DOCTOR OF PHILOSOPHY

The effect of supplementary light on the behaviour and performance of cattle

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Award date:
1997

Awarding institution:
University of Wales, Bangor

THE EFFECT OF SUPPLEMENTARY LIGHT ON THE BEHAVIOUR AND PERFORMANCE OF CATTLE

A THESIS SUBMITTED TO THE UNIVERSITY OF WALES

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IN CANDIDATURE FOR THE DEGREE OF
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DECEMBER, 1997

ACKNOWLEDGEMENTS

To the generous help I received from Dr. C.J.C. Phillips no return would ever seem equal and satisfactory to his enthusiasm in bringing my work to a complete finish.

I can make no other comment than THANKS.

I am grateful and indebted as well to Dr. Paul Chiy, Professor J.B. Owen, Dr H. Omed, Dr. A.G. Chamberlain, Dr I. Ap Dewi and Dr. I. Robinson for the encouragement they offered and which I needed all way through. I would also like to thank Dr. C. Whittaker from the Department of Mathematics for his advice concerning the statistical analysis.

I would like to express my deep sense of gratitude to Mr. P.N. Johnson and the staff at Drayton EHF in Stratford on-Avon for their valuable help and constant encouragement during this work; to the staff at the college farm.

I would like also to thank Mrs. P. Ellis for her help and encouragement during this work.

I would like to acknowledge my collaboration with a fellow research student. In the third and fourth experiments I worked with Caroline Lomas, who studied the production of the cows and measured intensities of the light.

I never forget to thank and to express my everlasting indebtedness to the Hariri Foundation whose financial help can never be forgotten during the first two

years of my study in this country and without which I could never have managed to do this work.

I would also like to thank my precious friend Abdullah and Aysha Al Shiek for their encouragement and great help during my course of study.

Finally, appreciation and love is also extended to my wife, Chirine and my daughter Deala for their patience and encouragement during the last two years of my study. Also, I appreciate the encouragement given by my brothers, my parent and uncles for me to improve my education.

Summary

The scientific literature on the effects of supplementary light on the behaviour, performance and production of cattle was reviewed.

Research into the effects of extended photoperiod on animal behaviour and performance has demonstrated that the behaviour of farm animals, milk production, growth rate and voluntary food intake can be positively affected by giving extra light to the animals.

The effects of extended photoperiod on cattle behaviour and performance was studied in a series of four experiments using steers, heifers and dairy cows. Investigations were also made of the preferences for light and darkness on bullocks.

Supplementary light had no major effects on the growth rate or feed intake of steers. Steers spent less time sleeping and more time standing with supplementary light and produced leaner carcases

Supplementary light increased lean percent and reduced fat percent in heifers. It also increased the time heifers spent lying but reduced the time spent sleeping.

Supplementary light was applied to lactating dairy cows during conditions of increasing and decreasing natural daylength. During decreasing daylength supplementary light increased the time cows spent lying down and considerably reduced feed intake, milk production, live weight and body condition, so that lights were installed in the feeding area for the second period of the trial, which partially restored intake and live weight. During increasing daylength supplementary light did not affect lying time, had less effect on feed intake and no effect on milk production or live weight.

Bullocks were given the opportunity to control their lighting schedule. They preferred to spend a slightly larger proportion (53.7%) of their activities in the light rather than in the dark. Feeding was the most dominant activity in the light, whereas ruminating was the least observed behaviour exhibited when the light was on.

It is concluded that providing growing cattle in winter with supplementary light can in particular reduce body fatness in both steers and heifers in winter and decrease the time cattle spend sleeping, but that there were no major effects on growth rate or feed intake.

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CHAPTER 1

INTRODUCTION

Chapter One

1.1 INTRODUCTION

Animal farming has played an important part in the development of human civilization. Food, clothing and transport are obtained by man from a wide variety of species (Broom, 1986a ; Messent and Broom, 1986).

By the start of the twentieth century, increased demand for farm animal products started to develop with the growth of human society. Keeping animals in concentrated populations became a common practice and, before 1970, intensive animal husbandry had arrived in the form of close confinement for cattle, pigs and poultry under new husbandry systems. Therefore a tangible new knowledge of the behaviour of livestock under intensive husbandry systems was needed to assess these systems of management, as well as to apply the acquired knowledge in the agriculture industry in order to improve production and welfare (Fraser & Broom, 1990).

The term ethology is often used for the observation and detailed description of behaviour with the objective of finding out how biological mechanisms function. Animal behaviour is the reaction of the whole organism to certain stimuli, or the manner in which it reacts to its environment. Applied behaviour research however is less developed than other applied sciences. For example throughout the years, the behaviour of poultry has received less attention than the quantity and the quality of the egg and meat produced. But modern breeding, feeding, and management have brought renewed interest in behaviour, especially as a factor in obtaining maximum production and efficiency. With the restriction, or confinement, of the flocks, many abnormal behaviours evolved to plague those who raise them, including cannibalism and a host of other behavioural disorders. Confinement has not only limited space, but it has interfered with habitat and social organization to which, through thousands of years of evolution, the species became adapted and best suited. It is known that a controlled environment must embrace far more than an air-conditioned chamber, along with ample feed and water. The poultry producers need to be concerned more with the natural habitat of their birds. By their nature, they need more than to eat, sleep, and produce eggs and meat.

In 1905, when lighting was first used to stimulate egg production, it was thought that the role of light was primarily a matter of increasing the "work day" of the bird. Today, the action of light is considered physiological. For example, light enters the eye of the bird and stimulates the pituitary gland. In turn, the pituitary gland releases certain hormones which cause ovulation. Because of this phenomenon, artificial lighting in the poultry house is very important. With pullets, an increase in the daylength during the growing period will stimulate early maturity. With mature layers, an increase in daylength will stimulate egg production (Ensminger, 1992).

The simplicity and safety associated with extending the photoperiod to increase growth rate means this method could potentially have significant practical applications, because certain other effective methods, for instance, the use of growth promoters is not allowed in some countries due to legislative restrictions (Roche and Boland, 1980). The livestock industry has responded by searching for alternatives to replace growth promoters. One result of this search has been the introduction of supplemental lighting into animal farms. Scientific evidence based on trials presented in specialised journals is very sparse and inconclusive. Furthermore, contradictory evidence has been published concerning the use of extending photoperiod to influence growth rates and milk yields of cattle. (e.g. Roche and Boland, 1980 vs Bourne et al, 1984).

Up to the late 1950s there had been little study of the effects of photoperiod on cattle production, although quite extensive work had been carried out with sheep. In recent years many experiments have shown that photoperiod affects productivity in dairy cattle and it appears to be the primary environmental cue that regulates seasonal breeding activity in ruminants. The amount of illumination that is optimal for farm animals kept in controlled environments in intensive husbandry systems is still a matter of controversy and some species, particularly pigs, poultry and calves, are often kept in low levels of lighting, which is believed to reduce activity and promote productivity. In poultry it is common practice to keep both broiler and laying strains in low light intensity (below 10 lux) in order to inhibit aggression and feather- pecking (Appleby et al., 1992; Fox, 1984).

Since activity is generally correlated with light intensity (Boshouwers and Nicaise, 1987), it has been anticipated that keeping young birds in dim light would reduce activity so that energy could be channeled into growth. Recently, on finding that supplementary light reduces daily activity levels and increases lying time in dairy cows housed in an environment where a large production response to supplementary light was obtained, Phillips and Schofield (1989) proposed that improved welfare and /or reduced maintenance requirements may be responsible for productivity increases. Recent experiments have also demonstrated that supplemental lighting stimulates growth in cattle (Peters et al., 1978). Nevertheless the influence of day length on cattle production is still a subject of much debate.

Research work around the world has produced results varying from positive benefits from artificially increased daylength to no effect and in some cases an apparent reduction in performance.

The objective of this thesis was to establish the effects of photoperiod on the behaviour and performance of intensively housed cattle and to investigate whether photoperiod changes are justified to improve animal welfare, should positive effects on behaviour and performance be established.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1 EFFECTS OF PHOTOPERIOD ON THE GROWTH AND CARCASE QUALITY OF CATTLE

2.1.1 Effects of photoperiod on the growth of cattle

It is well known that long days play an important role in the productivity and reproductivity of sheep and many other ruminant species including cattle. In a report by the Meat and Livestock Commission in the UK it was found that live weight gains of cattle were consistently greater in summer than they were in winter over a period of five years, with intermediate rates during spring and autumn (M.L.C.1974). It seemed that neither environmental temperature nor nutritional changes were directly responsible for these seasonal changes in growth cycle. First, because the critical temperature of yarded cattle fed *ad libitium* on rations of high digestibility is likely to be lower than winter temperature in the British lowland (MLC, loc. cit). Second, because data was collected from farms adopting *ad libitum* feeding of cereal based diets. Therefore, photoperiod changes among other things seemed to be the factor which could be responsible for the cycles of growth observed.

It seems reasonable to assume that the balance between positive and negative effects could depend on the influence of the environmental factor 'light' on animals' behaviour, since we can expect modifications in their activities with different light levels.

As the daylength changes and as the intensity differs between high and low, so does the degree of advantage to the animal, or so it can be hypothesised.

Additional daily illumination during winter has been reported to increase growth rates in both cattle and sheep. In controlled experiments, Peters et al. (1978) reported an increase in growth rate of 10-15% without requiring additional food in Holstein heifers when exposed to 16 hours of artificial lighting compared with natural daylight of 9-12 hours. Heart girth was increased by 16L:8D, suggesting that the effect was not solely due to gut fill. In a further experiment with heifers (Peters et al. 1980) natural winter photoperiods, 16L:8D and 24L:0D were compared. Weight gains were significantly elevated by 16L:8D compared with natural days (0.98 vs. 0.84 kg/day; $P<0.02$) but not by 24L:0D (0.88 kg/day). The authors concluded that an 8h period of darkness was necessary to achieve increases in weight gain when Holstein heifers were supplemented with light. In contrast, Marcek and Swanson (1984) observed that first-calf heifers, but not cows, exposed to continuous light gained weight significantly faster than those exposed to 18L:6D. Cows gained more weight when exposed to 18L:6D as compared with natural photoperiods. Tucker et al. (1984) reported that consistent increases in average daily gains of the cattle in response to longer duration photoperiods have not always been achieved. The lack of consistency may be associated with sexual maturity or rate of fattening of the animal. For instance, the stimulatory effects of 16L:8D photoperiods on liveweight gain are not readily manifested in immature prepubertal heifers, but occur primarily during the peripubertal period. In a series of six trials using fattening cattle (280-490 kg) Parsons et al. (1974) found that feed conversion of cattle given continuous lighting was 4.7% better than that of cattle exposed to a natural lighting pattern. Roche and Boland (1980) found that extending natural winter photoperiod by 8 h of light from 16.00 h to midnight did not affect total gain or feed efficiency of the calves. In a study on the effect of extended photoperiod in winter on the growth of heifer calves Bourne et al. (1984) reported that between early September and mid December animals on natural daylength grew significantly faster than those on 16L:8D daily photoperiod. There was a 9.5 kg difference in body weights by 2 December ($p<0.001$). However this difference gradually diminished from this date to the end of the trial, when there was no significant difference in body weights between the two treatments. No overall significant differences were found between treatments for either girth or height at shoulder measurements. In contrast to previously published findings their results suggest that an extended daily photoperiod inhibits heifers' growth rates in the first half of winter, whilst the effect appears to be reversed for the second part of winter. Long day photoperiods of 16 hours light (L) and 8 hours dark (D) stimulated a proportional increase in liveweight gain (LWG) of peripubertal Holstein heifers of 0.08 to 0.17 compared with heifers exposed to short days of less than 16 hours (L) per day (Peters et al., 1978; Zinn, et al., 1986). In contrast, heifers fed high energy diets gained more bodyweight and carcass fat when exposed to short days (Zinn et al., 1986b). Photoperiod alters growth in peripubertal bulls but not in prepubertal bulls or steers (Roch and Boland 1980; Tucker et al., 1984). Thus, photoperiod induced changes in growth may be dependent on gonadal steroids.

