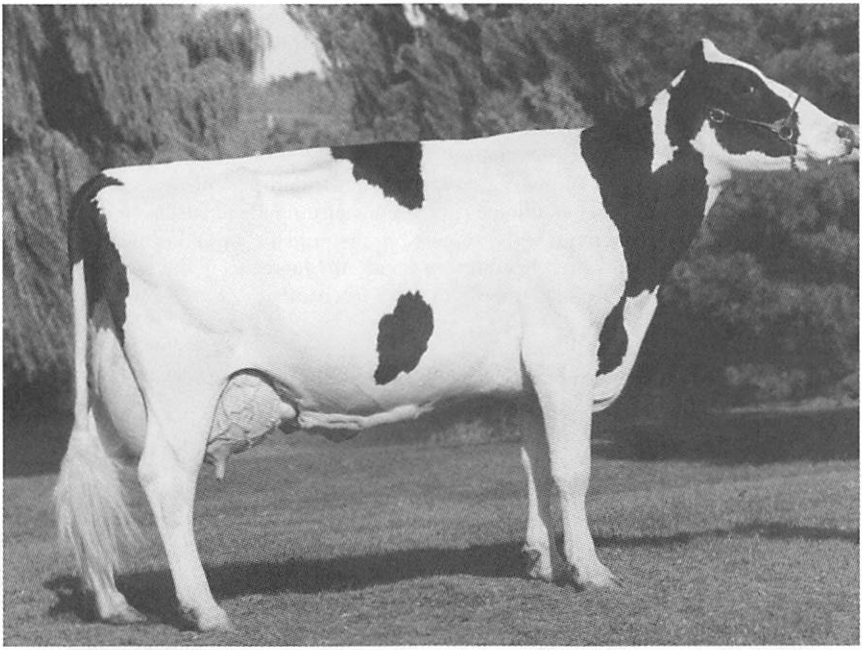
Impact of Thermal Challenges on Global Livestock Production

An Israeli Perspective



Brody Memorial Lecture XXIII

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Agricultural Experiment Station **Special Report 532**

Establishment of Brody Memorial Lectureship

A committee was appointed by Dean Longwell to consider the possibility of creating a memorial for Samuel Brody. It was the opinion of the committee that a permanent lectureship would be most suitable if sufficient funds were obtained from friends, relatives, organizations and the University Faculty invited to contribute to this memorial.

Friends, relatives and organizations interested in recognizing Dr. Brody provided the initial funds, which were supplemented by a generous grant from the King Ranch and matching funds from the Alumni Achievement Funds.

The Board of Curators approved the establishment of the Samuel Brody Lectureship Fund in April 1959. Lectures have been held as often as sufficient income from the interest provided expenses and a small honorarium for a distinguished lecturer.

The current Brody Memorial Lectureship Committee was appointed by Dean Roger Mitchell:

Dr. Donald E. Spiers, Sigma Xi Representative
Dr. Harold D. Johnson, Department of Animal Sciences
Dr. B. Ann Becker, ARS Representative
Dr. Ralph R. Anderson, Gamma Sigma Delta Representative

The Committee welcomes additional contributions from individuals or groups in academia or industry. Such funds will be applied to the principal or endowment of the now-established Brody Memorial Lectureship Fund. Any increases in the endowment fund, or course, will allow lectures to be held more frequently.

Previous Brody Lectures:

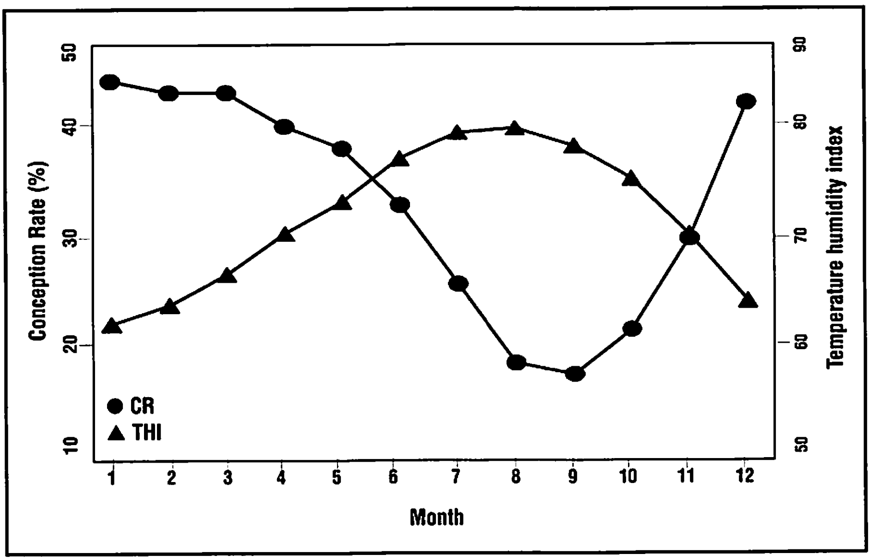
I. Max Kleiber, Dept. Animal Science, Univ. of Calif., Berkeley, 1960
II. Knut Schmidt-Nielsen, Dept. Zoology, Duke Univ., 1961
III. F. W. Went, Director, Missouri Botanical Garden, 1963
IV. K. L. Baxter, Dept. Nutrition, Hannah Dairy Research Institute, 1964
V. C. Ladd Prosser, Dept. Physiol., Univ. of Illinois, 1965
VI. H. T. Hammel, Physiol. Group, John B. Pierce Found. Lab., 1966
VII. H. N. Munro, Dept. Physiol. Chemistry, Mass. Institute of Tech., 1967
VIII. James D. Hardy, Dept. Physiol., Yale University, 1968
IX. Loren D. Carlson, Dept. Physiol., Univ. of Calif.-Davis, 1969
X. R. L. Baldwin, Dept. Animal Science, Univ. of Calif.-Davis, 1971
XI. John R. Brobeck, Dept. Physiol., School of Medicine, Univ. of Penn., 1972
XII. Bruce A. Young, Dept. Animal Science, Univ. of Alberta, 1974
XIII. D. E. Johnson, Dept. Animal Science, Colorado State Univ., 1975
XIV. Albert L. Lehninger, Dept. Physiol. Chem., The Johns Hopkins School of Medicine, Baltimore, 1976
XV. Henry A. Lardy, Dept. Biol. Science, Univ. of Wisc.-Madison, 1979
XVI. H. A. Tucker, Depts. Dairy Science and Physiol., Mich. State Univ., 1981
XVII. H. Russell Conrad, Dept. Dairy Science, The Ohio State Univ., 1982
XVIII. David Robertshaw, Dept. Physiol/Biophysics, Colorado State Univ., 1984
XIX. Allen Munck, Dept. Physiol., Dartmouth Medical School, 1986
XX. Lawrence J. Machlin, Dir. Clinical Nutrition, Vitamins and Fine Chemicals Division, Hoffman-LaRoche Inc., 1988
XXI. Keith W. Kelley, Dept. Animal Science, Univ. of Illinois, 1992
XXII. Clifton A. Baile, Dept. Animal Sciences, Univ. of Missouri, 1994

Introduction

This Brody Memorial Lecture concentrates on dairy cattle productivity and fertility, under heat stress conditions. Heat stress is a worldwide problem. It lowers the fertility of about 60% of the cattle population in the tropical, subtropical and temperate zones. The severity of the thermal stress in a specific region depends mainly on the levels of air temperature and relative humidity. In Israel, the conception rate of high-yielding Holstein dairy cows is about 45% in the winter, when the temperature humidity index (THI) is low, and it drops drastically to below 20% during the summer months, when the THI is higher (Figure 1). With even higher THI values in the hotter regions of the country, the conception rate falls below 10%. Similar relationships between climate and fertility, characterize many southern states in the USA, and many other countries worldwide. Interestingly, the fertility of cows in the autumn months, October and November, remains low (25 to 35%) even though air temperatures drop and cows are no longer under heat stress conditions. The low conception rates in the autumn clearly indicate a delayed effect of summer heat stress on autumn fertility.

