

# **Prediction of Fertility of Virginia Beef Heifers Using Expert Systems Technology**

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## **Technology**

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(ABSTRACT)

An expert system to predict the fertility of beef heifers was developed using the A.I. Toolkit KAPPA-PC 2.3 . The knowledge base was developed from scientific literature and from a beef cattle reproduction expert. The expert system computes an evaluation age, age both at the start and end of the breeding season, and weight per day of age to classify a heifer as having either a “LOW”, “GOOD”, or “EXCELLENT” likelihood of conception. The expert system summarizes the information that is entered into the computer and creates a text file of the summary. It also gives explanations for every prediction to help identify and alleviate any problem areas that may affect a heifer’s ability to reproduce. The program requires an IBM compatible computer installed with Windows 3.1 or greater. From simulated data for purebred or crossbred British cattle, there was 72% prediction agreement between the expert system and the expert. From analysis of historical data of Hereford-Angus crossbred cattle, heifers categorized as “LOW” and “GOOD” had significantly higher observed pregnancy rates than expected for each category. There was no significant difference between observed and expected pregnancy rates for heifers in the “EXCELLENT” category. Pregnancy rates for post-weaning and pre-breeding evaluations for the “LOW” heifers were found to be lower from the combined “GOOD” and “EXCELLENT” heifers at  $P=.03$  and  $P=.06$  respectively. Observed successful calving rates for heifers categorized as “LOW”, “GOOD”, and “EXCELLENT” did not differ significantly from the expected calving rates for each category.

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“You can take a Mainer out of Maine, but  
you can't take the Maine out of a Mainer!”

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## **Introduction**

Heifer reproduction is an important aspect of the beef cattle industry, since it can affect the productivity of an entire herd (Patterson and Bullock, 1995). Heifers kept as replacements that do not conceive become a financial burden to producers since they are not producing calves to generate a quick turn around of cashflow. Heifers that calve for the first time at two years rather than three years of age have a greater overall lifetime productivity (Pinney et al., 1972; Bernard et al., 1973; Chapman et al., 1978). Thus a means to identify and select heifers for replacement purposes based on probability of successful conception would be beneficial to the beef cattle industry.

Expert systems technology appears to be an appropriate tool to accomplish such a task. Because heifers have no past reproductive performance records, it is difficult to identify a heifer's conceiving ability. Research has shown a correlation of age and body weight with the attainment of puberty, which subsequently affects a heifer's reproductive ability. Yet this still remains an inexact science forcing experts to rely on heuristics, intuition, and subjective measurements to select heifers on conceiving ability. This makes expert systems an appropriate technology since it attempts to incorporate an expert's "thought process" into a computer program. The purpose of this study is to incorporate known research and heuristics of an expert concerning heifer reproduction that will categorize heifers for likelihood of conception.

# Chapter 1. Literature Review: Beef Heifer Reproduction

## *Introduction*

Due to low profit margins and the economic cyclicality of the beef cattle industry, producers should not expect to make a sound living just by producing calves. They must have some knowledge of genetics, physiology, economics, and production skills to maintain a successful enterprise. In order to remain successful, a producer must manage the business as efficiently as possible in all aspects of production, but most importantly in the area of reproductive management. Reproduction of beef cattle may be the most important aspect of the industry, because if live calves are not produced then all other decisions become trivial. A live calf is better than no calf at all, in environments where feed is readily available. The most important task is to select replacement heifers, since difficult decisions made here will affect the productivity of an entire herd (Patterson and Bullock, 1995). Because heifers have no past performance records for reproduction, numerous methods to identify fertile heifers have been developed using physiological processes that are related to the attainment of puberty (Patterson et al., 1992). This information can then be used with other criteria to make final selection decisions.

## *Calving Heifers at Two Years vs. Three Years of Age*

When heifers are bred to calve for the first time at two years of age, they will produce more calves over their lifetime than will heifers bred to calve at three years of age (Donaldson, 1968; Short and Bellows, 1971). Studies have shown that heifers that calve first at two years of age will experience more dystocia and related problems (Bellows, 1968) and produce fewer and smaller calves that first year than comparable heifers that calve for the first time at three years of age (Pinney et al., 1972; Bernard et al., 1973; Cundiff et al., 1974). It was once thought that

cows that calve for the first time at two years of age were never able to fully recover from the stress of calving at such an early age which subsequently affected lifetime production (McCampbell, 1920). Later studies have shown that this is not the case. In fact, heifers that calve at two years of age not only recover but surpass heifers that calve first at three years of age for lifetime productivity (Pinney et al., 1972; Bernard et al., 1973; Chapman et al., 1978). Working with Angus, Hereford, Shorthorn, and reciprocal crossbred cows, Nunez-Dominguez et al. (1991) showed that calving at two as compared to calving at three years of age reduced costs per unit output by 6 to 8% over the lifetime when cows were removed at terminal ages of 7 to 9 years. The earlier calving allows better cash flow for the producer since heifers start to pay for their maintenance expenses one year earlier.

Therefore most current heifer reproductive programs utilize calving at two years of age, which means that heifers must be bred as yearlings. This requires careful consideration of the following when selecting replacement heifers: their age at both the start and end of the breeding season, body weight, milk production potential, and the biological type of the heifer. Consideration of these factors will help to ensure that a high proportion of heifers will have attained puberty before the breeding season begins. After a heifer reaches puberty, the important questions become: What is the likelihood that a heifer will conceive, will deliver a live calf, and will rebreed successfully for her next parturition? A number of traits exhibited by the heifer can be used to predict successful reproduction. These include age and the attainment of puberty, body weight, body condition score, reproductive tract score (RTS), and time of conception.

### *Factors Affecting Puberty*

*Age.* Because puberty is the time at which sexual maturity is attained, the average age of heifers at puberty becomes a critical aspect when breeding heifers to calve as two year olds when a restricted breeding season is used (Ferrell, 1982). Thus the question that needs to be answered is the following: Will a heifer be at an age conducive to the attainment of puberty before, during, or after the scheduled breeding season? Calves born early in their own calving season tend to be older and heavier at the time that their first breeding season begins, which may lead to increased overall lifetime productivity of early born heifers (Patterson and Bullock, 1995). Management systems requiring heifers to calve as two year olds often result in heifers being bred on their pubertal estrus (Wiltbank, 1970). Yet the overall fertility of heifers when bred on their first estrus is significantly lower than on a subsequent estrus (Byerley et al., 1987). Therefore heifers should be capable of, and managed to reach puberty one to three months before the average age at which breeding will begin (Patterson and Bullock, 1995). Selecting replacement heifers that have reached puberty earlier than average for the breed or biological type will help ensure that a high proportion of the replacement heifers will attain sexual maturity before and during the scheduled

breeding season. This will allow more heifers to be experiencing their second and third estrus, thus increasing the overall likelihood of conception for the entire herd (Short et al., 1990).

*Body weight.* Weight of the heifer at the time of breeding is also important, since it has been shown that there is a minimum threshold level a heifer must attain before reaching her first estrus. The typical rule is that a heifer must attain 65 % of her mature body weight before showing signs of estrus (Bolze and Corah, 1993). Body weight and age in a growing animal are highly correlated since the older a animal is, the farther along the sigmoidal growth curve the animal lies, resulting in higher body weight. Growth can be quantified in several ways, average daily gain (ADG) or weight per day of age (WPDA) for example. These measures allow producers to assess the growth rate of their heifers and predict the weight at some time in the future. This in turn can be used to estimate whether a heifer is likely to reach puberty during the breeding season.

*Milk production.* Milk production of cattle also appears to play an important role in determining the age at puberty. That is, cows that produce more milk tend to have calves that reach puberty at an earlier age resulting in a higher likelihood of conception for a given breeding season. Thus, breeds that differ in milk production may differ in the age at puberty. Breeds with a high milk production potential also have calves with higher preweaning growth rate and earlier maturity than similar breeds with low milk production potential, due to higher milk consumption of the calves (Notter et al., 1978). Heifers that mature earlier should have a higher conception rate when bred to calve as two year olds, as opposed to later maturing heifers. Heifers in breeds with a selection history for milk production reach puberty earlier relative to mature body weight as compared to typical meat breeds, such as Angus and Hereford cattle. Dairy crossbred heifers have been shown to reach puberty at earlier ages than beef breeds, relative to mature body weight and independent of differences in the growth rate of the calf from milk yield of the dam (Laster et al., 1976, 1979). Selection for increased milk production may induce an endocrine profile favoring early sexual maturity.

*Breed differences/Biological types.* Bergmann and Hohenboken (1992) demonstrated that it is possible to predict likelihood of conception for heifers using logistic regression models that incorporate age, weight, growth rates, and maternal traits. They showed that different traits were predictive of pregnancy in Angus vs. Simmental heifers. Prediction equations may only work within the populations from which the data to formulate the equations were collected. A more appropriate technology to predict likelihood of conception may be necessary. Because different traits appear to be important in different breeds, it is logical to find a means to group like breeds into biological types so that the most important traits can be used to predict the likelihood of conception for a given type of heifers. Cundiff et al. (1993) has categorized beef cattle into different biological types based upon variation for the following traits: growth rate and mature size, lean to fat ratio, age at puberty, and milk production (Table 1). The

**Table 1. Breeds grouped into biological types on the basis of four criteria<sup>a, b</sup>**

Breed group	Growth rate and mature size	Lean:fat ratio	Age at puberty	Milk production
Jersey	X	X	X	XXXXX
Longhorn	X	XXX	XXX	XX
Hereford-Angus	XX	XX	XXX	XX
Red Poll	XX	XX	XX	XXX
Devon	XX	XX	XXX	XX
Shorthorn	XXX	XX	XXX	XXX
Galloway	XX	XXX	XXX	XX
South Devon	XXX	XXX	XX	XXX
Tarentaise	XXX	XXX	XX	XXX
Pinzgauer	XXX	XXX	XX	XXX
Brangus	XXX	XX	XXXX	XX
Santa Gertrudis	XXX	XX	XXXX	XX
Sahiwal	XX	XXX	XXXXX	XXX
Brahman	XXXX	XXX	XXXXX	XXX
Nellore	XXXX	XXX	XXXXX	XXX
Braunvieh	XXXX	XXXX	XX	XXXX
Gelbvieh	XXXX	XXXX	XX	XXXX
Holstein	XXXX	XXX	XX	XXXXXX
Simmental	XXXXX	XXXX	XXX	XXXX
Maine-Anjou	XXXXX	XXXX	XXX	XXX
Salers	XXXXX	XXXX	XXX	XXX
Piedmontese	XXX	XXXXXX	XX	XX
Limousin	XXX	XXXXX	XXXX	X
Charolais	XXXXX	XXXXX	XXXX	X
Chianina	XXXXX	XXXXX	XXXX	X

<sup>a</sup>X lowest, XXXXXX highest.

<sup>b</sup>From Cundiff et al., 1993.

groups can be thought of as continental European breeds with a selection history for draft purposes (e.g., Charolais, Chianina, and Limousin), dairy breeds and continental European breeds with a selection history for both meat and milk production (e.g., Brown Swiss, Gelbvieh, Holstein, Simmental, and Maine Anjou), British and British-like breeds (e.g., Hereford, Angus, Red Poll, Devon, South Devon, Tarentaise, and Pinzgauer), breeds of small size (e.g., Jersey and Longhorn), breeds containing *Bos indicus* influence, and *Bos indicus* breeds. Once a producer is able to identify the biological type to which his/her cattle belong, then the appropriate information can be used to identify which heifers will be most likely to conceive during a given breeding season. Actual values obtained by Cundiff et al. (1993) for growth and puberty traits of heifers are shown in Table 2. The heifers are F<sub>1</sub> progeny out of Hereford, Angus, or crossbred dams and sired by the breed listed in the table. Differences in breed crosses and between biological types for five different traits can be seen.

### *Factors Affecting Conception/Calving rate*

*Pubertal estrus vs. third estrus.* Byerley et al. in 1987 compared the pregnancy rate of heifers when bred to a fertile bull on pubertal estrus or on the third estrus. Only 57% of the heifers bred on the first estrus successfully conceived, whereas 78% of the heifers bred on their third estrus had a successful conception ( $P < .05$ ). Heifers bred during their third estrus were older and heavier at the time of breeding than the heifers bred at their pubertal estrus ( $P < .05$ ). Heifers from the two groups that did not conceive did not differ significantly in the amount of time required to return to estrus.

*Feed levels.* A study conducted by Short and Bellows in 1971 demonstrated the effect of feeding level on age at puberty and overall reproductive performance in spring-calving heifers (Table 3). Following weaning, winter diets were assigned which promoted low, medium, or high growth rate. At the end of the wintering period, the three groups differed significantly in body weight, pelvic area, and condition score, but differences among groups were reduced during the following spring grazing season. Although heifers on the medium and low feed levels exhibited compensatory growth when placed on pasture, they still were slower in reaching sexual maturity than heifers in the high group. This resulted in heifers in the high group reaching puberty at heavier body weights. Because heifers in the high group reached puberty earlier than heifers in the other groups, 83% of those heifers had already been in estrus prior to the scheduled breeding season. In the medium and low groups, only 24 and 7%, respectively, of the heifers had done so. During the breeding season, 80% of the heifers in the low group exhibited signs of estrus as compared to 97% in the medium group and 100% in the high group. There was also a difference in day of conception between the groups, which was due to a delay in reaching puberty and not to an increase in number of services per conception which did not differ between the groups. The pregnancy rate for the low group was 63%, significantly lower than 90% for both the medium

**Table 2. Breed group least squares means for growth and puberty traits of heifers<sup>a</sup>**

Breed group	Number	400-day weight (kg)	550-day weight (kg)	Puberty expressed (%)	Age at puberty (days)	Pregnancy rate (%)
Jersey	114	295	333	97.4	317	88.4
Longhorn	82	287	337	82.0	370	90.9
O <sup>b</sup> Hereford-Angus	414	320	362	92.2	365	87.9
C <sup>c</sup> Hereford-Angus	55	339	386	97.3	366	80.1
Red Poll	93	305	348	90.2	353	83.6
Devon	67	323	365	93.0	364	89.4
Shorthorn	73	349	393	95.8	359	89.0
Galloway	76	312	352	95.1	365	80.7
South Devon	118	329	369	96.0	352	84.5
Tarentaise	83	323	372	97.6	358	94.4
Pinzgauer	209	334	381	94.5	343	93.9
Brangus	63	333	373	92.2	385	85.5
Santa Gertrudis	41	335	380	90.0	391	92.7
Sahiwal	86	298	354	92.3	427	102.0
Brahman	101	332	392	93.5	439	94.3
Nellore	82	330	384	58.5	412	89.9
Braunvieh	129	327	375	90.0	346	91.6
Gelbvieh	185	329	379	87.1	341	87.4
Holstein	50	340	392	92.2	347	94.8
Simmental	155	340	383	94.4	360	86.4
Maine Anjou	88	342	391	90.6	370	92.8
Salers	90	346	396	101.0	365	89.0
Piedmontese	89	319	365	98.2	348	95.5
Limousin	155	325	362	88.0	391	83.7
O <sup>b</sup> Charolais	126	338	385	87.0	393	81.0
C <sup>c</sup> Charolais	36	354	410	96.3	361	79.0
Chianina	94	333	387	83.8	400	84.0

<sup>a</sup>From Cundiff et al., 1993

<sup>b</sup>Original = selected sires born in 1963-1970

<sup>c</sup>Current = selected sires born in 1982-1984



**Table 3. Effect of winter feed level on body measurements and puberty<sup>a</sup>**

Trait	Winter Feed Level		
	Low	Medium	High
<i>Percentage exhibiting estrus in relation to the breeding season:</i>			
Prior	7	24	83
During	73	72	17
After	20	4	0
<i>Pregnancy status:</i>			
Failed to conceive	37	10	10
Diagnosed pregnant	50	86	87
Apparent embryo mortality	13	4	3
<i>Weight (kg)</i>			
Puberty	238	248	259
Final	286	303	322

<sup>a</sup>Short and Bellows, 1971.

and high groups. The final calving rate for the low group was 50% as compared to the 86% and 87% levels in the medium and high groups respectively. Thus, the prenatal loss was greater for the low group as compared to the two higher groups ( $P < .05$ ) whereas, no significant difference existed between the high and medium groups.

*Body condition.* The percentage of body fat also appears to play an important role in the likelihood of conception but is difficult to measure in heifers. The easiest method of estimating body fat in heifers is body condition scoring. This is not very accurate, however, since young growing animals have little fat. This limits its use for predicting conception, except at the time of breeding. A study by Morrison et al. (1992) showed that the optimum range for body condition score of heifers at the time of breeding is within 5 or 6 on a scale of 1 to 9. Scores of 4 or 7 were associated with some decrease in reproductive performance. A score of 3 or less or 8 or higher resulted in cattle being too thin or too fat respectively and severely hindered reproductive performance.