The physiological mechanisms relating photoperiod to growth rate in beef cattle have not been clearly identified. However, it must be remembered that motivation for behavioural changes is caused by both exogenous and endogenous factors

(Immelonanm, 1976). The concentration of certain endogenous pituitary hormones associated with metabolism, notably prolactin, varies during the year according to daylength. Various experiments on heifers in Michigan, USA (Peters et al., 1981) and on lambs of both sexes in the UK (Forbes et al.,1979) have shown that long days (16 hours light and 8 hours darkness) increase concentrations of prolactin but not growth hormone or insulin in serum. These prolactin changes in animals on 16 hour light have also been associated with significant increases in daily liveweight gain and milk yield of cows (Roche and Boland, 1980). Various experiments on the effects of light supplementation on animal production in the USA (Peters et al., 1978 and Peters et al., 1980) have shown considerable increases in growth rate of 10 - 17% in Holstein heifers. Others have shown no growth rate response (Roche and Boland 1980) with either Friesian bull calves or Friesian finishing steers. Petitclerc et al. (1983) observed that in comparison with 8 h light:16 h dark to 16 h light: 8 h dark has stimulated body weight gain in Holstein heifers even when feed intake has been restricted to equal quantities in both groups of heifers. An explanation for this variation in responses comes from two sources. Firstly, the previous exposure to a given photoperiod may affect the response (Moore Ede et al., 1982). Secondly, the rate of change of light intensity at dawn and dusk may affect the growth response to light. In deer mice, a gradual transition in light intensity from dark to maximum intensity of light (and vice versa) is a more potent cue of a change in photoperiod than abrupt change from dark to maximum intensity of light and (vice versa) (Kavanau,1962). Cattle may also respond better to a gradual transition in light intensity (over 30 min.). Zinn et al. (1988) conducted a study with 64 heifers to determine the effects of gradual or abrupt dawn and dusk on the growth response to photoperiod. Abrupt transitions were less than 5 seconds. They found no clear differences between abrupt and gradual transition. In another experiment the authors investigated the effects of combinations of previous and subsequent photoperiod on growth, 64 Holstein heifers (85 kg body weight) were assigned to one of four treatments in a 2x2 factorial experiment. Main effects were: previous (P) exposure, 63 days; and subsequent (S) exposure, 151 days. Photoperiod was: 8L:16D (8L) or (16L):8D (16L). Average body weight gains were not different among animals exposed to P-16L:S-16L, P-16L:S-8L, P-8L:S-16L and P-8L:S-8L. But, P-16L:S-8L reduced body weight gains over time (197 kg) compared with P-8L:S-8L (209 kg, $p<.05$) and P-16L:S-16L (210 kg, $p<.05$). Their results demonstrated that a daily photoperiod of 8L containing gradual transitions of light intensity at dawn and dusk or a daily photoperiod of 8L preceded by 16L reduced body weight gains in Holstein heifers. Previous photoperiod that animals are exposed to and the speed of the transition of light intensity at dawn and dusk are factors that affect the magnitude of the photoperiod induced changes in growth (Zinn et al., 1988). Photoperiod induced differences in liveweight gains were significantly greater in heifers exposed to long versus short photoperiods when it was coupled with gradual changes in light intensity. However, Peters et al. (1980) reported a 0.17 proportional increase in liveweight gain in heifers exposed to 16L:8D (with abrupt transitions of light intensity at dawn and dusk) compared with those exposed to less than 12 h light/day with natural occurring gradual transitions of light intensity at dawn and dusk. In an experiment on calves using four levels of lighting (2, 20, 100, 130 lux), Dannenmann et al. (1984) reported that calves exposed to 2 lux tended to spend a longer time lying than those exposed to 130 lux, 20 or 100 lux levels of lighting. Animals do not accumulate 'photons' like plants therefore intensity does not influence the physiological response (in plant both intensity and duration affect response). Intensity may influence animal visual acuity and therefore behaviour.

It therefore apperas That the anabolic effects of increased duration photoperiods in cattle are dependent on the gonads (Tucker et al., 1984). Zinn et al. (1986b) demonstrated that photoperiod failed to influence body weight gains of steers. Exposure to 16L:8D partially prevented the loss in liveweight gain that occurred following overiectomy of heifers (Zinn et al., 1989a). Photoperiod cues evidently influence the endogenous rhythm.

Skeletal long (6L, 8D, 2L, 8D) photoperiods have been tested with growing cattle but appear to have less benefit than conventional long photoperiod (Zinn et al., 1986a).

2.1.2 Effects of photoperiod on carcase composition of cattle

Several studies have demonstrated that short days are conducive to fat deposition, while long days stimulate protein accretion in cattle (Petitclerc et al., 1983). Peters et al. (1978) and Petitclerc et al. (1983; 1984) reported that bodyweight gain and carcass protein in peripubertal heifers were higher in 16 hours of light than in 12 hours of light. In contrast, heifers fed high-energy diets gained more body weight (BW) and had greater percentages of fat and reduced percentages of protein in the soft tissue of the 9-10-11 rib sections when exposed to short days (Zinn et al., 1986b). Fat accretion was greater in carcasses of postpubertal heifers exposed to short days than heifers given long photoperiods, but there was no effect of photoperiod on protein accretion. With steers some researchers found no effect of photoperiod and no interaction between photoperiod and plane of nutrition on carcass weight, percentage of fat or protein in ribs or carcass accretion of fat or protein (Zinn et al., 1988). On the other hand, Ringuet et al. (1988) reported that photoperiod did not affect slaughter weight, but carcass yield increased significantly under 16L : 8D photoperiod. These findings are not in total agreement with those previously reported, although a slight but not significant increase in slaughter weight was observed when steers were exposed to 16L : 8D, carcass weights were not affected by supplemental lighting. These differences in response to photoperiod in various experiments could therefore be attributed to differences in plane of nutrition, age of animal and the light intensity used.

The capital economic benefit of extended photoperiod for growing cattle is the reduction in carcase fatness, permitting the producer to rear cattle to a heavier weight before slaughter. To a certain extent the reduction in carcass fatness could be offset in heifers by earlier puberty in light supplemented cattle (Fauconneau and Gauthier, 1984; Hansen et al., 1983)

2.1.3 Effects of photoperiod on serum concentration of prolactin

The mechanism whereby photoperiod controls growth in cattle and sheep has not been elucidated, but the interior pituitary hormone prolactin could be involved. Of all the hormones measured in cattle, prolactin is most affected by changing photoperiod. Bourne and Tucker, (1975) observed that calves exposed to 16 h light 8 h dark had higher blood prolactin levels than in calves exposed to 8 h light 16 h dark.

The importance of this hormone comes from its role in the differentiation of the mammary gland cells and as a signal in the differentiated cells to produce milk proteins and other constituents, but its importance once lactation has been fully established is less certain in the cow. Akers et al. (1980) reported that exposure of lactating cows to 16 hours of light per day stimulates prolactin secretion except when temperature approach freezing. With growing cattle, as with lambs, exposure to long days causes greatly increased prolactin secretion and sometimes reduces plasma levels of cortisol (Leining et al., 1980), the latter suggesting reduced stress.

Several studies have reported increased prolactin concentration when cows are exposed to long photoperiods compared to short winter daylength. Tucker (1985) reported that 16 h of light daily increased serum prolactin in comparison with heifers exposed to natural daylength of 9 to 12 h. However, ambient temperature below 0°C suppressed the ability of 16h L: 8 h D photoperiods to increase serum prolactin.

Stanisiewski et al. (1988) reported that serum concentrations of prolactin in bull calves receiving 16h of light daily were higher compared to those receiving 8h of light, and that the prolactin response to photoperiod was independent of the testes. However, 16h light-induced stimulation of serum concentrations was not maintained indefinitely, but declined to concentrations that were not significantly different from those in calves maintained under short days. Thus, increased prolactin concentrations in bull calves became refractory to a once stimulatory photoperiod. For more details see Lomas, (1994)

2.2 EFFECTS OF PHOTOPERIOD ON THE LACTATION OF DAIRY COWS

Physiologically, dairy cattle are not seasonal breeders. Possibly for this reason, comparatively little research has been dedicated to study the effects of season on lactation in dairy cattle, and most research of seasonal effects on the mammary function of the cow has focused on ambient temperature. From such studies it is clear that milk yield is generally lowest when ambient temperature exceeds the upper (Fuquay,1981; Morrison, 1983) and plunge below the lower (Young, 1981; 1983) critical temperature of the cow's thermoneutral zone. However, studies under controlled conditions have shown that photoperiod affects milk yield, feed intake, eating pattern and hormone secretion in dairy cattle.

2.2.1 Mammary growth

Increasing the number and activity of mammary epithelial cells stimulates milk yield while the number of milk-synthesising cells is one of the basic elements that limits milk production. Petitclerc (1985) reported that when daily exposure to light increased from 8 to 16 h it stimulated the mammary parenchyma to grow into the fat pad of the mammary gland of prepubertal and postpubertal, nonpregnant heifers. Although most allometric mammary growth occurs in response to hormones associated with puberty, pregnancy and milking stimulus. In a study investigating the response of mammary development to photoperiod and plane of nutrition in Holstein heifers, Petitclerc et al., (1983) reported that photoperiod did not influence measures of mammary development. Petitclerc et al. (1984) and Newbold et al. (1991) observed that photoperiod (16L:8D vs. 8L:16D) had no effect on total mammary gland weight, total extraparenchymal fat weight, or proportion of extraparenchymal fat in the mammary gland of pregnant dairy heifers. In contrast, mammary parenchyma weight increased in both prepubertal and postpubertal heifers when they were exposed to 16L:8D as compared with heifers exposed to 8L:16D.

2.2.2 Milk yield

In dairy cattle, 16 hours of light daily increase concentrations of serum prolactin (Bourne et al., 1975), an anabolic hormone (Bates et al., 1964) associated with lactational production (Koprowski et al., 1973). In a study investigating the effects of photoperiod of 16L:8D in Holstein cattle on milk yield, Peters et al. (1978) reported that cows exposed to 16 h of light daily (114 to 207 lux) increased milk yield 10 to 15% in comparison with cows exposed to natural daylength (39 to 93 lux) of 9 to12 h. Some of the results which have been published concerning the use of extended photoperiod on the effect of growth rates and milk production have shown significant increases in both. In controlled experiments using Holstein cows Peters et al. (1978) obtained a 7-10% increase in milk production from cows exposed to a 16 hour day compared to a natural daylength of 9-12 hours. Under similar circumstances Bodurov (1979) and Phillips and Schofield (1989) obtained increases in milk yield of 14 and 16% respectively. Research by Phillips and Schofield (1989) demonstrated that supplementary light and its intensity had no significant effects on the milk yield and liveweight change of the cows when 4 different levels of intensity were used, but milk fat concentration was reduced for cows receiving light at the highest intensity.

2.2.3 Milk composition

There is little information on the effect of an extended photoperiod on milk composition. Response of milk fat secretion to photoperiod has not been consistent across experiments. Peters et al. (1978, 1981) reported that the percentage of fat in milk was unaffected by photoperiod length. However, Bordurov (1979) reported that in comparison with short days, 16L:8D increased milk fat by a total of 0.3 percentage units. In more recent work in 13 commercial dairy herds, Stanisiewski et al. (1985) observed that cows exposed to 16L:8D produced 0.16 percentage units less milk fat than cows exposed to less than 13.5 h of light each day. A large reduction in milk fat with extended photoperiod was reported by Phillips and Schofield (1989), Although the effect was not statistically significant. Generally, an inverse relationship exists between milk yield and milk fat per cent (Rook and Campling, 1965). Phillips and Schofield (1989) observed that supplementary light reduced milk fat content in the absence of any effect on milk yield. Thus, one might expect that as milk yield increases in response to supplemental lighting, milk fat per cent may decline, and the precise effect of photoperiod on milk fat is yet to be determined.

In the only work available concerning the effect of light on milk protein Phillips and Schofield (1989) observed a reduction at high light intensity (529 lux at cow eye level), but not at lower intensities (101 or 191 lux).

2.3 THE EFFECT OF SUPPLEMENTARY LIGHT ON THE AGE AT PUBERTY IN CATTLE

Cattle, unlike some other domestic species living in temperate climates, ovulate and conceive throughout the seasons of the year. Domestic cattle may have evolved in situations where natural selection for seasonal breeding was reduced due to the provision of supplementary feeding, shelter and care for the young. This may reflect the intense selection of these animals by man to provide a year-round food supply.

Research has indicated that various aspects of cattle reproduction are altered by seasonal variations in environment. Gwazdauskas (1985) reported that much work has emphasized the detrimental effects of ambient temperature and humidity on reproductive processes. However, more research is required to partition acute from chronic and diurnal from mean temperature and humidity effects as well as impacts of wind, thermal radiation, precipitation, photoperiod, environmental contaminants, restraint, and management systems that can alter dairy cattle homeostasis. Effects of season are potentially important to cattle producers because manipulation of environmental stimuli, or of the physiological pathways through which they act, may result in an improvement in reproductive efficiency.

Effects of season interact in a complex manner with other environmental factors affecting reproduction, including breed, nutrition, level of milk production and suckling. While some of the seasonal variation is undoubtedly caused by variations in management, effects of season on puberty and the postpartum anoestrus can be mimicked by altering daylength, suggesting that photoperiod is one of the environmental stimuli responsible for seasonal effects.

