SOME FACTORS AFFECTING
SPERMATOGENESIS AND FERTILITY
OF DAIRY BULLS

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THESIS

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AND FERTILITY OF DAIRY BULLS

by

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SOME FACTORS AFFECTING SPERMATOGENESIS AND FERTILITY OF DAIRY BULLS

INTRODUCTION

The development of artificial breeding associations has directed increased attention toward factors affecting dairy bull fertility. The extensive use of older bulls with creditable breeding records has increased the average service age and made it imperative that management practices be evolved which will prolong the useful life of desirable sires.

Before one can successfully promulgate recommendations for maintaining high fertility standards, there must be a clear understanding of the factors affecting fertility. Furthermore, accurate critera for measuring fertility must be developed.

Although number of services per conception is the most useful measure of fertility at present, it has the disadvantage of requiring considerable time for record accumulation. Various investigators, therefore, have correlated semen characteristics with breeding results and semen quality is routinely used for determining probable fertility in artificial insemination work. Results reported from the various laboratories have differed somewhat, however, and it is evident that some of the semen characteristics have little correlation with actual fertility of the bull.

Seasonal variation in semen quality and bull fertility have also been reported although the literature is not entirely in agreement. There are also some differences of opinion as to the causes of these variations.

This study was undertaken in an effort to determine the correlation between semen characteristics routinely examined and fertility of bulls used commercially for artificial insemination. It was also thought worth while to investigate some of the climatic factors which may affect dairy bull fertility under Michigan conditions.

REVIEW OF LITERATURE

Reproductive processes of domestic animals are complex functions undoubtedly affected by many interrelated forces. To entirely separate and discuss them one by one is impossible. However, in this thesis an effort has been made to separate these factors in so far as is practicable.

Anderson (4) has reviewed much of the available literature concerning artificial insemination of all classes of livestock.

Semen Characteristics

The need for rapid measures of semen quality highly correlated with fertility is self evident. Many workers have studied this problem with varying results.

Anderson (2) early observed that the volume of semen collected from sterile bulls is less than that obtained from bulls of high fertility. The concentration and initial motility of spermatozoa was lower in semen from the sterile bulls. Observations of the percent of abnormal spermatozoa show that sterile bulls averaged 17.6 percent abnormals while fertile bulls averaged 8.1 percent.

Conflicting results were obtained by Dougherty and Ewalt (28) who were unable, with limited data, to establish any correlation between motility, percent of abnormal spermatozoa, concentration and actual fertility as determined by breeding results. Swanson and Herman (79) substantiated and furthered the work of Dougherty and Ewalt. The Missouri workers were also unable to correlate concentration, initial motility, percent of abnormal spermatozoa, volume, or pH with fertility. The property most nearly correlated with fertility was the length of spermatozoa survival with vigorous motility when the semen was stored at 40° F. When separate ejaculates from the same bull were considered, initial motility was roughly correlated with viability in storage.

These workers found, as had Donham and associates (27) ten years before, that separate ejaculates from the same bull may vary considerably in their characteristics.

Lasley and Bogart (41) obtained somewhat different results in a study of Missouri range bulls used for artificial breeding. In this study volume, concentration and total spermatozoa per ejaculate were positively correlated with fertility. Resistance of the spermatozoa when stored in egg yolk buffer was also correlated with fertility. These workers agreed, however, that initial motility and percent of abnormal spermatozoa were not significantly correlated with breeding results. They further observed that the percent of spermatozoa surviving a cold shock in non-diluted semen is not correlated with fertility. A later study by Lasley (42) indicated that semen rated at 40 percent motility is not as fertile as semen rated 61 - 70 percent motility.

Considerable variation was found between semen samples taken from the same bull and between bulls in this trial. One of the important factors causing semen variation was the frequency of collection. Semen volume, number of spermatozoa per ejaculate, percentage of abnormal spermatozoa and fertility of the bull increased as the interval between collections lengthened.

Swanson and Herman (80) in 1944 repeated their earlier study with similar results except for finding a significant curvilinear relationship between motility and conception rate. Although semen with a low motility rating was of lowered fertility, that containing 45 percent or more motile spermatozoa gave nearly as high conception rates as semen with a higher motility rating.

Mercier (46) and Mercier and Salisbury (47) obtained positive correlations between concentration and fertility and negative correlations between methylene blue reduction time, percent of abnormal spermatozoa and fertility. Not only were there significant differences between the semen characteristics of first and second ejaculates of the same bull and between bulls but a strong breed difference in fertility was observed. The study involved bulls of the Holstein and Guernsey breeds. The Holstein sires were superior in many of the semen characteristics examined and were of higher fertility as determined by breeding records.

That the semen from sterile bulls is characteristically alkaline has been shown by Anderson (3) and confirmed by Raps and Cannon (60). The increased alkalinity of sterile bull semen is associated with lowered volume, concentration and decreased motility according to Anderson. He also states that the second ejaculate is normally more acid than the first and is higher in spermatozoa concentration and motility. Raps and Cannon have also presented evidence indicating lowered fertility at high pH. As would be expected, the pH varied between bulls but tended to remain constant in the same bull.

Reid and coworkers (62) have recently conducted an extensive investigation into the correlation of the drop in pH of incubated semen to other semen characteristics. Highly significant correlations were found between the drop in pH and concentration, initial motility, viability, and percent of morphologically abnormal spermatozoa.

Laing (39) suggested that, although fertility appears to be impaired at low levels of semen quality, other factors operate to vary breeding results when semen of high quality is used. Mercier and Salisbury had the same opinion regarding Holstein and Guernsey fertility differences. The latter workers state their belief that the breed differences found are more than would be expected from the differences in semen characteristics alone.

Table I summarizes the correlations between semen characteristics and fertility as reported in the literature reviewed.

It is obvious that, although there is agreement on the relationship of some semen characteristics to fertility, the situation is not clear regarding the correlation between all semen qualities and breeding results. Apparently other factors operate to influence the results of studies of this kind. Additional investigations are necessary if uniform methods of semen examination which will consistently indicate its fertility are to be developed.

Seasonal Variation

Livestock breeders have long been aware that some classes of farm livestock are seasonal breeders. Although they may not be completely sterile during periods outside the mating season, their fertility is much impaired.

Parker and McSpadden (53) have found seasonal differences in semen quality and fertility of Rhode Island Red males. The volume and density of the semen and the total number of spermatozoa were at peak levels during April and May. Fertility levels were higher from December to May than from June to November.

A survey of conception records of milk goats in Great Britain has been made by Asdell (6). Conception rates gradually increased from August to October and then declined to a minimum during May. Very few conceptions occurred during the late spring and early summer months.

Turner (87) made a similar study of milking goats in the United States. The results of this survey are very similar to those obtained by Asdell who found that in favorable seasons, does may breed in August, regular estrus cycles occurring from September to February or March and an anestrus period

TABLE I. SEMEN CHARACTERISTICS CORRELATED WITH FERTILITY

	Anderson 1940	Dougherty	Swanson 1941	Lasley	Swanson 1944	Mercier	Anderson 1942	Raps
Volume	+		0	+				
Concentration	+	0	0	+	0	+		
Initial Motility	+	0	0	0	+			
Total Sperm				+				
Percent Abnormals	+	0	0	0	0	+		
pH			0		0		+	+
Survival Time			+	+	+			
Resistance to cold shock				0				
M B R T						+		

Legend = 0 Not correlated with fertility
+ Correlated with fertility

from April through July.

Shropshire rams underwent three periods of spermatogenic activity according to McKenzie and Berliner (45). Fertility was high from October to January, medium during the spring and very low in the summer months. Hampshire rams were of high fertility from August to January and were not as severely depressed in semen quality during the summer as the Shropshire rams.

Green (33) found the quality of ram semen decreases slightly but constantly from January to May. During June and July numbers of abnormal forms increased markedly. Density decreased from May to August. Semen quality improved during the fall reaching a peak in December.

Ram semen studied by Phillips and coworkers (56) showed significant seasonal differences in motility, number of spermatozoa per cc., total spermatozoa, and abnormal forms. Semen volume did not vary significantly. Karakul sheep bred during the fall with few conceptions occurring from late winter to early summer according to another study by Phillips and associates (57).

A number of workers have studied seasonal variation in semen quality and fertility of bulls. Miller and Graves (50) observed that the Beltsville herd required more services per conception in July, August and September than during the rest of the year. The late winter and early spring months were periods of high fertility in Dawson's report (25). Morgan and Davis (51) found fertility to be highest from October to January and low in February, March, August and September under Nebraska conditions. Sires used for artificial insemination in New Jersey were of lowest fertility in February and

and March according to Weatherby and associates (90). Breeding records of the Purdue University herd were examined by Erb and coworkers (30): May, with an average of 74.3 percent, was the month of highest efficiency and August, with 58.2 percent, had the lowest breeding efficiency. Seath and Staples (74) determined that Louisiana dairy herds required more services per conception in the summer than during the other seasons. In a later study of Louisiana dairy herds, Seath and associates (75) found breeding efficiency to be highest in the fall and winter and lowest during the spring and summer.

Elliott, Salisbury and Brownell (29) presented evidence which conflicted with the previous studies on seasonal variation in bull fertility. These workers found fertility of bulls used for artificial insemination in New York State to be low in midwinter and spring but high in August and September. Hilder and associates (36) also found February and March to be months of low fertility but disagreed with Elliott and coworkers in finding July, August and September to be months of lowest fertility. Mercier and Salisbury (48) (49) have recently made an extensive analysis of seansonal variation in fertility of bulls used in New York State and Eastern Canada. The percent of successful services was significantly lower in winter and spring and higher during the summer and fall.

An analysis of 51,587 breeding months in the Cornell University herd by Clapp (24) showed an average of 2.11 services per conception. There appeared to be a trend toward greater efficiency from March through July. Breeding efficiency dropped sharply in August and continued at a low level through February. July required 1.90 services per conception and February 2.29 services per conception.

Semen quality examinations by Erb and associates (31) showed it to be of superior quality in the spring and low in quality during the summer. The average semen volume and initial motility was least in July, August and September. The length of sperm survival was least in August and lower in July, September and November than during the other months. July, August and September were also months of high percentages of abnormal spermatozoa. Spermatozoa concentration and total spermatozoa per ejaculate were at high levels furing April, May and June.

Observations were made by Phillips and coworkers (55) on volume, motility, number of spermatozoa per cc., total abnormal spermatozoa and proportions of abnormal heads, necks, middle pieces and tails of semen collected from beef and milking Shorthorn bulls. Significant or highly significant seasonal differences were found in concentration, total sperm, and proportions of abnormal heads, necks, middle pieces and tails. Of 1,135 matings, 59.6 percent resulted in fertile matings in April and 40.8 percent in August.