Low summer fertility causes heavy economic losses to the dairy industry. (1) It results in an uneven distribution of calving between winter and summer. In Israel, for example, the monthly calving is 11% during winter and

Figure 1. Conception rate (CR) and temperature humidity index (THI)



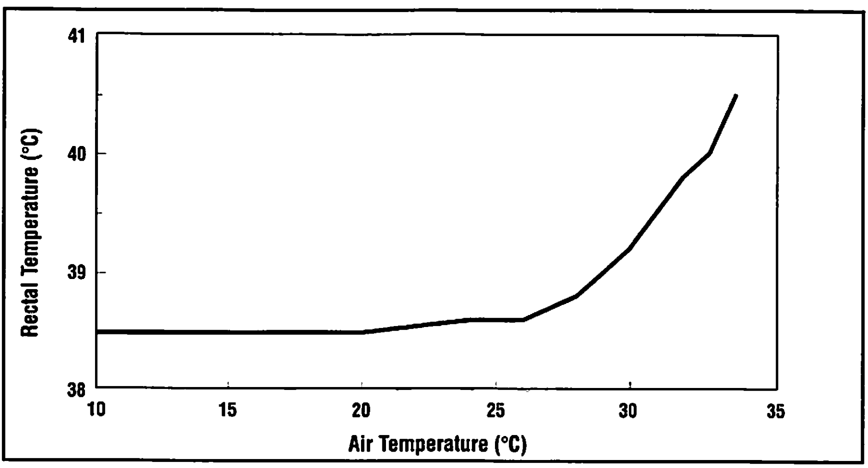
only 4% in summer. As a result, fewer cows are in peak lactation during the summer. Thus, milk production is about 25% lower in summer than in winter, and surplus milk is dried during the winter. (2) Low summer fertility interferes with breeding program optimization, preventing optimization of the calving interval. (3) Low summer fertility prevents efficient genetic improvement. (4) It also increases the costs of artificial insemination; a cow in summer and autumn requires to be inseminated three to five times until she conceives compared with two inseminations needed in the winter.

Hyperthermia

Why is fertility of dairy cattle so low in summer? What are the physiological causes of low summer fertility? Paradoxically, the more advanced and modern is the dairy industry – the more milk the cows produce — the greater the impact of the problem, and the more difficult it is to solve.

The annual milk yield of Holstein dairy cows tripled in the last 50 years in the world's modern dairy industries. In Israel, for example, the average annual yield in 1999 reached approximately 11,000 kg milk per year. This tremendous level of milk means very high endogenous metabolic heat production: a non-lactating cow produces about 14 Mcal/day whereas a 50 kg milk/day cow produces about 38 Mcal/day – about 2.5 times as much heat. According to the basic rules of thermoregulation, a cow (like any mammal or bird) maintains normothermia if the rate of heat production equals that of heat loss. In high yielding dairy cows hyperthermia is unavoidable, because metabolic heat production is higher than the relatively low heat loss (sweating rate).

Figure 2. Development of hypothermia during summer in lactating dairy cows.



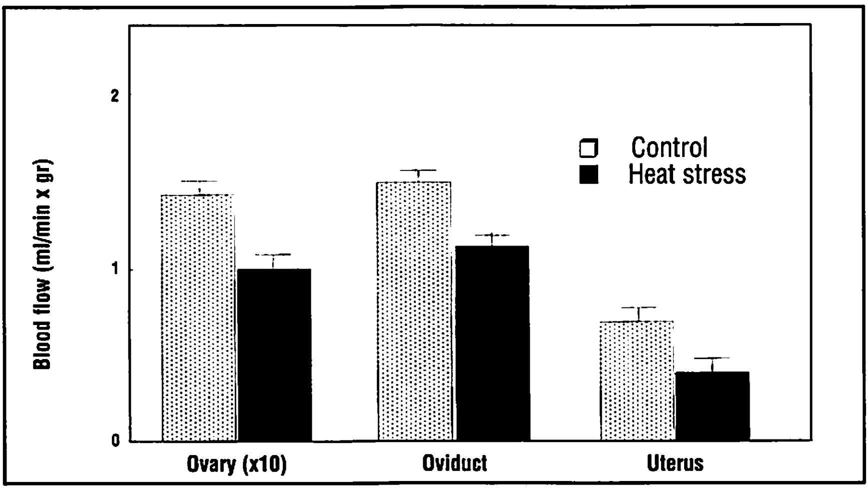
The acute rise of body temperature as air temperature rises is exponential in nature (Figure 2) with a rapid rise in body temperature. Cows exposed to 32°C (under humid conditions) in summer develop mild hyperthermia (39.4°C), whereas at 34°C they develop severe hyperthermia (40.5°C). Global warming, if it turns out to be genuine, would raise the air temperature, and even a small rise would shift cows towards the zone of severe hyperthermia. The rise of body temperature is the trigger of all the negative effects of summer heat stress on fertility and productivity.