It is clear that the natural light stimulus for those farm animals that show seasonal breeding is a complex one involving the absolute quantities of light and dark as well as relative quantities of light each day which change dynamically. Although it is generally believed that daily fluctuation in the photoperiod emphasize the change taking place in daily light rations, it is also clear that the fixed nature of the photoperiod is important, i.e. seasonal breeding animals maintain their breeding activities as long as an adequate quantity of light (or of dark) is delivered. When the photoperiod fails to provide adequate stimulation for the animal a refractory period develops during which the breeding performance is arrested.

It is an advantage to the farmer to have his animals reach puberty and breeding in a shorter time than they normally do, which could lead to more efficient food production from domestic cattle. Puberty in cattle is preceded by changes in gonadotropin secretion. Circulating concentrations of luteinizing hormone (LH) increase as puberty approaches (Swanson et al., 1972) as does the frequency of LH pulses (Schillo et al., 1982). Hansen (1985) reported that the hormonal mechanisms by which season alters age at puberty are incompletely understood. Seasonal modulation of puberty onset is accompanied by changes in ovarian volume and follicular development (Hansen et al., 1983). Hawk et al. (1954) observed that Holstein Friesian heifers born during the spring, the presumed natural season of birth, reached puberty at a significantly earlier age than those born during other seasons of the year. In a long-term experiment, Roy et al. (1980) observed that Friesian heifers born in the spring showed first oestrus approximately two months earlier (at six months of age) than those born in the autumn (at eight months). In contrast, Schillo et al. (1982) observed that autumn born heifers reached puberty at younger ages than spring born heifers. It seems that there is no one season that grants an animal or early puberty.

Discrepancies between experiments can be explained by the fact that sexual development in cattle occurs over several seasons. As a consequence, the season of birth is confounded with seasons at other stages of prepubertal development. Also, factors such as breed and nutrition alter the rate of sexual development. Grass et al. (1982) reported that heifers fed diets low in energy reached puberty later than those fed diets high in energy and that breed or breed-of-sire differences in age at puberty were not affected by dietary treatment.

Results obtained by Hansen et al. (1983) indicated that photoperiod is at least one environmental variable affecting puberty. Angus and Angus crossbred heifers exposed to 18 h of light per day after 22 or 24 weeks of age experienced first ovulation and oestrus at younger ages than heifers exposed to natural autumn and winter photoperiods. The authors concluded that age at puberty in the bovine female can be altered by photoperiod even though they are not seasonal breeders. It is unlikely that there has been much genetic selection for early puberty in cattle.

However, age at conception was not significant, service/conception tended to be greater, and percentage conception at first service was lower for heifers with supplemental light. This suggests that fertility was determined by light treatment because animals exposed to light were younger at first breeding than animals exposed to natural photoperiod.

2.4 EFFECT OF SUPPLEMENTARY LIGHT ON SOCIAL BEHAVIOUR IN CATTLE

There is still inadequate information on the effects of light intensity on the performance, behaviour or well being of animals (Smith, 1988). In an experiment with calves Dannenmann et al. (1984) reported that, calves spend more time in social contact, but tended to spend less time in social grooming at low intensity (2 lux) than at other light intensities (100 or 120 lux). In dairy cows Phillips and Schofield, (1989), reported that mounting activity and sniffing or licking the anogenital area was higher for cows with natural daylight only, than cows with additional supplementary light . It has been shown by Hall (1989) that social behaviour happens more frequently in daytime than at night. However, many of the effects on production and reproduction previously described are often assumed to arise from change in the animals' physiology, stimulated by photoreception. In relation to effects on production, the photic stimuli change the animals' environmental perception so dramatically that there are marked effects on behaviour, which could be partially responsible for observed effects.

A most pronounced feature in cattle behaviour is the active way in which individuals associate with each other. Such behaviour serves many purposes, including species cohesion and ecological integration (Syme and Syme, 1979). Social interactions exist among cows in a herd structure, therefore one cow can influence the behaviour of another cow. Feeding intake is a behavioural aspect of individual animals which is determined by the time that animal spends feeding, ruminating, standing, standing ruminating , lying and lying ruminating, which are part of many measures of the activity of the animal. In dairy cattle a small increase in lying and large reduction in walking has been recorded in 18L compared with natural 10L daylength (Phillips and Schofield, 1989). Social dominance effects can be very important in case of high stocking densities or poor farm design. Inadequate trough space, narrow races, inadequate space in indoor housing or lack of feeders can mean that dominant animals command resources at the expense of subordinate animals (Fraser and Broom, 1990). Previous research has shown that social dominance in dairy herds can be measured using replacements of one cow by another cow at feed stations (Rutter et al., 1987).

However, a study by Stakelum et al. (1987) found no relationship between grazing behaviour activities and dominance values, but age, body weight and daily milk yield were positively correlated with dominance (0.5, 0.6 and 0.47) respectively.

Wierenga (1983) reported that aggression is least frequent at pasture and most frequent in an over crowded cubicle house. The dominance order is established by frontal fighting and is then normally very stable except for a short period when new cows are introduced to the group.

The optimum light supplementation to stimulate production and reduce activity would therefore appear to be a long daylength (c. 16-18 L) of low intensity, which is the pattern adopted in most commercial controlled environments for pigs and poultry.

2.5 EFFECTS OF PHOTOPERIOD ON OTHER DOMESTICATED LIVESTOCK

2.5.1 Pigs

The published reports on the influence of supplemental lighting on the performance of the domestic pigs are conflicting. In pigs a long photoperiod of 16L, 8D had no benefit in weight gain and feed intake compared with short photoperiod of 8L, 16D (Mcglone et al., 1988; Gooneratne and Thacker, 1990). The length of the photoperiod has not usually been found to affect performance in young pigs (Wright et al., 1984). Increasing the natural photoperiod by means of artificial light had no effect on growth rate or feed efficiency of weaners (Dorn et al., 1979) or gilts (Diekman and Hoagland 1983). However, compared with 8L, 16D, a skeletal photoperiod of 2L, 5D, 2L, 15D has been shown to increase growth rate by 3% and feed conversion efficiency by 2%, and reduce the electricity consumption for lighting by 48% (Melhorn and Don, 1985).

2.5.2 Sheep

The effects of seasonal changes in daylength on reproduction in sheep are well known, but in recent years it has become apparent that improved growth rates and food intakes of sheep, are associated with long daylength. In general, the effects are greater in sheep of lowland breeds than in sheep of less improved breeds.

Research by Schanbacher and Crouse, (1980) demonstrated that there was no effect of photoperiod on liveweight gain, carcass weight and backfat thickness of growing lambs when exposed to two levels of lighting: 16 h light : 8 h dark or 7 h light:9 h dark: 1 h light:7 h dark. Photoperiod has been used by farm animals to time their activities in particular to their parturition in relation to the period of optimum feed availability. It is clear that there are seasonal fluctuations in the voluntary food intake and growth rate of sheep in the UK which can be explained neither by variations in quantity or quality of feed nor by changes in environmental temperature and humidity (Forbes et al., 1979). On the other hand, limited information is available on the effects of supplemental lighting on the growth and performance of young lambs. However, Schanbacher (1979) suggests that the growth rate of young lambs has been shown to be regulated in part by photoperiod. Exposure of young lambs to long daylengths (16 h of light and 8 h of dark, 16L:8D) as opposed to short daylengths (8L:16L) increases average daily gain by 15% in wethers and 20% in rams. These findings are in agreement with those reported by Forbes et al. (1979).

Several experiments have demonstrated that when growing lambs are exposed to a long photoperiod (16L : 8D) there is an increase in liveweight gain compared to those with 8L : 16D, however, at least 50% of the increase is due to an increase in gut contents (Forbes et al., 1975). In an attempt to separate the importance of daylength, time of light exposure, and prolactin on growth and performance of young lambs, a study was conducted by Schanbacher et al. (1981) where lambs were exposed to one of three contrasting photoperiods: short (8L:16D), long (16L:8D), and split (7L:9D:1L:7D) photoperiods. Their results demonstrated that when lambs were exposed to long daylength (16L:8D) and to a split photoperiod gained weight more rapidly than those exposed to short daylength (8L:16D). The authors suggested initially that changes in growth rate were a reflection of photoinduced changes in secretion of the anabolic hormone prolactin. Support for this statement has been gathered in experiments with both cattle (Peters et al., 1978 and Peters and Tucker, 1978) and sheep (Brown and Forbes, 1980). Whereas growth rate and prolactin secretion are enhanced in cattle exposed to supplemental lighting, pinealectomy in sheep reduced the prolactin response to daylength and tended to block the effect of daylength on liveweight gain. Concurrent photoinduced changes in feed intake and prolactin secretion provide additional incentive to question the mechanism of action for photoperiodic regulation of growth. It seems that long daylength stimulates growth and gut fill by some central control mechanism and/or maybe some reductions in animal activity levels and not solely by encouraging more feeding. In contrast, Hackett and Hillers

(1979) were unable to find any beneficial effect of artificial night lighting on growth and performance of young lambs maintained in an outdoor environment.

As with most other species, skeletal long photoperiods e.g. 7L, 9D, 1L, 7D have been successfully used to replace long photoperiod (Foster et al., 1988) and achieve the same increased in weight gain.

Like cattle, the carcass composition of lambs on long daylength tends to show increased protein and reduce fat content (Forbes et al., 1979, 1981). Schanbacher and Crouse (1980) reported that photoperiod and sex of lamb affected growth rate and feed efficiency but that only sex of lamb affected carcase quality. They added that when both rams and wethers exposed to long photoperiods had the heaviest carcases, ram carcasses were leaner, had better yield grades and were heavier than wether carcases. The authors suggests that testosterone and prolactin may independently affect growth and performance of growing- finishing lambs.

2.5.3 Other mammals

The mechanisms responsible for the initiation and termination of the breeding season in seasonally breeding mammals are poorly understood. There is a general recognition that photorefractoriness in both inhibitory and stimulatory photoperiods plays a central role in timing the breeding season (Nicholls et al.,1988). In a large number of seasonally breeding mammals, refractoriness to short photoperiods, rather than a direct response to increased daylengths, may be the primary factor responsible for inducing gonadal regression of reactivation in early spring. Thus, in sheep maintained in fixed winter solstitial photoperiods, the breeding season terminates irrespective of an increase in daylength or decrease in the duration of secretion of the pineal hormone melatonin (Robinson and Karsch, 1984). However, the precise timing of the termination of the breeding season has not been defined in the Tammar wallaby but occurs 6-8 weeks after the winter solstice in the Bennett's wallaby (Curlewis et al., 1987). In Syrian hamsters the reproductive systems are very sensitive to photoperiodic manipulation, such that when either males (Hoffman and Reiter, 1965; Gaston and Menaker, 1967) or females (Hoffman and Reiter, 1966; Reiter and Hester, 1966) are placed under short-day conditions that provide less than 12.5 h of light per day their peripheral reproductive organs undergo morphological (Reiter, 1968a,b) and functional involution (Sorrentino and Reiter, 1970; Reiter, 1973, 1974; Berndston and Desjardins, 1974). Furthermore, hypothalamic metabolism related to the function of the peripheral sexual organs is altered accordingly (Kumar et al., 1982;1984; Steger et al., 1984; Hastings et al.,1985a; Roberts et al., 1985). In a study on hamsters (Urbanski et al., 1983) it was found that under natural photoperiodic conditions the animals remain reproductively active during spring and summer until the decreasing autumnal photoperiods induce testicular regression and remain sexually inactive for approximately 5 months. Under laboratory conditions, exposure of sexually mature hamsters to photoperiods of less than 12.5 h light daily results in testicular regression (Gaston and Menaker, 1967), while conversely the transfer of sexually immature hamsters to long photoperiods before the onset of spontaneous recrudescence induces testicular growth (Elliott, 1976). There is a similarly well-defined photoperiodic threshold in the Djungarian hamster.

2.6 THE EFFECTS OF PHOTOPERIOD ON FEEDING BEHAVIOUR OF FARM LIVESTOCK

The initiation of feeding behaviour can be affected by diurnal rhythms and social factors but inputs from monitors of body state are of particular importance. Signals reported to be of importance in several species include visual input, input from taste receptors, input resulting from stomach contractions, insulin effects, plasma glucose detector input and fat store monitor inputs (Mogenson and Calaresu, 1978)

Taking into consideration this range of factors it appears that feeding is behaviourally and physiologically determined. Broom (1981) presumed that physiological facts alone do not explain all feeding characteristics. Feeding behaviour is strongly affected by reinforcement, both positive and negative, from food palatability effects to environmental and social associations in feeding. It is essential therefore, for the concept of motivation and reinforcement to be incorporated into any comprehensive view of food intake control. One current scientific conclusion is that as the animal develops, drinking and feeding may occur as natural complements of each other, and they may occur frequently and in modest amounts, not because the animal is constrained to restore accumulated deficits, but because it anticipates the pleasures of ingestion and thereby avoids the deficits entirely (Epstien,1983).