Swanson and Herman (81) studied monthly variations in initial motility, volume, concentration, livability in storage, pH and morphology of semen from bulls used in the University of Missouri dairy herd. The pH of the semen was significantly lower in the summer than in the fall. Initial mobility and viability in storage were lowest in the winter.

Salisbury (71) found a highly significant decrease in the percentage of motile spermatozoa during early spring and highly significant differences between months in total spermatozoa per ejaculate. The lowest spermatozoa count was in August. There were, however, no significant fertility differences from month to month.

Significant individual and monthly differences in density, motility, pH and percent of successful collection attempts have been indicated by Anderson (5). He also noted marked seasonal variation in semen quality but cautions that there is considerable variation between bulls, farms and years.

Table II shows the seasonal variation in fertility found by the authors reviewed in the foregoing and Table III presents a summary of the seasonal effects upon semen quality.

Endocrine Relationship to Fertility

The well established fact that there is a seasonal effect on semen quality and fertility of domestic animals suggests that climatic factors such as light and temperature may be responsible. If such is the case, a logical mode of action is through disturbances of the endocrine system which is known to control development and functioning of the primary and secondary sex organs.

Endocrine Interactions

Knowledge of the interactions of the hormones affecting sexual activity is meager. Some facts, however, have been well established. That the anterior pituitary gland must be present for reproduction to take place is accepted. It is known that the anterior pituitary gland secretes gonadotropic hormones which control the development and action of the gonads.

The thyroid gland also exerts an effect upon the gonads through its effect on cell metabolism. The thyroid gland also aids in regulating the rate of secretion of the anterior pituitary hormones. The anterior pituitary gland secretes a thyrotropic hormone which aids in controlling the amount of thyroxin

TABLE II. SEASONAL VARIATION IN FERTILITY

Author	Species	High fertility	Low Fertility
Parker	Fowl	Spring	Fall
Asdell	Goat	Fall	Late spring Early summer
Turner	Goat	Fall	Spring-summer
McKenzie	Ram	Fall	Summer
Green	Ram	Late fall	Summer
Phillips	Karakul sheep	Fall	Late winter to early summer
Miller	Bull		Summer
Dawson	Bull	Late winter Early spring	
Morgan	Bull	Fall Early winter	Early spring Summer
Weatherby	Bull		Late winter
Erb	Bull	May	August
Seath	Bull	Fall-winter	Spring-summer
Phillips	Bull	April	August
Elliott	Bull	Late summer	Mid-winter Spring
Hilder	Bull		Late winter Summer
Clapp	Bull	Spring	Late summer Fall
Mercier	Bull	Summer-fall	Winter-spring

TABLE III. SEMEN CHARACTERISTICS AFFECTED BY SEASON

	Parker	Green	Phillips	Erb	Phillips	Swanson	Salisbury	Anderson
	Fowl	Ram		Bull				
Volume	+			+				
Concentration	+	+	+	+	+			+
Total Sperm	+		+	+	+		+	
Motility			+	+		+	+	+
Percent Abnormals		+	+	+	+			
Survival Time				+		+		
pH						+		+

+ = Affected by season

secreted by the thyroid gland and gonadotropic hormones which regulate the activity of the gonads.

The gonads secrete hormones which depress the rate of secretion of gonadotropic hormones from the anterior pituitary.

It is logical to expect, therefore, that any factor which affects any one of these glands may exert a secondary effect on any of the others.

Effect of the Thyroid Gland

An extensive review of the physiology of thyroactive substances has been published by Reineke (65).

The exact mechanism by which thyroid functioning affects spermatogenesis and fertility is still a matter of conjecture.

The development of a relatively inexpensive synthetic compound having thyroidal activity by Reineke and Turner (64) (88) and realization of the value of thiouracil as a goitrogenic substance (9) has stimulated research into the thyroidal relationship to fertility of domestic animals.

Smelser (76) tested the effect of thyroidectomy of male rats on the gonadotropic activity of the anterior pituitary gland. No effect upon the amount of gonadotropic hormone in the anterior pituitary was found although the authors suggested that the release of the hormone into the blood stream is reduced. A definite depression of testicular function was observed and sperm production was decreased. The weight and morphology of the testes was not affected although reduced weights of the accessory glands indicated a reduction in testis hormone secretion. That the relationship between thyroidectomy and gonadotropic activity of the anterior pituitary gland is not clear is indicated by the fact that Reineke and associates (63) found decreased testes size and decreased gonadotropic hormone in the anterior pituitary of thyroidectomized goats.

Reineke and Turner (64) pointed out that after domestic animals have completed their growth the secretion of the thyroid gland gradually decreases lowering body metabolism and the animals begin to fatten; sluggishness, decreased sex drive and lowered fertility of bulls and irregular estrus cycles of cows are often found. Administration of thyroactive material will aid in returning these hypothyroid animals to normal sexual activity.

Many species of animals undergo a period of anestrus during the summer months. Thyroxine or thyroprotein administration has been found to inhibit this summer sterility. Thiouracil administration or thyroidectomy has caused spermatogenic effects similar to those normally found in summer sterility. These observations have indicated an effect of temperature upon the action of the thyroid gland and Dempsey and Astwood (26) have shown that the thyroid secretes less hormone when the temperatures are high.

Wells and Zealesky (91) changed ground squirrels from seasonal to continuous breeders by subjecting them to a low environmental temperature.

Jaap (37) fed daily doses of 0.25 to 1.0 gm. of dessicated thyroid to Mallard drakes whose testes normally increase in size during late winter and early spring. The testis size of those drakes receiving the thyroid preparation ranged from two to ten times the size of the controls. Increased spermatogenesis in proportion to the increase in testis size was also observed. The largest testes contained large numbers of fully formed spermatozoa while the smaller testes showed only division figures.

Testis growth of ducks, which is stimulated by light, is inhibited for a short time by thyroidectomy according to Benoit (12). Since the effect gradually decreases, it is probable that the thyroid is only one of the factors involved.

Blivaiss and Domm (16) observed that Brown Leghorn cockerels thyroidectomized when 4 to 20 days old exhibited only early stages of spermatogenesis by the time they were 8 months old.

When White Leghorn cockerels were fed 100 mg. of dessicated thyroid three times weekly, the usual seasonal decline in semen volume which occurs during May, was increased according to Titus and Burrows (85). When the treatment was discontinued semen volume temporarily increased indicating the dosage level was probably too high.

Greenwood and Chu (34) found that feeding 20 mg. of dessicated thyroid to a Brown Leghorn male completely prevented the regression in testis size and cessation of spermatogenesis observed in thyrodectomized controls.

Martinez-Campos (44) found that when 0.04 percent of thyroprotein was added to the ration of poultry marked increases in semen volume and total spermatozoa occur. Spermatozoa concentration also increases but to a lesser degree. At 0.01 percent and 0.02 percent levels the thyroprotein caused only slight increases in spermatogenesis. Th~~is~~se data ha~~s~~ been confirmed by Wilwerth (93) who also obtained marked increases at the 0.04 percent level. When fed as 0.08 percent of the ration thyroprotein greatly depressed the semen volume, concentration and total spermatozoa. These data would indicate therefore that the optimum level is approximately 0.04 percent of the ration for male fowl.

Gunn (35) found that seminal degeneration and low fertility of rams was associated with temperature. Berliner and Warbritton (13) have shown that temperature fluctuations affect the thyroid and, through it, the gonads of sheep. Bogart and Mayer (17) (18) concluded that a lack of thyroxine, inhibited by high summer temperatures, is a major cause of summer sterility in rams. Semen variations associated with summer sterility were decreased or prevented by feeding or injecting thyro-active materials providing the interstitial cells had not previously become degenerated. In the fall, when rams are normally fertile, thiouracil administration produced changes similar to those observed during the summer. Thyroxine counteracted the effects of thiouracil. That the effect of heat is not always produced by direct action on the testes is indicated by the fact that the temperatures causing relative sterility may be below the normal body temperature of the ram.

Turner and coworkers (89) were able to improve the quality of semen from a ram with good libido but low quality semen by feeding thyroprotein. They also increased the libido of a Toggenburg buck by feeding one gm. of thyroprotein daily.

Petersen and associates (54) thyroidectomized a male Jersey calf and observed its sexual development. Although his testes development was apparently normal, there was a complete absence of libido. Semen samples obtained by massaging the ampulla were fertile. Feeding 25 gm. of dessicated thyroid over a period of three days restored normal sexual behavior. These findings led to the conclusion that although libido may be controlled by the thyroid gland, spermatogenesis is apparently unaffected.

When a Jersey heifer was thyroidectomized she failed to exhibit any estrus cycles according to Brody and Frankenbach (21). Thyroprotein administration resulted in several observed estrus cycles.

Spielman and associates (78) also observed the lack of estrus in thyroidectomized cattle but reported that regular ovulation does occur. Artificial insemination as long as 453 days after thyroidectomy resulted in conception and the birth of normal offspring.

In field trials, Reineke (66) improved vigor and libido in ten of fourteen bulls with poor breeding records through feeding 0.5 to 1.0 gm. of thyroprotein per hundred pounds of body weight. Limited conception records indicated improved spermatogenesis. Knoop (38) fed eleven problem bulls a supplement of potassium iodide and skim milk. Semen of all the bulls showed improvement in one or more of the following qualities: volume, total spermatozoa, percent of living spermatozoa and initial motility. Improvement in libido was also evident.

Schultze and Davis (73) fed 1.0 to 1.24 gm. of thyroprotein per hundred pounds body weight daily to seven bulls for thirty days. Initial motility of the group showed definite improvement. The percent of abnormal spermatozoa changed little except in one bull where it decreased markedly. This particular bull formerly had a very high percentage of abnormal spermatozoa. Conception rates of five of the bulls increased from an average of 51.7 percent to 55.7 percent within the first ten days. After ten days the conception rate increased to 58.6 percent and during the ten days after feeding stopped the conception rate further increased to 60.4 percent. Seven other bulls used as controls exhibited no changes in breeding efficiency during this time.

The low summer breeding efficiency found among Louisiana dairy bulls by Seath and Staples (74) was attributed to the high temperatures found in that area. Clapp (24) made a similar suggestion regarding the lowered efficiency of the Cornell University herd during the month of August.

Effect of the Anterior Pituitary Gland

It has previously been indicated that it is probable that the effects of temperature and thyroid activity upon spermatogenesis are largely a matter of stimulation or inhibition of the activity of the anterior pituitary gland. There is evidence, however, that in some cases climatic factors may act directly upon the anterior pituitary.

