CANINE REPRODUCTIVE MANAGEMENT: FACTORS INFLUENCING LITTER SIZE

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Introduction

The ultimate goal of any mating is to produce viable offspring for the propagation of the species. For the bitch, reproductive success should be defined as the generation and weaning of an adequate size litter of healthy viable puppies reflecting the genetic potential of both the dam and sire. However, the degree of reproductive success in the bitch can be influenced by numerous factors including the bitch's health, plane of nutrition and age, as well as the type and quality of semen used for the mating. Although not comprehensive, this chapter will discuss some of the known factors influencing the degree of reproductive success in the bitch. Specific topics discussed will be the influence of breed, age, mating type, and nutrition.

Reproductive Influences

Breed: Although it has long been recognized that a bitch's breed will influence how many puppies she is expected to produce, there continues to be a lack of information on what is the typical litter size within a given breed. Therefore, we obtained a substantial sized database (728,271 litters) spanning a 3-year period for 15 popular breeds from the American Kennel Club (AKC). Each record contained the litter number, breed code, number of males born, number of males registered, number of females born, number of females registered, mating type of litter (natural, fresh semen, chilled extended semen or frozen semen), and age of bitch when bred. Unfortunately, the records do not indicate the number of puppies that the bitched weaned. Therefore we were not able to determine if the discrepancy between number born and number registered was due to a failure to thrive, substandard quality or sold with registration agreement (pet only). Practically speaking, it is probably a combination of all the factors. The breeds included the Labrador Retriever, Poodle, Dachshund, Pomeranian, Chihuahua, Yorkshire Terrier, Shih Tzu, Rottweiler, German Shepherd Dog, Beagle, American Cocker Spaniel, Golden Retriever, Miniature Schnauzer, Shetland Sheepdog, and American Boxer. Individual breed characteristics are presented below in Table 1. Not surprisingly, breed was a significant factor with the large breeds producing larger litters than small breeds. The Labrador Retriever and Golden Retriever were found to produce the largest litters with almost 70% of all litters containing 7 or more pups. In contrast, the Poodle, Pomeranian, Chihuahua, and Yorkshire Terrier were found to produce the smallest litters with approximately 80% of all litters containing 4 or less pups.

Typical litter size for a breed is often difficult for the breeder to obtain, since many sources simply report the average litter size for a breed. While this practice provides the breeder or veterinarian with a rough number, it does not provide enough information to distinguish between typical and atypical litters due to animal to animal variation. A good example of this is the Labrador Retriever. Most reports indicate that a Labrador Retriever bitch should whelp 7 to 8 puppies. While this number is considered the breed average, it only accounts for approximately

30% of all litters. A more practical method for determining the typical litter size would be to define "Typical" as the range, in whole numbers, encompassing the mean $\pm$ 1 standard deviation;

Table 1. Summary of typical and mean litter sizes for various canine breeds.