Diurnal patterns of eating are characteristic of grazing behaviour in horses, sheep and cattle. Distribution patterns of grazing periods are correlated with hours of darkness and light. Regina and Wangsness, (1980) reported the distribution of time spent actually eating, summed over the 21 cow day in 1 h intervals. Of the total time spent eating during each 24 h, averaging 253.6 minute/cow/day, approximately 68% was between 0600 and 1800 h. The general pattern agrees with previously reported work by Chase et al. (1976).

A review by Hancock (1953) reported that grazing peaks occur at dawn and dusk with the majority of grazing occurring during the day. He also reported night grazing to be reduced in the higher latitudes when daylength was very long. More recently, reports of grazing patterns have added support to Hancock's observation that diurnal eating patterns of cattle follow the described crepuscular rhythm (i.e. associated with sunrise and sunset). Movement monitoring devices called vibracorders were first used by Stobbs (1970) to record grazing behaviour of cattle. Stricklin et al. (1976) used vibracorders in Pennsylvania to determine grazing patterns of cattle on summer pasture and on the same cows during winter while being fed corn silage. Cows began grazing at dawn and continued until dusk with intermittent breaks. Grazing was most intense just after sunrise and just prior to sunset.

Controlled studies of the effects of photoperiod on feeding behaviour have been carried out by several researchers. The intake of complete pelted feeds by lambs is stimulated by long days (Forbes et al., 1979a) or by a nocturnal "flash" (Schanbacher and Crouse, 1981).

Feeding behaviour of cattle has been described by Hafez and Bouissou (1975) who suggested that eating behaviour of cattle depends not only on photoperiod but also on social and environmental facts. There is evidence that supplementary light produces an additional peak of feeding activity. With dairy cows Forbes et al. (1987) show a peak of feeding around midnight followed by reduced feed intake for the rest of the night.

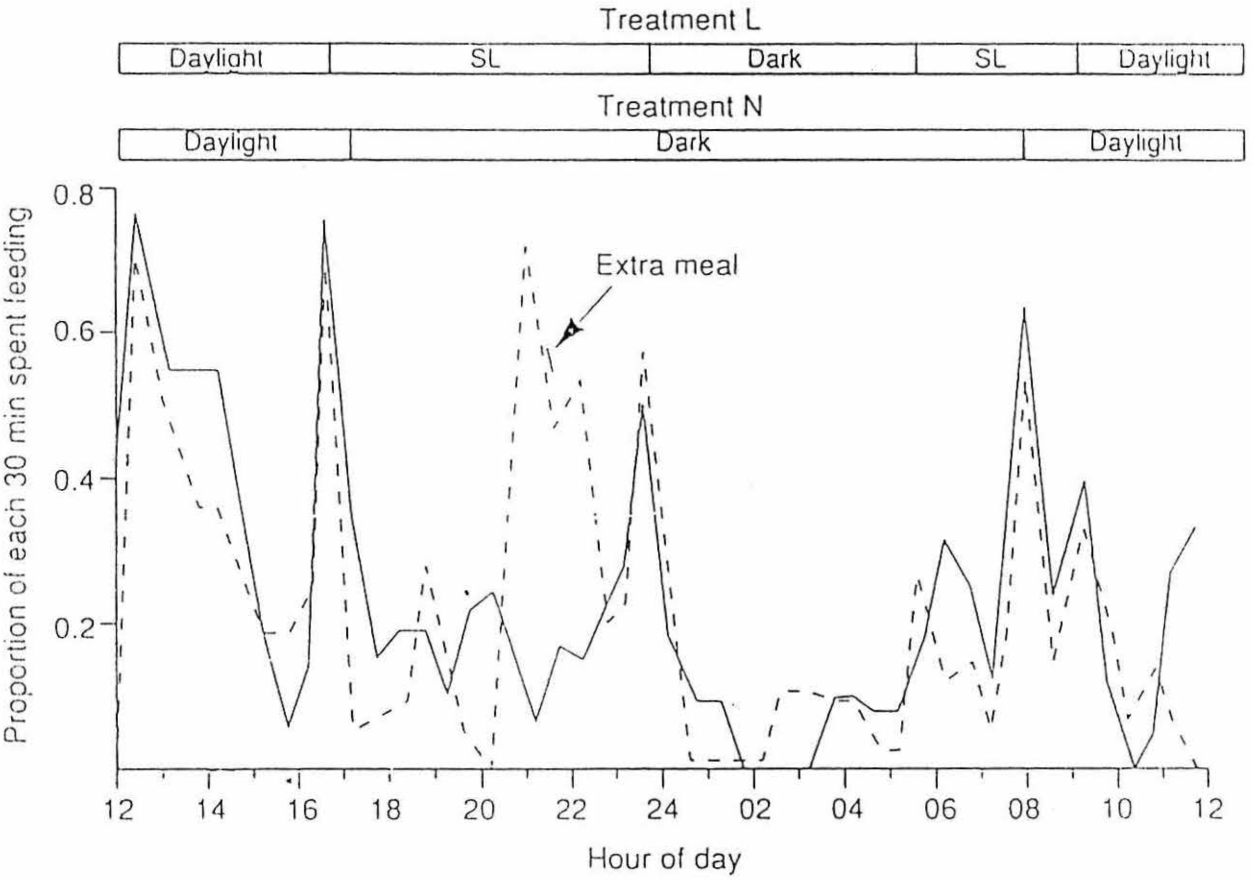
Grazing peaks at dawn and dusk were reported by Stricklin (1988), but he adds that when the feeding space is restricted, feeding is more continuous throughout the day and eating becomes faster. Phillips and Schofield (1989) found that supplementary light of 10 hours produced a marked increase in the number of feeding bouts of dairy cows compared with cows with no supplementary light.

Total daily feeding times were not increased, although the periodicity of feeding was affected, with more feeding tended to occur in the light supplementation period (Figure 2.1). They add that other peaks of feeding activity were noticed after each milking, after feeding in the morning and at around midnight.

Similar results on the effect of artificial lighting in changing the periodicity of feeding behaviour have been reported by Chase et al., 1976; Zinn, Chapin and Tucker (1983) and Tanida et al. (1984) to be towards the end of the period of supplementation, which is the artificial dusk for the cow. Peaks of feeding activity at dusk have been reported by several authors in grazing and housed cows (Hughes and Reid, 1951; Stricklin and Gonyou., 1981; and Stricklin., 1987).

Figure 2.1. Periodicity of time spent feeding by cattle with and without supplementary light.

Treatment N (——) and L (--------) SL = Supplementary light



Source: (Phillips and Schofield, 1989)

Clearly, cattle prefer to feed and be active in the light, which is probably a latent defence mechanism, but also need to spread out the periods of ingestion evenly over the day for efficient digestion. The broad features of ingestive behaviour of sheep are common to those of cattle. There are periods of movement and eating along with drinking, idling and lying down and ruminating, interspersed with periods of intensive ingestive activity. In a study of the ingestive behaviour of dairy cows, Phillips and Hecheimi (1989) observed that grazing bout number was greatest and the bout duration least in midsummer when photoperiods are naturally long. The longest and also the most intensive period of grazing takes place in the morning and from late afternoon to dusk. However, several workers have reported that either rumen or blood metabolite concentration are key factors in controlling ruminant voluntary feed intake. Rakes and Coffindaffer, (1967) studied the eating habits of steers and noted two periods of concentrated eating daily. However, these were believed to be related to diurnal fluctuation in natural light intensity. This theory was supported by work by Chase et al. (1971) who reported that peaks of eating activity are largely concentrated into two periods, climaxing at 0800 and 1700 hr. Also, they noted the presence of two additional periods of lower concentration between 1900 to 0400 hr. Putnam et al. (1965) reported that eating pattern of steers could be altered by artificial light.

Generally, the increase in the milk yield of cows exposed to extended photoperiods is accompanied by greater dry matter intake. Peters et al. (1980) observed that heifers exposed to 16L:8D consumed significantly ($p<0.01$) more dry matter than those exposed to 24L:0D or natural photoperiods. In a comparison of eating behaviour of dairy cows under 18L:6D or continuous light Tanida et al. (1984) found that lighting regime had no effect. Peters et al. (1981) reported that the 6.1% increase in dry matter intake of dairy cattle receiving 16h of light could account for the increased milk yield. Phillips and Schofield (1989) also observed an increase in complete diet intake when dairy cows exposed to extended photoperiod. The rate of dry matter intake was also increased, but time spent feeding was not affected.

2.7 MANIPULATION OF LIGHT CONDITIONS IN ANIMAL HOUSING

2.7.1 Artificial illumination in cattle housing

Over the centuries, animals have been provided protection from climatic variables by sheds, barns, and other buildings as a matter of humane treatment. More recently, however, there has been increased use of environmental control to enhance rate and efficiency of production. Animals kept outdoors are exposed to daylight of varying intensity and duration. However for those which are housed indoors, lighting may be manipulated to alter its intensity, duration or quality. Manipulation of the physical or managerial environment to enhance productivity is a potentially important tool for use by animal scientists. The adoption of techniques must be based on an assessment of the risks, costs, benefits and indirect effects associated with environmental manipulation (Ames and Ray, 1983).

In the United Kingdom, adverse weather conditions usually result in cattle being housed for up to seven months of the year. Daylength declines from the summer solstice in June and only starts to lengthen again after the winter solstice in December. As the daylength declines into winter there are fewer hours of sunlight and more cloud cover, making the shorter days darker. Cows are housed in buildings which may be open-ended or have sky lights in the roof, but the illuminance level in these buildings is lower than outside. It is not known what effects these dark conditions have on the mental health of cattle. A form of depressive illness in man known as seasonal affective disorder, occurs only in autumn and winter and can be treated successfully by means of daily exposure to bright light either in the early morning or evening. Light therapy works by entraining the circadian rhythm to the light-dark cycle. Whether it is possible to reduce the impact of the natural environment and improve the housed environment of cattle by providing artificial illumination is an important question.

Practical advice, on current evidence, would be confined to suggesting the lighting necessary for adequate supervision of stock as recommended in the welfare codes for cattle. The code suggests that during the hours of daylight the level of indoor light, natural or artificial, should be such that all housed cattle can be seen clearly. This implies an illuminance of c. 20 lux. The code further suggests that adequate lighting should be available for satisfactory inspection at any time. An illuminance of 50 lux should meet this requirement (ADAS- pers.comm).

2.7.2 Types of lighting

The Electricity Council (1986) reported that good farm lighting should serve its purpose, be economical to install and use, and be durable and safe. The light should be sufficiently bright and evenly distributed over the lighted area and should not produce glare. The lighting installation should be capable of withstanding the conditions in the place of use. Choosing the type of lamp is an important factor in achieving these objectives. Ordinary tungsten lamps are poor producers of light compared with fluorescent tubes and high intensity discharge lamps. Under typical conditions, if a lamp is used for an average of ten hours or more per week, it will be economical to use a fluorescent tube or high intensity discharge lamp, rather than a tungsten filament lamp.

For half the days in the year, natural light is sufficient for most purposes inside farm buildings, although weather conditions may reduce the available light at any particular time. Most farm buildings are fitted with roof lights or side windows, or have openings in the sides which admit light. Although suitable for practical purposes, the illuminance levels from even very good electric lighting are only a very small fraction of daylight levels. Daylight can and should be used in most farm buildings.

2.7.3 Recommended light intensities

Daylight usually enters farm buildings via openings in the sides or ends and by translucent roof sheets. The recommended amount of daylight inside farm buildings is roughly equivalent to one-twentieth (5%) of the amount of daylight available outside the farm buildings at the same time. This level is also agreed by the Ministry of Agriculture, the Chartered Institution of Building Services Engineers Code for Interior Lighting and complies with British Standard 5502 (Electricity Council, 1986).

Light intensity is most often measured in units called lux, one lux being the amount of illumination of a surface area measuring one square metre receiving a luminous flux of one lumen . One lumen is equivalent to 10.764 foot-candles, the latter being an obsolete measurement of light intensity.

Bright sunlight	80 000 lux
Overcast day, outdoors	5 000 lux
Clear, starlit night	0.2 lux

In Britain, the Electricity Council (1986) recommended 50 lux as a minimum intensity provided by electric lighting. However, the recommended level is reduced to 20 lux where adequate daylight is used. This results in a considerable saving in both fittings and running costs. The recommended minimum intensity varies in different countries. The minimum level recommended by German law on the protection of animals is 20 lux (Dannenmann et al., 1984).