Light has been found to stimulate spermatogenesis, presumably by acting directly upon the anterior pituitary gland. Rowan (68) has reviewed the literature regarding the effects of light upon spermatogenesis in some fifty species of animals, birds and fish. He has suggested that the effect of light on birds may simply be one of keeping them awake and active. This activity in itself stimulates the anterior pituitary gland to produce increased amounts of the gonadotropic hormones (67).

Bissonnette (14) however, has presented rather convincing evidence that the effect of light is through the eye and along nerve channels to the pituitary. There are species differences in response to light stimuli. Some species increase in sexual activity as the days grow longer and others decrease in activity. The response in either case appears to be in direct proportion to the amount of stimulus.

Fiske (32) demonstrated that the anterior pituitaries of female rats kept in the dark were low in follicle stimulating hormone and high in leutinizing hormone. As would be expected, the esturs cycles were abnormal. The pituitaries, gonads and vesicles of male rats kept in the dark were smaller than those kept in the light.

Through increasing periods of illumination from October 10 onward, Bissonnette and Csech (15) were able to change the breeding season of raccoons from February to December.

When Southdown sheep were transported across the equator they changed their breeding season to correspond with the hours of daylight even though it meant two breeding seasons in one year according to Marshall (43).

Wilson (52) has shown that exposure to direct sunlight is not necessary for normal reproduction of cattle.

A decrease in the number of services per conception when cattle were exposed to unrestricted sunlight was found by Quinlan and Roux (59). Anderson (1) has presented evidence of a correlation between periodicity and duration of estrum in cattle and hours of sunshine. Clapp (24) attributed the variations noted in breeding efficiency of the Cornell University dairy herd to be largely due to changes in the length of day. Mercier and Salisbury (48) (49) have extensively studied the effect of light upon breeding efficiency of dairy cattle kept under New York and eastern Canadian conditions. In both cases light and breeding efficiency were significantly correlated.

Variable results have been obtained when gonadotropic hormones were used to treat sterility in cattle. Bottomley and coworkers (19) were able to restore fertility to three bulls and several cows through injecting varying amounts of human pregnancy urine extract. Asdell and associates (7), however, were unable to note any results from administering gonadotropic hormones to sterile cows. The latter workers caution that the high rate of spontaneous recoveries often encountered render it difficult to give correct interpretation to the findings.

Other Factors Affecting Fertility

Effect of Age

A difference in breeding efficiency between young and old bulls was found by Miller and Graves (50) in a study of the Beltsville herd. Young bulls appeared to be more fertile than mature bulls when bred to fertile cows.

Tanabe and Salisbury (84) found cows increase in conception rate up to four years. Between five and seven years they remain at a high level of fertility and then gradually decline with advancing age. Young bulls, however, gave greater breeding efficiency than older bulls. The peak conception rate was for two year old bulls although those from one to three years old were of higher fertility than those of other ages.

An age difference in response to seasonal variation was observed by Mercier and Salisbury (48). Young and old cattle appeared to be more readily influenced by climatic conditions than mature cattle. Bulls under six years of age did not respond to light variations as well as older bulls. The authors suggest these younger bulls may be more subject to other influences than older bulls.

Baker and Queensberry (10) were unable to find any fertility differences between old and young range beef bulls. However, since the older bulls had been selected for high fertility it is likely that any differences were obscured.

Heifers required more services for their first conception than for later conceptions in a study by Bowling and associates (20). A higher fertility level among young bulls was apparent since the heifers required fewer services per conception when bred to them than when mated to older bulls. There was a gradual decrease in breeding efficiency of bulls as they grew older. This decrease was significant with six year old bulls.

Studies among human females by Ashley (8) indicated that many of them are sterile for up to several years after puberty due to lack of ovulation. This same sterility of immature females has been claimed for the mouse, rat and cow. These findings may indicate one of the reasons for a lower conception rate among heifers bred for the first time.

Effect of Exercise

That proper exercise contributes to the physical well-being of the bull and increases spermatogenic activity has been indicated by some workers. Bartlett and Perry (11) found regular exercise of the bull increases the volume of the semen. Woodward (94) increased motility and longevity of the spermatozoa by daily exercise. Service time was also decreased in the case of slow bulls. The lower quality of semen obtained during February and March by Weatherby and associates (90) was believed to be due to lack of exercise during these months.

Effect of Time of Breeding

Trimberger (86) has found the duration of estrum to range from 2.5 to 28 hours with an average of 16.9 hours. Ovulation occurs three to 18 hours, with an average of 10.5 hours after the end of estrum. Breeding results indicated a trend toward higher conception rates if cows were bred six to 24 hours before ovulation. Conception rates were low among cows bred within 12 hours after ovulation.

These results indicate that cows first observed to be in heat in the morning should be bred that afternoon, and those in heat in the afternoon should be bred the following morning.

The findings of Trimberger confirmed earlier data presented by Werner and coworkers (92) which showed that most cows ovulate by the end of the second half day following estrus. In this study 56 of 113 cows were in heat for only one-half day.

Laing (40) has reported similar findings in England. Estrus varied in length from six hours in December to 30 hours in July. The yearly average was 16.1 hours which is very close to that reported by Trimberger (86).

Except for the winter months Laing found hand breeding to be less efficient than free service of the cows. A suggested explanation is that often, when breeding time is controlled, the cows are bred early in the heat period and the spermatozoa die before ovulation takes place. No pregnancies resulted in this trial when cows were bred more than 16 hours before ovulation.

Effect of Ascorbic Acid

Of 29 bulls which Phillips and coworkers (58) treated with ascorbic acid, improved fertility occurred in all but four. One of these rapidly improved when vitamin A was administered. One bull which failed to respond to ascorbic acid treatment had atrophied testicles. Eleven of the bulls were returned to active service after treatment although they were to have been discarded prior to administration of the ascorbic acid.

Scheidenhelm (72) recently tested the effect of feeding chlorobutanol to problem bulls and cows. An increase in libido was evident and the number of services per conception was reduced. Young sires were more readily affected than older bulls. Chlorobutanol administration also aided in settling some difficult cows.

Reid and Sykes (61) presented evidence which indicated that ascorbic acid acts in the guinea pig by stimulating the production of gonadotropic hormones by the anterior pituitary gland.

Effect of Hyaluronidase

Hyaluronidase has been shown to disperse the cumulus cells surrounding an ovum in vitro but its role in actual fertilization is uncertain.

Swyer (82) found a close correlation between hyaluronidase content of the semen and numbers of spermatozoa in rabbits, bulls, boars, and men. No correlation was evident in the case of dogs and fowl. The fact that semen from cryptorchids contains no hyaluronidase indicates that it is secreted by the seminiferous epithelium rather than by the accessory glands.

In a later study Swyer (83) found at least three-quarters of the hyaluronidase in semen is associated with the spermatozoa. The spermatozoa appear to act as liberators rather than producers of the hyaluronidase.

Recent studies by Chang (23) have led him to conclude that the seminal fluid rather than hyaluronidase really increases the fertilizing capacity of spermatozoa.

Summary of Review of Literature

Reports of the relationship of semen quality to bull fertility have varied (2) (28) (41) (47) (79) (80). Recent investigations (60) (62) indicate that initial semen pH or the fall in pH after incubation for one hour may be the best laboratory measure of semen fertility.

Many semen characteristics have been shown to be influenced by climatic changes (5) (31) (55) (71) (81). That the seasonal variation in fertility is not uniform from one geographical location to another is evident (31) (49) (75). Several workers (17) (26) (35) have demonstrated that fertility may be affected by temperature while others (15) (48) (49) (77) have shown an effect of light variation upon spermatogensis and fertility.

Other factors such as age (84), amount of exercise (11) and time of breeding (86) may affect breeding results. Improved fertility has resulted in some cases through ascorbic acid therapy (58). The hyaluronidase content of the semen may also be a factor in determining male fertility (82) although its role in fertilization is not known.

OBJECT

The purpose of this investigation is to study the relationship between semen qualities routinely determined in an artificial breeding cooperative and actual fertility of the bulls involved and to investigate the effect of light and temperature upon spermatogenesis and fertility under southern Michigan conditions.

EXPERIMENTAL PROCEDURE

Source of Data

Records of the Michigan Artificial Breeders Association whose bull stud is located at East Lansing, Michigan were the source of data for this study.

Scope of the Study

Semen and breeding records of 24 fertile bulls of the Holstein and 17 bulls of the Guernsey breeds used by the association between June 1, 1944 and April 30,1947 are included. More than 4,000 semen collections and over 107,000 breeding records are represented.

Management of the Bulls

Until late in 1945 bulls of the two breeds were housed together in a poorly lighted barn equipped with box stalls. The Guernseys were then moved to another poorly lighted barn and were confined in stanchions.

Both groups received the same ration which consisted of a 15 percent protein concentrate mix and average quality alfalfa-bromegrass hay. The ration met all nutritional requirements so far as is known.

None of the bulls received adequate exercise. During warm weather in 1944 and 1945 they were tied out of doors much of the time but the amount of exercise received was limited. Later the number of bulls became too great to be staked out. A mechanical bull exerciser was obtained but has not worked satisfactorily. During cold weather the bulls have been given even less exercise.

It was planned that the bulls would be ejaculated into an artificial vagina, with a cow chronically in heat as a teaser, at weekly intervals. However, because of fluctuations in demand and other reasons, the intervals varied somewhat. Usually the variation was toward longer periods between collections. In most cases the bulls were ejaculated twice with a short interval between the first and second collections. In a few cases third collections were made but these have been omitted from this study.

<u>Method of Semen Handling</u>

Semen collections were made on Monday, Wednesday and Friday mornings of each week. At first all of the bulls were ejaculated in a breeding shed attached to the laboratory of the association and the semen taken into the laboratory immediately after the collection was made. After the Guernsey bulls were moved to the second barn, which was located about an eighth of a mile from the laboratory, they were ejaculated there. As soon as it was collected, the test tube containing the semen was placed in a thermos bottle containing water at 35-40° F. and then taken to the laboratory by automobile. It normally was in the laboratory within five to ten minutes after the collection.

In the laboratory, the semen volume was first recorded and a sample taken for concentration determination in a photoelectric colorimeter, (Salisbury and coworkers (70)), and motility rating under the microscope. The concentration is reported as thousands of spermatozoa per mm^3. and initial motility as percent of progressively motile spermatozoa. If the concentration and motility were adequate, the semen was diluted with buffered egg-yolk citrate prepared by the method of Salisbury and associates (69) and placed in a room refrigerated to 40° F.

The diluted semen was then packaged in special containers containing ice for parcel post shipment to the inseminators. The semen was dispatched the same morning in which it was collected and received by the inseminators that afternoon or the next morning. Thus the semen used was never more than three days old when the cows were bred.