Breed	Number of Litters	Typical[x] Litter Size Range	Mean ± SD	Percentage (%) of Litters Reported by Puppy Number[y]										
				1	2	3	4	5	6	7	8	9	10	≥ 11
Labrador Retriever	85113	5 - 10	7.6 ± 2.6	1.89	2.73	3.40	5.01	7.03	10.62	13.89	**16.54**	15.57	11.90	11.41
Poodle	69755	2 - 5	3.4 ± 1.8	11.46	20.55	**25.01**	21.03	11.36	5.67	2.17	1.19	0.72	0.44	.42
Dachshund	59935	2 - 6	3.9 ± 1.6	7.22	13.78	20.45	**24.04**	18.39	10.53	3.94	1.33	0.22	0.08	.03
Pomeranian	56976	2 - 4	3.0 ± 1.4	14.91	24.61	**26.90**	19.98	9.21	3.47	0.73	0.16	0.03	0.01	0.01
Chihuahua	55513	2 - 5	3.3 ± 1.5	11.47	20.03	**23.99**	23.05	13.66	6.08	1.39	0.27	0.05	0.02	0.00
Yorkshire Terrier	53141	2 - 5	3.3 ± 1.5	13.15	20.62	**24.08**	21.70	12.80	5.70	1.57	0.30	0.06	0.01	0.01
Shih Tzu	48667	2 - 6	4.1 ± 1.6	6.07	11.94	18.36	**23.69**	20.67	12.97	4.63	1.37	0.27	0.03	0.01
Rottweiler	46805	4 - 10	6.6 ± 2.9	3.70	5.99	7.45	9.25	10.13	12.05	**12.44**	11.85	9.85	8.19	9.11
German Shepherd	44537	4 - 9	6.6 ± 2.7	3.41	5.40	6.35	8.80	10.45	12.96	13.62	**14.08**	10.87	7.71	6.35
Beagle	42823	3 - 7	5.0 ± 2.1	5.21	8.31	11.72	15.24	**17.67**	17.37	12.33	7.55	3.00	1.24	0.37
American Cocker Spaniel	39019	3 - 7	5.0 ± 2.0	4.58	8.06	11.17	16.22	**18.62**	18.16	12.54	6.88	2.60	0.87	0.29
Golden Retriever	38233	5 -10	7.6 ± 2.7	2.10	3.04	3.53	4.96	6.79	9.72	12.54	**16.17**	15.88	13.06	12.21
Miniature Schnauzer	32235	3 - 6	4.6 ± 1.8	4.69	8.76	13.34	19.99	**21.01**	17.68	9.55	3.84	0.87	0.20	0.07
Shetland Sheepdog	28421	2 - 6	4.3 ± 1.9	7.61	11.65	15.67	**20.03**	19.34	14.42	6.99	2.99	0.93	0.27	0.09
American Boxer	27098	4 - 8	5.8 ± 2.4	3.98	6.25	8.61	11.85	13.82	**16.17**	14.84	11.95	6.93	3.72	1.88

[x]Typical litter is defined as the whole number of puppies within ± 1 standard deviation of the mean.

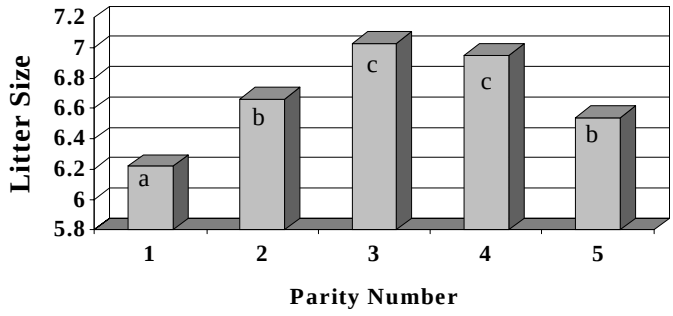
[y]Bolded number denotes the highest percentage occurrence for a given breed.

any litter outside that range would be defined as "Atypical". Using this method, the typical litter size for the Labrador Retriever would range from 5 to 10 with a mean of 7.6 $\pm$ 2.6 puppies. This range would account for approximately 75% of all litters and would allow for a more accurate reproductive management plan to be developed. Using the mean $\pm$ 1 standard deviation method, at least 70% of all litters across all breeds were categorized as typical (see Table 1).

Age: One of the most common questions with regard to canine reproduction is "How long can I breed my bitch"? Theoretically, the answer is "As long as she will conceive". However, this does not mean that the bitch should be bred or if bred that she will perform at a normal level. As reproductive professionals, it is imperative that we identify and understand the existence of a critical age for a given breed to aid in the reproductive management of the bitch.