*Reproductive tract scores (RTS).* Reproductive tract score (RTS) evaluation of heifers within 60 d of the breeding season has been shown to be a valuable tool to predict the likelihood of conception (Anderson et al., 1991). The RTS system attempts to estimate the pubertal status of heifers by rectal palpation of the uterine horns and ovaries (Anderson et al., 1991; Table 4). Heifers receiving a RTS of 1 have small infantile tracts characterized by toneless uterine horns and small, inactive ovaries. A RTS of 2 is characterized by larger uterine horns and ovaries. A RTS of 3 indicates signs of uterine tone and palpable follicles. A RTS of 4 has the characteristics of a mature reproductive tract with large uterine size, coiling of the uterine horns, uterine tone, and follicular development. A RTS of 5 is the same as a RTS of 4 except an ovary will contain a palpable corpus luteum.

As shown in Table 5 (Patterson and Bullock, 1995), RTS is predictable from body weight. Heifers with a RTS of 1 and a RTS of 2 differed in body weight ( $P < .05$ ) and in pregnancy rate ( $P < .05$ ). There were no further significant differences among reproductive tract scores for pregnancy rate, whereas body weight did significantly increase until a RTS of 4 was reached. Heifers receiving reproductive tract scores of 1 tend to be the youngest heifers at the time of evaluation; likewise heifers receiving a RTS of 5 tend to be the oldest heifers at the time of evaluation (Anderson et al., 1991). It is likely that a RTS of 1 is associated with low pregnancy rates because many of the heifers will not reach their pubertal estrus before the end of the breeding season. Heifers with a RTS of 2 and 3 may face future culling because they are likely to conceive towards the end of the breeding season, when they most probably will be experiencing their second or third estrus. Heifers that conceive late will tend to calve late, making it more difficult to get them rebred (Burriss and Priode, 1958; Lesmeister et al., 1973). Heifers with a RTS of 4 or 5 are less likely to become problematic in the future because they will tend to conceive early in the breeding season, calve early during the calving season, and thus recover from

**Table 4. Reproductive tract scoring system<sup>a</sup>**

RTS	Uterine Horns	Ovarian length (mm)	Ovarian height (mm)	Ovarian width (mm)	Ovarian structures
1	Immature, < 20 mm diameter, no tone	15	10	8	No palpable follicles
2	20-25 mm diameter, no tone	18	12	10	8 mm follicles
3	20-25 mm diameter, slight tone	22	15	10	8-10 mm follicles
4	30 mm diameter, good tone	30	16	12	> 10 mm follicles, corpus luteum possible
5	> 30 mm diameter	> 32	20	15	Corpus luteum present

<sup>a</sup>From Anderson et al., 1991.

**Table 5. Reproductive summary of Kentucky beef heifer field data<sup>e</sup>**

RTS	Weight (lbs)	Pelvic Area (cm <sup>2</sup> )	Pregnancy Rate (%)
1	594 <sup>a</sup>	152 <sup>a</sup>	65 <sup>a</sup>
2	620 <sup>b</sup>	158 <sup>a</sup>	91 <sup>b</sup>
3	697 <sup>c</sup>	166 <sup>b</sup>	93 <sup>b</sup>
4	733 <sup>d</sup>	172 <sup>c</sup>	93 <sup>b</sup>
5	754 <sup>d</sup>	172 <sup>c</sup>	93 <sup>b</sup>

<sup>a,b,c,d</sup>Unlike superscripts within columns denote significance (P<.05).

<sup>e</sup>From Patterson and Bullock, 1995.

postpartum anestrus before the next breeding season begins. Heifers with a RTS of 4 or 5 are less likely to suffer from dystocia because their pelvic areas are significantly larger than those of heifers with lower reproductive tract scores ( $P<.05$ ).

## Chapter 2. Literature Review: Expert Systems

### *Introduction*

Expert systems (ES) are a branch of Artificial Intelligence (AI) which store the knowledge of an “expert” in the form of a computer program. The knowledge which is stored in the ES is then used to analyze input information and provide a solution for a well-defined problem. Expert systems employ the use of two components to develop a program: the knowledge base (KB) and the inference engine (IE). An analogy can be drawn between an ES and the human brain; a rule would be analogous to the memory storage of the brain cell and the IE would mimic the human thought process. The KB contains the “knowledge of an expert” in the form of rules, which are in an IF... THEN... format. An example of a rule follows: “IF a live beef animal is predominantly black, THEN the carcass is eligible for Certified Angus Beef (CAB).” The IE controls how the ES searches through the rule base. Two possible methods are forward and backward chaining. Forward chaining is a data driven strategy where information entered into the computer is used to drive the IE forward to a conclusion. Backward chaining is a goal driven strategy where the ES has certain goals it seeks to fulfill and queries the user for information to satisfy the goal. The means by which forward and backward chaining search through the rule-base can be demonstrated using the example rule above.

Using a forward chaining method of propagation, all the data or facts necessary to qualify or disqualify a beef animal for CAB are entered into the ES. The ES is then asked to analyze each fact one at a time. The first fact may be that the animal is “black,” a qualification for CAB. The ES searches the entire rule base until the rule concerning the color of the animal is activated or fired. The rule base is reset and the next fact is analyzed by the entire rule-base until a rule is fired concerning that fact. This continues until the last fact has been analyzed. At this point the ES renders its diagnosis of whether or not the animal qualifies for CAB based on all of the given facts. Changing the first fact from “black” to “red,” which does not meet CAB qualifications, or

any other fact from qualify to disqualify for CAB and vice-versa does not change the rule firing process as described above.

Using a backward chaining method of propagation, all the facts necessary to qualify a beef animal for CAB are elicited one at a time, attempting to satisfy a predetermined goal. In this example the first goal states that “the beef animal must be black.” The ES queries the user “Is your beef animal black?” If the user responds “yes” and satisfies the goal, the next goal is activated and the ES queries the user to satisfy that goal. This process continues until all the goals in the ES have been satisfied, qualifying an animal for CAB or until a goal has not been satisfied, which discontinues the analysis and disqualifies an animal for CAB. At this point the ES renders its diagnosis of whether or not the beef animal qualifies for CAB based on all the facts that it has received.

Because first generation ES would solve only narrowly-defined problems, different types of ES have been developed to help solve more complex problems. Multi-domained ES have the ability to solve problems in more than one area of expertise, allowing complex problem solving from the interaction of the expertise domains. A hybrid ES may incorporate conventional programming, spreadsheets, databases, simulations, and other tools into the final program. Hybrid ES, recognized as a valid form of ES in both operations research and the artificial intelligence fields (Gum and Blank, 1990), are analogous to an expert who has access to tools to aid in reaching a decision.

Why do we need such technology in the livestock industry? As agricultural departments face severe budget cuts, they have been forced to operate as efficiently as possible (Gum and Blank, 1990). Agricultural extension services have been forced to cover larger areas with less manpower. They need to identify economical, fast, and reliable methods to transmit information and advice to clientele. With the recent accessibility of the internet, computers can transmit a variety of educational and decision-support programs with the click of a mouse; multimedia programs, simulation models, conventional programs, and ES are available to clientele (Gum and Blank, 1990). These programs can teach, simulate, advise, and predict outcomes of decisions made on a farm. Expert system technology can accomplish all of the above; thus an ES may be able to educate while at the same time advise clientele on how to solve problems.

Because much agricultural research is beyond the comprehension level of most producers, it is not readily adopted by industry. A means of allowing producers to use this research is needed. Research may be encoded into the KB of an ES, allowing producers to indirectly use the knowledge by using the ES. Widespread adoption of such systems could reduce farm-to-farm variation in management practices, allowing producers to produce the more uniform product that is demanded of the meat animal industries. This technology has already been shown to reduce variation in manufactured products from factory-to-factory (Hochman et al., 1991). The degree

to which farm-to-farm variation will be reduced is uncertain, because biological industries have much more variation than manufacturing industries (Hochman et al., 1991).

### *Some Example Expert Systems and Validation Techniques*

“Integrated Expert System for Culling Management of Beef Cows” by Oltjen et al. (1990) was developed to base culling decisions on economic and biological evaluation of the future potential of the cows in question. This system contains twenty rules to recommend a decision of either keep, cull, or rank. The rules evaluate age, pregnancy status, udder score, body condition score, eye damage, calving difficulty, performance index, and history of Cesarean calvings to reach a final decision. If a cow does not fall into either the keep category or the cull category, she is evaluated based on her net present value. A producer can then decide where a culling level must be set for the ranked cows. This ES is simple, narrowly-defined, and straight forward.

Another ES with culling management as its goal is called “Range Cow Culling and the Value of Pregnancy Testing: A Decision Support System via the World Wide Web” by Tronstad and Gum (1995). This system bases its recommendations for culling on current market conditions and is available on-line. Factors used to make the decision are cow age, calf price, replacement price, slaughter price, season, and production costs. The decision on what to do with a cow is made by use of a decision tree. Advantages of this ES are that market prices can be kept up to date by qualified Extension Agents, it can make recommendations to producers on what to do, on-line explanations can be accessed to explain why particular information is relevant, and on-line feedback from users is available. Disadvantages of the system are as follows: biological information is not used to any great extent to make culling decisions, potential users must have access to the internet and have computers powerful enough to run Windows, and a user is expected to download and install software necessary to read files.

“DXMAS: An Expert System Program Providing Management Advice to Dairy Operators” by Schmisser and Gamroth (1993) was developed to identify management problems for dairy producers in Tillamook county, Oregon. It was written using M.I development shell program which uses PROLOG as its foundation code. The ES employs a backward chaining method of propagation with limited ability for forward chaining. The program attempts to identify major management problems that will affect the profitability of a dairy herd, calculate the amount of losses incurred because of the identified problems, and recommend strategies to alleviate the problems. During consultation, the program asks questions and elicits pertinent data to identify any problems that may exist. The ES can be asked to explain its reasoning during the consultation or asked to explain how it reached its final conclusions at the end of the consultation. A field test using 45 dairy operators demonstrated that the ES identified and diagnosed management problems on nine dairy farms successfully. That is, the dairy producers



found the results of the program a valuable tool in their ability to make management decisions. The remaining dairy producers did not find the results to be immediately useful.

“A Fuzzy Logic Expert System for Dairy Cow Transfer Between Feeding Groups” by Grinspan et al. (1994) was developed using fuzzy logic. Fuzzy logic is a mathematical tool for dealing with uncertainty, ambiguity, and vagueness (Dubois and Prade, 1980, 1988). Fuzzy logic attempts to translate qualitative terms into quantitative terms. Fuzzy sets are groups of rules that employ fuzzy logic to analyze data. The ES shell was developed using Turbo Pascal 6.0 with the ability to modify and add new fuzzy sets to the ES as necessary. The ES extracts information from three different databases: a REFERENCE file (ID, calving date, parity), a MILK file (average weekly milk production), and a WEIGHT file (average weekly body weight). The ES attempts to identify cows that are low milkers that should be placed in a low feed level group, moderate milkers that should be placed in a moderate feed level group, or high milkers that should be placed in a high feed level group. The ES was tested using a sample of 40 cows and comparing the results of the ES to the recommendation of three experts. The experts and the ES were in agreement in 70% of the cases and the ES was considered superior in 10% of the cases. In the remaining 20% of the cases, there was disagreement between the ES and the experts. The percentage agreement between experts was not given.

“Expert System for Evaluation of Reproductive Performance and Management” by Domecq et al. (1991) identifies management problems affecting reproductive performance in dairy cattle. It was developed using an expert system shell called PC Expert Professional and Turbo Pascal. The ES examines days open, days to first breeding, estrus detection, and conception rate to identify any problems that may exist. Once a problem has been determined to exist, the ES evaluates the most potentially damaging factors first. Information can be entered into the ES by use of a keyboard, or it has the ability to access and analyze a Direct Access to Records by Telephone (DART) report converted to an ASCII file. The ES was tested by using ten commercial dairy herds with conception rates less than 40%, and the results were compared with conclusions of an expert. After analyzing the DART reports, both the ES and the expert identified 47 potential problem areas with an 85% agreement rate between the two. The expert system also has the ability to recommend solutions and give suggestions on how to alleviate problems.

“An Expert Diagnostic Aid for Reproductive Problems in Dairy Cattle” by Levins and Varner (1987) is an ES developed using BASIC to diagnose reproductive problems in dairy cattle. The ES contains a set of 36 questions that it may ask the user during an initial evaluation. The questions asked by the ES deal with herd status, anestrus, fertility status, cystic ovarian disease, abortions, other factors, and estrus detection efficiency. After the questions have been answered, the ES uses its rule base to determine which of 222 subreports to assemble into a final diagnostic report. The subreports are text files containing solutions to various reproductive problems. The

ES was tested using 26 dairy herds in Maryland. The information was elicited from each dairy farm and entered into the computer. Responsible veterinarians were contacted and asked their opinion of the reproductive problems for each herd. The ES and veterinarians were in agreement 69% of the time, and 19% of the time the ES was more accurate than the veterinarian. As compared to the ES, the veterinarians provided superior solutions 12% of the time. The ES was also given to five county agents in Maryland to be tested and to give their opinions. The agents claimed that the ES gave them confidence in providing recommendations they normally felt deficient in. They found, during consultation with dairy producers, that the ES matched the diagnosis of veterinarians. The ES was found to have limited use working with clients concerning non-reproductive problems.

“Hybrid Expert System for Beef-Forage Grazing Management” (Tao et al., 1991) is a hybrid ES to assist producers in making pasture grazing management decisions. The basic structure of this ES is composed of forage, animal, and balance subsystems. The user interface consists of maps, menus, and queries to elicit information from the user. Once all the information has been collected, a backward chaining method of rule propagation is used to make a final decision.

The forage subsystem incorporates ES technology to predict pasture production based on current pasture condition. The subsystem is used to estimate the following: pasture stocking rate, pasture yield potential, seasonal distribution of pasture production, and pasture forage quality. Pasture stocking rate is estimated using information on species of forage, soil type, and location. Pasture yield is determined from response to fertilizer, precipitation, soil erosion, weed competition, and grazing management. Pastures are rated as severe, moderate, light, and none for risk of soil erosion and weed competition. Response to fertilizer is a function of amount, location, season, forage species, and precipitation. Precipitation is estimated by location average and standard deviation for rainfall. Finally, grazing management is given as either continuous, simple, or complex. Seasonal distribution of production and quality is based on forage species and time of year.

The animal subsystem uses a database to develop livestock inventory and demand. This subsystem attempts to estimate bi-weekly livestock forage demand which varies due to breed, type, age, frame size, and production level of the animals. Each animal is converted into proportions of an animal unit (AU), which is the amount of forage consumed bi-weekly by a 454 kg cow with above average milking ability and with a calf less than four months of age. The year-round bi-weekly animal demands are calculated using the animal inventory adjusted to AU. The balance subsystem then uses the results from above to simulate grazing and instructs the user how to balance pasture production and animal demand.

Development of a beef cattle crossbreeding ES, called X-Breed, has taken more than five years and currently is still under construction. Four publications (Hochman and Pearson, 1991; Hochman et al., 1991, 1993, 1994) chronicle the development of X-Breed. The first paper called for the development of an ES involving three co-dependent domains: pasture agronomy, farm management, and cattle breeding. By combining all three domains into one system, an attempt can be made to evaluate interactions between them.

X-Breed was developed for use by professional advisors of commercial cattle producers. It has the potential to recommend nine major breeding strategies, of which three use terminal sires. With the three terminal breeding strategies, it has the option to recommend one of ten different bull breeds. The KB stores estimates of variation, due to genotype, within a given environment for eight economically important traits, those being: growth rate, maturity, calving ease, calf survival, disease resistance, milk production, temperament, and fertility. It contains rules on how each breeding strategy can influence each selected trait. The objective of X-Breed is to improve economically important traits while not hindering the expression of other traits. To do this, three groups of rules were developed to perform a specific task.

The first rule group identifies constraints that would nullify the use of any of the nine breeding strategies. Constraints are dependent upon the producer's existing capital and/or managerial resources. The second rule group identifies the producer's production or marketing goals that are currently not being satisfied. These goals are then incorporated into the remaining breeding systems. The third rule group ranks the breeding strategies by assigning a confidence value, based on how well the goals will be achieved and the economic benefits from achieving them. Lastly, if any of the breeding strategies evaluate to a confidence of 60% or more, a suitable bull breed is recommended. Limitations to the ES are that a producer must raise purebred British cattle, and recommendations cannot be made outside of the 10 available bull breeds.

The latest publication on X-Breed described some changes to the system. The first was the addition of a pasture quality domain using the following: class of plant, species of plant, climate, time of year, and fertilizer use. The quality of the pasture is determined by estimating crude protein content, digestibility, and legume content. The pasture is then placed into one of five dietary categories and allowed to interact with the breeding domain by what is known as "Blackboard Architecture."

Blackboard architecture is a symbolic method of solving problems from more than one domain by a group of experts that differ in their expertise. The solution from the breeding domain is placed into a database while at the same time the solution from the pasture domain is placed into the same database. The ES then accesses both kinds of information, analyzes the data, and forms a recommendation or solution. The information may then be transferred to other

subdomains which will recommend what terminal sire is needed, whether an F<sub>1</sub> cow should be purchased or produced, and whether to sell calves before or after weaning.