Tabulation of Data

Records of each attempted collection from each bull whether the semen was used or not was considered and monthly averages tabulated for the following:

1. Number of attempted collections.
2. Number of successful collections.
3. Number of collection failures.
4. Time required for service.
5. Semen volume per ejaculate.
6. Spermatozoa concentration per ejaculate.
7. Total spermatozoa per ejaculate.
8. Percent initial motility.
9. Number of cows bred.
10. Number of cows returning for service within 30 to 60 days after breeding.
11. Percent of cows not returning within 30 to 60 days after service.

The monthly averages were then combined with the same months over the thirty-five month period covered by this study. The monthly data, therefore,

~~is~~ are presented in twelve monthly periods.

Seasonal data were obtained by combining the monthly data into four seasons composed as follows:

Winter	Spring	Summer	Fall
December	March	June	September
January	April	July	October
February	May	August	November

In the calculations to determine the percent of cows not returning for service within 30 to 60 days after insemination the number of cows bred and the number of cows returning for service were totaled for each of the twelve monthly periods and the percent of non-returns determined. Seasonal variation in percent of non-returns was calculated in a like manner.

In the determination of the relationship between semen characteristics and fertility only that semen shipped to the inseminators was considered.

RESULTS

Tables IV and V and Figures 1 through 4 summarize the monthly and seasonal data on semen quality obtained in this study.

Volume

With the exception of the months of June and July the Guernsey bulls excelled the Holsteins in semen volume. This was the only semen characteristic in which the Guernseys were superior to the Holsteins. The Guernsey bulls produced a greater volume of semen per ejaculate during each of the four seasons than the Holstein bulls. Both groups of bulls gave a greater volume of semen per ejaculate during the spring months than at other times during the year. Fall was the season of least volume for the Holsteins while the Guernsey bulls were at equally low levels during the summer and fall.

Concentration

Semen from the Holstein bulls was consistently of higher spermatozoa concentration than that from the Guernsey bulls. Considerable monthly variation in concentration was found. The season of highest concentration was found to be the summer while the lowest concentration was found during the winter for both breeds.

Total Spermatozoa

As would be expected from the greater semen volume of the Guernsey bulls and higher concentration of spermatozoa from the Holstein bulls, the total number of spermatozoa per ejaculate did not differ greatly between the two breeds. An examination of the monthly averages shows the Holsteins were in

TABLE IV. MONTHLY VARIATION IN SEMEN QUALITY

Month	Volume Ml.		Concentration 1000/mm³.		Total Spermatozoa Billions		Initial Motility Percent	
	H	G	H	G	H	G	H	G
January	5.3	5.5	1232	1008	6.53	5.54	70	66
February	5.7	6.1	1185	1063	6.75	6.48	71	69
March	5.8	6.4	1205	1128	6.99	7.21	74	72
April	5.6	6.6	1265	1058	7.08	6.98	74	70
May	6.2	6.3	1267	1238	7.86	7.80	77	76
June	5.7	5.6	1248	1188	7.11	6.65	75	74
July	6.0	5.5	1230	1186	7.38	6.52	75	75
August	5.6	6.1	1359	1201	7.61	7.33	73	73
September	5.3	5.9	1237	1127	6.56	6.65	74	74
October	5.1	5.5	1193	1104	6.08	6.07	73	71
November	5.5	5.8	1241	1072	6.83	6.22	69	68
December	5.1	5.7	1196	1063	6.10	6.06	70	67
Av.	5.6	5.9	1238	1120	6.91	6.63	73	71

TABLE V. SEASONAL VARIATION IN SEMEN QUALITY

Season	Volume Ml.		Concentration $1000/mm^3$		Total Spermatozoa Billions		Initial Motility Percent	
	H	G	H	G	H	G	H	G
Winter	5.4	5.8	1204	1045	6.49	6.03	70	67
Spring	5.9	6.4	1246	1141	7.31	7.33	75	73
Summer	5.6	5.7	1279	1192	7.36	6.83	74	74
Fall	5.3	5.7	1224	1101	6.49	6.31	72	71

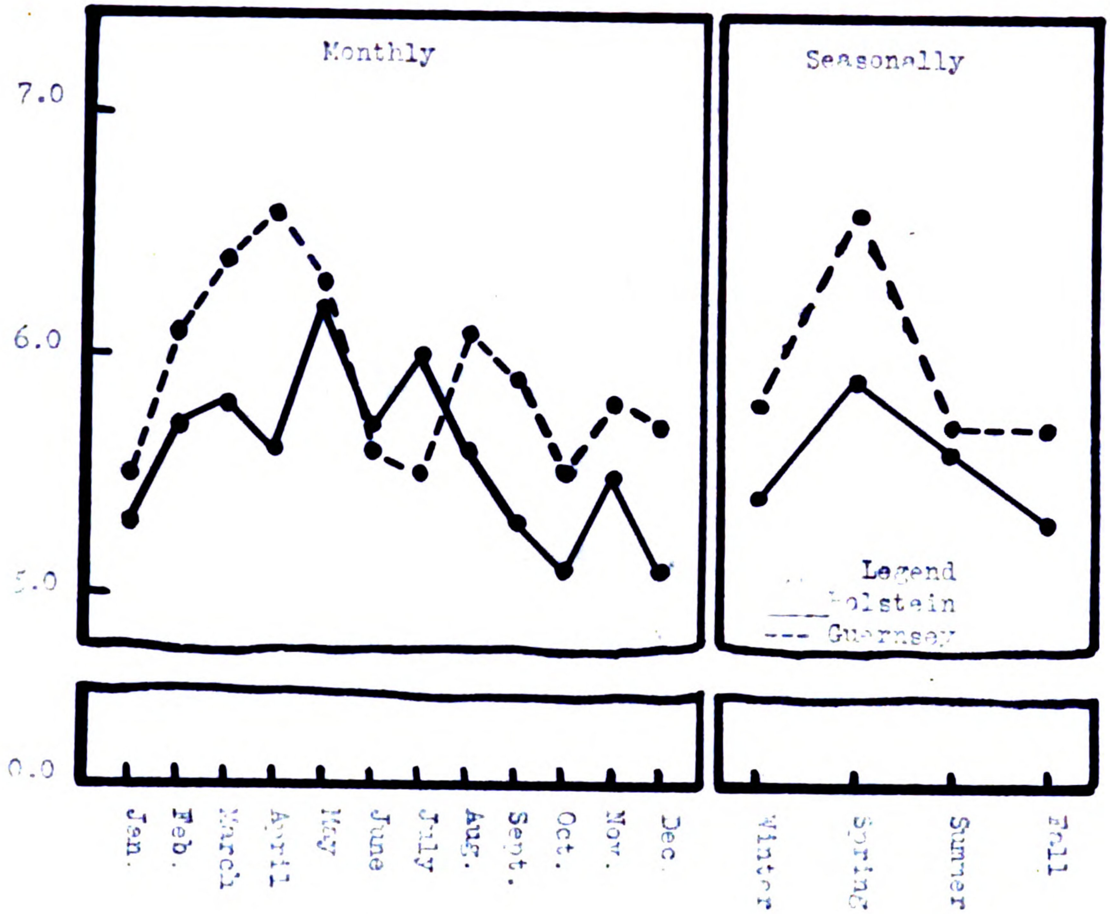

Fig. 1. Ml. Semen Per Ejaculate.

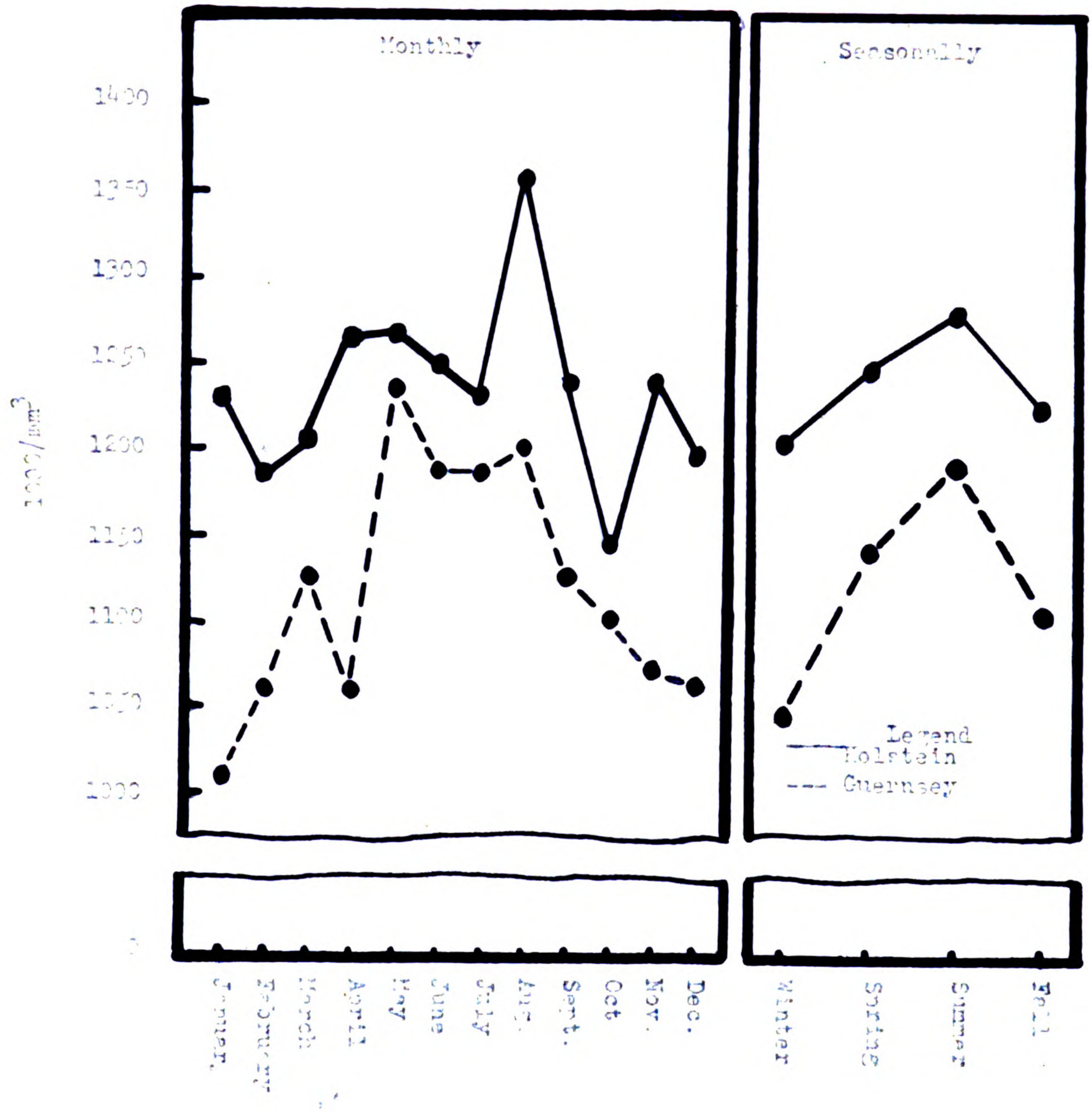

Fig. 2. Concentration of Spermatozoa Per Ejaculate.