Previous efforts have demonstrated that parity number influences litter size in the Beagle bitch[1]. Overall, the Beagle bitch was found to produce her largest litters in the 3rd and 4th parities, then decline thereafter (Figure 1). This is not to say that all bitches follow this pattern. Of the 17,000 litter analyzed, some 10% of the bitches experienced significant declines following the 2nd litter (3 years). In contrast, there was also a small (< 5%) subpopulation of the older (> than 5 years of age) bitches that did not significantly decline in litter size through 7 parities. It is also critical for readers to note that the effects of parity and age were not separated. In practice, it is much easier to account for effects of age than parity since one can chose at what age to first breed a bitch but cannot increase the parity number without also increasing age.

Figure 1. The effect of parity on litter size in the Beagle bitch.



Significant differences denoted by opposing superscripts

Litter Size reported as total number of puppies born

Analysis of the previously described AKC database demonstrated that litter size is influenced by the bitch's age in almost all of the breeds examined. In general, reproductive performance of large breed bitches declined at a younger age than smaller breed bitches. This observation is logical, since larger breeds generally have shorter life expectancies. For reporting purposes, we defined the "Apparent Critical Age" as the age in years where the average litter size for a breed is $\geq$ 15% below the breed average. The findings for each breed examined are shown in Table 2. The age at which bitches produce the largest litters ranged from as low as 1-2 years of age for the American Boxer to as high as 1-7 years of age for the Yorkshire Terrier. Several of the larger breeds were found to have an apparent critical breeding age of 5 years; these breeds included the Labrador Retriever, Rottweiler, German Shepherd Dog, and Golden Retriever. In contrast, an apparent critical age was not detected for the Pomeranian and Chihuahua breeds; reported as 10+ years since only bitches 10 years and younger were included in the analysis (> 99.5% of the total records). An interesting point of this observation was that the Pomeranian and Chihuahua were

found to produce some of the smallest litter size averages at 3.0 ± 1.4 and 3.3 ± 1.5 pups per litter, respectively. The lack of an observed apparent critical age for these breeds does not imply that Pomeranian and Chihuahua bitches should be bred at 7 to 10 years of age. Both breeds were found to produce their largest litters between 1 and 4 years of age. Beyond 4 years of age, litter size did numerically decline, however never achieved the qualifying level of ≥ 15%. It remains unknown how breeding an older bitch will affect her health or the health of her puppies. Although it should be noted that the percentage of puppies registered from a litter was reduced in most bitches 6 years of age and almost always for 7-year-old bitches, regardless of breed.

Table 2. Age[1] associated effects on canine reproduction across breeds.

Breed	Age of Peak Litter Size[2]	Apparent Critical Age[3]
Labrador Retriever	1 - 3	5
Poodle	1 - 5	9
Dachshund	1 - 4	8
Pomeranian	1 - 4	10 +
Chihuahua	1 - 4	10 +
Yorkshire Terrier	1 - 7	8
Shih Tzu	1 - 4	8
Rottweiler	1 - 3	5
German Shepherd	1 - 3	5
Beagle	2 - 3	6
American Cocker Spaniel	1 - 3	6
Golden Retriever	1 - 3	5
Miniature Schnauzer	2 - 3	6
Shetland Sheepdog	1 - 4	8
American Boxer	1 - 2	5

[1]Age reported in years. [2]Based on the number of puppies reported born.
[3]Critical age defined as year when litter size declines more than 15% below breed average.

Mating Type: One of the key decisions that a breeder must make prior to a bitch's estrus is what type of service will be used to achieve the wanted pregnancy. Of the two choices, natural service or artificial insemination (AI), the vast majority of canine litters are produced by natural matings. While the utilization of AI has been dramatically increasing over the past few years, the exact percentages of natural versus AI matings are unknown. However, based on the analysis of the data obtained from the AKC, the actual percentage would not be expected to be high. Analysis of the AKC database (described earlier) revealed that less than 0.5% of the 728,271 litters were reported as AI produced with the highest percentages reported in the Labrador Retriever (1.01%), Shetland Sheepdog (0.97%) and, the Golden Retriever (0.93%) breeds.