Impairment of reproductive functions

Several functions are impaired under heat stress. The following is a brief review of the alterations of responses and functions of the main organs/tissues in the reproductive system.

Blood flow. Normal blood supply is essential to maintain normal functioning of body organs. During hyperthermia, animals redistribute their cardiac output: skin blood flow increases and that to inner body organs decreases (7). Blood flow to several parts of the reproductive system has been found to decrease under heat stress conditions (Figure 3). Reduced blood flow to the ovary may lower the outflow of progesterone secreted by the ovarian corpus luteum. Reduced uterine blood flow may lower supplementation of nutrients to the embryo, so that embryonic development is affected.

Figure 3. Effect of heat stress on blood flow to reproductive organs (rabbit).



Pituitary. The effect of heat stress on LH secretion is debatable. We recently found the plasma concentration of LH under heat stress in lactating cows to be dependent on the concentration of estradiol in plasma (4): chronic heat stress during summer decreased the GnRH-induced preovulatory surge in plasma LH concentration in cows with low concentrations of plasma estradiol, but not in cows with high concentrations of plasma estradiol (Figure 4). A low preovulatory LH surge may interfere with the normal process of corpus luteum formation, resulting in a sub-optimal corpus luteum and decreased secretion of progesterone.

Ovarian follicles. Follicular growth, development and functioning have been reported to be impaired by thermal stress. Attenuation of dominance of the large, dominant follicles was found to be associated with alterations in follicular dynamics (9, 14). A decrease in the steroidogenic capacity of dominant follicles under heat stress was evident (1). The thecal cells in the wall of the follicle are more susceptible to thermal stress than the granulosa cells (13). Androstenedione production by thecal cells obtained from dominant follicles in summer was lower than that by cells obtained in the winter (Figure 5). Moreover, the very low production of this steroid in the autumn indicated a delayed effect of summer heat stress on the steroidogenic capacity of thecal cells (13). The ovarian follicles are a prime target for the induction of a delayed effect of heat stress, because it takes about 50 days for a 0.1-mm follicle to grow into a 12-17-mm dominant, preovulatory follicle. Therefore, a small follicle damaged by heat stress in mid-summer (August, for example) might carry this damage with it until the autumn (October-November).

Figure 4. Effect of heat stress on plasma LH surge.