Harrison (1990) reported numerous ways to validate an ES. ES validation is accomplished through feedback from experts, user feedback, and field trials. Feedback can be provided by users by filling out an evaluation form on how the ES performed a specific task. Performance may be rated as poor, fair, average, good, or excellent. Feedback from experts and field trials may tell the developers whether or not the ES works, while user feedback may tell whether or not the user liked the ES. Simple statistical analysis can be performed on the results of feedback and field trials to check the agreement between experts, experts and the ES, and the ES and field trials.

## *Conclusions*

Expert systems have demonstrated their effectiveness in certain areas and have the potential to expand in many others in the livestock industry. Currently most ES are developed only for professional advisers, but there is potential for their direct use by the commercial segment of the livestock industry. In 1992, Wagner reported that more than 100 ES relating to agriculture had been developed and since then that number has expanded. Agricultural decision-support systems need to be able to make recommendations and explanations that a user can easily understand and trust in order for these programs to be adopted into industry use (Greer et al., 1994).

## Chapter 3. Expert System Development

### *Expert System Development*

The ES, Heifer Fertility Prediction: Expert (HFP: Expert), was developed using the AI Toolkit KAPPA-PC 2.3 . KAPPA-PC 2.3 was written in C and employs many features of C language to create an ES. It is a Windows -based toolkit that allows a developer to easily set up and display screens in the form of windows. A runtime licensing fee must be obtained, at a cost of \$450, to allow the program to be distributed to users. Once the licensing fee is obtained, the program can be compiled using a C compiler. The versatility of KAPPA-PC 2.3 allows an entire system to be developed using only the Toolkit itself. Numeric calculations are performed using Methods that are imbedded within Objects. IF-THEN rules are written into the Toolkit by means of a Rule Editor. These rules contain heuristic knowledge and facts necessary to make a proper decision and collectively constitute the knowledge base (Appendix 1).

The knowledge base of HFP: Expert is divided into ten knowledge groups, each containing information for a specific trait such as growth. A function editor is also provided to allow the developer to assign specific tasks to be performed at the correct time to ensure a sensible decision. A goal editor is also provided but was not used since goals are used by backward chaining systems and the current ES uses a forward chaining mode of propagation.

The ES will run on an IBM compatible PC equipped with Windows 3.1 or higher and can be accessed from the hard drive or a floppy drive. The interface screens contain radio buttons, sliders, drop down menus, and text boxes to prompt the user for the desired information and help. The program was developed as a tool for commercial beef cattle producers with some Windows experience. Development of the knowledge base came from a reproductive beef cattle expert and data published in the scientific literature.

## *User Interface*

The user enters most of the information into the computer using mouse commands only, with minimal keyboard entries at the start of the consultation; eliminating the need to switch from keyboard to mouse during use. Necessary types of information are dates (birth, breeding, and animal evaluation), estimated age of heifer if birth date is not available, breed type, ID, and body weight. If the date the animals are evaluated is within 60 days of the breeding season, the ES allows the user to include three additional (optional) traits for evaluation: RTS, health code, and body condition score. The ES then assigns a heifer a “LOW”, “GOOD”, or “EXCELLENT” likelihood of conception based on the information provided by the user. Recommendations are made to correct problems if a heifer is placed in either the “LOW” or “GOOD” category. A report is generated to display information that was entered by the user, variables calculated by the ES, and the prediction and recommendations made by the ES for each heifer. The report can be viewed on screen or can be printed out using a text editor. This collectively is known as the user interface (Appendix 2).

## *Evaluation of Biological Type*

The user chooses the biological type or breed which best characterizes each heifer (Table 6). Selecting a breed instead of a type does not cause access of information specific to that particular breed but access to information from the biological type in which that breed is categorized. The average criteria for WPDA and age at puberty for that biological type are accessed. The accessed criteria are compared to the information supplied by the user, which is described in greater detail in the following sections.

## *Evaluation of Age*

The age of a heifer is necessary information for the ES to make an accurate prediction of fertility. Age is the “limiting amino acid” for the attainment of puberty; that is if a heifer has not attained an age conducive to puberty at the time of breeding she cannot conceive. Once age has been determined to be satisfactory, then growth and body condition factors become important determinants. The ES determines three different ages for each heifer with each age performing a different function in the decision process. To determine the ages the user must enter the length of the breeding season and three dates as follows: the date on which the heifers were evaluated, date at the start of the breeding season, and birth date of each heifer. The ES uses these three dates to determine the age of the heifer when she was evaluated, the age of the heifer at the start and end of the breeding season, and the number of days from the evaluation date to the start of the breeding season.

**Table 6. Heifers categorized into biological types used by HFP: Expert<sup>a</sup>**

Breed group	200-day weight (lbs)	400-day weight (lbs)	550-day weight (lbs)	Age at puberty (days)
Biological Type 1				
Longhorn	406	633	742	370
Average	406	633	742	370
Biological Type 2				
Hereford-Angus	458	747	850	366
Red Poll	426	672	768	353
Devon	445	711	805	364
Shorthorn	460	769	867	359
Galloway	429	688	777	365
South Devon	435	726	813	352
Tarentaise	446	713	821	358
Pinzgauer	445	736	839	343
Average	442	721	819	354
Biological Type 3				
Brahman	460	733	865	439
Brangus	439	735	823	385
Nellore	474	727	846	412
Santa Gertrudis	443	739	838	391
Sahiwal	432	657	780	427
Average	450	715	831	416
Biological Type 4				
Braunvieh	453	720	826	346
Maine Anjou	456	753	861	370
Salers	464	763	873	365
Simmental	458	725	836	341
Gelbvieh	456	749	844	360
Average	457	739	844	354
Biological Type 5				
Limousin	443	717	797	391
Charolais	479	781	903	361
Chianina	459	734	854	400
Piedmontese	452	703	805	348
Average	453	724	823	380

<sup>a</sup>Adapted from Cundiff et al., 1993

The age at evaluation computed for each heifer is used to calculate her weight per day of age (WPDA), the heifer's weight divided by age in days. This number is rounded to one decimal accuracy, allowing for a range of different body weights to be accrued into one class, which allows the ES to more easily process the information. For example, a heifer weighing 600 lbs at 266 days of age would have a WPDA of 2.256 or 2.3 lbs, while a heifer weighing 620 lbs at the same age would have a WPDA of 2.331 or 2.3 lbs as well. For a given biological type, the ES can access the threshold WPDA for successful conception at a given age and determine whether the heifer has an actual WPDA less than, equal to, or greater than the threshold WPDA. If a birth date is not available, the user is allowed to enter an estimate of the age in days and this number is used to compute the WPDA.

The ES also determines the age at the start and end of the breeding season. The heifer's ages at both the start and end of the breeding season are then compared to the allotted average age at puberty for the breed type to which the heifer belongs. Again the ES evaluates whether the start and end ages are less than, equal to, or greater than the average age. The age at the start of the breeding season is computed directly from the birth date of each heifer and the date of the start of the breeding season. To determine the age at the end of the breeding season, the ES adds the length of the breeding season to the age at the start of the breeding season. If the birth date of a heifer is not available to a user and the age in days was entered, the number of days contained in the interval between the current date and the start of the breeding season is added to the age in days to obtain the age at the start of the breeding season.

### *Evaluation of Growth Traits*

Growth of a heifer is monitored by the ES by using WPDA. Weight per day of age is a measure of body weight/day at a given age. Table 7 shows the minimum WPDA heifers should attain, depending upon age and biological type, in order to have a high likelihood of achieving timely puberty. For instance a Type 1 heifer at an age of 212 days would be placed into the WPDA bracket of 190 days (range of 190 to 214) and have a threshold WPDA of 2.0. This allows each individual heifer to be judged according to target weights at specific ages. The total range the ES will handle starts at a minimum of 190 up to a maximum of 560 days of age. Weight per day of age values were linearly interpolated from 200, 400, and 550 day weights converted to WPDA. This incremental method allows a user to use the ES anytime after weaning. It also allows a user to periodically monitor the growth and reproductive progress of heifers.

The interval of days between the current date and the start of the breeding season is used to determine ADG required to reach timely puberty and an acceptable probability of conception. The heifer's current weight is subtracted from an average weight at puberty for the given breed type. The difference is divided by the number of days in the interval. This is the ADG



**Table 7. Threshold WPDA (col. 1) necessary to achieve timely puberty for heifers of different biological types at different ages at the time of evaluation**

WPDA(lbs)	Age in days at evaluation for biological type:				
	1	2	3	4	5
2.3			190-204	190-204	190-204
2.2		190-214	205-224	205-234	205-224
2.1		215-244	225-254	235-274	225-264
2.0	190-214	245-294	255-294	275-324	265-304
1.9	215-254	295-354	295-354	325-394	305-364
1.8	255-294	355-414	355-414	395-434	365-424
1.7	295-344	415-464	415-464	435-484	425-464
1.6	345-414	465-514	465-524	485-534	465-514
1.5	415-474	515-560	525-560	535-560	515-560
1.4	475-544				
1.3	545-560				

necessary for a heifer to achieve in order to meet the threshold body weight for puberty. The computed ADG is for recommendation/explanatory purposes only. If a heifer's current weight is greater than the allotted threshold weight, no target ADG is computed.

### *Evaluation of Likelihood of Conception*

The first step in making a decision is to evaluate a heifer's age in days at the start and end of the breeding season. A heifer should reach puberty sixty days before the start of the breeding season to ensure a high likelihood of conception. Heifers predicted to reach puberty during the first half of the breeding season will fall into a moderate likelihood of conception. Heifers reaching puberty in the last half of the breeding season or later will fall into a "LOW" likelihood of conception. At this point the likelihood of conception is a tentative measure based on age alone, and as more information is processed the decision is refined (Table 8). A heifer that receives a tentative evaluation of very low is characterized by not having an acceptable age at the start or end of the breeding season. An evaluation of low is tentatively assigned to a heifer with an unacceptable age at the start of the breeding season, but which does attain an acceptable age by the end of the breeding season. Three possibilities exist for a heifer to receive an intermediate evaluation. They are the following: 1. An unacceptable age at the start of the breeding season with a desirable age at the end of the breeding season. 2. An acceptable age at both the start and end of the breeding season. 3. An acceptable age at the start of the breeding season with a desirable age at the end of the breeding season. For a heifer to receive a high evaluation, she must have a desirable age at both the start and end of the breeding season.

The second step is the evaluation of growth for each individual heifer. To retain the initial assignment of "EXCELLENT" likelihood of conception, a heifer should have a WPDA value equal to or greater than the average value at puberty, from the scientific literature, for the given breed type and age. The tentative weight evaluation is combined with the tentative age evaluation, to determine a final likelihood of conception, assuming the evaluation date is not within 60 days of the start of the breeding season (Table 9). A heifer that is older than 325 days of age is evaluated by the following: 1. WPDA less than the average for her biological type minus .3 is categorized as very low. 2. WPDA equal to the biological type average minus .2 is categorized as low. 3. WPDA equal to the biological type average minus .1 or equal to the average is categorized as average. 4. WPDA greater than the biological type average plus .1 is categorized as high.

Any heifer that is younger than 325 days of age is evaluated as follows: 1. WPDA less than the biological type average minus .3 is categorized as very low. 2. WPDA equal to the biological type average minus .2 is categorized as low. 3. WPDA equal to the biological type average minus .1 is categorized as average. 4. WPDA greater than or equal to the biological type

**Table 8. Tentative likelihood of conception based on age at the start and end of the breeding season**

Beginning age	Ending age	Likelihood of conception
Low	Low	Very Low
Low	Intermediate	Low
Low	High	Intermediate
Intermediate	Intermediate	Intermediate
Intermediate	High	Intermediate
High	High	High

**Table 9. Final likelihood of conception based on age and weight<sup>a</sup>**

Weight	Conception based on age during the breeding season <sup>b</sup>			
	Very Low	Low	Intermediate	High
Very Low	Very Poor	Very Poor	Very Poor	Very Poor
Low	Very Poor	Poor	Poor	Poor
Intermediate	Very Poor	Poor	Good	Good
High	Very Poor	Poor	Good	Excellent

<sup>a</sup>assuming evaluation date is not within 60 days of the breeding season

<sup>b</sup>values taken from the results of table 8

average is categorized as high. Heifers younger than 325 days of age do not have as strict a challenge to obtain the “EXCELLENT” ranking because they have more time to exhibit compensatory growth. It must be remembered that all predictions are made for the given breeding season and that both very poor and poor heifers will receive a “LOW” final likelihood of conception. A distinction is made between the two categories for use when combined with information on health, RTS and body condition score, which are described later.

If the date of evaluation is within 60 days of the start of the breeding season, three more options will be provided to the user. The traits to be evaluated are health, body condition score, and RTS. This information is used simply to verify the prediction already made. If a user chooses not to use or does not have this information available, the default value of none will be put in place for all three categories, leaving the prediction unchanged.

Health is simply whether a heifer is in good health or in poor health. Health of a heifer should not be evaluated earlier than 60 days before breeding since a sick animal in the growth stage will show a reduction in growth rate. Therefore an unhealthy animal will already be penalized by a decrease in growth rate. Unhealthy heifers at the time of breeding will have a reduced likelihood of conception regardless of physiological maturity. Heifers should have a health problem that has persisted for more than two weeks to be categorized in poor health. If a heifer is determined to be in good health, this will not alter the prediction already made. A heifer in poor health will suffer a reduction in predicted likelihood of conception.

Body condition scoring is seldom done in young growing heifers and its use would be most beneficial near the time of breeding. At the time of breeding, heifers should have attained a body condition score of a 5 or 6 to keep the prediction at the same level or to receive an “EXCELLENT” evaluation. A score of 4 or 7 may reduce a prediction from “EXCELLENT” to “GOOD”, whereas the remaining body condition scores will result in a “poor” evaluation. Table 10 shows the tentative effect of health and body condition score on the likelihood of conception. This information is combined with the effects of weight and age to make a final prediction, if the evaluation date is within 60 days of the start of the breeding season (Table 11).

Reproductive tract score can affect the final decision most prominently. It serves to back up the previous information but, when evaluated within 60 days of the breeding season, will ignore all other information. A RTS of 1 will lead to a prediction of a “LOW” likelihood of conception no matter what other information is present. A RTS of 2 or 3 will result in assignment of a “GOOD” likelihood of conception and a RTS of 4 or 5 will result in assignment of an “EXCELLENT” likelihood of conception, regardless of any previous information. Reproductive tract score data have the power to override all other information because RTS evaluates the actual progress of the reproductive tract of heifers at or near the time of breeding. Therefore if a heifer is a little small with slow growth, but her reproductive tract seems to be

**Table 10. Tentative likelihood of conception based on body condition score and health status**

Health	Body condition score			
	None	1 and 2	4 and 8-9	5-7
None	No change	Poor	Good	Excellent
Low	Poor	Poor	Poor	Good
High	No change	Poor	Good	Excellent

**Table 11. Final likelihood of conception based on the combination of age and weight and the combination of body condition score and health status, with RTS = None**

Age and weight <sup>b</sup>	Body condition score and health <sup>a</sup>			
	No change	Poor	Good	Excellent
Very Poor	Low	Low	Low	Low
Poor	Low	Low	Good	Good
Good	Good	Low	Good	Good
Excellent	Excellent	Low	Good	Excellent

<sup>a</sup>values taken from the results of table 10

<sup>b</sup>values taken from the results of table 9

functioning well with a RTS of 5, then she should receive an “EXCELLENT” likelihood of conception. Likewise a heifer with better than average growth and size and age but with a RTS of 1 (conducive to a non-functioning reproductive system at the time of breeding), a prediction of “LOW” likelihood of conception should be made.

### *Explanations*

The ES has the ability to describe problem areas for each heifer. If a heifer does not have any problem areas, a message stating that appears along with ADG between the time of evaluation and the start of the breeding season required for her to have an “EXCELLENT” likelihood of conception. If there is a problem with age or weight, an explanation stating the severity of the problem will appear along with the heifer’s data. The explanations are an attempt to educate or remind producers what they need to look for when selecting replacement heifers. They are also used to help gain the trust of potential users in the decision making process by providing insight into how the ES made its prediction. Appendix 3 contains a list of the explanations contained within the ES.



## Chapter 4. Validation

### *Simulation of Data for Initial Validation*

Simulated data were utilized in the first method of program validation. Data for Biological Type 2 (Table 6) were simulated using a coefficient of variation (CV) of 12% for individual weight, and a correlation (r) of .8 between repeated body weight measurements on a heifer. Random numbers (RN) were generated, with a mean of 0 and a standard deviation of 1, using Microsoft Excel's random number generator. The CV divided by 100 to express it as a proportion was multiplied by the mean body weight for heifers at a given age to obtain an estimated standard deviation (s). An initial random deviate ( $RD_1$ ) for body weight was computed using  $RN_1$  multiplied by the  $s_1$  for body weight in the age group (equation [1]).

$$RD_1 = RN_1 \times s_1 \quad [1]$$

The  $RD_1$  was then added to the mean body weight ( $MBW_1$ ) for the age group to obtain the simulated heifer's initial body weight ( $BW_1$ ) (equation [2]).

$$BW_1 = RD_1 + MBW_1 \quad [2]$$

Subsequent random deviates ( $RD_n$  with  $n > 1$ ) were computed by adding the product of the previous random number ( $RN_{n-1}$ ) and r to the product of the square root of 1 minus the coefficient of determination ( $r^2$ ) and  $RN_n$ , this whole quantity multiplied by  $s_n$  (equation [3]).

$$RD_n = [(r \times RN_{n-1}) + (\sqrt{1 - r^2} \times RN_n)] \times s_n \quad [3]$$

The new body weight ( $BW_n$ ) was computed by adding  $RD_n$  to the  $MBW_n$  for the given age (equation [4]).

$$BW_n = RD_n + MBW_n \quad [4]$$

Birth dates were also randomly assigned by generating RN and multiplying the RN by an assumed s of 15 days around an average birthdate of April 11, 1995. The start of the breeding season was set at May 20, 1996 with a length of 60 days. There were 10 simulated heifers, and body weights were simulated at fifty day intervals starting at an average age of 200 days. This

created 50 records to be evaluated by the ES and an expert in the field of beef cattle reproduction. The prediction of likelihood of conception for each simulated heifer was compared to the judgment of the expert.