Artificial insemination can be accomplished using 3 types of semen: fresh, chilled extended or frozen. Fresh semen AI offers little advantages when compared to natural service due to the fact that both the bitch and dog are present or at least in close proximity. This type of AI is often employed because either the bitch or the dog is reluctant to the breeding act.

The use of chilled extended semen is probably the most frequently used AI technique. The major advantage is that semen can be shipped from practically anywhere to the bitch's owner or veterinarian. This allows the bitch's owner to select the litter's sire based on specific breed traits, not location. While vast improvements have been made in transportation of animals with regard to safety, it is still costly and requires time. By comparison, chilled extended semen can be

economically shipped overnight. However, this convenience does not occur without some disadvantages. The main disadvantage is the decreased viability time of the semen. Naturally deposited or fresh semen is often viable in the bitch's reproductive tract for 5 to 7 days whereas the viability time for chilled extended semen is reduced to approximately 3 days, although advancements in the extenders are helping increase the viability time. However, at present, breeders should be encouraged to have the bitch tested to ensure that the semen is deposited just prior (days 2-3 post ovulation) to the fertile period of the cycle, not just when the bitch is receptive.

The use of frozen semen remains relatively uncommon in the canine. In most cases, the use of frozen semen involves a top bitch and semen from an extremely high performing dog that is no longer fertile or in most cases deceased. While it is recommended that breeders determine that ovulation has occurred when using chilled extended semen, it is imperative when using frozen semen. Previous work has shown that thawed sperm has reduced motility[2] and oocyte penetration.[3] In addition, the viability of frozen semen is dramatically less than fresh or chilled extended semen, usually less than 24 hours. Collectively, these factors leave little room for an erroneously timed breeding if the bitch is to become pregnant.

Despite the increasing popularity of AI, little information is available on how AI affects litter size. To address this question, we analyzed the previously described AKC database for litter size (total puppy number), accounting for mating type. Depending on breed and semen type, litters produced by AI were reduced by as little as 2% or as much as 49% when compared to natural service produced litters. Across all breeds, litter size was reduced by approximately 15% when produced by fresh or chilled extended semen and by 25% when produced by frozen semen relative to natural service produced litters. While this data suggest that litter size is reduced when AI is utilized, extreme caution must be taken with this interpretation. There are several factors that were accounted for: 1) were precautions taken to predict when the bitch ovulated? 2) were all or a subpopulation of the AI litters produced by bitches with a history of reproductive complications? 3) what percentage of the AI breedings were performed professionally versus by the novice hand? In addition, the number of observations for the two mating types was extremely unbalanced; less than 0.5% of all observations were reported as AI produced. Perhaps there will be definitive information forthcoming in the near future to resolve if the reduction in litter size by AI matings is real.

Nutrition: Nutrition has long been recognized as having an influence on reproductive success. For the bitch, the successful weaning of a litter is probably the most demanding and stressful metabolic act that she will experience as an adult. In spite of this fact, little advancement has been made in understanding the relationship between nutrition and bitch reproductive performance. Campbell and Phillips[4] and Ontko and Phillips[5] provided some of the earliest insight into the specialized nutritional requirements for the reproducing bitch. In both studies, diets known to be sufficient for canine growth and maintenance were found to be inadequate for reproduction. Both studies also demonstrated that reproductive performance could be improved through selective nutritional supplementation. While it is often easy to recognize mal-nourishment, the distinction between dietary sufficiency and optimal nutrition can be vague. Collins[6] concluded that the stress associated with reproduction would manifest even the smallest of nutrient inadequacies in diets assumed to be complete. While it is unlikely that these