Human efficiency is greatly affected by the quantity and quality of light available for vision. Stockman performance may be impaired at low light intensities. For good visual efficiency, light intensities in excess of 100 lux are required (Durrant., 1977).

A more modern measure of light intensity is the quantum or photon. A quantum is a discrete packet of energy associated with electromagnetic radiation. The term photon is also used, but sometimes implies a quantum of visible light. The radiation is expressed in terms of Einsteins per square metre per second. An Einstein (E) or mole (mol) is 6x 10^{23} quanta or photons.

2.7.4 Measurement of light intensity

There is very little information concerning the effects of light intensity on the performance and behaviour of cattle and most of the studies on the effects of photoperiod frequently omit to describe the method of measuring light intensity. As in the case of many reported effects of day length the results were inconsistent. One possible source of this inconsistency was the level of light intensity. Smith (1988) reported that the "box" technique should be most commonly adopted when measuring light intensity in animal trials. This entails facing the light meter in the six directions corresponding to the faces of a cube. The average of the six measurements is taken as the reading . The position of the measurement must be decided in terms of both the horizontal and vertical plane. The horizontal plane measurement may be critical where animals are confined in a small area. Vertical plane measurements are often taken at both the standing head height and the lying head height of the animals concerned. Method of light measurement has important implications for research involving different levels of light intensity, especially when attempting to interpret the results.

2.7.5 Skeleton photoperiod

Night interruption experiments are often referred to as skeleton photoperiods since they are designed to stimulate the time of lights-on and lights-off of complete photoperiods. In diverse mammalian species, interruption of the night at certain circadian phases with brief pulse of light can lead to a long day response of the reproductive system.

Brinklow and Forbes (1984) reported that exposing lambs to skeleton long photoperiod (7L:10D:1L:6D) significantly increased plasma levels of prolactin and significantly reduced cortisol concentrations compared with short photoperiods (8L:16D). These light induced effects are blocked by surgical removal of the pineal gland. Lamb weight gains have been shown to be increased with a 1 hour "flash" of light interrupting the dark period (Forbes, 1982). Despite the general increase in liveweight under the "flash" treatment, carcass weights were not improved, although there were consistent tendencies for them to be larger and leaner. The use of "flashes" of light demonstrates the potential of using a small quantity of extra light to stimulate additional growth (Forbes, 1988).

2.8 CONCLUSIONS FROM THE REVIEW OF LITERATURE

The research reported in this chapter provides some evidence that supplementary light influences the behaviour and production of sheep. However, in the case of cattle the available research is so inconsistent that it can not be relied upon in its present state. Clearly other variables than those reported as treatments are affecting the responses and it is the purpose of this program of research to identify the factors influencing the response of cattle to supplementary light. The responses in growth and carcase composition, male (castrate) and female (entire) behaviour and prolactin are therefore measured in a series of experiments designed to investigate extended daylengths of c. 16 h applied in British winter when natural daylength was about 9 hours.

CHAPTER III

EXPERIMENT ONE AND TWO

EXPERIMENT ONE AND TWO

THE EFFECTS OF SUPPLEMENTARY LIGHT ON THE GROWTH, BODY COMPOSITION AND BEHAVIOUR OF STEERS AND HEIFERS

3.1 ABSTRACT

In two experiments the growth, body composition and behaviour of steers and heifers kept in a building with natural daylength only (average 9.7 h/day, treatment N) were compared with similar groups of animals kept in identical housing with the daylength artificially extended to 16 h/day, (treatment L). The effects were recorded for 126 day in steers and 180 days in heifers, with both groups of animals being slaughtered in March when the two experiments ended. There were no effects over the entire experiment on the growth rate or food intake of either steers or heifers. The growth of the steers was reduced in the first two weeks after the lights were switched on (Treatment N 1.48, Treatment L 1.05 kg/d, s.e.d. 0.13, $P<0.05$), but they gained more weight to compensate over the next 8 weeks (Treatment N 0.95, Treatment L 1.16 kg/d, s.e.d. 0.036, $P<0.05$). Over the whole experiment there was no treatment effect on food conversion ratio for either steers or heifers but it was reduced for steers on treatment L over the first 10 weeks. Body scanning of the heifers showed that compared with treatment L, those in treatment N deposited more fat tissue between autumn and winter and less between winter and spring.

The behaviour of steers in treatment L did not vary over the experiment, but steers in treatment N changed their behaviour with season. They spent more time sleeping in winter and less time in Spring. Over the whole period of the experiment steers in treatment L spent less time sleeping and more time lying ruminating than those in treatment N, but the total time spent lying was not affected by treatment. In contrast, the heifers in treatment L lay down for longer than those in treatment N (L 747 vs 713 min./d) , suggesting that the effect of supplementary light on lying time, which has been observed previously with dairy cows, is confined to female cattle. Heifers in treatment L started mounting each other earlier than heifers in treatment N, like the steers, they spent less time sleeping in winter and more time in spring. Blood prolactin concentrations were increased by supplementary light, particularly in the first half of the experiment. It is concluded that extending the photoperiod for cattle in winter reduced body fatness in both steers and heifers and increased the time heifers spend lying down but that there were no major effects on growth rate or feed intake.

3.2 INTRODUCTION

Investigation into the use of artificial light to supplement short natural daylengths with beef cattle has produced a variety of results. Some have shown increased growth rates with supplementary light in winter (e.g. Peters, Chapin, Emery and Tucker, 1980; Mossberg and Jonsson; 1996), while others show no effect of extending natural daylight (e.g. Roche and Boland, 1980). The response appears to be greater in postpubertal cattle (Hansen et al., 1983; Petitclerc et al., 1983), but attempts to identify the hormone involved have so far not been conclusive (Koprowski and Tucker, 1973; Peters and Tucker, 1978; Leining, Tucker and Kesner, 1980). Prolactin is most responsive to changes in photoperiod, and it has been suggested that together prolactin and growth hormone function as chronic coordinators of nutrient partitioning among tissues (Baumann, Eisenmann and Currie, 1982).

Changes observed in the growth rate or milk yield of ruminant with supplementary light appear to be independent of nutrient intake (Forbes, 1982; Petitclerc et al., 1983; Phillips and Schofield, 1989; Mossberg and Jonsson, 1996), although *ad libitum* feed availability increases the stimulatory effect of long daylength on the growth rate of sheep (Forbes, Brown, Al-Banna and Jones, 1981). However, Forbes, Drive, Brown and Scanes (1979b) have observed that in sheep at least half of the observed increase in body weight is due to changes in the weight of the contents of the gastrointestinal tract.

One reason for the large variation in observed effects of supplementary light on cattle growth rates may be that the composition of the growth is affected. In post-pubertal heifers experiments have shown that extending the daylength in winter reduces fat accretion (Petitclerc, Chapin and Tucker, 1984; Zinn, Purchas, Chapin, Petitclerc, Merkel, Bergen and Tuker, 1986). It is likely that post-pubertal heifers entering the short days of winter would have derived evolutionary benefit from restricting body growth in order to store energy as fat to be used during restricted food availability in winter and spring. Many would be pregnant, with parturition and increased nutrient requirements occurring in spring. It is not clear how widespread this phenomenon is. No effect was observed in steers by Zinn, Chapin, Enright and Tucker (1989), which was attributed to the lack of functional gonads by the authors. Forbes, El-Shahat, Duncan and Boaz (1979) and Forbes et al. (1981)

reported the same effect in male castrated lambs. Further, the balance between protein and fat accretion and the nutrient supply may explain why some cattle have been observed to grow faster with supplementary light in winter and some have not.

The effects of photoperiod on cattle behaviour are also inconclusive. There is some evidence that increasing the daylength in winter increases resting behaviour in cows that are intensively housed (Phillips and Schofield, 1989), which suggests that maintenance energy may be saved, but no effect of extended daylength on the lying times of bulls was observed by Dechamps, Nicks, Canart and Istasse (1989). Webster, Smith and Mollinson (1982) report a reduction in basal metabolic rate in the autumn in bulls in natural daylength.

This study was designed to investigate the effects of supplementary light in winter on the growth, carcase composition and behaviour of steers and heifers in their final period of growth.

3.3 MATERIALS AND METHODS

3.3.1 Experiment 1.

3.3.1.1 Animal management

The experiment was carried out at Drayton Experimental Husbandry Farm, Stratford-on-Avon, England for 126 days between 1 November, 1988 and 29 March 1989. Sixty-four Hereford x Friesian steers, of approximately 12 months of age, were blocked in pairs according to weight and within blocks were randomly allocated to two treatments. For this purpose the steers were weighed full on two consecutive days and then after 24 h of fasting prior to the start of the experiment.

The animals in the two treatments were housed 20 days before the start of the treatments in two identical halves of a portal-framed building. The housing comprised eight pens of 6.8 x 6.0 m in two rows of four on either side of the building, separated by a 2.5 m concrete feeding passage. The building was split in two by a light proof barrier, giving four pens for each treatment, two on each side of the building. The building had open ends and skylights to allow daylight to enter the building.

In one half of the building, 32 steers received both natural and supplementary light for a total of 16h from 04.00 h to 20.00 h and darkness for 8 h from 20.00 h to 0.400 h (treatment L). Times for turning supplementary lights on and off were selected so that natural daylight would not extend beyond the 16 hour light. Six twin tube (2 x 80 W) fluorescent lights were fitted per pen at a height of 1 m above cattle eye level. After 84 days the light fittings were raised by 50 cm because of the accumulation of straw bedding. Mean light intensities, as measured at 1 m^2 intervals across the pens with a lightmeter (Photometer,Weston Model. S511, UK) pointed in the direction of the six faces of a cube, were 353, 374, 445 and 473 Lux at 0, 50, 100 and 180 cm above ground level respectively. A programmable photocell was fitted to switch off the lights when natural lighting levels were at 500 Lux or above. The lights were turned on and off gradually (one every 5 minutes in each pen) over a period of 30 minutes to simulate dawn and dusk. In the other half of the building, 32 steers received natural daylight only (treatment N). The mean natural daylight during the experiment was 9 h 43 min. (range 7 h 44 min. to 12 h 08 min.). Temperature and humidity were recorded hourly (Squirrel data loggers) from 22-28 November and were similar between treatments (mean temperature treatment N 3.0, treatment L 4.0 °C, s.e.d 0.24; humidity treatment N 94.2, treatment L 95.4 %, s.e.d 0.41).

The steers were weighed at 14 day intervals during the trial. At the end, two full weights and a weight after 24 hour fasting were taken on 3 consecutive days. Animals were then selected for slaughter over a period of 1 month, during which time lighting treatment continued but food intake was no longer recorded due to the disruption of removing animals from the treatment groups. Grass silage was delivered from a forage wagon at 09.00 h daily and was offered *ad libitum,* so that approximately 10% remained on the following morning as a refusal. Refusals were collected, weighed and discarded once weekly. A mineralized rolled barley concentrate supplement was fed on top of the silage at a rate of 2 kg per animal daily up to 42 days, after which this was increased to 2.5 kg/head until the end of the experiment. Representative samples of silage and concentrate were collected once each fortnight and, following analysis by the procedures of Ministry of Agriculture, Fisheries and Food (1986), were found to contain 281 and 852 g dry matter (DM) per kg fresh weight; 150 and 134 g crude protein (CP.), 87 and 28 g ash and 11.5 and 13.2 MJ metabolizable energy (ME) per kg DM, respectively. The silage had a pH of 4.1 and contained 75 g ammonia-nitrogen per kg total nitrogen (N) and 792 g digestible organic matter/kg DM. The synchronized weighing of weekly silage refusals together with weighing of animals enabled calculation of feed conversion ratios for each pen. Water was available freely and the animals were bedded on wheat straw, which was added to the pens three times weekly.

Blood samples were taken from the jugular vein into heparinized tubes at approximately 30 day intervals for analysis of prolactin by radioimmunoassay.

At the end of the experiment all steers were taken to an abattoir where carcase weights and fatness / conformation classes (MLC, 1984) were recorded.

3.3.1.2 Behaviour recording

All animals were identified with large numbers painted on the back and side. Animals in each treatment were observed separately for all 24 h of the day once in the first, second and third six week periods of the experiment (referred to subsequently as autumn, winter and spring respectively). In each period there were six observations, each of 4h. Each pen was observed for a continuous 4 minutes in a rotation lasting 16 minutes for the four pens in each treatment. During this period the dominant behaviour of each animal was recorded as feeding, standing, standing ruminating, lying alert, lying ruminating, or lying sleeping. In addition, grooming (self or other animals) and sniffing or licking inanimate objects were recorded as behavioural events within each 4 minutes period (maximum one recording of each event per period): A 1.5 W handtorch was used to aid animal identification in the dark, and was not expected to influence behaviour since cattle are less sensitive to small changes in light intensity than humans (Phillips and Weiguo, 1991) and the animals used in this study were well accustomed to the presence of the observer.