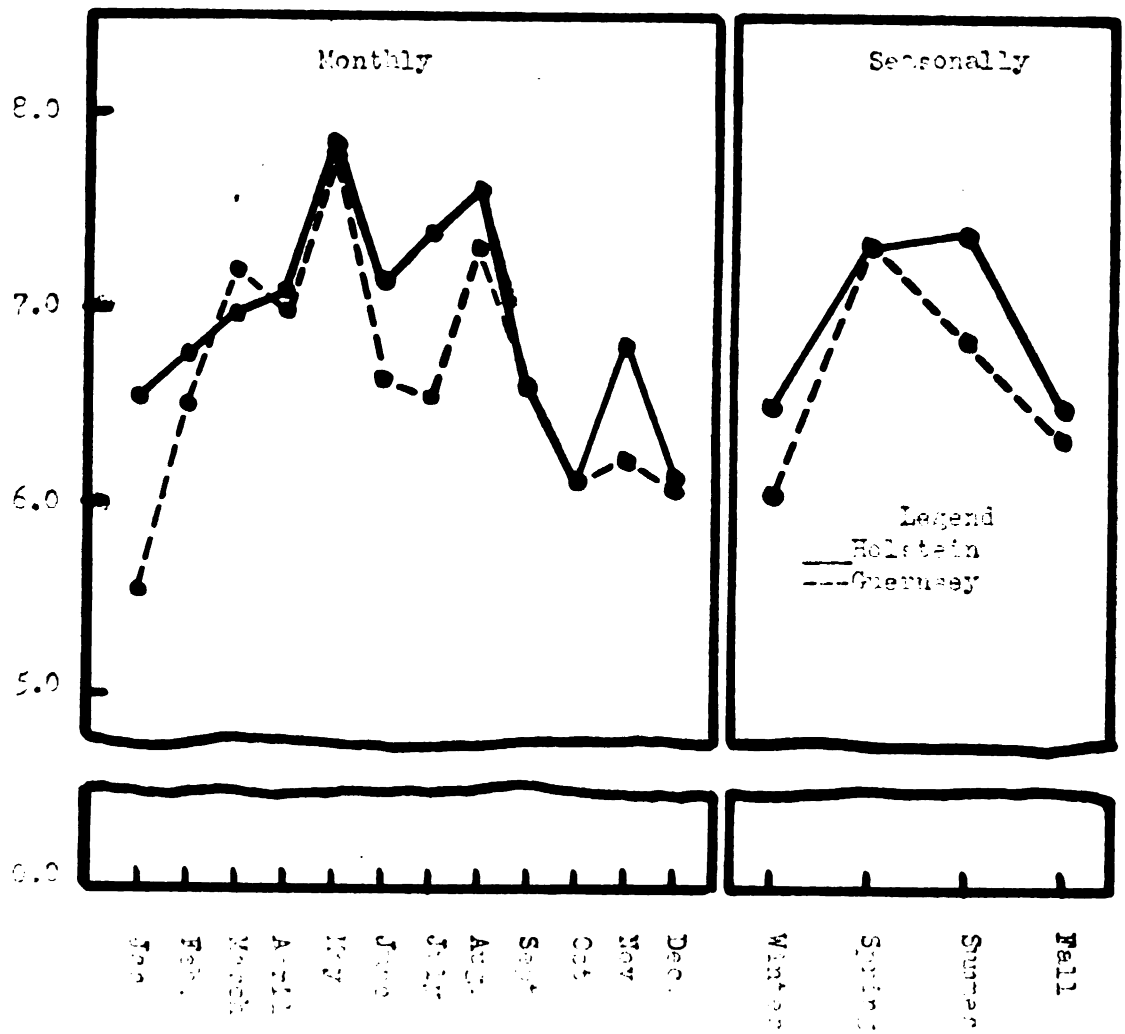

Fig. 3. Billions of Spermatozoa Per Ejaculate.

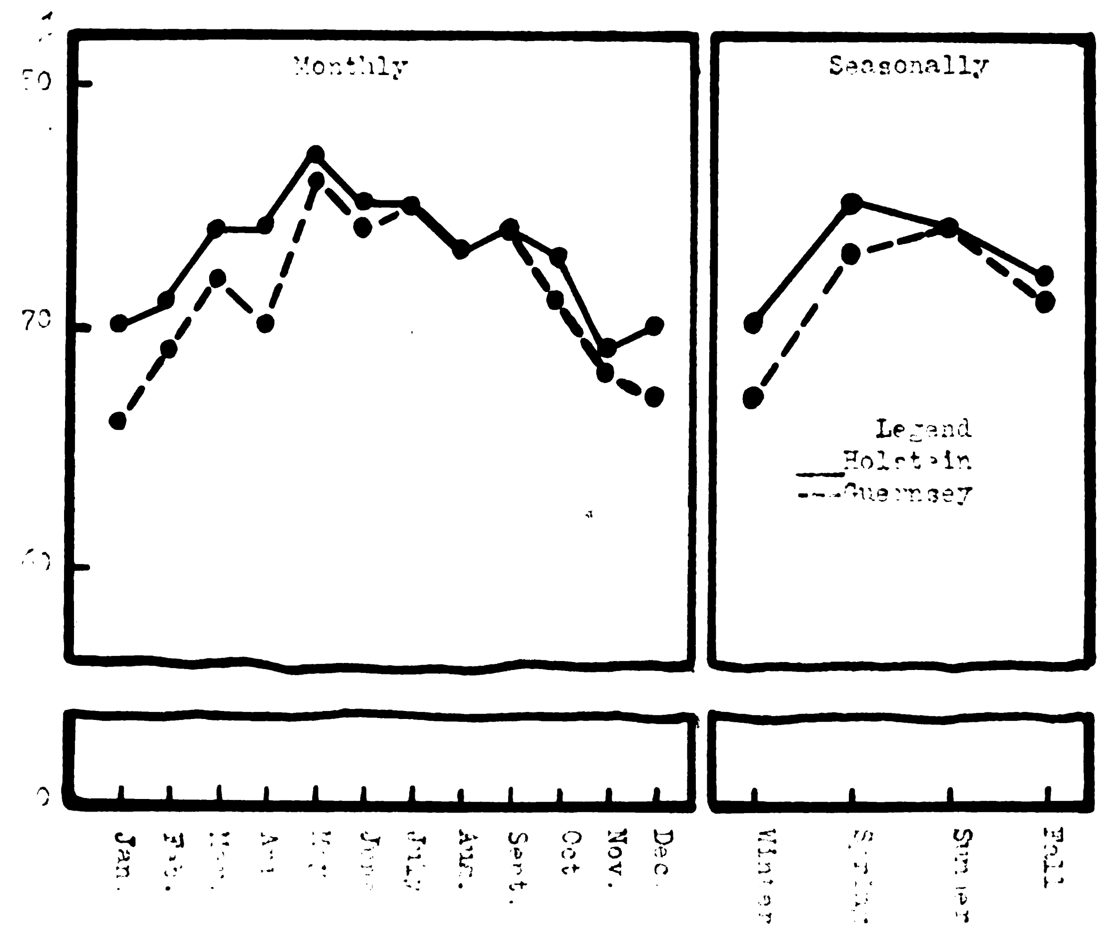

Fig. 4. Initial Motility Per Ejaculate.

general slightly superior to the Guernsey bulls.

The total number of spermatozoa per ejaculate were at high and low levels during the spring and winter respectively for the Guernsey bulls. The Holstein sires produced slightly more spermatozoa per ejaculate during the summer than during the spring. Fall and Winter were seasons of lowest total spermatozoa counts for the Holstein bulls.

Initial Motility

The Holstein bulls slightly exceeded the Guernseys in percent of progressively motile spermatozoa observed immediately after collection of the semen. The percentage of initial motility was at high and low levels during the spring and winter respectively for both breeds.

Individual and Monthly Variation

Since observation of the data indicated a variation in semen characteristics between bulls and between months, the analysis of variance according to the method of Snedecor (77) was made.

Highly significant individual differences between bulls of both breeds ~~was~~ were found in every semen characteristic measured. Variation in total spermatozoa per ejaculate between months was highly significant in the Holstein semen. The Guernsey semen exhibited significant monthly variation in initial motility although the value was low. ~~This~~ These data ~~is~~ are summarized in Table VI.

Correlation Between Semen Characteristics

Correlation coefficients between the various semen characteristics were calculated in order to ascertain any possible interactions between them.

TABLE VI. SUMMARY OF ANALYSIS OF VARIANCE OF SEMEN CHARACTERISTICS

	Source of Variation			
	Bulls		Months	
	H	G	H	G
Volume	8.55**	7.02**	0.94	0.72
Concentration	3.43**	3.27**	0.48	0.82
Total Sperm	5.71**	5.98**	3.13**	1.05
Initial Motility	6.32**	3.46**	1.51	1.94*

* Statistically significant at 5 percent level of probability
** Statistically significant at 1 percent level of probability

TABLE VII. CORRELATION BETWEEN SEMEN CHARACTERISTICS

	Concentration		Total Sperm		Initial Motility	
	H	G	H	G	H	G
Volume	0	0	#	#	*	0
Concentration	---	---	#	#	0	#
Total Sperm	---	---	---	---	*	#

0 - Not statistically significant
* - Statistically significant at 5% level of probability
\# - Statistically significant at 1% level of probability

The results are contained in Table VII.

Highly significant correlations between volume and total spermatozoa per ejaculate and concentration and total spermatozoa were obtained for both breeds. Semen of the Holstein bulls also showed a significant correlation between volume and initial motility. Correlations between concentration and initial motility were highly significant for the Guernseys. A significant correlation between total spermatozoa and initial motility was obtained in the Holstein semen. The same correlation was highly significant for the Guernsey bulls.

Effect of Light and Temperature upon Spermatogenesis

In view of the seasonal variation in semen quality found in this study and reports of climatic effects upon spermatogenesis, correlations between light, temperature and semen characteristics were calculated. To allow for any delayed effect of these climatic factors upon spermatogenesis the correlations were determined for the current, first and second preceeding months and seasonally.

The correlations between light and spermatogenesis are summarized in Table VIII and the data for temperature effects in Table IX. Figure 5 shows the hours of daylight and degrees of temperature by month and season for comparative purposes. The data on light and temperature ~~was~~ were obtained from the United States Weather Bureau at East Lansing.