### *Validation using Simulated Data*

The simulated data were entered into a prototype of HFP: Expert for a first trial (ES<sub>1</sub>) to obtain predicted outcomes. The same data were given to a beef cattle reproduction expert who was asked to predict a likelihood of conception category for each heifer. The expert's predictions and those of ES<sub>1</sub> were compared and then discussed by the expert and the knowledge engineer. Potential problem areas with the KB of ES<sub>1</sub> were identified and the necessary changes were made to the ES. The KB was made more lenient in evaluating WPDA and assigning likelihood of conception for younger heifers. The changes were made because younger heifers have the ability for compensatory growth over time. A second trial now by HFP: Expert (ES<sub>2</sub>) containing the finalized KB was conducted and results were again compared to those of the expert. The predicted values for both trials and from the expert are listed in Table 12. The dates in the first column of Table 12 are the simulated evaluation dates HFP: Expert used to determine the various ages for each simulated heifer.

Tables 13 and 14 show the correspondence between the expert and the predictions of ES<sub>1</sub> and ES<sub>2</sub> respectively. The downward sloping diagonal lists the number of agreements for the "LOW", "GOOD" and "EXCELLENT" categories between the expert and the ES<sub>x</sub> trials. The number of disagreements are listed both above and below the diagonals. The area above the diagonal shows where the ES assigned a higher category than the expert, and the area below the diagonal shows where the ES assigned a lower category than the expert. Trial ES<sub>1</sub> yielded a 40% agreement between the ES and the expert, whereas trial ES<sub>2</sub> increased to 72% agreement between the ES and the expert. Trial ES<sub>1</sub> overestimated the expert 24% of the time, which was decreased to 2% overestimation in trail ES<sub>2</sub>. Underestimation of the expert declined moderately between trial ES<sub>1</sub> and ES<sub>2</sub>, yielding disagreements of 36% and 26% respectively. It should also be noted that the ES never categorized a heifer as "LOW" that was categorized as "EXCELLENT" by the expert, or vice-versa.

### *Historical Data*

Historical data from the Shenandoah Valley Agricultural Experiment Station of Virginia Polytechnic Institute and State University, Steeles Tavern, VA (STAV) were also used to validate the ES. The cattle at STAV were Hereford-Angus crossbreds and were used to test HFP: Expert Biological Type 2. The crossbreds were produced by artificially inseminating

**Table 12. Predicted likelihood of conception categories from simulated data by trial ES<sub>1</sub>, trial ES<sub>2</sub>, and the expert**

		Heifer I.D.									
		One	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten
<u>October 28, 1995</u>											
ES <sub>1</sub>		Good	Good	Low	Good	Good	Good	Good	Excellent	Good	Excellent
Expert		Excellent	Excellent	Good	Excellent	Excellent	Excellent	Good	Excellent	Good	Excellent
ES <sub>2</sub>		Excellent	Good	Low	Good	Excellent	Excellent	Low	Excellent	Good	Excellent
<u>December 17, 1995</u>											
ES <sub>1</sub>		Good	Good	Low	Good	Good	Good	Good	Excellent	Good	Good
Expert		Excellent	Excellent	Good	Excellent	Excellent	Excellent	Good	Excellent	Good	Excellent
ES <sub>2</sub>		Excellent	Good	Low	Good	Excellent	Excellent	Low	Excellent	Good	Good
<u>February 5, 1996</u>											
ES <sub>1</sub>		Good	Good	Low	Good	Good	Good	Good	Excellent	Good	Excellent
Expert		Excellent	Excellent	Low	Excellent	Excellent	Excellent	Good	Excellent	Good	Excellent
ES <sub>2</sub>		Excellent	Good	Low	Good	Excellent	Excellent	Low	Excellent	Good	Excellent
<u>March 26, 1996</u>											
ES <sub>1</sub>		Excellent	Excellent	Good	Good	Excellent	Excellent	Excellent	Excellent	Good	Excellent
Expert		Excellent	Good	Low	Good	Excellent	Good	Excellent	Excellent	Low	Good
ES <sub>2</sub>		Excellent	Good	Low	Good	Excellent	Good	Good	Excellent	Low	Good
<u>May 15, 1996</u>											
ES <sub>1</sub>		Good	Excellent	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Low	Excellent
Expert		Low	Good	Low	Good	Good	Good	Good	Excellent	Low	Excellent
ES <sub>2</sub>		Good	Good	Low	Good	Good	Good	Good	Excellent	Low	Excellent

**Table 13. Correspondence between predictions of trial ES<sub>1</sub> and the expert**

Expert	ES <sub>1</sub>		
	Low	Good	Excellent
Low	2	4	0
Good	2	7	8
Excellent	0	16	11

**Table 14. Correspondence between predictions of trial ES<sub>2</sub> and the expert**

Expert	ES <sub>2</sub>		
	Low	Good	Excellent
Low	5	1	0
Good	5	12	0
Excellent	0	8	19

Angus cows of two different age groups (1976 and 1982 birth years) to 49 Polled Hereford bulls. The cows were bred to calve in the spring and wean calves in the fall. Pasture consisted mainly of fescue throughout the year. During the winter fescue hay, corn silage, and(or) whole shelled corn were given as supplemental feed. The breeding season began in May and lasted for an average of 64 days. Estrus was synchronized before the breeding season using norgestomet implants and(or) melengestrol acetate (MGA) was added in the feed. Marht et al. (1990) has published a more complete description of the matings. Three groups were used, those being 1985, 1986, and 1987 born heifers with 49, 49, and 35 individuals respectively. All three groups were bred to Simmental bulls in an experiment relating calving ease to birth weight which is explained in detail by Nugent and Notter (1991) and Nugent et al. (1991).

Each birth year group was evaluated twice to furnish data to test the ES. The first evaluation for each group was conducted in late November to early December, a few months after weaning. The second evaluation was in late April to early May for the 1985 and 1986 heifers and early February for the 1987 heifers. Records were first evaluated using ES<sub>1</sub>, then again using ES<sub>2</sub>, to determine whether the modifications to the program had increased its accuracy. Table 15 summarizes observed pregnancy rates with confidence limits for heifers in “LOW”, “GOOD”, and “EXCELLENT” categories as assigned from post-weaning and pre-breeding evaluation by ES<sub>1</sub> and ES<sub>2</sub>. All the confidence limits overlapped except for the “LOW” and “GOOD” heifers in the post-weaning evaluations by ES<sub>2</sub>. This suggests a significantly lower pregnancy rate for the “LOW” group as compared to the “GOOD” group. Also the range in observed pregnancy rates between groups was greater from ES<sub>2</sub> than from ES<sub>1</sub> predictions for both post-weaning and pre-breeding evaluations. Therefore the changes made in the KB did moderately increase HFP: Expert’s accuracy of predictions. Because ES<sub>1</sub> was a prototype, it was tested here only to verify if changes in the KB enhanced HFP: Expert’s prediction ability, which it did in some cases. The remaining validation of HFP: Expert uses only ES<sub>2</sub> for prediction.

The logistic regression procedure of SAS (SAS, 1990) was used to test for differences in pregnancy rate between the “LOW” heifers and the “GOOD” and “EXCELLENT” heifers combined. For post-weaning and pre-breeding evaluations, respectively, pregnancy rates of “LOW” heifers were lower than pregnancy rates of combined “GOOD” and “EXCELLENT” heifers at  $P = .03$  and  $P = .06$ . Therefore heifers predicted by HFP: Expert to have a “LOW” likelihood of conception did have lower observed pregnancy rates than heifers categorized as “GOOD” or “EXCELLENT.”

Tables 16 and 17 show the post-weaning and pre-breeding results of ES<sub>2</sub> evaluations respectively. The tables show the total number of heifers that were assigned to the “LOW”, “GOOD”, and “EXCELLENT” categories per birth year group and evaluation. They also show the breakdown for each category of heifers that did not calve, that calved successfully, and that

**Table 15. Observed pregnancy rates, with confidence ranges at  $\alpha=.1$ , for heifers classified post-weaning and pre-breeding by ES<sub>1</sub> and ES<sub>2</sub>**

Prediction	Post-weaning evaluation observed pregnancy rates (%)		Pre-breeding evaluation observed pregnancy rates (%)		Expected pregnancy rates (%)
	ES <sub>1</sub>	ES <sub>2</sub>	ES <sub>1</sub>	ES <sub>2</sub>	
Low	80.6 ± 6.6 <sup>a</sup>	78.6 ± 6.8 <sup>a</sup>	80.5 ± 5.2 <sup>a</sup>	78.9 ± 8.0 <sup>a</sup>	50
Good	89.5 ± 11.6 <sup>a</sup>	100.0 ± 0 <sup>b</sup>	84.2 ± 6.3 <sup>a</sup>	86.5 ± 9.3 <sup>a</sup>	51-80
Excellent	87.5 ± 7.7 <sup>a</sup>	87.5 ± 13.6 <sup>a,b</sup>	86.5 ± 8.4 <sup>a</sup>	88.0 ± 10.7 <sup>a</sup>	>80

<sup>a,b</sup>different superscript denotes that confidence limits do not overlap

**Table 16. STAV heifers as categorized by HFP:  
Expert for post-weaning evaluation**

Birth year	Low	Good	Excellent
Total			
1985	37	8	4
1986	39	8	2
1987	22	3	10
Calved successfully			
1985	21	5	4
1986	24	7	2
1987	8	2	5
Lost calf after parturition			
1985	12	3	0
1986	5	1	0
1987	7	1	3
Did not calve			
1985	4	0	0
1986	10	0	0
1987	7	0	2



**Table 17. STAV heifers as categorized by HFP:  
Expert for pre-breeding evaluation**

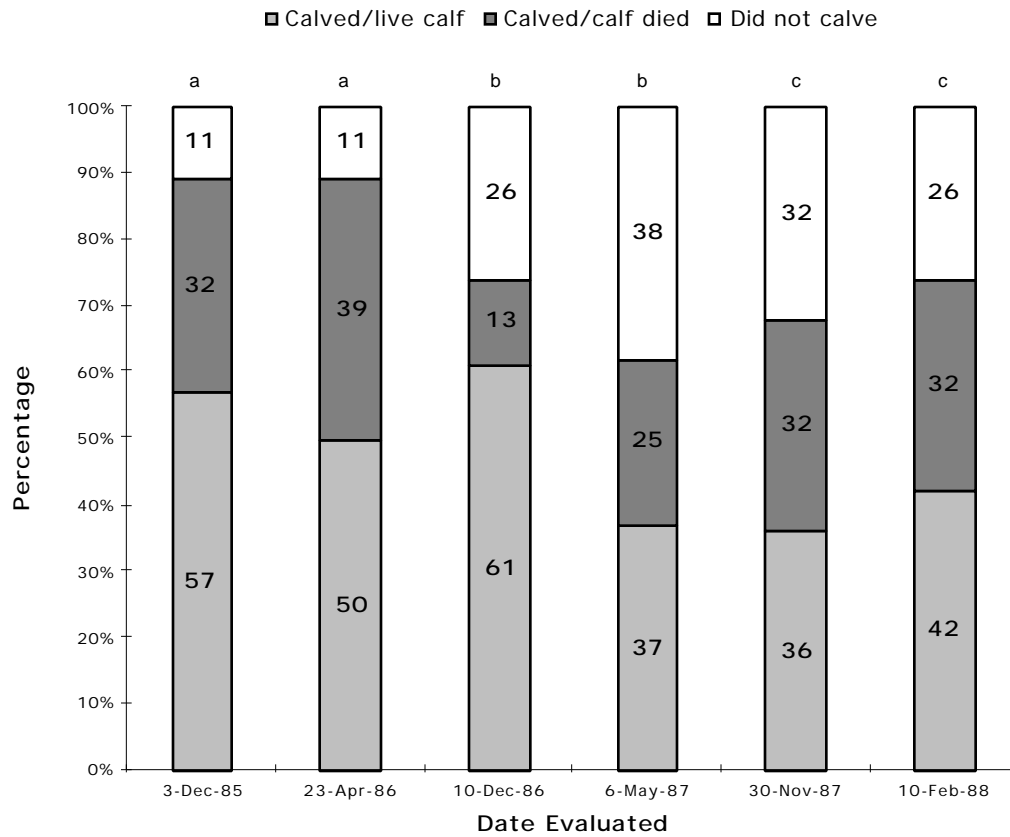
Birth year	Low	Good	Excellent
<b>Total</b>			
1985	36	11	2
1986	16	17	16
1987	19	9	7
<b>Calved successfully</b>			
1985	18	10	2
1986	6	12	15
1987	8	3	4
<b>Lost calf after parturition</b>			
1985	14	1	0
1986	4	2	0
1987	6	4	1
<b>Did not calve</b>			
1985	4	0	0
1986	6	3	1
1987	5	2	2

calved but lost calves after parturition. The expected pregnancy rates were 50% or less, 50 to 80%, and greater than 80% for the “LOW”, “GOOD”, and “EXCELLENT” categories respectively. The expected successful calving rates were 40% or less, 40 to 70%, and greater than 70% for the “LOW”, “GOOD”, and “EXCELLENT” categories respectively.

For post-weaning and pre-breeding evaluations and for each birth year group, Figure 1 shows the percentage breakdown of reproductive outcomes for heifers predicted by HFP: Expert to have a “LOW” likelihood of conception. Overall pregnancy rate of heifers falling in the “LOW” category from post-weaning evaluation was  $77/98 = 78.6\%$ , considerably higher than the expectation of 50% or less. Of 71 heifers scored as “LOW” by the pre-breeding evaluation, 56 or 78.8% calved. The expected pregnancy rate of 50% or less was exceeded by all the “LOW” groups. The higher than expected pregnancy rate may have been caused by the high energy and protein diet the heifers were being fed as the breeding season approached. This was recommended by the ES for many of the “LOW” categorized heifers. Figure 2 shows a similar breakdown for heifers categorized as having a “GOOD” likelihood of conception. The observed pregnancy rate greatly exceeded the expected rate of 75% in most cases. In fact, all of the heifers falling into the “GOOD” category at the post-weaning evaluations became pregnant, whereas overall pregnancy rate of the 37 “GOOD” heifers from the pre-breeding evaluation was 86.4%. These “GOOD” heifers tended to have lower proportions that did not produce a calf or who lost calves than the heifers categorized as “LOW.” Figure 3 shows the percentage breakdown of heifers in the “EXCELLENT” category. The pregnancy rate fell short of the expected for the 1987 born heifers for the pre-breeding evaluation in February.

The expected successful calving rate of less than 40% was met by 2 of the 6 evaluations for the “LOW” groups. This was because the heifers in the “LOW” group tended to contain most of the heifers that failed to calve and to have a higher percentage which lost calves as compared to the “GOOD” and “EXCELLENT” categories. The high percentage of lost calves may be due to the low body weights of the heifers in the “LOW” category which may have caused an increased incidence of dystocia. For heifers categorized as “GOOD” the percentage of successful calvings tended to be within the expected range. It only exceeded heifers in the “EXCELLENT” category once and only fell below “LOW” categorized heifers once. The expected successful calving rate for “EXCELLENT” categorized heifers was met in all but the 1987 born heifers where the successful calving rate for the “EXCELLENT” heifers barely reached the target for “GOOD” heifers.