inadequacies will be severe enough to inhibit reproduction, they most likely would prevent her from performing at her genetic potential and/or would require an increased nutrient mobilization from her body stores to meet the nutritional requirements of her progeny. Furthermore since deficiencies in maternal nutrition in other species have now been associated with adult disorders in progeny,[7] it is essential that we understand and optimize maternal nutrition. It is also critical to remember that optimal nutrition for the bitch extends beyond maintenance levels. Optimal nutrition will supply not only maintenance level nutrients, but all the nutrients required for the growth of her reproductive tissues and for the growth and development of the puppies. To meet these demands, the bitch has only a single nutrient source, her diet. Required nutrients would include all of the essential amino acids, the essential fatty acids (functional components of cellular membranes and the endocrine system) as well as various vitamins and minerals. If the bitch's diet fails to meet the required levels, she will respond by prioritizing her reproductive tissues and growing offspring at the sacrifice of her body's maintenance. This would include mobilization of nutrients from body fat, muscle, and skeletal tissue. In extreme cases, her body's only solution may be to reduce the demand by decreasing the number of offspring or aborting the pregnancy all together.

This is not to imply that one should simply switch to a diet with the highest available nutrient (protein or energy or both) content or use various dietary supplements to enhance a food. Excess nutrition can be as detrimental as nutrient deficiencies. Excess dietary energy can often contribute to extreme maternal weight gain, which dramatically increases the chance of dystocia during parturition.

The key to optimal nutrition is supplying a food that has a balanced nutrient profile at levels that meet the animal's need. Mosier[8] concluded that "only by feeding well managed balanced diets can the health of an individual be maximized". Thus all nutrient components of a diet should be considered collectively, not just a minimum level of one nutrient or a maximum level of another nutrient. The dietary matrix as a whole, including nutrient sources and the relationship of certain nutrient levels (eg protein to fat ratio) should be carefully evaluated.

Protein: Numerous publications have discussed the effects of dietary protein on bitch reproductive performance. Platt and Stewart[9] reported that bitches fed suboptimal dietary protein had reduced weight gains during pregnancy and produced smaller litters containing reduced birth weight puppies (individual). In addition, puppies from the more severe protein-restricted bitches experienced reduced growth rates during the nursing period. The reduction appears to be a permanent imprinting with reduced growth rates observed post-weaning even when puppies are fed a protein sufficient diet. Mosier[10] attributed reduction in neonatal liver to brain weight ratio to insufficient maternal protein intake during gestation. In addition, numerous publications have associated maternal protein malnutrition with intrauterine growth retardation (IUGR) in other species, including man, non-human primates, and rodents.

The protein content of diets recommended for reproduction can vary widely, depending on protein sources. The dietary protein minimum for reproduction, as established by the Association of American Feed Control Officials[11] (AAFCO), is 22%. However, the majority of commercially available diets recommended for reproduction generally ranged between 25 and 34% protein, with a few diets as high as 37%. As mentioned earlier, however, more does not always mean

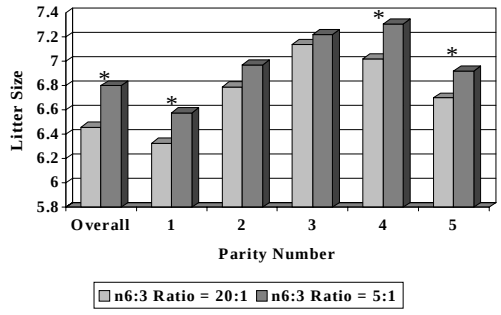
better. Excess protein intake may present health problems for both the bitch and developing puppies. It has long been thought that excessive protein intake increases the risks of oxidative stress, although recent work[12] suggests that oxidative stress may be more dependent upon the animal's antioxidant status than protein intake. However, given the association between oxidative stress and pregnancy complications, including reduced placental function, caution should be taken to avoid excessive protein intake until further clarification can be made.