An examination of Tables VIII and IX shows that light variation appears to have a greater effect upon spermatogenesis than does temperature. Both current light and current temperature appear to be more effective in influencing spermatogenesis than the light and temperature of previous months.

TABLE VIII. CORRELATION BETWEEN LIGHT AND SPERMATOGENESIS

	Current Month		One Month Previous		Two months Previous		Seasonal	
	H	G	H	G	H	G	H	G
Volume	*	0	0	0	0	0	0	0
Concentration	0	≠	*	≠	0	*	*	*
Total Sperm	≠	*	0	0	0	0	0	0
Initial Motility	≠	≠	*	≠	0	*	0	*

0 - Not statistically significant
* - Statistically significant at 5 percent level of probability
≠ - Statistically significant at 1 percent level of probability

TABLE IX. CORRELATION BETWEEN TEMPERATURE AND SPERMATOGENESIS

	Current Month		One Month Previous		Two Months Previous		Seasonal	
	H	G	H	G	H	G	H	G
Volume	0	0	0	0	0	0	0	0
Concentration	0	≠	0	*	0	0	0	0
Total Sperm	0	0	0	0	0	0	0	0
Initial Motility	≠	≠	0	*	0	0	0	0

0 - Not statistically significant
* - Statistically significant at 5 percent level of probability
≠ - Statistically significant at 1 percent level of probability

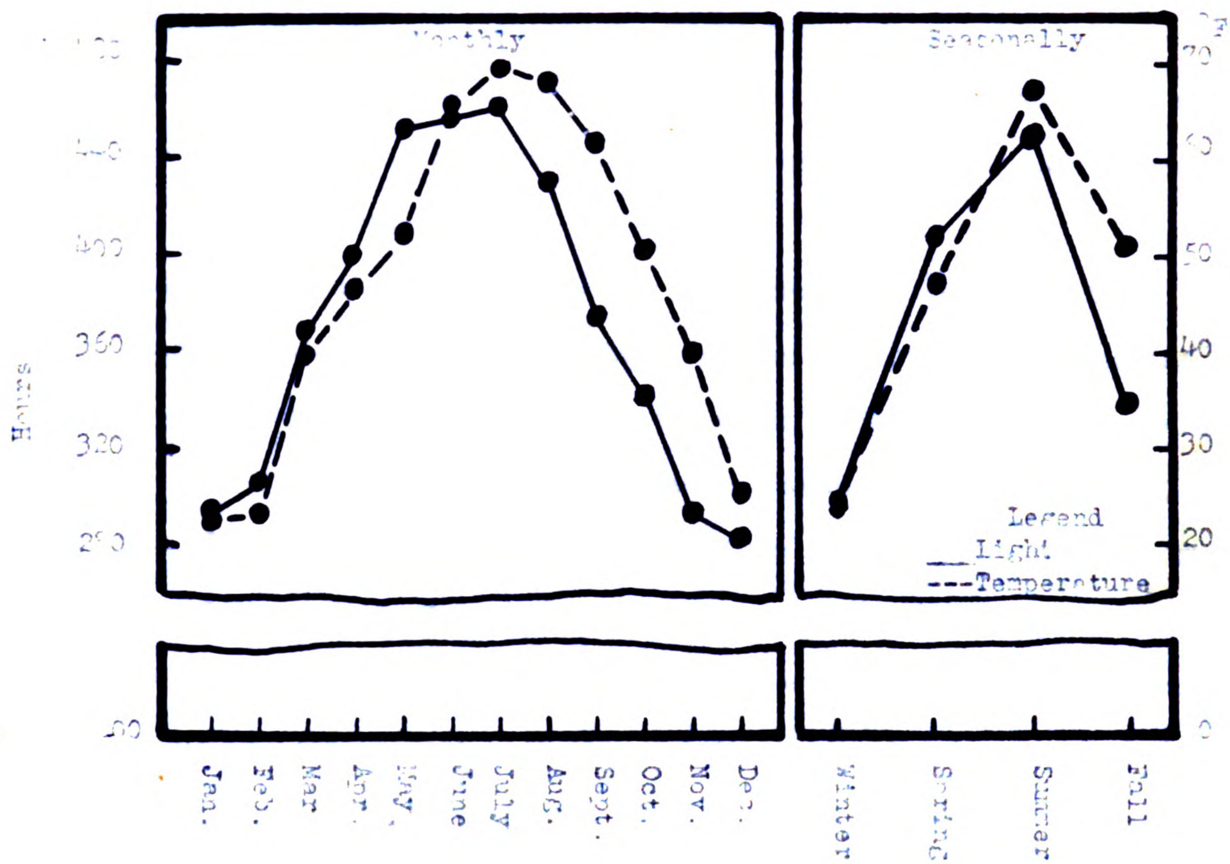

Fig. 5. Hours of Daylight and Degrees Fahrenheit.

There are some indications in these data that there may be a breed difference in response to light and temperature stimulation. No significant seasonal effect of temperature was observed from these data. Light variation significantly affected semen concentration of both breeds and the initial motility of the Guernsey semen.

Since light and temperature are highly correlated it was believed that the data in Tables VIII and IX might be confounded. Therefore, partial correlations were calculated between these two variables and semen characteristics. Data for the second previous month was omitted from these calculations because of the very slight effect it had shown in the previous data. The results of the partial correlations are summarized in Tables X and XI.

The decrease in effect of both light and temperature when considered alone as compared to the results when they are considered together is doubtless due to the interaction of these two factors. Neither one alone is as effective as the two combined.

Relation of Semen Quality to Fertility

The data on semen volume, concentration, total spermatozoa per ejaculate and initial motility of the semen shipped for breeding purposes was correlated with breeding results, based on the percent of 30-60 day non-returns after service. Statistical analysis showed none of these measures of semen quality to be significantly correlated with breeding results in the field.

TABLE X. EFFECT OF LIGHT WITH TEMPERATURE CONSTANT

	Current Month		One Month Previous		Seasonal	
	H	G	H	G	H	G
Volume	*	0	0	0	0	0
Concentration	0	0	0	0	0	*
Total Sperm	*	0	0	0	*	0
Initial Motility	≠	≠	0	0	0	0

0 - Not statistically significant
* - Statistically significant at 5 percent level of probability
≠ - Statistically significant at 1 percent level of probability

TABLE XI. EFFECT OF TEMPERATURE WITH LIGHT CONSTANT

	Current Month		One Month Previous		Seasonal	
	H	G	H	G	H	G
Volume	*	0	*	0	0	0
Concentration	0	0	0	0	0	0
Total Sperm	0	0	0	0	0	0
Initial Motility	0	≠	0	*	0	0

0 - Not statistically significant
* - Statistically significant at 5 percent level of probability
≠ - Statistically significant at 1 percent level of probability

Variation in Fertility

Data regarding the number of collections attempted, shipped, and unsuccessful attempts with the percentage of each are shown by month and season in Tables XII and XIII. Figures 6 and 7 present graphically the monthly and seasonal variations in percent of collections shipped and percent of collection failures, respectively.

Percent of Collections Shipped

The month of May with 93 percent of all collections attempted being shipped was the peak month. A lower percentage of the semen was shipped during November, December and January than at other times of the year. Spring and summer seem to be seasons of optimum semen production.

Collection Failures

The percent of unsuccessful collection attempts was higher for the Guernsey bulls than for the Holsteins. The percentage of collection failures for both breeds were at lowest level during the fall months. The highest percent of failures in the Guernsey breed occurred in the winter while the Holsteins had a slightly higher number during the spring than in the winter.

Libido

An estimate of the time required for each collection was made by the collectors and has been used as a rough measure of libido. Figure 8 gives a graphical summary of the data.

No great breed difference was observed although some individual variation was evident. In general, libido when measured in this manner appeared to be at lowest levels during the hot summer months and highest during the winter.

TABLE XII. COLLECTION DATA SUMMARIZED BY MONTHS

	Number Attempted		Number Shipped		Number Failures		Percent Shipped		Percent Failures	
	H	G	H	G	H	G	H	G	H	G
January	257	178	199	130	14	19	77.4	73.0	5.4	10.7
February	204	135	175	104	13	17	85.8	77.0	6.4	12.6
March	249	145	208	114	16	13	83.5	78.6	6.4	9.0
April	246	132	207	106	14	11	84.1	80.3	5.7	8.3
May	126	86	117	80	6	7	92.9	93.0	4.5	8.1
June	159	117	133	91	3	4	83.6	77.8	1.9	3.4
July	189	132	160	114	3	9	84.7	86.4	1.6	6.8
August	209	135	175	114	4	7	83.7	84.4	1.9	5.2
September	203	136	168	111	2	6	82.8	81.6	1.0	4.1
October	219	162	179	122	0	7	81.7	75.3	0.0	4.3
November	212	165	158	107	5	6	74.5	64.8	2.4	3.6
December	234	149	183	103	9	8	78.2	69.1	3.8	5.4
Total	2507	1672	2062	1296	89	114	-	-	-	-
Av.	209	139	172	108	7.4	9.5	82.7	78.4	3.4	6.8

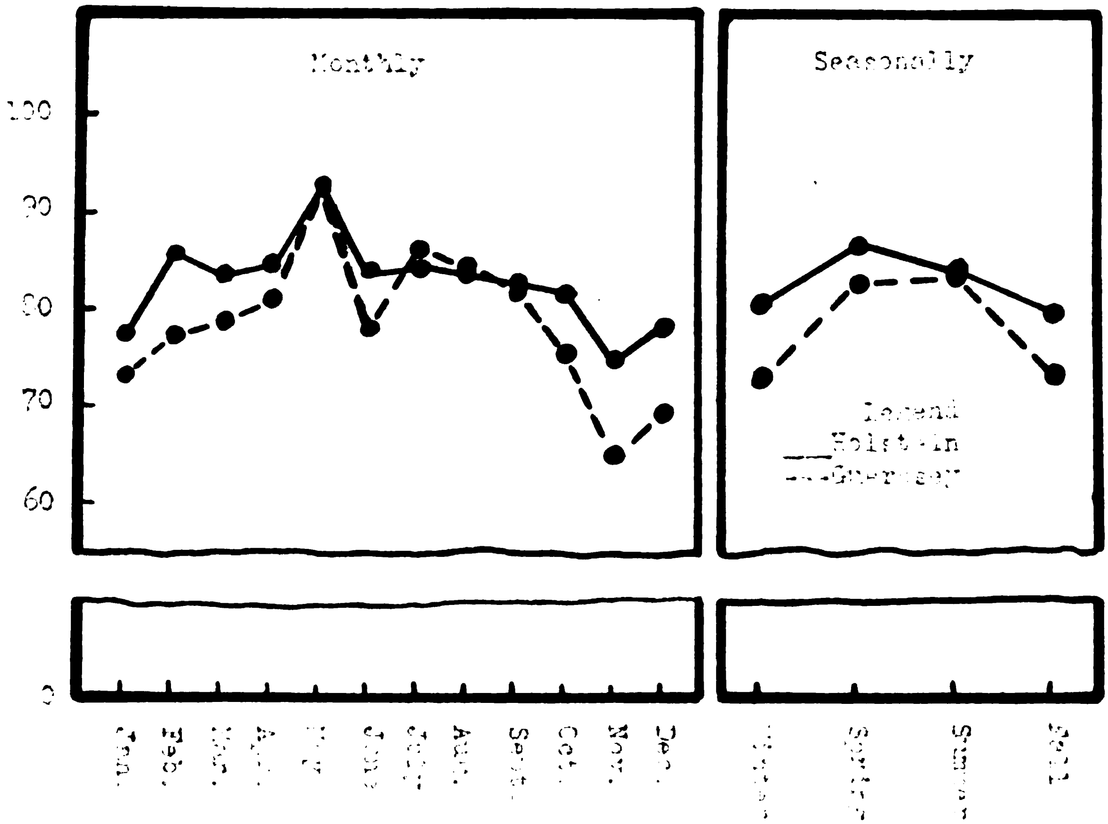

Fig. 6. Percent of Collections Shipped.