The 1986 and 1987 born heifers were evaluated again by the ES for the pre-breeding dates of April 23, 1986 and May 6, 1987 respectively, this time adding body condition scores to the evaluation. Only these two trials were used since they were the only evaluation dates within 60 days of their respective breeding seasons. Tables 18 and 19 shows the results of the ES

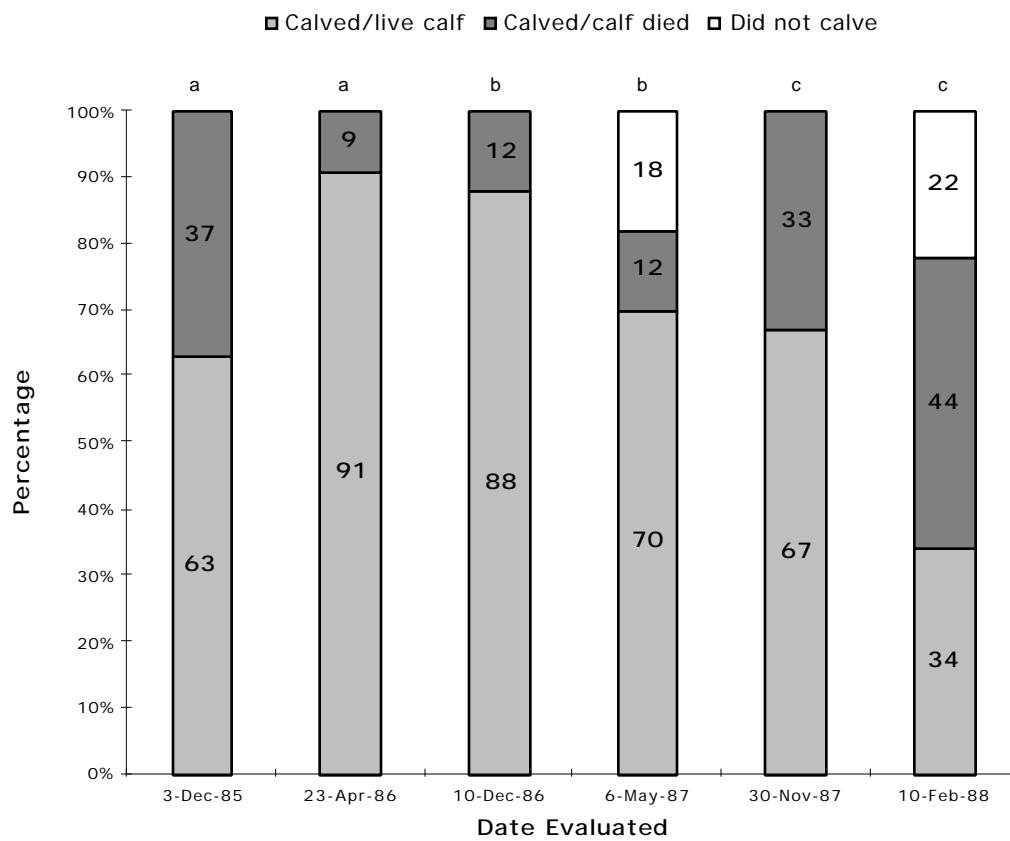


**Figure 1. Pregnancy rates for STAV heifers categorized as “LOW” likelihood of conception**

<sup>a</sup>1985 born heifers

<sup>b</sup>1986 born heifers

<sup>c</sup>1987 born heifers

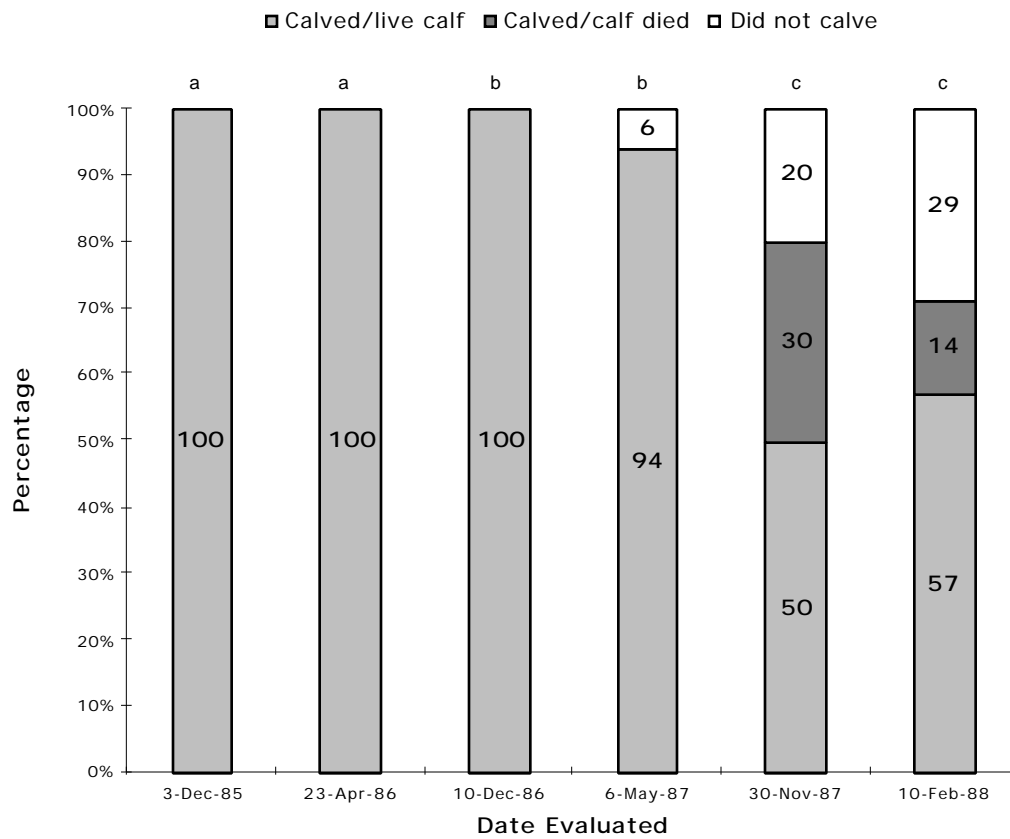


**Figure 2. Pregnancy rates for STAV heifers categorized as “GOOD” likelihood of conception**

<sup>a</sup> 1985 born heifers

<sup>b</sup> 1986 born heifers

<sup>c</sup> 1987 born heifers



**Figure 3. Pregnancy rates for STAV heifers categorized as “EXCELLENT” likelihood of conception**

<sup>a</sup> 1985 born heifers

<sup>b</sup> 1986 born heifers

<sup>c</sup> 1987 born heifers

**Table 18. Re-evaluation of 1985 born heifers with inclusion of body condition scores**

1985 heifers	Low	Good	Excellent
<b>Total</b>			
Initial evaluation	36	11	2
Evaluation with body condition scores	31	16	2
<b>Calved successfully</b>			
Initial evaluation	18	10	2
Evaluation with body condition scores	15	13	2
<b>Lost calf after parturition</b>			
Initial evaluation	14	1	0
Evaluation with body condition scores	13	2	0
<b>Did not calve</b>			
Initial evaluation	4	0	0
Evaluation with body condition scores	3	1	0

**Table 19. Re-evaluation of 1986 born heifers with inclusion of body condition scores**

1986 heifers	Low	Good	Excellent
Total			
Initial evaluation	16	17	16
Evaluation with body condition scores	5	28	16
Calved successfully			
Initial evaluation	6	12	15
Evaluation with body condition scores	0	18	15
Lost calf after parturition			
Initial evaluation	4	2	0
Evaluation with body condition scores	3	3	0
Did not calve			
Initial evaluation	6	3	1
Evaluation with body condition scores	2	7	1

evaluation for 1985 and 1986 heifers respectively. Body condition scores were at a desirable level which caused a number of heifers to be shifted from the “LOW” to “GOOD” category.

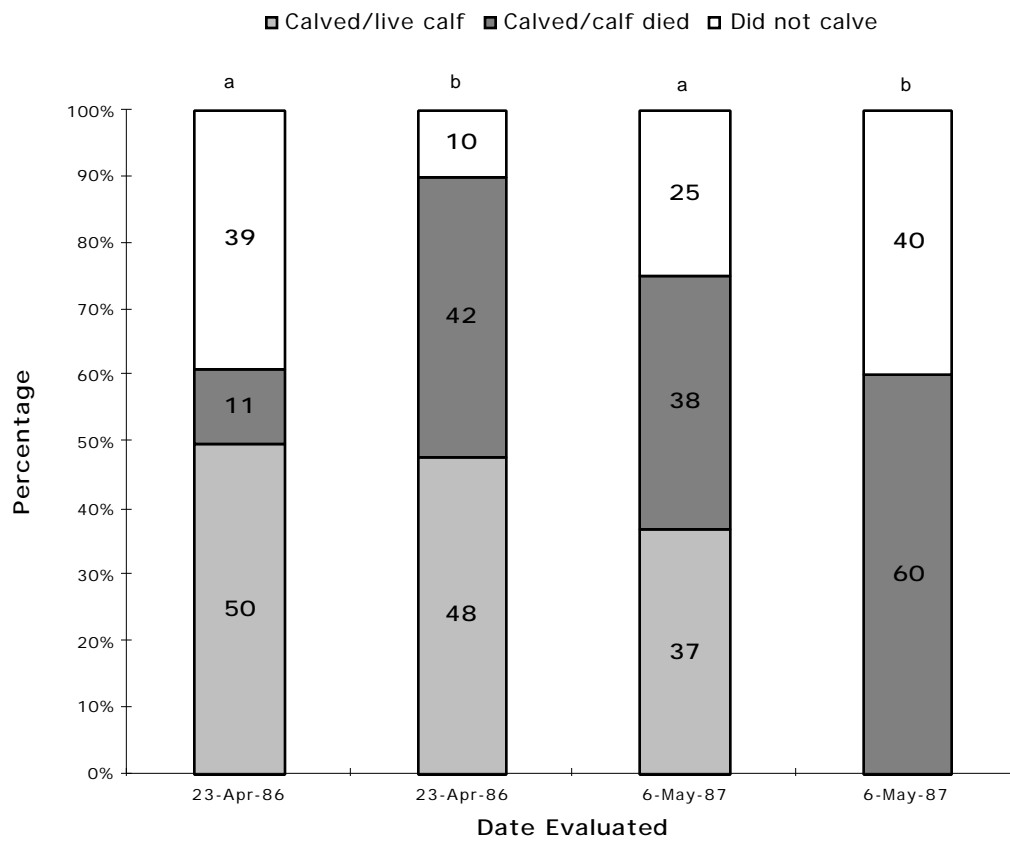
Figure 4 shows the comparison in the percentage breakdown of reproductive outcomes for the initial and subsequent evaluation for the two “LOW” groups. The 1985 born heifers showed a 31% increase in the percentage of heifers bearing but losing a calf and a 29% decrease in the percentage of heifers that did not calve. The 1986 born heifers saw a large shift from heifers categorized as “LOW” to “GOOD”. This reduced percentage of successful calving from 37% to 0% and increased the percentage of lost calves from 38% to 60%. This was due to the shift of moderately low body weight heifers that did have a successful pregnancy from the “LOW” category to the “GOOD” category when body condition score of a heifer was desirable. Figures 5 and 6 show the comparison in percentage breakdown of the initial and subsequent evaluation for “GOOD” and “EXCELLENT” categorized heifers. In both groups very little change was observed.

A chi-square test was conducted to compare the expected and observed number of pregnant vs. not pregnant heifers, as well as percentages of successful and unsuccessful calvings for the “LOW”, “GOOD”, and “EXCELLENT” category heifers. The expected values were computed by multiplying the sample size by the expected pregnancy rate of 50% for the “LOW” categories, multiplying the sample size by the expected pregnancy rate of 75% for the “GOOD” categories, and multiplying the sample size by the expected pregnancy rate of 85% for the “EXCELLENT” categories. The “LOW” and “GOOD” categorized heifers were found to have a significantly higher observed pregnancy rate than expected. There was no statistically significant difference between the expected vs. observed pregnancy rates for the “EXCELLENT” categorized heifers. The chi-square values for the “LOW”, “GOOD”, and “EXCELLENT” categories were 30.3, 5.1, and .1 respectively.

Substitution of the 1985 and 1986 born heifers’ initial pre-breeding evaluation with the pre-breeding evaluation containing body condition for chi-square analysis did have an impact on HFP: Expert’s prediction ability. The “GOOD” categorized heifers changed from having a significantly different observed vs. expected pregnancy rate to not having a significantly different observed vs. expected pregnancy rate ( $\chi^2=2.8$ ). Both the “LOW” and “EXCELLENT” categories remained the same with chi-square values of 29.7 and .1 respectively.

Data from heifers categorized as low were examined to determine whether those which did conceive differed systematically from those which did not for any recorded traits. “LOW” heifers that did conceive and those which did not deviated on average -.14 and -.15 kg from the required WPDA. The comparison also found that the “LOW” heifers that did not conceive were on average 13 d younger than the “LOW” heifers that did. This difference, however, was not statistically significant. Therefore there was no consistent pattern of misclassification.

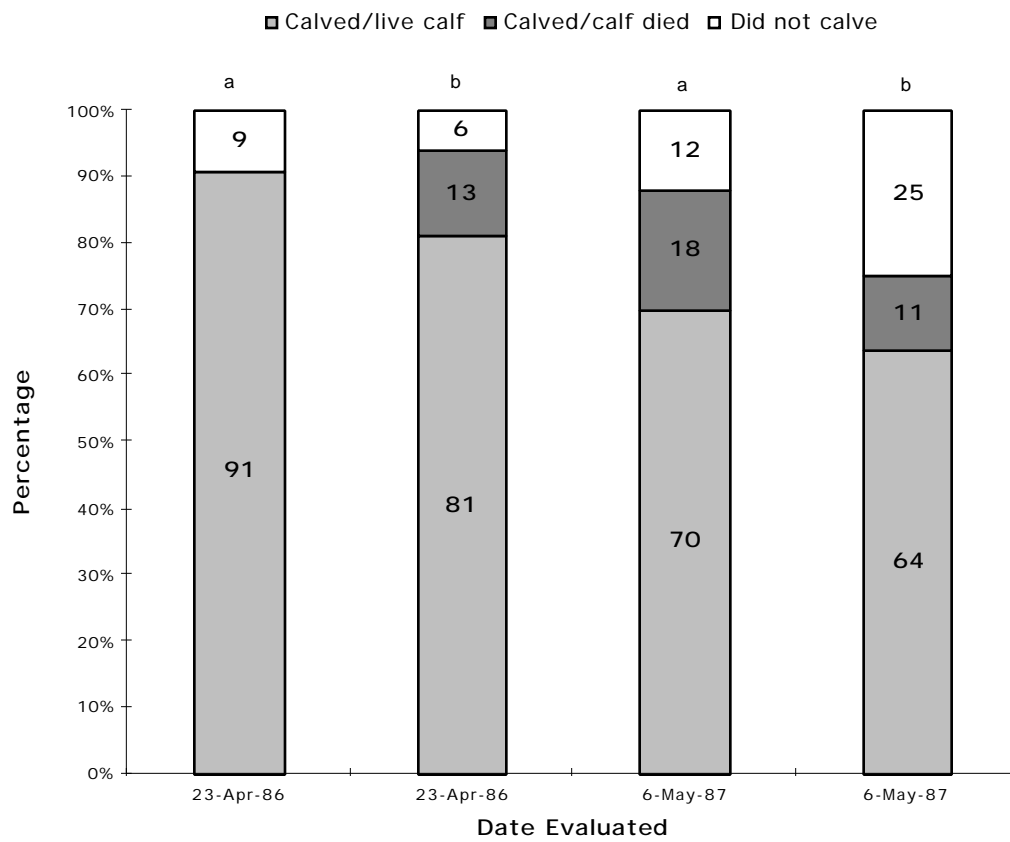




**Figure 4. Comparison of percentage breakdown of pregnancy between initial and subsequent evaluation for 1985 and 1986 born heifers categorized as “LOW”**

<sup>a</sup>Initial trial without body condition scores

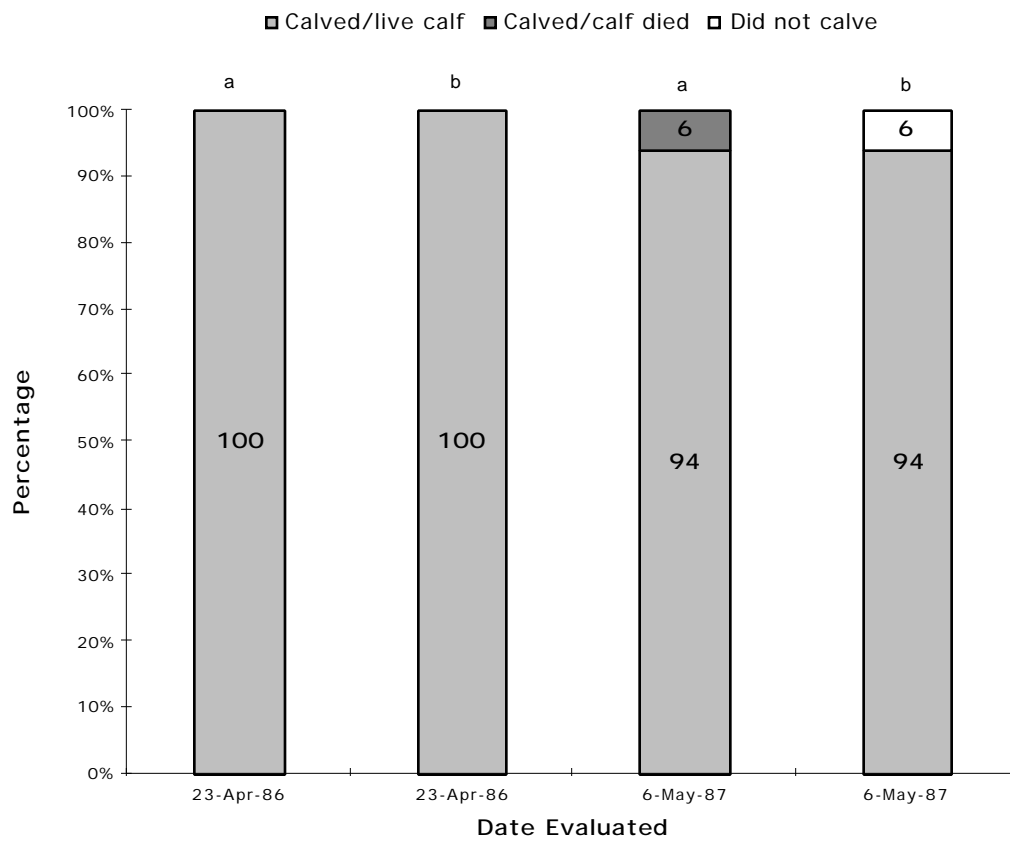
<sup>b</sup>Subsequent trial with body condition scores



**Figure 5. Comparison of percentage breakdown of pregnancy between initial and subsequent evaluation for 1985 and 1986 born heifers categorized as “GOOD”**

<sup>a</sup>Initial trial without body condition scores

<sup>b</sup>Subsequent trial with body condition scores



**Figure 6. Comparison of percentage breakdown of pregnancy between initial and subsequent evaluation for 1985 and 1986 born heifers categorized as “EXCELLENT”**

<sup>a</sup>Initial trial without body condition scores  
<sup>b</sup>Subsequent trial with body condition scores

The expected values for successful calving rate were computed by multiplying the sample size by 40%, 64%, and 77% for the “LOW”, “GOOD”, and “EXCELLENT” categories respectively. The successful calving rate percentages were computed by multiplying the expected pregnancy rate by .80, .85, and .90 for the “LOW”, “GOOD”, and “EXCELLENT” categories respectively. This calculation was performed to account for the increase in the incidence of dystocia, due to the nature of the study that was being conducted with the heifers. It was assumed from the results of the STAV data that only 80% of the calves born from heifers in the “LOW” category would survive, with 85% survival for the “GOOD” and 90% survival for calves from heifers in the “EXCELLENT” category. None of the categories showed a statistically significant difference for observed vs. expected successful calving rates for either evaluation, but the “LOW” category in the initial evaluation did approach statistical difference. The respective chi-square values for “LOW”, “GOOD”, and “EXCELLENT” categories were 3.61, .40, and .01 for the initial pre-breeding evaluation without body condition scores and 2.89, .09, and .01 for the subsequent pre-breeding evaluation with body condition scores.