The dominance of each steer during aggressive interactions was recorded by recording the winner and the loser in social interactions, with the aim of identifying any change in the relationship between dominance and behaviour caused by the supplementary light. Winners were those who caused the subordinate to yield space, either through the animal's presence as a threat or by force. A dominance value for each steer was calculated as the ratio of encounters won to total encounters (Schein and Fohrman, 1955) and rank orders were calculated and related to weight gain and behaviour using Pearson's Correlation Coefficients.

3.3.1.3 Statistical analysis

Data were tested for normality in order to justify analysis by parametric methods. All parameters were analysed using Genstat 5 release 1.3 (VAX/VMS4, Laws Agricultural Trust, 1980) in a two-factor design including treatment and pen, although the effects of the latter were not significant. In addition Pearson's correlation coefficients were calculated between the mean values for weight gain and each behaviour (including dominance) on an individual animal basis. Prolactin data were normalized by taking $\log_{10}$ values and analysed by a general linear model (GLM) in the Minitab statistical package using a model with cow as a random factor nested within treatment.

3.3.2 Experiment 2.

3.3.2.1 Animal management

Forty-eight Charolais x Freisian heifers of approximate age 9 months were allocated to the same two treatments as in (section 3.3.1.1) experiment 1. The study lasted for 196 days between 20 September 1989 and 4 April 1990.

Subcutaneous fat and lean measurements were made by ultrasonic scanning (Wells-Krautkramer Scanner) according to the method of Miles et al. (1983) on all animals on three different occasions (14th November 1989, 23rd January 1990 and 27th March 1990, referred to subsequently as autumn, winter and spring measurements respectively). The equipment used for fat and lean measuring was developed at the AFRC Institute of Food Research, Bristol (Miles et al., 1982). Velocity measurements of ultrasound (VOS) passage through combined fat and muscle tissue were made at two hindquarter sites using an adjustable clamp and at a shoulder site. The reciprocal speed of passage of the ultrasound transmission was then related to the volume fraction of fat using equations already established (Miles et al., 1983). Blood samples were taken for prolactin analysis as in (section 3.3.1.1) experiment 1.

3.3.2.2 Behaviour recording

All animals were individually identified by the same method as in (section 3.3.1.2) experiment 1. The major behavioural activities of the heifers were examined in three 24-h observations, one in each 8-week period starting 2

November - 28 December 1989, 4 January - 22 February 1990, 1 March - 19 April 1990 (referred to subsequently as autumn, winter and spring). The heifers were observed for 8-h daily for three consecutive days at the beginning of each period. Treatments were observed separately. At 15 minute intervals, the main activity of each animal was classified as feeding, standing, standing ruminating, lying, lying ruminating and sleeping. In addition, the following behavioural incidents were recorded within each 5 minute period (maximum one recording of each incident per 5 minute period): grooming (self or other heifers), biting and licking inanimate objects (bars of pen and other objects), drinking and mounting activity. Dominance was recorded as in (section 3.3.1.2) experiment 1.

3.3.2.3 Statistical analysis

The analysis of the data was conducted using the same method as in (section 3.3.1.3) experiment 1. At the end of the experiment the carcase of each heifer was graded and the distribution of animals by carcase grades and treatment was examined using the chi-square test.

3.4 RESULTS

3.4.1 Experiment 1.

3.4.1.1 Food intake, live-weight gain and body composition.

There were no significant treatment effects on weight gain from the beginning to the end of the experiment or on fasted or carcase weight at the end of the experiment (Table 3.1). However weight gain was reduced in the first 14 days

November - 28 December 1989, 4 January - 22 February 1990, 1 March - 19 April 1990 (referred to subsequently as autumn, winter and spring). The heifers were observed for 8-h daily for three consecutive days at the beginning of each period. Treatments were observed separately. At 15 minute intervals, the main activity of each animal was classified as feeding, standing, standing ruminating, lying, lying ruminating and sleeping. In addition, the following behavioural incidents were recorded within each 5 minute period (maximum one recording of each incident per 5 minute period): grooming (self or other heifers), biting and licking inanimate objects (bars of pen and other objects), drinking and mounting activity. Dominance was recorded as in (section 3.3.1.2) experiment 1.

3.3.2.3 Statistical analysis

The analysis of the data was conducted using the same method as in (section 3.3.1.3) experiment 1. At the end of the experiment the carcase of each heifer was graded and the distribution of animals by carcase grades and treatment was examined using the chi-square test.

3.4 RESULTS

3.4.1 Experiment 1.

3.4.1.1 Food intake, live-weight gain and body composition.

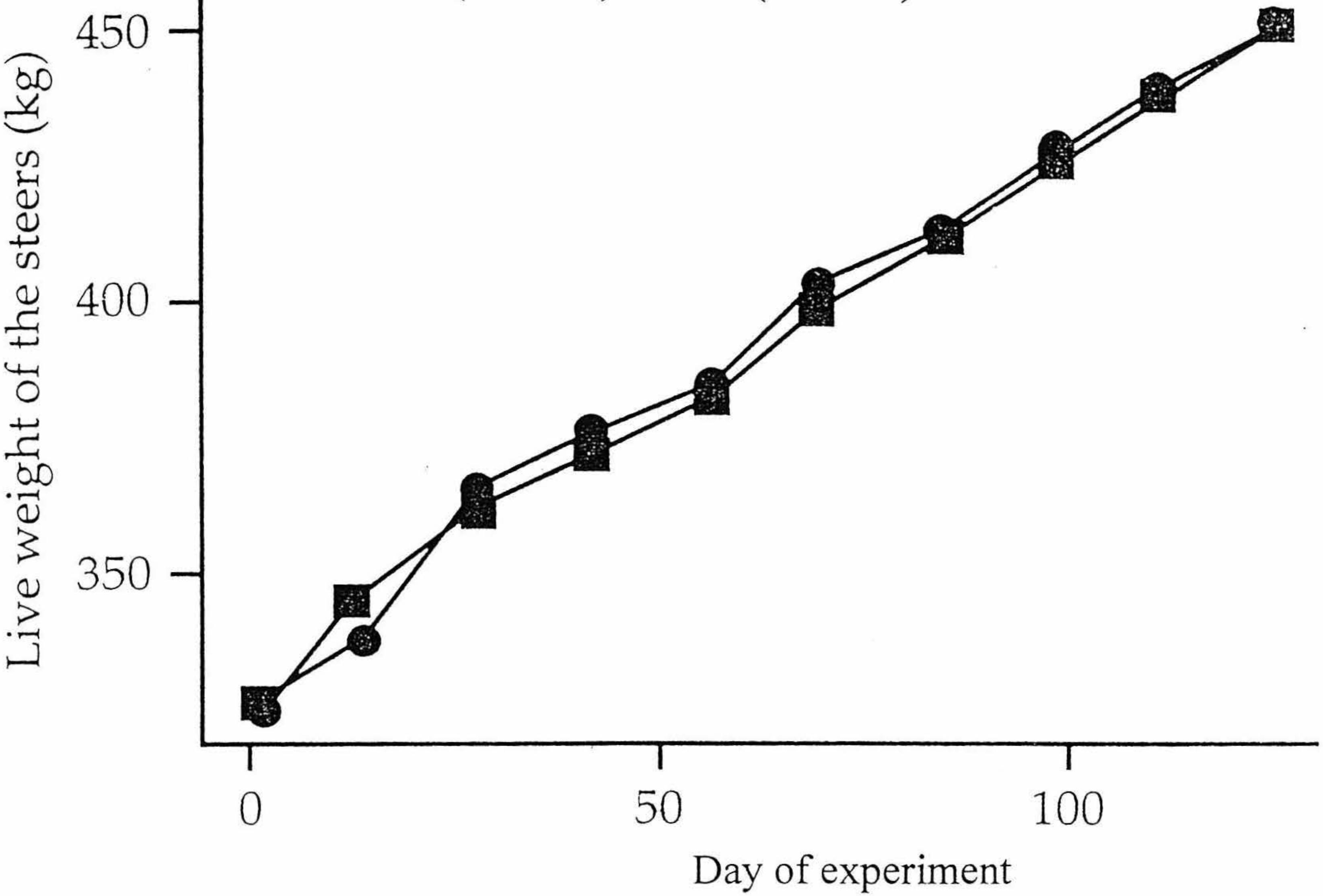
There were no significant treatment effects on weight gain from the beginning to the end of the experiment or on fasted or carcase weight at the end of the experiment (Table 3.1). However weight gain was reduced in the first 14 days by supplementary light (Treatment N 1.48, Treatment L 1.05 kg/d, S.E.D 0.131, $P<0.05$), but increased from 14 up to 70 days (Treatment N 0.95, Treatment L 1.16 kg/d, S.E.D 0.036, $P<0.05$) (Figure 3.1). Silage DM intake was not affected by treatment at any time in the experiment. Feed conversion ratio over the entire experiment was not affected, but it was reduced by supplementary light between the start and 70 days (Treatment N 7.0, Treatment L 6.4 S.E.D 0.15, $P< 0.05$).

Table 3.1 Carcass, liveweight gain and silage DM intake for steers on treatments N and L

	Treatment L	Treatment N	SED†	Probability
Initial weight (kg)	308	309	5.1	NS
Final weight (kg)	431	427	6.7	NS
Weight gain (kg/d)	1.11	1.06	0.028	NS
Carcase weight (kg)	249	247	3.6	NS
Killing out %	54.1	53.7	0.31	NS
Silage DM intake (kg/d)	5.6	5.6	0.20	NS
Feed conversion ratio (kg DM feed /kg gain)	6.6	6.8	0.17	NS

†None of the treatment effects was significant ($P>0.05$)

Figure 3.1 Changes in live weight for steers in experiment 1 treatment L (●——●) and N (■——■)



3.4.1.2 Cattle behaviour

Considering the experiment as a whole, the standing and feeding times of the steers were not affected by treatment, but steers in treatment L spent more time lying ruminating and less time lying asleep or alert than steers in treatment N (Table 3.2). They also spent more time allogrooming, but self grooming and licking objects were not affected by treatment. The behaviour of steers in treatment L was not affected by season, however steers in treatment N changed their behaviour with season. The time that they spent feeding was longer in winter and shorter in spring, and to compensate standing and standing ruminating were decreased in winter and increased in spring. In winter when the steers in treatment N were lying they were more likely to be sleeping and less likely to be ruminating than those in treatment L. In spring they spent less of their lying time sleeping or ruminating and more time alert. There were no significant correlations between any behaviour variables and the growth or dominance of the animals in either treatment ($P>0.05$).

Table 3.2 The effects of supplementary light on the behaviour of steers in autumn, winter and spring.