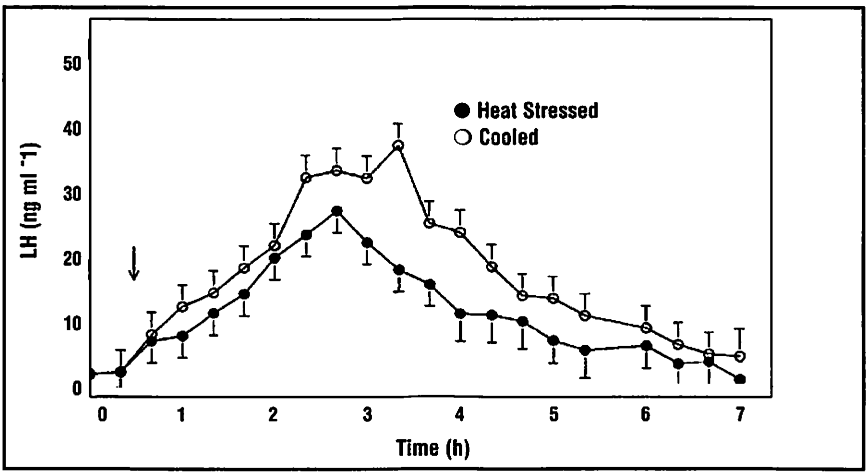
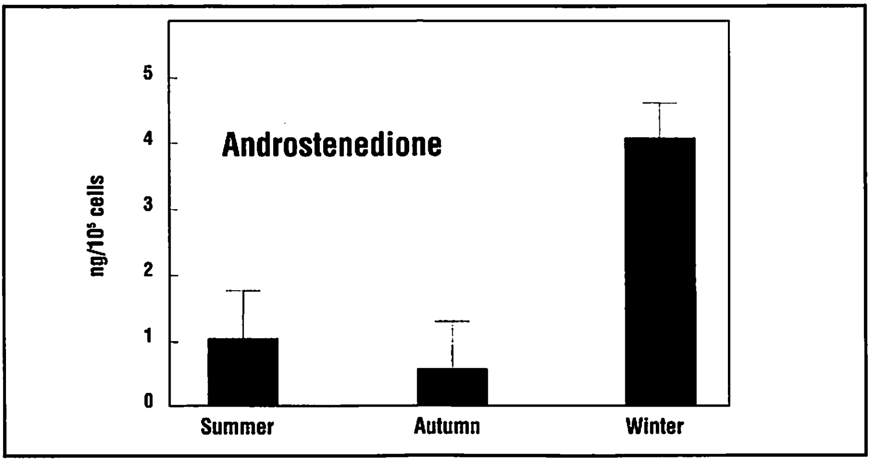
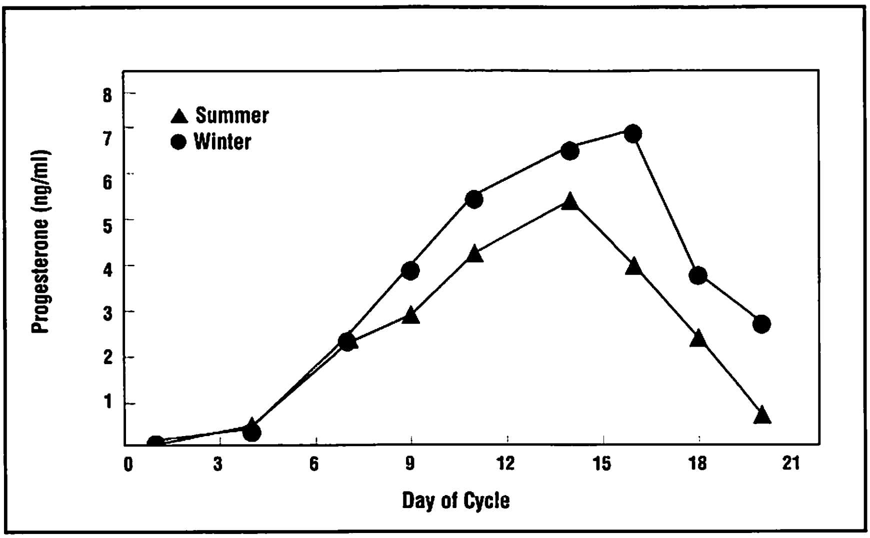


Figure 5. Seasonal effect on steroid production by dominant follicles



Oocyte quality. A delayed effect of heat stress on oocyte quality has also been detected (8). Recently we aspirated oocytes from 3-8-mm follicles during four consecutive estrous cycles in the autumn, from lactating cows previously subjected to summer heat stress. The low percentage of grade 1 (best) oocytes in early autumn increased towards late autumn. Similarly, the percentage of embryos developed in vitro, following oocyte maturation and

Figure 6. Plasma progesterone in winter and summer in lactating cows



activation, was significantly greater in late than in early autumn. Furthermore, the enhanced removal of a pool of bad follicles that had been damaged previously, in the summer, that was achieved by frequent aspirations of follicles from the ovaries, led to the more rapid emergence of healthy oocytes in the autumn (8).

Corpus luteum. The issue of the effect of heat stress on corpus luteum function is controversial, but is definitely important, because a decrease in progesterone secretion may be associated with low fertility. Classification of studies according to the type of heat exposure indicated that in most studies in which cows were exposed to acute/short-term heat stress, plasma progesterone concentrations were not altered or were even slightly elevated. In contrast, in most studies in which cows were exposed to chronic, summer heat stress, plasma progesterone concentrations decreased (6, 11). Figure 6 shows that plasma progesterone concentrations during the luteal phase of cows was significantly lower in summer than in winter. Further studies in our laboratory indicated that the formation of a sub-optimal corpus luteum in summer was determined to a great extent by the 'quality' of the ovulatory follicle from which it originated. They also indicated that the decreased steroidogenic capacity of theca-derived small luteal cells is the major cause for the decrease in plasma progesterone during summer.