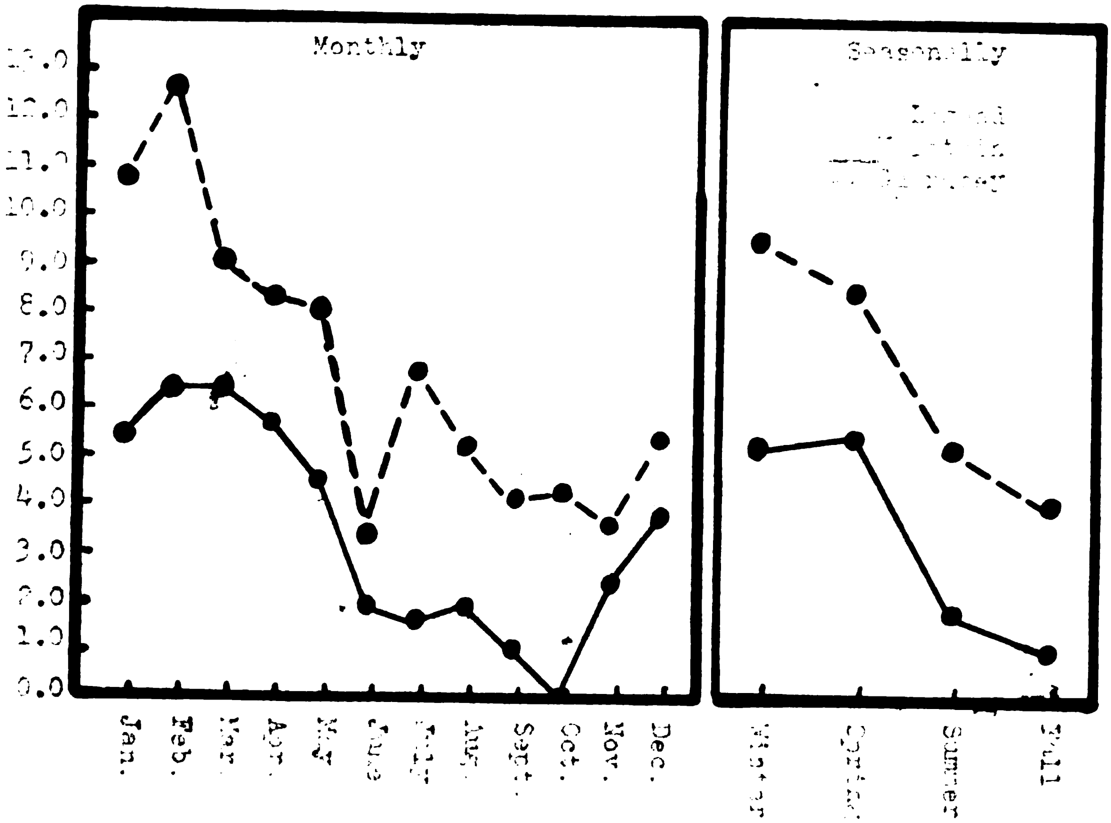

Fig. 7. Percent of Collection Failures

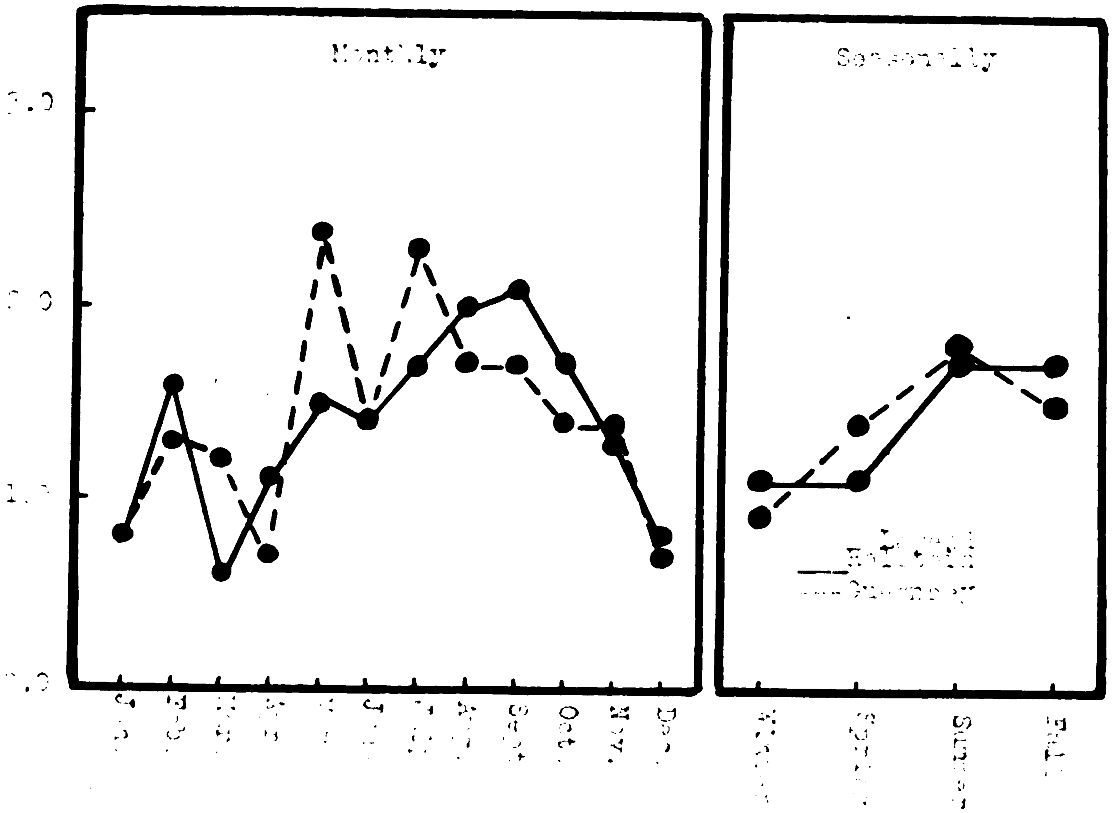

Fig. [illegible]. Minutes Required for Service

TABLE XIII. COLLECTION DATA SUMMARIZED BY SEASON

	Number Attempted		Number Shipped		Number Failures		Percent Shipped		Percent Failures	
	H	G	H	G	H	G	H	G	H	G
Winter	695	462	557	337	36	44	80.1	72.9	5.2	9.5
Spring	621	363	532	300	36	31	85.7	82.6	5.8	8.5
Summer	557	384	468	319	10	20	84.0	83.1	1.2	5.2
Fall	634	463	505	340	7	19	80.0	73.4	1.1	4.1

Breeding Results

A summary of the numbers of cows bred monthly and seasonally and the breeding results may be found in Tables XIV and XV. The percent of 30-60 day non-returns is also shown graphically in Figure 9.

The Holstein bulls maintained a considerably higher breeding efficiency than the Guernseys. The percent of non-returns for the Holstein breed was much higher during the spring than during the other seasons. The Guernseys appeared to be at peak efficiency in the fall.

The months of the highest percent of non-returns were March and April for the Holsteins. The Guernseys were at their highest levels in March, October and November. The percent of non-returns for both breeds fell sharply in December. July was the month of lowest efficiency for the Guernseys and December the lowest month for the Holstein bulls.

An analysis of variance showed significant differences between the Holstein bulls in percent of non-returns. The variation between the Guernsey bulls was highly significant.

Although there was a monthly variation in percent of non-returns, statistical

TABLE XIV. SUMMARY OF MONTHLY BREEDING DATA

	Number of Cows Bred		Number of 30-60 Day Returns		Percent of Non-returns	
	H	G	H	G	H	G
January	7532	4548	2504	1851	66.8	59.3
February	6351	4114	2188	1775	65.5	56.9
March	7627	4609	2393	1762	68.6	61.8
April	7623	4313	2396	1749	68.6	59.4
May	4485	2953	1554	1263	65.4	57.2
June	5616	3680	2072	1547	63.1	58.0
July	4847	3276	1813	1437	63.9	56.1
August	4089	2931	1376	1183	66.3	59.6
September	3796	2500	1339	1038	64.7	58.5
October	4109	2417	1391	903	66.1	62.6
November	4412	2365	1566	882	64.5	62.7
December	6280	3439	2443	1477	61.1	57.1
Total	66767	41145	23035	16867	-	-
Av.	5564	3429	1920	1406	65.4	59.1