## Chapter 5. Conclusions

### *Program Development and Validation Problems*

Finding a mechanism to categorize breeds into biological types was a difficult task. After many hours of research the MARC data on biological types were chosen because they gave the most comprehensive and practical representation of information. To not hinder the versatility of the ES, a method allowing different age heifers at different weights to be evaluated by the ES needed to be implemented. The ES was developed to allow evaluation to occur at anytime between 200 and 550 days of age, rather than at discrete times such as 200, 300, and 400 days-of-age. The continuous evaluation has two advantages over the discrete categories: 1. It allows producers the option to select their own evaluation age. 2. A herd of cattle very seldom all have the same age; thus an animal's weight can be more accurately evaluated with the corresponding age. Body condition score enhanced HFP: Expert's prediction ability, but because BCS is a subjective measurement a more objective measurement of evaluating condition score may enhance the ability of the ES to predict likelihood of conception.

A limitation to the program is that it does not have the ability to access a database for information, which would allow for more efficient data entry and analysis. All information is entered into the ES via user interface screens, mostly through point and click mouse commands with a limited need for keystrokes. It was also found during the validation process that only a limited number of heifers could be evaluated during any given session. Although the ES allows an unlimited number of heifers to be entered into the ES for evaluation, it is recommended that no more than 25 heifers be evaluated at any given session. This is because a larger number caused the program to stop responding to a 75 MHz Pentium computer with 16 megabytes of RAM. If this ES is found to be inefficient to enter and/or process data, a more efficient version of HFP: Expert can be developed either by restructuring the current ES or using the KB as a model to

design a new ES. Like other small computer programs, continued testing and refinement can improve HFP: Expert's knowledge base and usability.

Validation was a problem since reproductive expertise for all breeds was limited. Therefore prediction comparisons with an expert were limited to biological type 2 cattle. Historical data with all the necessary information were difficult to find as well. Since Virginia beef cattle are primarily Biological Type 2 and because these were the most accessible records, validation by historical data was limited to Biological Type 2 cattle. Information from purebred farms was of limited value since selection and management techniques caused most of the cattle to be categorized as "EXCELLENT" with a limited number of "GOOD", although purebreds did furnish the most accurate and complete records. A field trial is currently being conducted on a group of Biological Type 2 heifers with promising preliminary predictions by the ES. Again only Biological Type 2 cattle are being tested. More tests need to be conducted on all of the biological types to ensure that the expert system's knowledge base works across all biological types. HFP: Expert should not be used for other breeds until further evaluation is completed.

## Implications

Failure of heifers to conceive can result in a decline in profitability for beef cattle producers. HFP: Expert is an attempt to identify a heifer's likelihood of conception. The results have shown an ability to identify heifers with an "EXCELLENT" and "GOOD" likelihood of conception. Heifers with a "LOW" likelihood of conception are not identified by the expert system as well as the above two categories. But HFP: Expert was able to identify the "LOW" group as having a lower pregnancy rate than the combined "GOOD" and "EXCELLENT" group. Possible reasons why the "LOW" heifers had a higher than expected pregnancy rate may have been due to the high energy diet being fed prior to the breeding season to increase growth rate and to the use of norgestomet implants and MGA feed additive to synchronize estrus. Both estrus synchronizing compounds are known to artificially induce estrus in non-pubertal heifers, which may have induced puberty in the misclassified "LOW" heifers that were on average 13 d older than the "LOW" heifers that did not become pregnant. Evaluations closer to the breeding season combined with body condition scores enhanced the expert system's ability to make accurate predictions. However the expert system did exhibit the ability to accurately identify heifers in each category for successful calving rate for heifers at various evaluation ages.

More intensive field tests need to be conducted for all biological types of cattle before the program is distributed to producers. It is recommended that field tests be conducted as a team effort by extension agents and producers to ensure accurate results. Once field testing is complete and the expert system is shown to accurately predict the likelihood of conception, it should be distributed to producers and used without the aid of an extension agent. This study has shown that the likelihood of conception can be predicted using ES technology with varying degrees of accuracy for the different categories. HFP: Expert should be useful to beef cattle producers once a thorough field testing validation has been conducted. HFP: Expert should not be used to make selection decisions solely on the prediction it provides, but should be used as a

decision aid. The prediction should be combined with other information like EPDs, economic values, visual appraisal, etc. and then final selection decisions can be made.



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## Appendix 1. Knowledge Base

### *Date Rules*

```
/*  
**** RULE: Date1  
*****/  
MakeRule( Date1, [x|Heifers],  
x:Month #= January,  
x:DaysRemain = 365 - x:Day );
```

```
/*  
**** RULE: Date2  
*****/  
MakeRule( Date2, [x|Heifers],  
x:Month #= February,  
x:DaysRemain = 334 - x:Day );
```

```
/*  
**** RULE: Date3  
*****/  
MakeRule( Date3, [x|Heifers],  
x:Month #= March,  
x:DaysRemain = 306 - x:Day );
```

```

/*****
**** RULE: Date4
*****/
MakeRule( Date4, [x|Heifers],
  x:Month #= April,
  x:DaysRemain = 275 - x:Day );

/*****
**** RULE: Date5
*****/
MakeRule( Date5, [x|Heifers],
  x:Month #= May,
  x:DaysRemain = 245 - x:Day );

/*****
**** RULE: Date6
*****/
MakeRule( Date6, [x|Heifers],
  x:Month #= June,
  x:DaysRemain = 214 - x:Day );

/*****
**** RULE: Date7
*****/
MakeRule( Date7, [x|Heifers],
  x:Month #= July,
  x:DaysRemain = 184 - x:Day );

/*****
**** RULE: Date8
*****/
MakeRule( Date8, [x|Heifers],
  x:Month #= August,
  x:DaysRemain = 153 - x:Day );

```

```

/*****
**** RULE: Date9
*****/
MakeRule( Date9, [x|Heifers],
  x:Month #= September,
  x:DaysRemain = 122 - x:Day );

/*****
**** RULE: Date10
*****/
MakeRule( Date10, [x|Heifers],
  x:Month #= October,
  x:DaysRemain = 92 - x:Day );

/*****
**** RULE: Date11
*****/
MakeRule( Date11, [x|Heifers],
  x:Month #= November,
  x:DaysRemain = 61 - x:Day );

/*****
**** RULE: Date12
*****/
MakeRule( Date12, [x|Heifers],
  x:Month #= December,
  x:DaysRemain = 31 - x:Day );

/*****
**** RULE: BSDate1
*****/
MakeRule( BSDate1, [x|Dates],
  x:Month #= January,
  x:DaysPast = x:Day );

```



```

/*****
**** RULE: BSDate2
*****/
MakeRule( BSDate2, [x|Dates],
  x:Month #= February,
  x:DaysPast = 31 + x:Day );

/*****
**** RULE: BSDate3
*****/
MakeRule( BSDate3, [x|Dates],
  x:Month #= March,
  x:DaysPast = 59 + x:Day );

/*****
**** RULE: BSDate4
*****/
MakeRule( BSDate4, [x|Dates],
  x:Month #= April,
  x:DaysPast = 90 + x:Day );

/*****
**** RULE: BSDate5
*****/
MakeRule( BSDate5, [x|Dates],
  x:Month #= May,
  x:DaysPast = 120 + x:Day );

/*****
**** RULE: BSDate6
*****/
MakeRule( BSDate6, [x|Dates],
  x:Month #= June,
  x:DaysPast = 151 + x:Day );

```

```

/*****
**** RULE: BSDate7
*****/
MakeRule( BSDate7, [x|Dates],
  x:Month #= July,
  x:DaysPast = 181 + x:Day );

/*****
**** RULE: BSDate8
*****/
MakeRule( BSDate8, [x|Dates],
  x:Month #= August,
  x:DaysPast = 212 + x:Day );

/*****
**** RULE: BSDate9
*****/
MakeRule( BSDate9, [x|Dates],
  x:Month #= September,
  x:DaysPast = 243 + x:Day );

/*****
**** RULE: BSDate10
*****/
MakeRule( BSDate10, [x|Dates],
  x:Month #= October,
  x:DaysPast = 273 + x:Day );

/*****
**** RULE: BSDate11
*****/
MakeRule( BSDate11, [x|Dates],
  x:Month #= November,
  x:DaysPast = 304 + x:Day );

```

```

/*****
**** RULE: BSDate12
*****/
MakeRule( BSDate12, [x|Dates],
  x:Month #= December,
  x:DaysPast = 334 + x:Day );

```

### *Biological Type Rules*

```

/*****
**** RULE: biotype1
*****/
MakeRule( biotype1, [x|Heifers],
  {
(x:Breed #= Longhorn) Or (x:Breed #= Small_Framed_Breeds);
  },
  {
x:BioType = Type1;
x:TargetWt = Type1:pweight;
  } );

```

```

/*****
**** RULE: biotype2
*****/
MakeRule( biotype2, [x|Heifers],
  {
(x:Breed #= Angus) Or (x:Breed #= Hereford) Or (x:Breed #= Red_Poll)
  Or (x:Breed #= Devon) Or (x:Breed #= Shorthorn) Or (x:Breed #= Galloway)
  Or (x:Breed #= South_Devon) Or (x:Breed #= Tarentaise)
  Or (x:Breed #= Pinzgauer) Or (x:Breed #= British_Breeds)
  Or (x:Breed #= British_Like_Breeds);
  },
  {
x:BioType = Type2;
x:TargetWt = Type2:pweight;
  } );

```

```

/*****
**** RULE: biotype3
*****/
MakeRule( biotype3, [x|Heifers],
{
(x:Breed #= Brangus) Or (x:Breed #= Santa_Gertrudis) Or (x:Breed #= Sahiwal)
  Or (x:Breed #= Bos_Indicus) Or (x:Breed #= Bos_Indicus_Influenced)
  Or (x:Breed #= Brahman) Or (x:Breed #= Nellore);
},
{
x:BioType = Type3;
x:TargetWt = Type3:pweight;
} );

/*****
**** RULE: biotype4
*****/
MakeRule( biotype4, [x|Heifers],
{
(x:Breed #= Braunvieh) Or (x:Breed #= Brown_Swiss) Or (x:Breed #= Maine_Anjou)
  Or (x:Breed #= Salers) Or (x:Breed #= Simmental) Or (x:Breed #= Gelbvieh)
  Or (x:Breed #= Euro_Cont_Dual_Purpose);
},
{
x:BioType = Type4;
x:TargetWt = Type4:pweight;
} );

```

```

/*****
**** RULE: biotype5
*****/
MakeRule( biotype5, [x|Heifers],
{
(x:Breed #= Limousin) Or (x:Breed #= Charolais) Or (x:Breed #= Piedmontese)
Or (x:Breed #= Chianina) Or (x:Breed #= Euro_Cont_Draft);
},
{
x:BioType = Type5;
x:TargetWt = Type5:pweight;
});

```

### *Puberty Rules*

```

/*****
**** RULE: puberty1
*****/
MakeRule( puberty1, [x|Heifers],
{
x:BioType #= Type1;
},
x:PubertyPar = Type1:puberty );

/*****
**** RULE: puberty2
*****/
MakeRule( puberty2, [x|Heifers],
{
x:BioType #= Type2;
},
x:PubertyPar = Type2:puberty );

```

```

/*****
**** RULE: puberty3
*****/
MakeRule( puberty3, [x|Heifers],
{
x:BioType #= Type3;
},
x:PubertyPar = Type3:puberty );

/*****
**** RULE: puberty4
*****/
MakeRule( puberty4, [x|Heifers],
{
x:BioType #= Type4;
},
x:PubertyPar = Type4:puberty );

/*****
**** RULE: puberty5
*****/
MakeRule( puberty5, [x|Heifers],
{
x:BioType #= Type5;
},
x:PubertyPar = Type5:puberty );

```

## *Growth Rules*

```

/*****
**** RULE: aWPDA
*****/
MakeRule( aWPDA, [x|Heifers],
x:Age > 0,
x:WPDA = x:Weight / x:Age );

```

```

/*****
**** RULE: WPDA1.1
*****/
MakeRule( WPDA1.1, [x|Heifers],
{
(x:BioType #= Type1 And x:Age >= 100 And x:Age < 215 )
Or ( x:BioType #= Type2 And x:Age >= 245 And x:Age < 295 )
Or ( x:BioType #= Type3 And x:Age >= 255 And x:Age < 295 )
Or ( x:BioType #= Type4 And x:Age >= 275 And x:Age < 325 )
Or ( x:BioType #= Type5 And x:Age >= 265 And x:Age < 305 );
},
x:WPDAPar = Parameters:wpda4 );

/*****
**** RULE: WPDA1.2
*****/
MakeRule( WPDA1.2, [x|Heifers],
{
(x:BioType #= Type1 And x:Age >= 215 And x:Age < 255 )
Or ( x:BioType #= Type2 And x:Age >= 295 And x:Age < 355 )
Or ( x:BioType #= Type3 And x:Age >= 295 And x:Age < 355 )
Or ( x:BioType #= Type4 And x:Age >= 325 And x:Age < 395 )
Or ( x:BioType #= Type5 And x:Age >= 305 And x:Age < 365 );
},
x:WPDAPar = Parameters:wpda5 );

/*****
**** RULE: WPDA1.3
*****/
MakeRule( WPDA1.3, [x|Heifers],
{
(x:BioType #= Type1 And x:Age >= 255 And x:Age < 295 )
Or ( x:BioType #= Type2 And x:Age >= 355 And x:Age < 415 )
Or ( x:BioType #= Type3 And x:Age >= 355 And x:Age < 415 )
Or ( x:BioType #= Type4 And x:Age >= 395 And x:Age < 435 )
Or ( x:BioType #= Type5 And x:Age >= 365 And x:Age < 425 );
},
x:WPDAPar = Parameters:wpda6 );

```

```

/*****
**** RULE: WPDA1.4
*****/
MakeRule( WPDA1.4, [x|Heifers],
{
(x:BioType #= Type1 And x:Age >= 295 And x:Age < 345 )
Or ( x:BioType #= Type2 And x:Age >= 415 And x:Age < 465 )
Or ( x:BioType #= Type3 And x:Age >= 415 And x:Age < 465 )
Or ( x:BioType #= Type4 And x:Age >= 435 And x:Age < 485 )
Or ( x:BioType #= Type5 And x:Age >= 425 And x:Age < 465 );
},
x:WPDAPar = Parameters:wpda7 );

```

```

/*****
**** RULE: WPDA1.5
*****/
MakeRule( WPDA1.5, [x|Heifers],
{
(x:BioType #= Type1 And x:Age >= 345 And x:Age < 415 )
Or ( x:BioType #= Type2 And x:Age >= 465 And x:Age < 515 )
Or ( x:BioType #= Type3 And x:Age >= 465 And x:Age < 525 )
Or ( x:BioType #= Type4 And x:Age >= 485 And x:Age < 535 )
Or ( x:BioType #= Type5 And x:Age >= 465 And x:Age < 515 );
},
x:WPDAPar = Parameters:wpda8 );