Figure 7. Effect of heat stress on uterine PGF$_{2\alpha}$ Metabolite (PGFM) concentrations in plasma

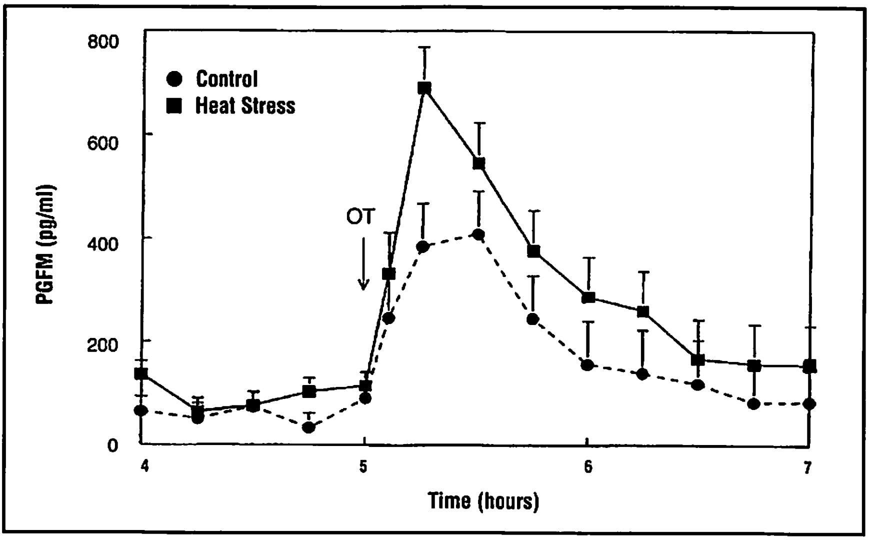
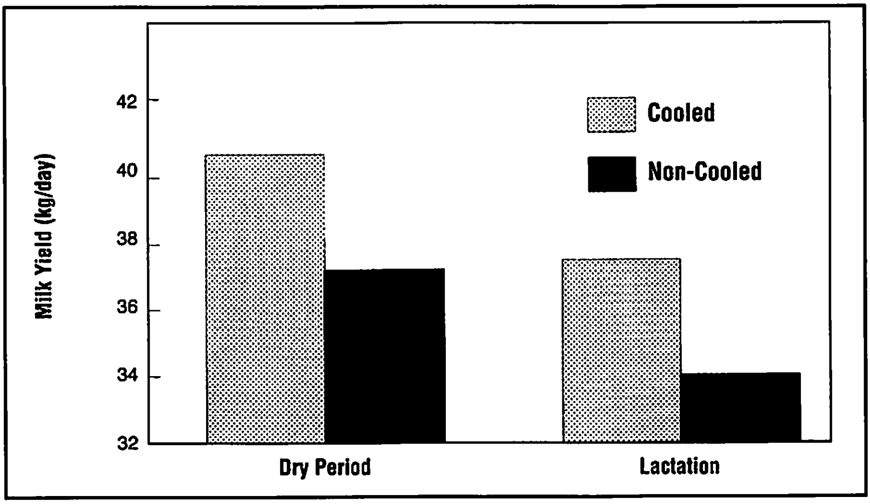


Figure 8. Effect of cooling during the dry period or during lactation on milk production