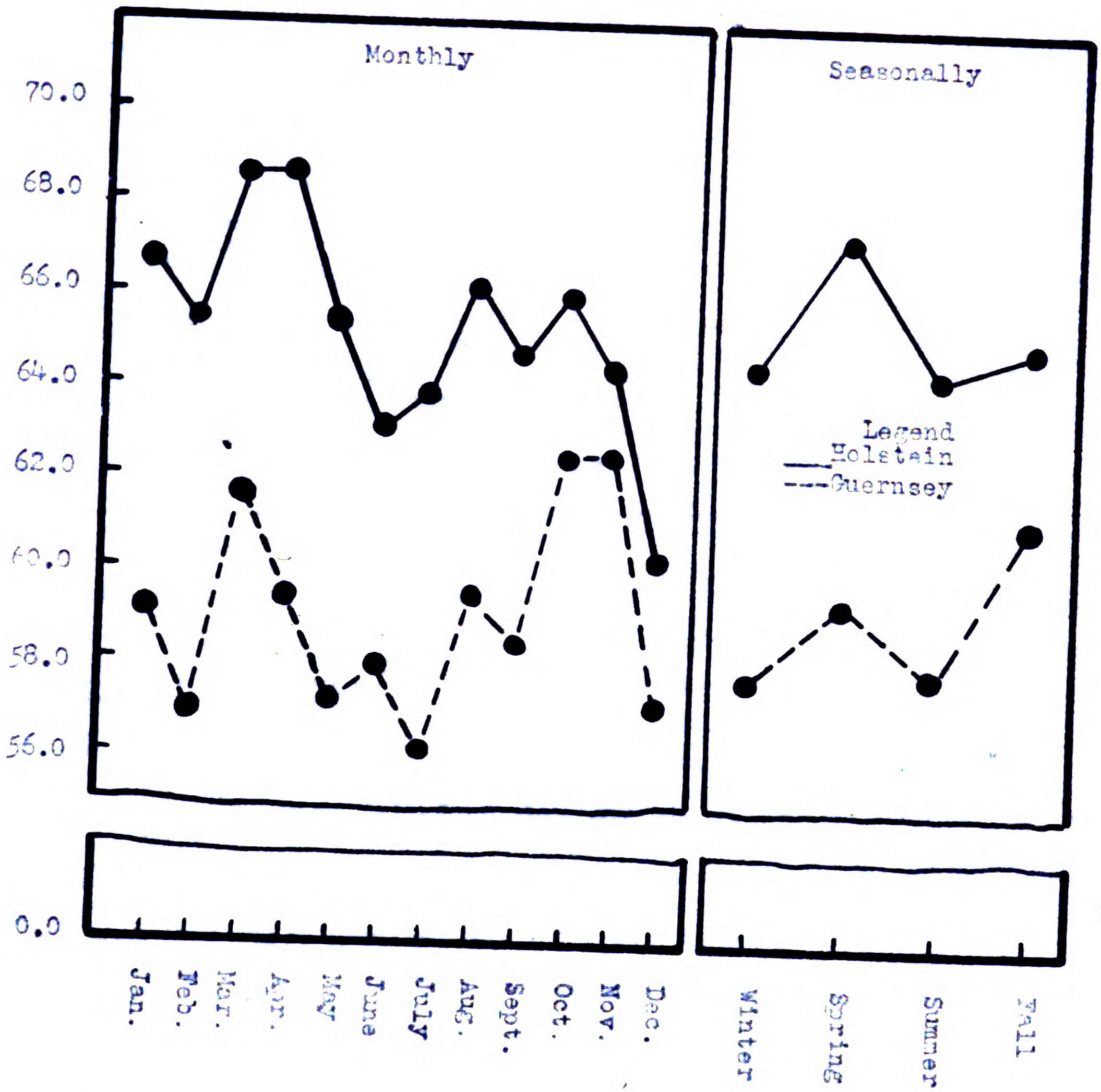

Fig. 9. Percent of 30-60 Day Non-Returns.

TABLE XV. SUMMARY OF SEASONAL BREEDING DATA

	Number of Cows Bred		Number of 30-60 Day Returns		Percent of Non-returns	
	H	G	H	G	H	G
Winter	6721	4034	2378	1701	64.5	57.8
Spring	6578	3958	2114	1591	67.5	59.5
Summer	4851	3296	1754	1389	64.4	57.9
Fall	4106	2427	1432	941	65.1	61.3

analysis showed it to be not significant.

Effect of Light and Temperature on Breeding Results

A statistical analysis of the effects of light and temperature on the percent of non-returns failed to show any significant correlations when the two are considered together. Partial correlations, however, show that light from the first previous month had a highly significant negative correlation (P = - 0.834) with the percent of non-returns for the Guernsey bulls. The correlation was significant for the Holstein sires (P = - 0.730). Partial correlations in which the light of the previous month was eliminated and only the current temperature considered showed the temperature effect on fertility to be essentially as great as the delayed effect of light but of positive effect. The correlation coefficients were, Guernseys P = 0.827 and Holsteins P = 0.722. These were highly significant and significant, respectively.

DISCUSSION

None of the semen characteristics studied in this investigation (volume, concentration, total spermatozoa, and initial motility) were significantly correlated with fertility. Previous workers have reported varying results. Anderson (2) found volume, concentration and initial motility to be related to fertility. Lasley and Bogart (41) correlated volume, concentration and total sperm but not initial motility, with fertility. Swanson and Herman (80) found initial motility but not concentration to be an index of fertility. Mercier and Salisbury (47) state that concentration is a guide to breeding results. Dougherty and Ewalt (28) and Swanson and Herman (79) were unable to establish any relationship between concentration, initial motility or volume and fertility.

It is not unlikely that some of this variability of results stems from the standards required of the semen before it is used for insemination. Semen abnormally deficient in any quality will not give as good breeding results as that which is normal. When semen is selected for field use in artificial insemination it usually must meet certain minimum standards in several of the measures of semen quality. It is probable that these minimum specifications are set at levels above which quality variations are not important in determining fertility. When the standards are lowered or unselected semen is used semen quality may be expected to be more highly correlated with fertility.

The variation in reported relationship of semen quality does, however, indicate the desirability of a single measure of semen quality highly correlated with semen characteristics and fertility.

Investigations by Anderson (3), Raps and Cannon (60) and Reid and associates (62) indicated that determination of the semen pH either initially or the drop in pH after incubation for one hour at 40° C. may be a desirable method of indirectly determining semen quality. It has the advantage of requiring little specialized equipment or training.

Considerable variation in semen quality was observed between bulls of the same breed and between breeds in this investigation. Similar findings have been published by Mercier (46) and Mercier and Salisbury (47).

Seasonal trends in spermatogenic activity of the bulls were also found. In general the semen was of higher quality during the spring and summer than during the fall and winter. However, the monthly variations were not statistically significant.

The diversity of results obtained by other investigators, (24) (25) (29) (30) (31) (36) (48) (49) (50) (51) (55) (74) (75) (81) (90), indicate that seasonal trends vary with the geographical location of the bulls under study.

Mercier and Salisbury (48) (49) have concluded that light is one of the major climatic factors affecting spermatogenesis. Statistical analysis of their data also indicated a lag of about one month before the maximum response to light variation was reached. The results of this study also indicate that light variations are more important than temperature effects in influencing spermatogenic activity. However, the delayed effect of light reported by Mercier and Salisbury was not evident in so far as its action on semen quality was concerned.

Partial correlations to determine the effect of light and/or temperature alone indicated that neither of these factors by itself is as effective as the two working together.

It is appreciated that the percent of 30-60 day non-returns is not a desirable measure of bull fertility. As Casida and associates (22) have indicated, use of this fertility index introduces approximately a fifteen percent error into the fertility data. However, records of the association did not permit use of a longer time. It is believed too that while more accurate fertility data might have changed the individual figures the trends observed would have remained the same.

Highly significant differences in fertility of individual bulls were found. A breed difference in fertility level was also evident. However, the monthly variations in percent of non-returns was not significant. These results are in accord with those reported by Salisbury (71). A breed difference in seasonal trends was observed. The Holstein bulls were of highest fertility during the spring and lowest in winter and summer. The Guernseys were also of low fertility during the winter and summer but peak fertility came in the fall.

Bulls of both breeds tended towards more prompt service of the cows during the summer and fall months. It is likely that the longer hours of daylight and higher temperatures act as stimuli to libido in bulls.

A breed difference and a seasonal variability in the percent of collection failures were also found. A greater percentage of Guernsey bulls either refused to serve or were unable to ejaculate semen. The percentage of such failures was lower in the summer and fall than during the other months for both breeds.

The observed superiority of the Holstein bulls in fertility and some semen characteristics is similar to the findings of Mercier and Salisbury (47).

In view of the difference in fertility level observed between the Holsteins and Guernsey breeds it is interesting to note the difference in pH of the semen of the two breeds. Raps and Cannon (60) found that the semen of Holstein bulls was more acid than that of Guernsey bulls. This may be one of the factors responsible for the lower fertility of the Guernsey bulls.

It is unlikely that the superiority in semen quality observed here entirely accounts for the fertility differences between the breeds. The semen used for insemination was selected in both cases. At times the standard of quality for shipment of Guernsey semen had to be lowered due to the low quality of the semen produced and the necessity of using some of it for breeding purposes. It is believed, however, that at no time was the quality of the semen shipped low enough to affect breeding results.

The findings of this study confirm the earlier report of Mercier and Salisbury (49) in so far as noting a lag before the maximum effect of light variation upon fertility is concerned.

Mercier (46) found a difference in response to light and temperature variation between bulls kept in New York State and those in Eastern Canada. Both temperature and light were negatively correlated with fertility of bulls used in artificial insemination in New York State. Under natural breeding conditions in Eastern Canada both factors were positively correlated with breeding results.

The data shown here indicate that under South Central Michigan conditions bull fertility is negatively correlated with light and positively correlated with temperature. The influence of these variables appears to be of the same magnitude. These results would indicate that factors other than light and temperature cause the observed variations in fertility within breeds.

The suggestion is offered that in other geographical locations where either temperature or light may vary considerably more than in Michigan, one or both of these factors may be of greater importance in influencing spermatogenesis and fertility of dairy bulls. The differences found in reports of seasonal fertility may thus be explained.

SUMMARY

1. Records of semen production and breeding results of 24 Holstein and 17 Guernsey bulls used in artificial insemination during a 35 month period were analyzed. Over 4,000 semen collections and 107,000 breeding records were tabulated in this study.

2. Significant or highly significant correlations for one or both breeds were obtained between volume and total spermatozoa per ejaculate, volume and initial motility, concentration and total spermatozoa, concentration and initial motility, and total sperm and initial motility.

3. Highly significant differences between bulls of the same breed were observed in every semen characteristic studied.

4. A breed difference in semen volume, concentration and initial motility was evident.

5. Monthly variation in semen quality was not significant although the quality was higher in the spring and summer than during the fall and winter.

6. Light and temperature were both positively correlated with spermatogenesis. Light appeared to exert the greater effect.

7. No significant correlations between variations in semen selected for shipment and actual fertility were found.

8. Libido of both breeds appeared to be highest in the winter.

9. Fertility of the Holstein bulls was consistently higher than that of the Guernsey bulls.

10. Highly significant fertility differences were observed between bulls.

11. Fertility of the Holstein bulls was highest during the ~~summer~~ spring. The Guernsey bulls were of highest fertility in the fall.

12. Monthly variations in fertility of either breed were not statistically significant.

13. A negative effect of light on fertility was noted. The maximum effect was after one month lag.

14. A positive effect of current temperature on fertility of the same magnitude as the light effect was found.

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