```

```

/*****
**** RULE: WPDA1.6
*****/
MakeRule( WPDA1.6, [x|Heifers],
{
(x:BioType #= Type2 And x:Age >= 100 And x:Age < 215 )
Or ( x:BioType #= Type3 And x:Age >= 205 And x:Age < 225 )
Or ( x:BioType #= Type4 And x:Age >= 205 And x:Age < 235 )
Or ( x:BioType #= Type5 And x:Age >= 205 And x:Age < 225 );
},
x:WPDAPar = Parameters:wpda2 );

```



```

/*****
**** RULE: WPDA1.7
*****/
MakeRule( WPDA1.7, [x|Heifers],
{
( x:BioType #= Type2 And x:Age >= 215 And x:Age < 245 )
Or ( x:BioType #= Type3 And x:Age >= 225 And x:Age < 255 )
Or ( x:BioType #= Type4 And x:Age >= 235 And x:Age < 275 )
Or ( x:BioType #= Type5 And x:Age >= 225 And x:Age < 265 );
},
x:WPDAPar = Parameters:wpda3 );

/*****
**** RULE: WPDA1.8
*****/
MakeRule( WPDA1.8, [x|Heifers],
{
( Heifers:BioType #= Type3 And x:Age >= 100 And x:Age < 205 )
Or ( Heifers:BioType #= Type4 And x:Age >= 100 And x:Age < 205 )
Or ( Heifers:BioType #= Type5 And x:Age >= 100 And x:Age < 205 );
},
x:WPDAPar = Parameters:wpda1 );

/*****
**** RULE: WPDA1.9
*****/
MakeRule( WPDA1.9, [x|Heifers],
{
( x:BioType #= Type1 And x:Age >= 415 And x:Age < 475 )
Or ( x:BioType #= Type2 And x:Age >= 515 And x:Age < 560 )
Or ( x:BioType #= Type3 And x:Age >= 525 And x:Age < 560 )
Or ( x:BioType #= Type4 And x:Age >= 535 And x:Age < 560 )
Or ( x:BioType #= Type5 And x:Age >= 515 And x:Age < 560 );
},
x:WPDAPar = Parameters:wpda9 );

```

```

/*****
**** RULE: WPDA2.1
*****/
MakeRule( WPDA2.1, [x|Heifers],
{
x:BioType #= Type1 And x:Age >= 475 And x:Age < 545;
},
x:WPDAPar = Parameters:wpda10 );

/*****
**** RULE: WPDA2.2
*****/
MakeRule( WPDA2.2, [x|Heifers],
{
x:BioType #= Type1 And x:Age >= 545 And x:Age < 560;
},
x:WPDAPar = Parameters:wpda11 );

/*****
**** RULE: aADG
*****/
MakeRule( aADG, [x|Heifers],
x:Weight >= x:TargetWt,
x:ADG = 0 );

/*****
**** RULE: aADG2
*****/
MakeRule( aADG2, [x|Heifers],
x:Weight < x:TargetWt,
x:ADG = ( x:TargetWt - x:Weight ) / ( x:BeginAge - x:Age );

```

## Age Rules

```

/*****
**** RULE: BeginAge1
*****/
MakeRule( BeginAge1, [x|Heifers],
{
x:BeginAge <= x:PubertyPar + 30;
},
x:conceptionBAge = low );

/*****
**** RULE: BeginAge2
*****/
MakeRule( BeginAge2, [x|Heifers],
{
x:BeginAge >= x:PubertyPar + 50;
},
{
x:conceptionBAge = high;
} );

/*****
**** RULE: BeginAge3
*****/
MakeRule( BeginAge3, [x|Heifers],
{
x:BeginAge < x:PubertyPar + 50
And x:BeginAge > x:PubertyPar + 30;
},
{
x:conceptionBAge = average;
} );

```

```

/*****
**** RULE: EndAge1
*****/
MakeRule( EndAge1, [x|Heifers],
{
x:EndAge <= x:PubertyPar + 50;
},
x:conceptionEAge = low );

/*****
**** RULE: EndAge2
*****/
MakeRule( EndAge2, [x|Heifers],
{
x:EndAge >= x:PubertyPar + 90;
},
{
x:conceptionEAge = high;
} );

/*****
**** RULE: EndAge3
*****/
MakeRule( EndAge3, [x|Heifers],
{
x:EndAge < x:PubertyPar + 90 And x:EndAge > x:PubertyPar + 50;
},
{
x:conceptionEAge = average;
} );

/*****
**** RULE: AgeFlag
*****/
MakeRule( AgeFlag, [x|Heifers],
x:Year > 0,
x:flag = 1 );

```

## Weight Rules

```

/*****
**** RULE: conwt1
*****/
MakeRule( conwt1, [x|Heifers],
{
(x:WPDA >= (x:WPDAPar - .15) And x:Age > 325) And
(x:WPDA < (x:WPDAPar + .05) And x:Age > 325);
},
x:conceptionWt = average );

/*****
**** RULE: conwt2
*****/
MakeRule( conwt2, [x|Heifers],
{
x:WPDA >= (x:WPDAPar + .05) And x:Age > 325;
},
x:conceptionWt = high );

/*****
**** RULE: conwt3
*****/
MakeRule( conwt3, [x|Heifers],
{
(x:WPDA < (x:WPDAPar - .15) And x:Age > 325) And
(x:WPDA >= (x:WPDAPar - .25) And x:Age > 325);
},
x:conceptionWt = low );

/*****
**** RULE: conwt4
*****/
MakeRule( conwt4, [x|Heifers],
{
x:WPDA < (x:WPDAPar - .25) And x:Age > 325;
},
x:conceptionWt = verylow );

```

```

/*****
**** RULE: conwt5
*****/
MakeRule( conwt5, [x|Heifers],
{
x:WPDA >= (x:WPDAPar - .05) And x:Age <= 325;
},
x:conceptionWt = high );

/*****
**** RULE: conwt6
*****/
MakeRule( conwt6, [x|Heifers],
{
(x:WPDA #= (x:WPDAPar - .05) And x:Age <= 325) And
(x:WPDA >= (x:WPDAPar - .15) And x:Age <= 325);
},
x:conceptionWt = average );

/*****
**** RULE: conwt7
*****/
MakeRule( conwt7, [x|Heifers],
{
(x:WPDA < (x:WPDAPar - .15) And x:Age <= 325) And
(x:WPDA >= (x:WPDAPar - .25) And x:Age <= 325);
},
x:conceptionWt = low );

/*****
**** RULE: conwt8
*****/
MakeRule( conwt8, [x|Heifers],
{
x:WPDA < (x:WPDAPar - .25) And x:Age <= 325;
},
x:conceptionWt = verylow );

```

## *Body Condition Rules*

```

/*****
**** RULE: conbc1
*****/
MakeRule( conbc1, [x|Heifers],
{
x:BodyCondition #= Five Or x:BodyCondition #= Six Or x:BodyCondition #= Seven;
},
x:conceptionBC = high );

/*****
**** RULE: conbc2
*****/
MakeRule( conbc2, [x|Heifers],
{
x:BodyCondition #= Three Or x:BodyCondition #= Four Or x:BodyCondition #= Eight
Or x:BodyCondition #= Nine;
},
x:conceptionBC = average );

/*****
**** RULE: conbc3
*****/
MakeRule( conbc3, [x|Heifers],
{
x:BodyCondition #= One Or x:BodyCondition #= Two;
},
x:conceptionBC = low );

/*****
**** RULE: conbc4
*****/
MakeRule( conbc4, [x|Heifers],
{
x:BodyCondition #= None;
},
x:conceptionBC = none );

```

## *Health Rules*

```

/*****
**** RULE: conhealth1
*****/
MakeRule( conhealth1, [x|Heifers],
{
x:HealthStatus #= Excellent;
},
x:conceptionHealth = high );

/*****
**** RULE: conhealth2
*****/
MakeRule( conhealth2, [x|Heifers],
{
x:HealthStatus #= Poor;
},
x:conceptionHealth = low );

/*****
**** RULE: conhealth3
*****/
MakeRule( conhealth3, [x|Heifers],
{
x:HealthStatus #= None;
},
x:conceptionHealth = none );

```



## *RTS Rules*

```

/*****
**** RULE: conrts1
*****/
MakeRule( conrts1, [x|Heifers],
{
x:RTS #= Four Or x:RTS #= Five;
},
{
x:CONCEPTION_FINAL = EXCELLENT
x:conceptionRTS = high
});

/*****
**** RULE: conrts2
*****/
MakeRule( conrts2, [x|Heifers],
{
x:RTS #= Three Or x:RTS #= Two;
},
{
x:CONCEPTION_FINAL = GOOD
x:conceptionRTS = average
});

/*****
**** RULE: conrts3
*****/
MakeRule( conrts3, [x|Heifers],
{
x:RTS #= One;
},
{
x:CONCEPTION_FINAL = LOW
x:conceptionRTS = low
});

```

```

/*****
**** RULE: conrts4
*****/
MakeRule( conrts4, [x|Heifers],
{
x:RTS #= None;
},
x:conceptionRTS = none );

```

### *Conception Rules*

```

/*****
**** RULE: CONCEPTION1
*****/
MakeRule( CONCEPTION1, [x|Heifers],
{
( x:conceptionBAge #= low And x:conceptionEAge #= average
And x:conceptionWt #= low ) Or
( x:conceptionBAge #= low And x:conceptionEAge #= high And
x:conceptionWt #= low ) Or
( x:conceptionBAge #= average And x:conceptionEAge #= high
And x:conceptionWt #= low ) Or
( x:conceptionBAge #= average And x:conceptionEAge #= average
And x:conceptionWt #= low ) Or
( x:conceptionBAge #= low And x:conceptionEAge #= average
And x:conceptionWt #= average ) Or
( x:conceptionBAge #= low And x:conceptionEAge #= average
And x:conceptionWt #= high ) Or
( x:conceptionBAge #= high And x:conceptionEAge #= high
And x:conceptionWt #= low );
},
x:CONCEPTION = Low );

```

```

/*****
**** RULE: CONCEPTION2
*****/
MakeRule( CONCEPTION2, [x|Heifers],
{
(x:conceptionBAge #= low And x:conceptionEAge #= high
And x:conceptionWt #= average ) Or
(x:conceptionBAge #= high And x:conceptionEAge #= high
And x:conceptionWt #= average ) Or
(x:conceptionBAge #= average And x:conceptionEAge #= high
And x:conceptionWt #= average ) Or
(x:conceptionBAge #= average And x:conceptionEAge #= high
And x:conceptionWt #= high ) Or
(x:conceptionBAge #= average And x:conceptionEAge #= average
And x:conceptionWt #= high ) Or
(x:conceptionBAge #= low And x:conceptionEAge #= high
And x:conceptionWt #= high ) Or
(x:conceptionBAge #= average And x:conceptionEAge #= average
And x:conceptionWt #= average );
},
x:CONCEPTION = Average );

/*****
**** RULE: CONCEPTION3
*****/
MakeRule( CONCEPTION3, [x|Heifers],
{
x:conceptionBAge #= high And x:conceptionEAge #= high
And x:conceptionWt #= high;
},
x:CONCEPTION = High );

```

```

/*****
**** RULE: CONCEPTION4
*****/
MakeRule( CONCEPTION4, [x|Heifers],
{
( x:conceptionBC #= low And x:conceptionHealth #= low )
Or ( x:conceptionBC #= low And x:conceptionHealth #= none )
Or ( x:conceptionBC #= none And x:conceptionHealth #= low )
Or ( x:conceptionBC #= low And x:conceptionHealth #= high )
Or ( x:conceptionBC#= average And x:conceptionHealth #= low );
},
x:CONCEPTION2 = Low );

/*****
**** RULE: CONCEPTION5
*****/
MakeRule( CONCEPTION5, [x|Heifers],
{
( x:conceptionBC #= average And x:conceptionHealth #= high )
Or ( x:conceptionBC #= high And x:conceptionHealth #= low )
Or ( x:conceptionBC #= average And x:conceptionHealth #= none );
},
x:CONCEPTION2 = Average );

/*****
**** RULE: CONCEPTION6
*****/
MakeRule( CONCEPTION6, [x|Heifers],
{
( x:conceptionBC #= high And x:conceptionHealth #= high )
Or ( x:conceptionBC #= high And x:conceptionHealth #= none );
},
x:CONCEPTION2 = High );

```

```

/*****
**** RULE: CONCEPTION7
*****/
MakeRule( CONCEPTION7, [x|Heifers],
{
( x:conceptionBC #= none And x:conceptionHealth #= none )
Or ( x:conceptionBC #= none And x:conceptionHealth #= high );
},
x:CONCEPTION2 = None );

/*****
**** RULE: CONCEPTION8
*****/
MakeRule( CONCEPTION8, [x|Heifers],
{
( x:conceptionBAge #= low And x:conceptionEAge #= low )
Or ( x:conceptionWt #= verylow );
},
x:CONCEPTION = VeryLow );

/*****
**** RULE: FINAL_CONCEPTION1
*****/
MakeRule( FINAL_CONCEPTION1, [x|Heifers],
{
( x:CONCEPTION2 #= Low And x:CONCEPTION #= Low
And x:conceptionRTS #= none )
Or ( x:CONCEPTION2 #= Low And x:CONCEPTION #= Average
And x:conceptionRTS #= none )
Or ( x:CONCEPTION2 #= None And x:CONCEPTION #= Low
And x:conceptionRTS #= none )
Or ( x:CONCEPTION2 #= Low And x:CONCEPTION #= High
And x:conceptionRTS #= none )
Or ( x:CONCEPTION #= VeryLow );

},
x:CONCEPTION_FINAL = LOW );

```

```

/*****
**** RULE: FINAL_CONCEPTION2
*****/
MakeRule( FINAL_CONCEPTION2, [x|Heifers],
{
(x:CONCEPTION2 #= High And x:CONCEPTION #= Average
And x:conceptionRTS #= none )
Or ( x:CONCEPTION2 #= Average And x:CONCEPTION #= High
And x:conceptionRTS #= none )
Or ( x:CONCEPTION2 #= Average And x:CONCEPTION #= Low
And x:conceptionRTS #= none )
Or ( x:CONCEPTION2 #= High And x:CONCEPTION #= Low
And x:conceptionRTS #= none )
Or ( x:CONCEPTION2 #= Average And x:CONCEPTION #= Average
And x:conceptionRTS #= none )
Or ( x:CONCEPTION2 #= None And x:CONCEPTION #= Average
And x:conceptionRTS #= none );
},
x:CONCEPTION_FINAL = GOOD );

/*****
**** RULE: FINAL_CONCEPTION3
*****/
MakeRule( FINAL_CONCEPTION3, [x|Heifers],
{
(x:CONCEPTION2 #= High And x:CONCEPTION #= High
And x:conceptionRTS #= none );
Or ( x:CONCEPTION2 #= None And x:CONCEPTION #= High
And x:conceptionRTS #= none );
},
x:CONCEPTION_FINAL = EXCELLENT );

```

## Appendix 2. User Interface

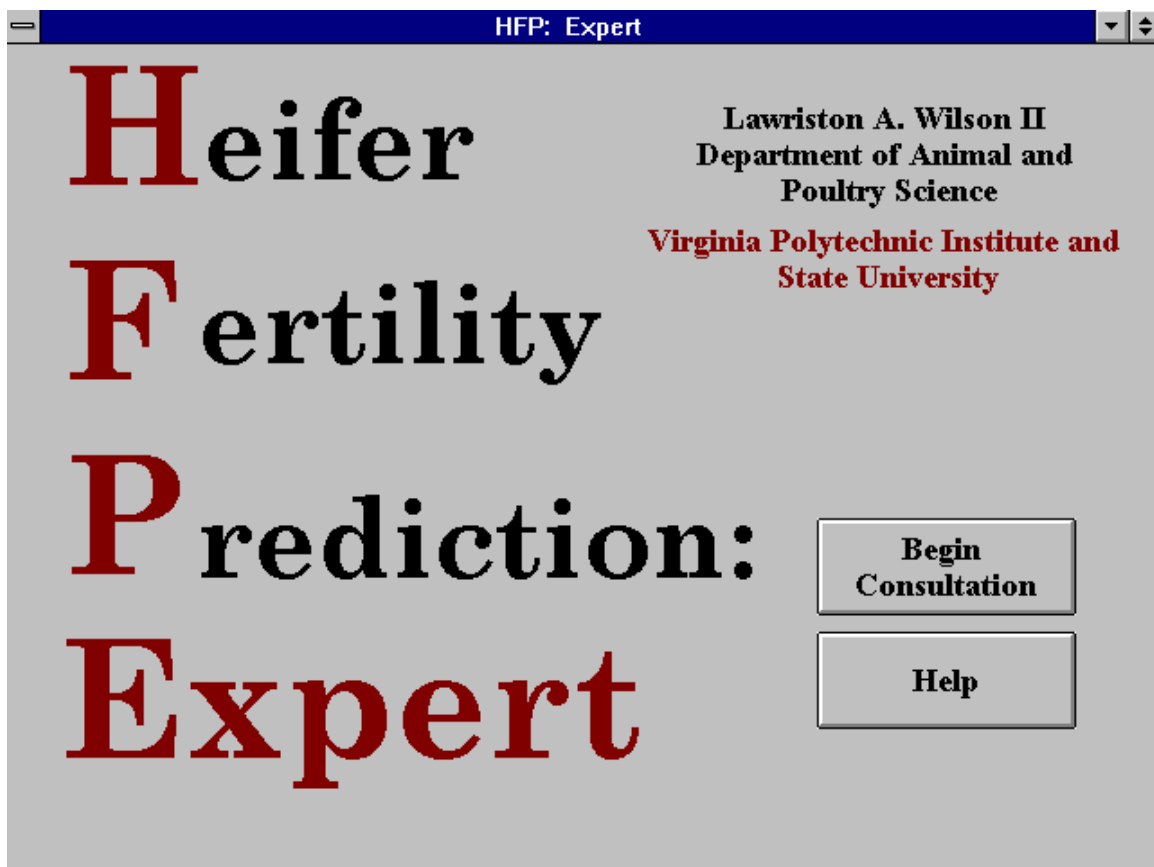


Figure 7. HFP: Expert title screen

HFP: Expert - Breeding Season and Measurement Dates		
Enter the Month the breeding season will begin: January	Enter the Month in which the heifers were evaluated: January	
Enter the Day the breeding season will begin: 1 31 1 Day of the Month	Enter the Day the heifers were evaluated: 1 31 1 Day of the Month	
Enter the Year the breeding season will begin: 1990	Enter the Year the heifers were evaluated: 1990	
Enter the ID of the heifer to be added: a100	Enter the length of the breeding season (in Days): 65	Select the breed that best describes all of your heifers (OPTIONAL):
<input type="button" value="Next Screen"/> <input type="button" value="Help"/>		<b>HFP: Expert</b>