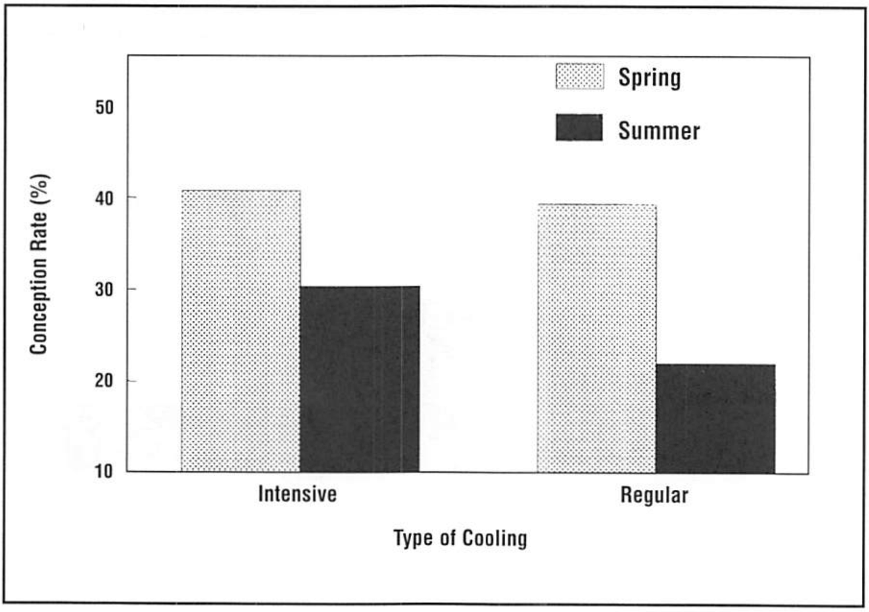
Uterus. Reduced progesterone secretion could affect uterine function and secretion. The increase of uterine $PGF_{2\alpha}$ under heat stress conditions (Figure 7) could be related to reduced progesterone secretion or to retardation of embryo development, resulting in attenuation of the antiluteolytic embryonic signals (10). A rise in $PGF_{2\alpha}$ could induce regression of the corpus luteum and as a result pregnancy might terminate.

Alleviation of heat stress

Provision of shade for dairy cows is not enough to maintain normothermia during the summer. Likewise, cooling with fans to increase air movement and convective heat loss is insufficient for dissipation of the elevated metabolic heat output of the high-yielding cow. The sprinkling and ventilation cooling system, which was developed in Israel, in cooperation with colleagues at the University of Florida, more than 15 years ago, has become the most commonly used cooling system in Israel, southern states of USA and other hot countries (2, 5). The system is based on direct cooling of the cow using large drops of water that penetrate the hair coat and wet the skin within a short time (seconds), together with air from fans to evaporate the water from the skin.

Successful cooling increases milk yield by 2-4 kg per cow per day; sometimes by as much as 5-6 kg per day (Figure 8). Application of cooling has

Figure 9. Intensive cooling improves fertility during the summer



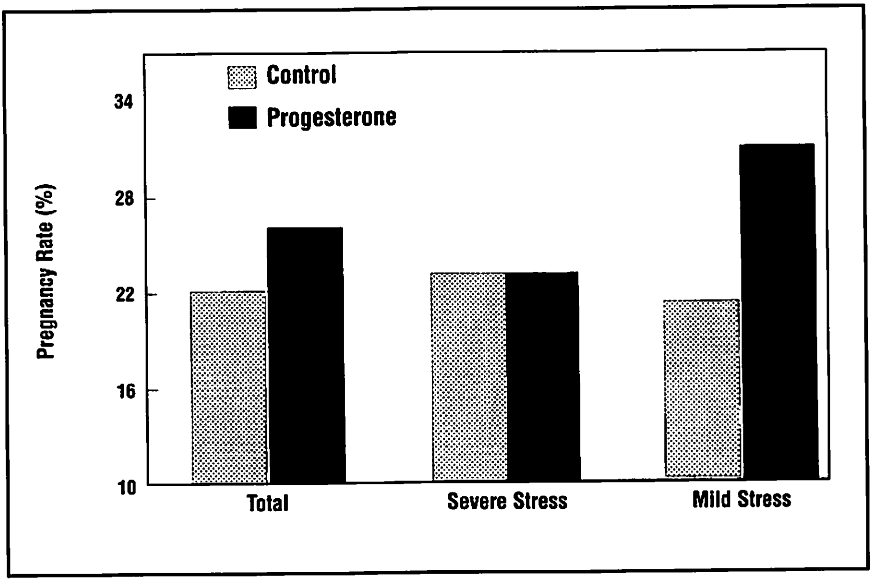
beneficial effects both during the dry period before calving and during lactation. Calculations made recently (based on the Israel Herd Book data), indicate that efficient cooling may narrow the gap between winter and summer milk production by more than 50%.