Considerations for dietary protein must also be expanded beyond just the level. The type of protein is as, if not more, critical as the actual level. Just as ingredients vary in protein content, they can and will also vary greatly in amino acid profile. Because of this, breeders should be encouraged to feed diets that are high in animal-based proteins to provide a balanced supply of amino acids. However, even this does not ensure that the bitch's needs will be met, since some commercial pet food companies utilize animal protein sources that contain high levels of connective tissue, which can be rich in the non-essential amino acids. Although AAFCO has established minimum levels for the 10 essential amino acids, this only ensures dietary adequacy, not optimal nutrition. Therefore based on current information, it is recommended that pregnant or lactating bitches should be fed a diet that contains between 27 and 34% protein (primarily animal-based sources), with 29-32% being preferred.

Dietary Lipids: Dietary lipids (fat) are the major source of calories for the dog. However, relative to dietary protein, much less is known about the effects of lipids on canine reproduction. Similar to proteins, dietary fat is composed of both essential and non-essential components. The essential fatty acids (EFA) include those belonging to the omega-6 (n-6) and omega-3 (n-3) families. The parental EFA are linoleic acid (18:2n-6) and linolenic acid (18:3n-3), both which can be elongated and further desaturated through the Δ6 and Δ5 pathways into arachidonic acid (20:4n-6) and docosahexaenoic acid (22:6n-3), respectively.

Until recently, the majority of the published literature has addressed the effects of fat level with little attention given to the make up (fatty acid profile, FAP) of the fat beyond linoleic acid. A recent study[1] suggested that both fat level and type can influence bitch reproductive performance. Comparisons revealed that bitches consuming 20% fat diets consistently produced larger litters than bitches consuming 16% fat diets. In addition, it was found that the FAP of the diet was also a critical influence on litter size. This observation was based on a comparison of bitches consuming diets that were similar in fat content (20%) but contained different n-6 and n-3 fatty acid ratios (5:1 vs 20:1). Bitches receiving the 5:1 diet produced larger litters with fewer stillbirths and misconceptions than bitches consuming the 20:1 diets (Figures 2 & 3). The biological mechanism(s) for these occurrences

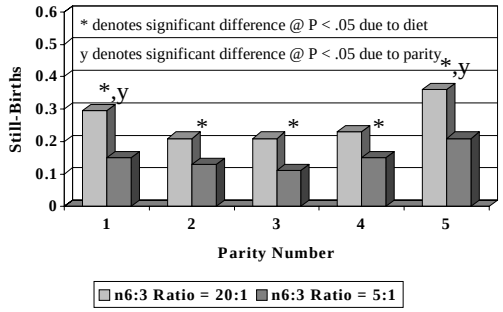
Figure 2. Effect of dietary FAP on litter size in the bitch.



* denotes significant difference @ P < .05

have not yet been identified in the canine, however, in other species it has been well documented that pregnancy and lactation dramatically reduce the maternal EFA status[13]. In addition, there is an increasing body of literature linking n-3 fatty acids with neural and lung development, which may lend a plausible explanation for the reduction in the number of stillbirths observed in the Kelley[1] study. Regardless of the mechanisms involved, it is clear that the FAP of a diet should be a one of the criteria evaluated when selecting a formula for the reproducing bitch. The diet should contain at least 18% fat and provide a balanced supply of both n-6 and n-3 fatty acids.

Figure 3. Effect of dietary FAP on still-birth number in the bitch.



Carbohydrates: The requirement of dietary carbohydrates for the reproducing bitch remains a debatable topic. Ramios[14] concluded that bitch performance and puppy viability is compromised in bitches fed carbohydrate-free diets. However, subsequent studies[15,16] have reported slightly contrasting conclusions. Both of the latter studies concluded that the bitch does not require dietary carbohydrates, provided that the dietary protein level is sufficient to provide substrates for gluconeogenesis. However, this conclusion does not eliminate the possibility that optimal nutrition may include a carbohydrate component. Thus the breeder should be encouraged to feed a diet that supplies 20 to 30% of the diet's calories as carbohydrates. While not common, there are commercial diets that are recommended for reproduction which supply 40% or more of its calories as carbohydrates. These diets should be fed with extreme caution, since they often have detrimentally displaced the protein or fat component in favor of the less expensive carbohydrates.