Figure 8. HFP: Expert dates screen



The screenshot shows a software window titled "HFP: Expert - Datasheet (without Advanced Options)". The interface is organized into several sections:

- Top Left:** "Select the I.D. of the heifer to be edited:" with a dropdown menu containing "a100".
- Top Right:** "Select the month of birth (OPTIONAL):" with an empty dropdown menu.
- Middle Left:** "Select the breed of cattle that best describes this heifer:" with an empty dropdown menu.
- Middle Right:** "Select the day of birth:" with a spinner control showing "1" and "31", and the label "0 Day of the Month".
- Bottom Left (Top):** "Enter the body weight:" with a spinner control showing "300" and "1200", and the label "0 Weight (lbs)".
- Bottom Left (Bottom):** "Enter the age (OPTIONAL):" with a spinner control showing "190" and "560", and the label "0 Age in days".
- Bottom Right (Top):** "Select the year of birth:" with a spinner control showing "1988" and "1994", and the label "0 Year".
- Bottom Right (Middle):** "Enter the name of the file you want the data written to:" with a dropdown menu containing "data.txt".
- Bottom Right (Bottom):** "Enter the name of the file you want the explanations written to:" with a dropdown menu containing "explain.txt".
- Bottom Center:** A "Previous Screen" button.
- Right Side:** A vertical column of buttons: "Analyze Data", "View Report", "Delete Heifer", "Delete All Heifers", "Help", and "Quit HFP: Expert".
- Large Text:** The text "HFP: Expert" is displayed in a large, red, serif font on the right side of the window.

Figure 9. HFP: Expert datasheet without advanced options

**HFP: Expert - Datasheet (with Advanced Options)**

<p>Select the I.D. of the heifer to be edited:</p> <input type="text" value="a100"/>	<p>Select the month of birth (OPTIONAL):</p> <input type="text"/>	<p>Health Status (OPTIONAL):</p> <input type="text" value="None"/>
<p>Select the breed of cattle that best describes this heifer:</p> <input type="text"/>	<p>Select the day of birth:</p> <input type="text" value="1"/> <p style="text-align: center;">0 Day of the Month</p>	<p>Body Condition Score (OPTIONAL):</p> <input type="text" value="None"/>
<p>Enter the body weight:</p> <input type="text" value="300"/> <p style="text-align: center;">0 Weight (lbs)</p>	<p>Select the year of birth:</p> <input type="text" value="1988"/> <p style="text-align: center;">0 Year</p>	<p>Reproductive Tract Score (OPTIONAL):</p> <input type="text" value="None"/>
<p>Enter the age (OPTIONAL):</p> <input type="text" value="190"/> <p style="text-align: center;">0 Age in days</p>	<p>Enter the name of the file you want the data to be written to:</p> <input type="text" value="data.txt"/>	<p>Analyze Data</p> <p>View Report</p> <p>Delete Heifer</p> <p>Delete All Heifers</p> <p>Help</p> <p>Quit HFP: Expert</p>
<p>Previous Screen</p>	<p>Enter the name of the file you want the explanations to be written to:</p> <input type="text" value="explain.txt"/>	

**HFP: Expert**

Figure 10. HFP: Expert datasheet with advanced options

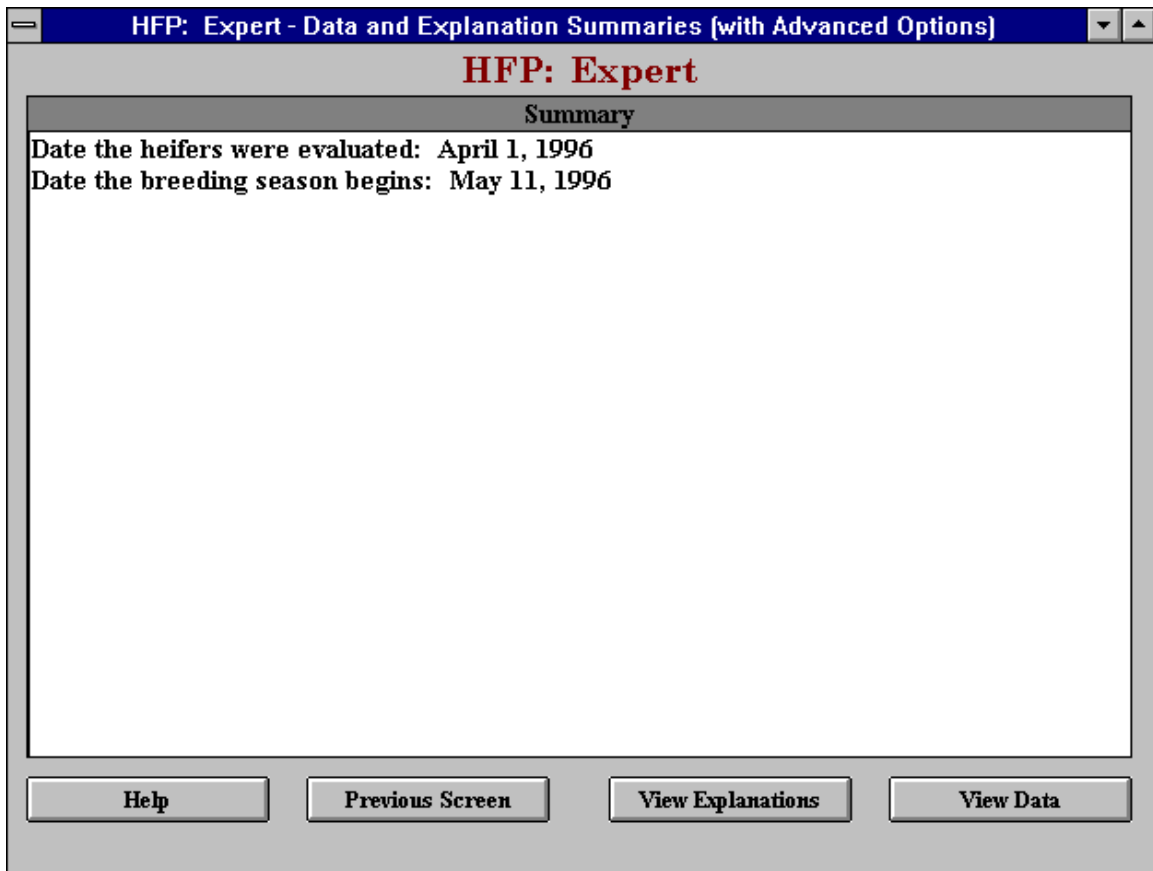


Figure 11. HFP: Expert summary sheet with advanced options

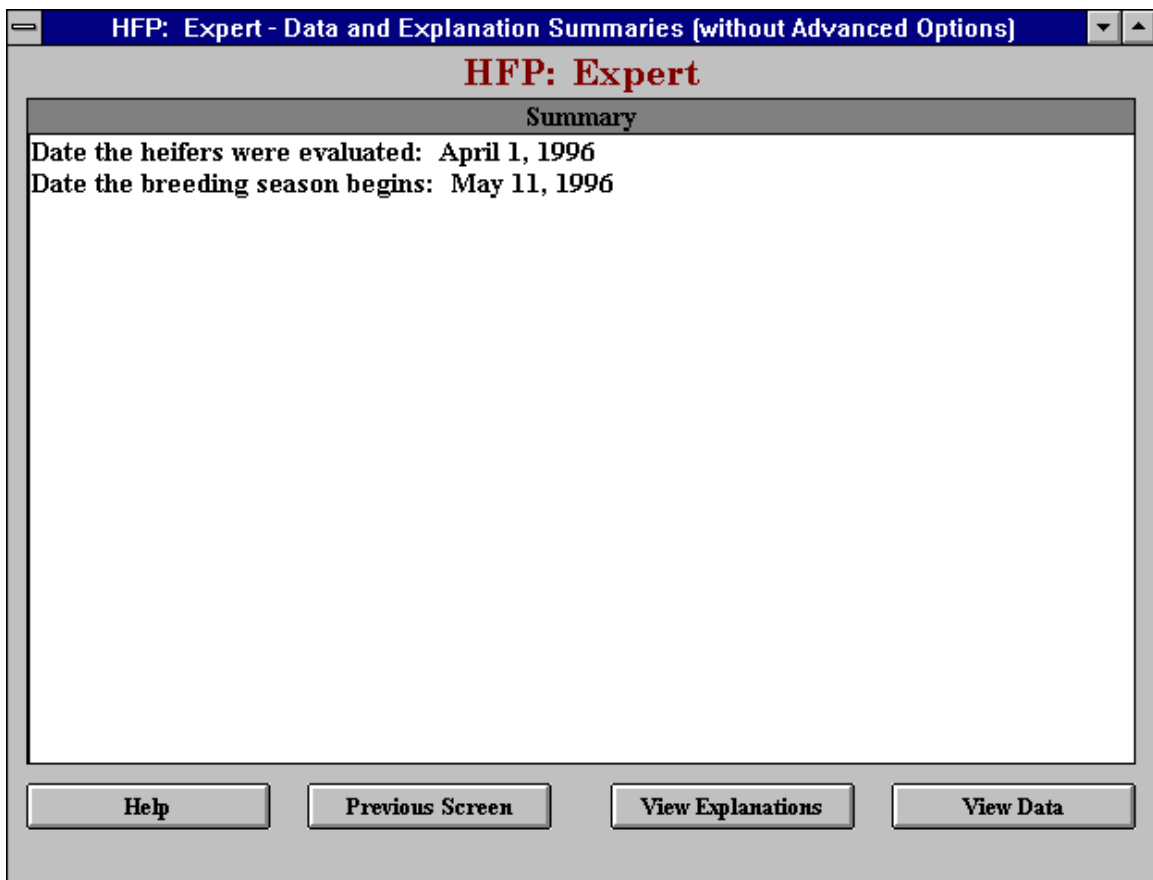


Figure 12. HFP: Expert summary sheet without advanced options



Figure 13. HFP: Expert help screen

## Appendix 3. Explanations<sup>a</sup>

### *Age explanations*

Ending Age	Beginning Age		
	Low	Intermediate	High
Low	E1	E3	E4
Intermediate	E2	E3	E4
High	E2	E3	E4

- [E1] Heifer (*name*)’s age at the start (*age in days*) or the end (*age in days*) of the breeding season is not conducive to reaching puberty. The average age at puberty for (*breed*) cattle is (*puberty age*) days of age. Due to her young age, this heifer will more than likely not become pregnant during the breeding season and it is recommended that this heifer not be used for breeding.
- [E2] Heifer (*name*)’s age at the start (*age in days*) or the end (*age in days*) of the breeding season is undesirable. Although this heifer could exhibit her first estrous cycle before the breeding season ends, she is more likely to conceive late during the breeding season and calve late during the calving season. Heifers that calve late have difficulty rebreeding during the next breeding season.

- [E3] Heifer (*name*)’s age at the start (*age in days*) of the breeding season is desirable. This heifer should exhibit her first estrous cycle by the start or during the beginning of the breeding season. The fertility of heifers increases with each of the first three successive estrous cycles. This heifer has a good chance to conceive during the first half of the breeding season.
- [E4] Heifer (*name*)’s age of (*age in days*) days at the start of the breeding season is excellent. This heifer should exhibit her first estrous cycle before the breeding season begins. The fertility of heifers increases with each of the first three successive estrous cycles. Based on her age, this heifer has an excellent chance to conceive early during the breeding season.

*Body weight and ADG explanations*

Body weight				ADG	
Very Low	Low	Intermediate	High	Zero	> Zero
E5	E6	E7	E7	E8	E9

- [E5] The current weight of (*weight*) lbs for this heifer is very low for (*breed*) cattle within her age group. It is unlikely she will reach a weight conducive to puberty before the breeding season. It is recommended that the protein and energy requirements needed to reach the target weight (65% of mature weight) be rechecked. If necessary, this heifer may need to receive a diet higher in energy and/or protein to increase her growth rate, prior to breeding.
- [E6] The current weight of (*weight*) lbs for this heifer is slightly low for (*breed*) cattle within her age group. It is recommended that the protein and energy requirements needed to reach the target weight (65% of mature weight) be rechecked. If necessary, this heifer may need to receive a diet higher in energy and/or protein to increase her growth rate, prior to breeding.
- [E7] The current weight of (*weight*) lbs for this heifer is at or above the desired level for the attainment of puberty for (*breed*) cattle within her age group.
- [E8] This heifer has already surpassed the average threshold body weight necessary for the attainment of puberty for (*breed*) cattle of her age.

[E9] The necessary ADG to reach the average threshold body weight for puberty for (*breed*) cattle within this heifer’s age group is (*ADG*) lbs per day.

*Body condition score explanations*

Body condition score									
1	2	3	4	5	6	7	8	9	None
E10	E10	E11	E11	E13	E13	E13	E12	E12	E14

[E10] The body condition score of (*BC*) is too low for this heifer to have a good chance to conceive and maintain pregnancy during the breeding season.

[E11] The body condition score of (*BC*) is slightly low for this heifer, which may decrease her ability to conceive and maintain pregnancy. You may want to consider rechecking her protein and energy requirements and if necessary adjust her dietary protein and/or energy level to increase her conditioning.

[E12] The body condition score of (*BC*) is slightly high for this heifer, which may decrease her ability to conceive. If the current date is not within 50 days of the breeding season, you may want to consider limiting her feed intake to decrease her conditioning. Limiting feed intake at or near the time of breeding can severely hinder the ability of a heifer to become pregnant.

[E13] The body condition score of (*BC*) for this heifer is at an optimum level.

[E14] This heifer’s body condition score was not available.



## Health and RTS explanations

Health			RTS			
Low	High	None	Low	Intermediate	High	None
E15	E16	E17	E19	E20	E21	E18

[E15] The current health of this heifer may decrease her ability to conceive.

[E16] The current health of this heifer should not affect her ability to conceive.

[E17] The current health of this heifer was not available.

[E18] There was no reproductive tract score given for this heifer.

[E19] Heifer (*name*)'s reproductive tract score of (*RTS*) may not be conducive for the attainment of puberty during the scheduled breeding season. This heifer is less likely to become pregnant due to her low reproductive tract score, but she may exhibit her first estrous cycle by the end of the breeding season. It is recommended that this heifer not be used for breeding.

[E20] Heifer (*name*) is not likely to conceive early in the breeding season based on her reproductive tract score of (*RTS*). She is more likely to become pregnant late in the breeding season and to calve late during the calving season. Heifers that calve late have difficulty rebreeding during the next breeding season.

[E21] Based on heifer (*name*)'s reproductive tract score of (*RTS*), she has an excellent chance to conceive early during the breeding season.

## **Appendix 4. Computer Software**

Computer software used for program development

KAPPA-PC 2.3

Intellicorp

1975 El Camino Real West

Mountain View, CA 94040

Phone: (415) 965-5700

Fax: (415) 965-5647

Homepage: <http://www:intellicorp.com/>

## Vita

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Gardiner, Maine 1985-90

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Blacksburg, Virginia 1990-94  
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Publications:  
Miller, B. F., K. L. Armstrong, **L. A. Wilson**, W. D. Hohenboken, and R. G. Saacke, 1994. Variation among inbred and lincross mice in response to fescue toxicosis. *J. Anim. Sci.* 72:2896.

Lawriston A. Wilson II