - (Ross) E 4 | 1.56 | -3.42 | 6.54 |
| (Ross) E 5 - (Ross) E 4 | 1.70 | -3.29 | 6.68 |
| (Cobb) A 2 - (Ross) E 4 | 1.71 | -2.95 | 6.38 |
| (Cobb) F 4 - (Ross) E 4 | 2.12 | -2.54 | 6.78 |
| (Cobb) G 2 - (Ross) E 4 | 2.12 | -2.54 | 6.78 |
| (Ross) D 2 - (Ross) E 4 | 2.18 | -2.81 | 7.16 |
| (Cobb) F 2 - (Ross) E 4 | 2.25 | -2.74 | 7.23 |
| (Cobb) A 1 - (Ross) E 4 | 2.44 | -2.22 | 7.11 |

Numbers next to Farm (A-H) indicate House number (1-6) on that particular farm

**Table D.1.5 Summary of the results for the Tukey test results based on model Ia**

| Comparisons significant at the 0.05 level are indicated by ***. |                          |                                   |       |     |
|-----------------------------------------------------------------|--------------------------|-----------------------------------|-------|-----|
| Farm comparison                                                 | Difference between means | Simultaneous 95% Confidence Limit |       |     |
| (Cobb) G - (Cobb) F                                             | 0.14                     | -0.96                             | 1.24  |     |
| (Cobb) A - (Cobb) H                                             | 0.22                     | -5.29                             | 5.73  |     |
| (Cobb) F - (Cobb) A                                             | 0.51                     | -0.64                             | 1.66  |     |
| (Ross) E - (Ross) D                                             | 0.51                     | -0.72                             | 1.74  |     |
| (Cobb) G - (Cobb) A                                             | 0.65                     | -0.73                             | 2.03  |     |
| (Cobb) F - (Cobb) H                                             | 0.73                     | -4.72                             | 6.18  |     |
| (Cobb) G - (Cobb) H                                             | 0.87                     | -4.63                             | 6.37  |     |
| (Cobb) H - (Ross) E                                             | 5.17                     | -0.29                             | 10.63 |     |
| (Cobb) A - (Ross) E                                             | 5.39                     | 4.19                              | 6.59  | *** |
| (Cobb) H - (Ross) D                                             | 5.68                     | 0.17                              | 11.20 | *** |
| (Cobb) F - (Ross) E                                             | 5.90                     | 5.04                              | 6.76  | *** |
| (Cobb) A - (Ross) D                                             | 5.90                     | 4.45                              | 7.35  | *** |
| (Cobb) G - (Ross) E                                             | 6.04                     | 4.90                              | 7.19  | *** |
| (Cobb) F - (Ross) D                                             | 6.41                     | 5.23                              | 7.60  | *** |
| (Cobb) G - (Ross) D                                             | 6.55                     | 5.15                              | 7.96  | *** |