	Autumn		Winter		Spring		Period		Treatment		Interaction	
Treatment	L	N	L	N	L	N	SED	Sig.	SED	Sig.	SED	Sig.
Main behaviours (min/24 h)												
Feeding	309	311	308	328	308	281	9.4	*	7.7	NS	13.2	*
Standing	260	262	260	234	260	284	7.6	NS	6.27	NS	10.8	**
Standing ruminating	86	85	86	64	87	112	6.8	**	5.6	NS	9.7	**
Lying alert	146	145	147	146	146	208	8.1	**	6.6	**	11.4	**
Lying ruminating	548	544	548	524	548	472	10.47	**	8.55	***	14.82	*
Lying sleeping	90	92	91	144	91	86	6.7	***	5.5	**	9.6	***
Events (no/24 h)												
Grooming self	2.6	2.3	1.4	1.3	1.3	1.2	0.13	NS	0.10	NS	0.07	NS
Allogrooming	1.8	1.1	1.8	1.4	2.3	1.4	0.26	NS	0.80	***	0.21	NS
Biting/licking objects	1.3	1.6	1.3	1.6	1.1	1.3	0.11	NS	0.25	NS	0.02	NS

Most of the carcases graded 4L and 4H (Table 3.3) on the Meat and Livestock Commission Fat Class. Steers given supplementary light produced more carcases of 4L classification and less of 4H than steers without supplementary light ($X^2 = 6.1$, $P<0.05$). There was no difference in conformation class due to treatment ($X^2 = 0.37$, $P>0.05$)

Table 3.3 Effect of supplementary light on carcase fat and conformation classes of steers

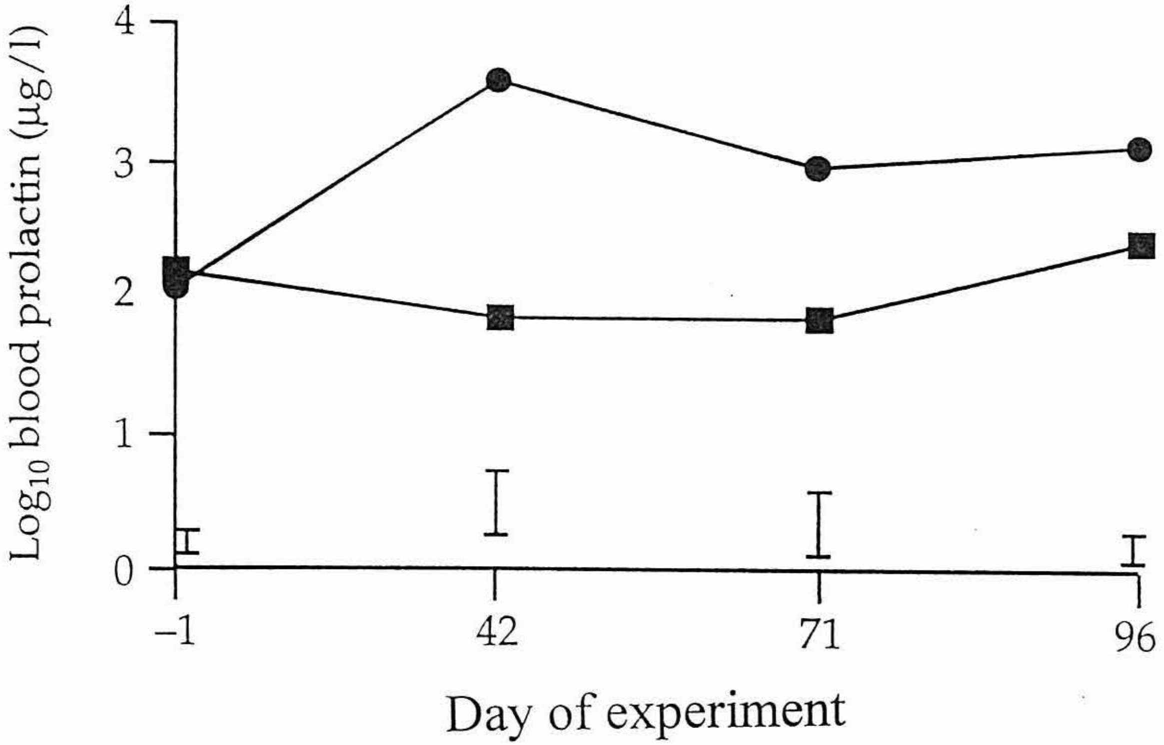
	Treatment L	Treatment N
Fat Class †		
3 (thin)	1	0
4L	12	5
4H	17	24
5 (fat)	2	3
Conformation Class ‡		
U- (good)	2	3
R	16	14
O+	12	13
O- (poor)	2	2

† $\chi^2 = 6.1$, $p< 0.05$. ‡ $\chi^2 = 0.4$, $p>0.05$.

3.4.1.3 Prolactin

The changes in blood plasma concentration of prolactin in the steers during exposure to extended photoperiod are presented in (Figure 3.2). Blood prolactin concentrations were significantly increased by supplementary light on days 42, 71 and 96 of the experiment (P=0.01, 0.04 and 0.01 respectively), with the greatest difference between treatments in log10 blood concentration at the first measurement.

Figure 3.2 Effect of supplementary light on blood prolactin concentration of steers in experiment 1 treatment L (●——●) and N (■——■) treatment L (●——●) and N (■——■). Bars = standard error of the difference between the two means.



3.4.2 Experiment 2

3.4.2.1 Food intake and live-weight gain.

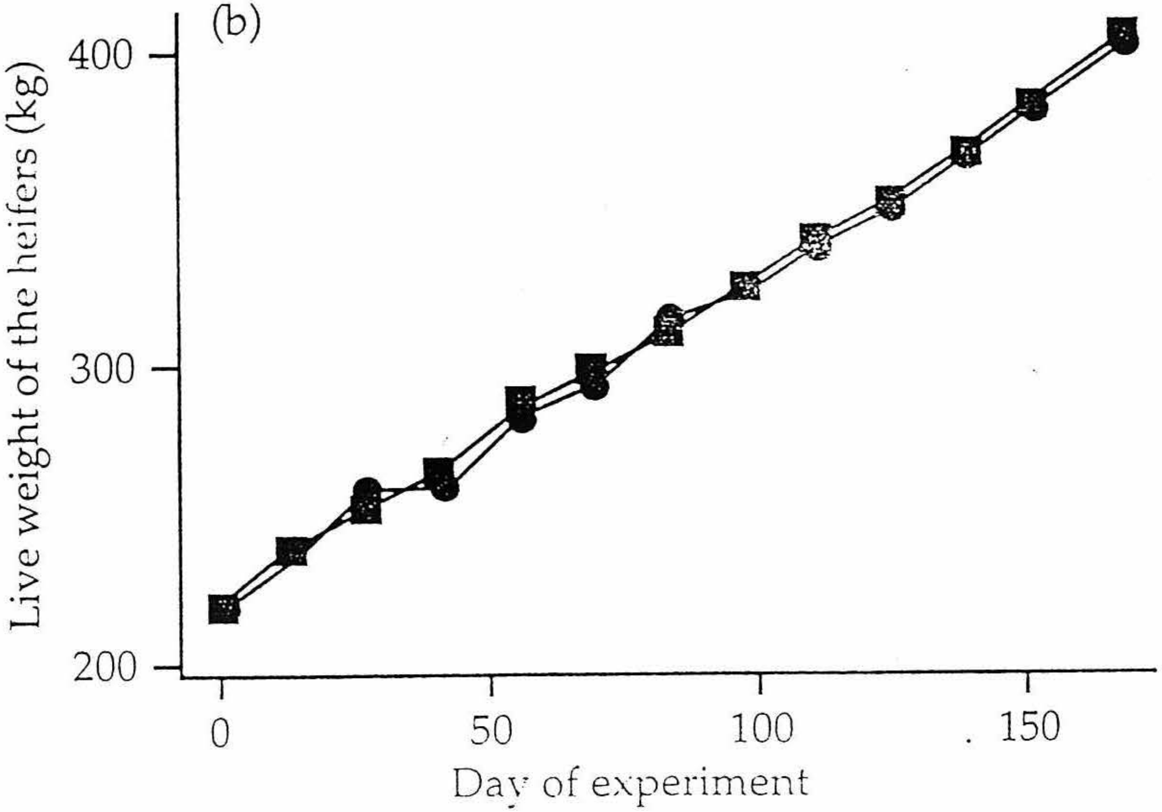
There were effects of no treatment effects on weight gain, silage DM intake or feed conversion ratio (Table 3.4), either over the whole experiment or at any point in the experiment Figure 3.3.

Table 3.4 Liveweight gain and silage DM intake and food conversion ratio for heifers on treatments N and L

	Treatment L	Treatment N	SED†	Probability
Initial weight (kg)	219	219	0.66	NS
Final weight (kg)	410	407	4.8	NS
Weight gain (kg/d)	1.08	1.07	0.013	NS
Silage DM intake (kg/d)	5.7	5.9	0.38	NS
Feed conversion ratio (kg DM feed /kg gain)	5.3	5.5	0.19	NS

† None of the treatment effects was significant ($P>0.05$)

Figure 3.3 Changes in live weight for heifers in experiment 2 treatment L (●——●) and N (■——■)



3.4.2.2 Body composition

Supplementary light did not affect fat or lean contents in autumn, but it decreased fat and increased lean contents in winter (Table 3.5). However, between winter and spring there was a greater increase in fat content and decrease in lean content in the light supplemented treatment, so that there was no difference between treatments in fat or lean content in the spring.

Table 3.5 The effect of supplementary light on fat and lean content and the change between the seasons for heifers

Treatment	**L**	**N**	**SED**	**P-value**
Fat (g/kg)				
Autumn	182	186	6.5	NS
Winter	202	222	5.9	**
Spring	232	228	7.3	NS
Lean (g/kg)				
Autumn	649	642	4.6	NS
Winter	631	616	4.6	**
Spring	610	611	5.4	NS
Fat change (g/kg/d)				
Autumn - Winter	0.26	0.52	0.108	*
Winter - Spring	0.48	0.09	0.088	***
Autumn - Spring	0.37	0.32	0.073	NS
Lean change (g/kg/d)				
Autumn - Winter	0.03	-0.04	0.070	NS
Winter - Spring	-0.34	-0.09	0.067	***
Autumn - Spring	-0.03	-0.02	0.043	NS

3.4.2.3 Cattle behaviour

The behavioural results are presented in (Table 3.6). The behaviour of the heifers was affected more by the period of the experiment than by supplementary light. Nevertheless, the supplementary light reduced the time spent sleeping but increased the total time spent lying down. The only interaction between light provision and the period of the experiment occurred in mounting behaviour. In autumn the amount of mounting behaviour was small. In winter the heifers receiving supplementary light performed a lot of mounting behaviour, but those without supplementary light did not. In spring both treatments performed mounting behaviour with no significant difference between treatments.

As the experiment progressed the time spent feeding declined and standing and standing ruminating increased. Lying alert or ruminating decreased, but sleeping increased. Allogrooming and biting/licking objects declined.

There were no significant correlation coefficients between any behaviour variables and the growth or dominance of the animals in either treatment ($P>0.05$).

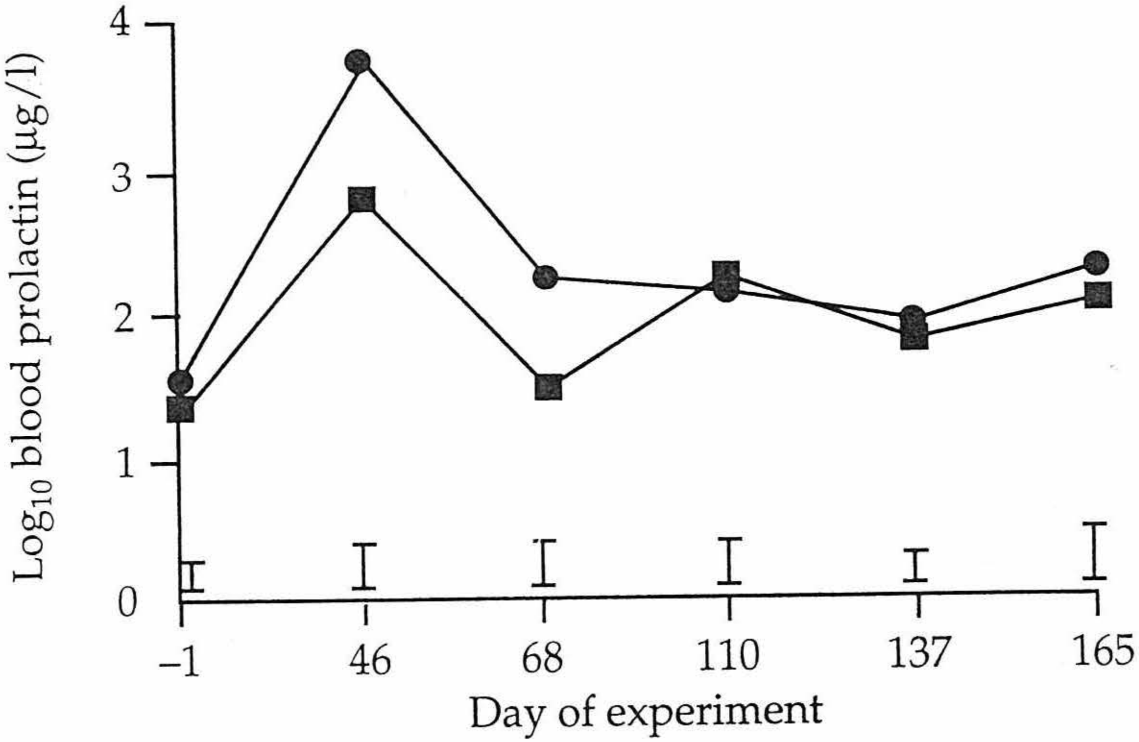
Table 3.6 Effect of supplementary light on the behaviour of heifers in autumn, winter and spring

	Autumn		Winter		Spring		Period		Treatment		Interaction	
Treatment	L	N	L	N	L	N	SED	Sig.	SED	Sig.	SED	Sig.
Main behaviours(min/24 h)												
Feeding	352	346	312	330	273	297	11.3	***	9.2	NS	16.0	NS
Standing	216	240	261	264	289	285	14.1	***	11.5	NS	20.0	NS
Standing ruminating	60	77	63	68	110	107	9.8	***	8.0	NS	13.9	NS
Lying ruminating	520	520	493	456	477	447	14.2	***	12.0	NS	20.0	NS
Lying alert	253	212	260	283	237	233	11.8	**	9.7	NS	16.7	NS
Lying sleeping	38	46	45	51	53	72	5.7	**	7.3	*	9.9	NS
Total lying	774	732	753	726	714	680	17.9	**	14.6	*	25.3	NS
Events (no/24 h)												
Grooming self	3.7	3.2	2.4	2.1	2.2	3.1	0.95	NS	0.08	NS	0.03	NS
Allogrooming	1.9	2.2	1.2	1.2	1.1	1.3	0.80	***	0.14	NS	0.11	NS
Biting/licking objects	3.4	3.1	1.8	1.5	1.2	1.3	1.5	***	0.30	NS	0.11	NS
Drinking	3.7	3.7	1.6	2.3	3.1	3.3	1.7	***	0.46	NS	0.40	NS
Mounting	0.5	0.2	1.5	0.1	0.7	1.2	0.6	NS	0.74	NS	0.92	*
Mounted	0.6	0.2	1.5	0.1	0.7	1.1	0.53	NS	0.77	NS	0.89	*

3.4.2.4 Prolactin

Blood prolactin results are presented in (Figure 3.4) shows that heifers with extended light had higher blood prolactin levels on days 46 and 68 (p=0.01 and 0.03 respectively) but not on days 110, 137 or 165 (all p>0.05; Figure 3.4).