We compared farms using intensive cooling (five to six 30 to 40 min cooling periods a day) with those using regular cooling (three cooling periods a day). Both types of farms had a similar fertility, of about 40%, during spring, but in summer the regular-cooling farms had conception rates of about 20%, compared with 30% for the intensive-cooling farms (Figure 9). It can be concluded that efficient cooling in commercial farms improves summer fertility, but never to such an extent that it exceeds winter fertility. Nevertheless, cooling is a prerequisite for any hormonal treatment, which aims to improve summer fertility.

Hormonal treatments

Several attempts to improve summer fertility were either unsuccessful or only marginally successful, or, if successful, they were not applicable in commercial herds. The following are three approaches to the improvement of summer fertility of dairy cattle.

Figure 10. Effect of progesterone supplementation after insemination on summer conception rates

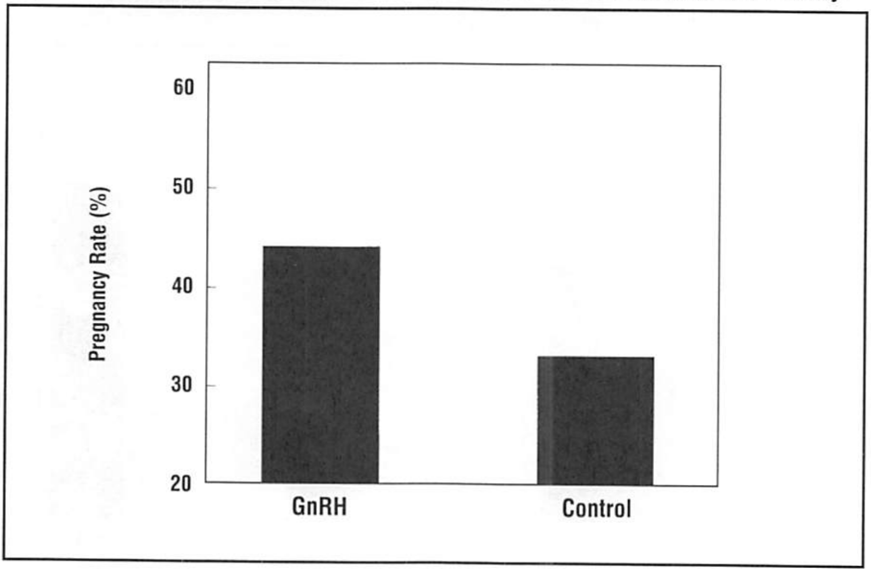


One approach is to increase plasma progesterone by an intra-vaginal progesterone insert (CIDR) on day 7 post-insemination for 11 days (12). The overall conception rate was not improved by the treatment, but the data are encouraging, because under mild heat stress, the treatment tended to improve summer fertility by about 10%, whereas no beneficial effect was noted in cows under severe heat stress (Figure 10). This, again emphasizes the need to alleviate heat stress as much as possible, in order to gain a benefit from any hormonal manipulation.

Another approach to improving reproductive performance in summer is the timed insemination synchronization procedure (3). It involves two injections of GnRH agonist and one of $PGF_{2\alpha}$, and insemination of all cows at a fixed time following the second injection of GnRH. It has been shown recently that the synchronization treatment improved pregnancy rate and decreased the number of days to first insemination, resulting in a decrease in the number of days open. This protocol may solve the problem of poor estrus detection in summer.

A different way to improve summer fertility is to inject a single dose of GnRH agonist at the beginning of estrus. This could be applicable in farms in which computerized systems are used to detect and record estrous behavior. A recent study in Israel showed an 11% unit rise in summer and

Figure 11. Effect pf GnRH injection at estrus on summer and autumn fertility.



autumn conception rates of lactating cows that had been treated with GnRH agonist at the beginning of standing estrus (Figure 11).

Summary

- Hyperthermia impairs several reproductive functions in the high-yield dairy cow.
- Alleviation of summer heat stress by an efficient cooling system is a prerequisite for any attempt to improve summer fertility.
- The knowledge gained in the last decade enables us to examine hormonal and nutritional strategies to optimize reproductive function and to improve the fertility of cattle exposed to heat stress in summer.

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