Vitamins & Minerals: Information on the effects of dietary vitamins and minerals on canine reproduction is limited. Historically, the majority of reports have been generated using deficiency or excess models. In a study using typical (~ 250% AAFCO minimum) dietary levels, Kuhlman and Rompale[17] found that bitches fed chelated mineral (zinc, copper and manganese) sources had larger litters when compared to bitches fed inorganic minerals. However, the majority of the available information for vitamin and mineral levels has arisen from mandatory AAFCO feedings. As mentioned earlier, passing an AAFCO feeding study only indicates that sufficient nutrient levels are present for reproduction whereas the breeder's goal should be to supply optimal nutrition not just adequate. This would include avoiding both nutrient deficiencies and excesses. The latter of these (nutrient excess) is a major concern, given the common practice by breeders to utilize dietary supplements, particularly mineral supplements for calcium.

Dietary Supplements: The use of dietary supplements for the gestating and lactating bitch has been the topic of many debates. Numerous publications have hinted at the benefits of nutrient

supplementation.[4,5,10] Some of the most commonly mentioned nutrients include protein, calcium, and vitamins. In practice, the only reason to utilize dietary supplements is when the diet fails to supply the needed amount of a given nutrient. However, the theory of supplementation is often much easier than putting it into practice. The majority of currently available commercial foods are formulated to provide a well-balanced supply of various nutrients, with "balanced" being the key word. A critical point to remember is that nothing can be added to or taken away from a diet without affecting the overall nutrient profile. One should also remember that few supplements are pure sources of a given nutrient. For example, cottage cheese (for calcium) and liver (for protein) are 2 commonly used diet supplements for the breeding bitch. However, since neither of these foods is composed of a single nutrient, the net result is that more than just the desired nutrient is delivered. For example, both cottage cheese and liver add large quantities of phosphorus. In fact, cottage cheese adds more phosphorus than calcium, the targeted nutrient (Table 3). Thus if incorporated into the diet, the calcium to phosphorus ratio of the diet will be altered. While the intention is good, it is important not to confuse an increase in the level of nutrition required with a need to change the diet profile. The bitch does require that nutrient intake be increased during the latter phase of pregnancy and lactation, however, the increase does not mean that the diet profile should be altered. It is critical to remember that during these periods, the bitch will be consuming a greater volume of food, which will increase her nutrient intake but maintain dietary balance with regard to the formulation (Table 3).

Table 3. Effect of dietary supplements on the nutrient balance of a commercial diet[a].

	Protein (g)	Fat (g)	Calcium (mg)	Phosphorus (mg)	Ca: P ratio
300 grams dry food	93	63	3500	2900	1.2:1
Plus	Total	Total	Total	Total	Total
½ cup cottage cheese	106	67.5	3563	3080	1.15:1
3 oz. Beef Liver	115	67	3509	3305	1.05:1
100 g Extra Food	124	84	4700	3850	1.2:1

[a]Based on the average analysis of Eukanuba® Premium Performance, guaranteed to contain 30% protein, 20% fat and 4452 kcal ME.

Conclusions: The use and expectations of the breeding bitch vary as widely as the personalities of their owners. Regardless of the expectation, there is little more satisfying to the dog breeder than producing a great litter of future champions. However, the level of success can be dependent upon many factors such as the age of the bitch, number of previous litters, and the plane of nutrition. There is a common link between most of the influences that affect bitch reproduction. The breeder, not the bitch, controls them. With very few exceptions, the bitch will devote everything to ensure that she produces and weans a healthy litter, be it 1 or 10 puppies. By establishing a sound reproductive management system, the breeder can ensure that the bitch remains healthy and is provided with the tools that she needs to achieve a high degree of reproductive success, including optimal nutrition.

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