Figure 3.4 Effect of supplementary light on blood prolactin concentration of heifers in experiment 2 treatment L (●——●) and N (■——■) treatment L (●——●) and N (■——■). Bars = standard error of the difference between the two means.



3.5 DISCUSSION

3.5.1 Live-weight gain

The reduction in growth rate of steers in treatment L in the first 14 days coincided with a sudden increase in daylength from before the experiment (from 9 to 16 hours). Silage DM intake was not significantly reduced in treatment L, however, (treatment L 5.0, treatment N 5.2 kg DM per day, s.e.d 0.25) during this period, and there was an increase in food conversion ratio during this period in treatment L (treatment L 6.9, treatment N 4.7 kg feed DM/kg weight gain, s.e.d 0.98). However this could be an artifact of a reduced weight of gastrointestinal contents in the morning, when the steers were weighed. When daylength is extended artificially into the evening, an extra feeding bout occurs during this time (Phillips and Schofield, 1989) and there may have been less intensive feeding in treatment L when feed was delivered at 9 a.m., leading to an apparent reduction in live weight at 14 days. The overall result, however, that daylength did not affect weight gain of the steers or feed conversion efficiency agrees with Roche and Boland (1980) for male Friesian cattle. The reduction in food conversion ratio over the first 70 days may relate to an increased lean content of the carcases, which was evident both in experiment 1 at slaughter and in the autumn in experiment 2.

The absence of any effect of photoperiod on the growth rate of heifers conflicts with the work of Hansen et al. (1983) and Petitclerc et al. (1983). If changes in growth rate derive from changes in body composition, then the elimination of treatment differences by the end of the experiment may explain why growth rate was not affected.

3.5.2 Carcase Composition

Both experiments demonstrated that long days increase carcase fatness. Carcase fatness was reduced in winter in light-supplemented heifers (experiment 2), but this effect had disappeared by the spring. In steers carcase fatness was reduced in light-supplemented steers at the time of slaughter in spring. Previous researchers have found reductions in body fatness of post-pubertal heifers with long days (Zinn et al., 1986; Petitclerc et al., 1984), but results from experiment 2 suggest that declining day length stimulates lipogenesis in cattle, which can be avoided by supplementary light. There was a steady increase in fat content between seasons in heifers on treatment L, as expected due to maturation but those in treatment N increased their fat concentration considerably between autumn and winter, which then remained constant until spring. This conclusion has important implications for the optimum time of slaughtering heifers. Extending the day length in autumn or winter will reduce the fat class or allow the heifers to be taken to a heavier weight at the same fat class. This experiment confirms that supplementary light can reduce body fatness in steers as well as in post-pubertal heifers, in contrast to the work of Zinn et al. (1989). Although Zinn et al. (1989) attributed the absence of effect on carcase composition of steers to the absence of a functional gonad, there may have been other differences in their experimentation that explain the lack of effect.

3.5.3 Prolactin

The increase in prolactin concentrations in blood serum with extended daylength confirms previous research (Peters et al., 1981; Newbold et al., 1991).

The increase in prolactin concentration did not last longer than 100 days in either experiment and Stanisieski et al. (1988) on observing the same phenomenon, suggested that the pituitary gland becomes refractory to increased daylength. It has also been suggested that the response is not to photoperiod *per se* but the change in photoperiod (Zinn *et* al.,1988), which would concur with the increase in prolactin diminishing after the shortest day in both experiments.

3.5.4 Behaviour

The increase in sleeping time of steers in treatment N in winter and decrease in spring would from an evolutionary perspective have had two benefits: energy is conserved during the coldest period of the year when least food is available and the animals are immobilised during the long hours of darkness when the risk of perdition is greatest.

The results in experiment 2 demonstrated that heifers exposed to extended photoperiod spent longer time lying down compared to those exposed to natural daylength only, but this was not observed in experiment 1 with steers. Previously Phillips and Schofield (1989) observed a reduction in lying time of cows with supplementary light in winter, but Nicks et al. (1988) and Dechamps et al. (1989) observed no effect of supplementary light on the lying times of bulls. A small but significant reduction in the amount of walking in mostly female peripubertal cattle with supplementary light was observed by Weiguo and Phillips (1991), but no effect on lying times was observed, that were mostly female was recorded. This suggests that the effect may be confined to postpubertal female cattle lactating cows, its aetiology is as yet uncertain. adult cows are known to show a strong preference for maintaining lying time (Metz, 1984) and it may be that the ability of dominant cows to see subordinate cows for most of the day encourages the latter to lie in the cubicles that offer some protection, rather than walking around the building. Subordinate cows spend a considerable amount of time moving around to avoid the attention of dominant cows (Potter and Broom, 1987) and they usually make more of their visits to feed at night than dominant cows. Alternatively since effects of photoperiod on the reproduction of postpubertal cattle are only reported in the female (Phillips, 1991), it is possible that the effect on lying time is an associated behavioural effect.

It is notable that mounting behaviour was one of the few behaviours strongly affected by photoperiod extension. Supplementary light increased mounting activity among heifers in autumn and winter. However, it reduced the mounting activity during the spring season compared to the natural daylength. Phillips and Schofield (1989) reported that artificially extending the daylength in winter can reduce mounting behaviour and activity in general. However, Sweetman (1950) provides evidence that artificially extending daylength in winter to 16L:8D improves reproductive performance. Under natural daylength cows that calve in the early spring period have delayed return to oestrous cycling (King and Macleod, 1984), because animals conceiving at this time would lead to birth in mid winter. Delaying oestrus is assumed to confer adaptive significance if food is less available at this time. Cows conceiving in summer, with a daylength approximately the same as that of the light supplemented treatment in these experiments, would lead to birth in spring. This may explain why mounting was most evident in winter in the light supplemented treatment.

3.6 CONCLUSION

It is concluded that in this experiment extending the photoperiod for cattle in winter reduced body fatness in both steers and heifers and increased the time heifers spent lying down but that there were no major effects on growth rate or food intake.

CHAPTER V

EXPERIMENT (THREE AND FOUR)

EXPERIMENTS (THREE AND FOUR)

THE EFFECT OF SUPPLEMENTARY LIGHT ON THE BEHAVIOUR AND PRODUCTION OF HOUSED DAIRY COWS DURING DECLINING AND INCREASING DAYLIGHT

4.1 ABSTRACT

The use of supplementary lights in winter for housed dairy cows has been promoted on the basis that they increase milk production, encourage more feeding, and frequently increase lying time, which would reduce the maintenance requirements and could reduce the stress levels in cows so that production and performance is improved, thus increasing profitability. Two experiments were conducted to compare the response of lactating cows to supplementary light in their lying area during increasing and decreasing natural daylength using sixty-six in Experiment 3 and sixty four in Experiment 4. The Friesian cows were allocated to pairs. One cow from each pair in Experiments 3&4 was kept in cubicle house with natural light only (average 11.6L:12.4D, treatment N ; 8.8L:15.2D, treatment N) respectively. The other cows were allocated to identical cubicle housing with the daylength artificially extended to 18L:6D (treatment L) for both Experiment 3&4. The effects were recorded for 90 days in Experiment 3, and for 56 days in Experiment 4. Milk production, composition, stress physiology and cow behaviour in both experiments were compared between treatment N and treatment L in an attempt to understand the complex effects of extending daylength for cows at different times of the year. It was found that extending daylight artificially reduced feed intake in autumn, winter and in the beginning of spring. Milk yield was reduced only in winter (Experiment 4) and was not affected over the whole period in Experiment 3 for cows in treatment L. Cows in treatment L spent less time feeding and ruminating in Experiments 3&4. Blood plasma protein concentration was increased by supplementary light in Experiment 3, and it was no affected in experiment 4. β-endorphin concentration was decreased after two weeks and cortisol after nine weeks for cows in treatment L in Experiment 3, but cortisol was increased by supplementary light in period 1 of Experiment 4. It is concluded that providing supplementary light in the cubicle area during short and declining photoperiod restricts the feed intake of dairy cows, leading to reduced milk production. In longer and increasing photoperiod the reduction in feed intake is less and milk production may not be adversely affected, although milk fat concentration is consistently reduced. Under such conditions stress hormones may be reduced in the blood, but this does not appear related to increases in lying times with supplementary light.

4.2 INTRODUCTION

Providing supplementary light in winter has generally been found to increase the milk production of dairy cows, although some research has found milk fat content to be reduced (Stanisiewski et al., 1985; Phillips and Schofield, 1989). If feed intake is increased, it is as a result of a faster rate of intake, rather than a longer time spent feeding (Phillips and Schofield, 1989). Hence any increase in intake seems to be the result, rather than the cause of increased milk production. The aetiology for the increase in milk yield is still uncertain, but an increase in lying time has been frequently observed in cattle given supplementary light (Phillips and Schofield, 1989; Weiguo and Phillips, 1991; Phillips et al., 1996), which would reduce the maintenance requirements and could reduce the stress levels in the cows. Supplementary light has been found to reduce the basal concentrations of plasma cortisol in cattle (Leining et al., 1980). If increased lying is associated with production benefits, it may be sufficient to provide supplementary light in the lying area only. In modern portal framed buildings the feeding area is usually under the apex of the roof, where it is difficult to provide much light at cow level. Ceiling height is usually less in the cubicle areas and supplementary light can be easily provided.

Responses to supplementary light may depend on photoperiod change as well as, or instead of photoperiod *per se*. In evaluating the effects of photoperiod changes over the year, Mossberg and Jonsson (1996) found that photoperiod change had more effect on the growth of bulls than photoperiod, although only photoperiod was related to feed intake. Intake was greatest on long days, but growth was fastest about 30 days before the longest day.

This chapter reports the results of two experiments where supplementary light was provided in the lying area for dairy cows, one during increasing daylength and one during decreasing daylength. Apart from the milk production and composition, measurements were made of stress physiology and cow behaviour in an attempt to understand the complex effects of providing additional light for cows at different times of the year on the welfare of the cows.

4.3 Materials and Methods

4.3.1 Experiment 3. Increasing daylength

4.3.1.1 Animal management

Sixty-six Friesian cows, with a mean calving date of 25 October, were allocated to pairs on the basis of calving date, parity and production characteristics. One cow from each pair was allocated to be kept in a cubicle house with natural light only (Treatment N). The other cow was allocated to identical housing but with supplementary light provided to give a total of 18 h light and 6 hours dark daily (treatment L). The experiment was conducted between 10 February and 9 April, 1992.

The house was divided into a cubicle area and feeding passage by a solid barrier, and the supplementary light was provided to the cubicle area only in treatment L (Figure 4.1). The light was provided by two rows of twelve 80 W fluorescent tubes, which were automatically illuminated during the hours of darkness from 04.30 to 22.30 h. Mean natural daylength was 11.6 h, increasing from 9.5 h at the start to 13.7 h at the end. Measurements of light intensities were taken at 15 different position in the cubicle area, as illustrated in (Figure 4.2). Mean artificial light intensity was 2.0×10^{18} photons at cow standing height (130 cm) and 1.2×10^{18} photons at cow lying height (50 cm), as measured in the six faces of a cube (Smith, 1988) by a quantum sensor[1] connected to an integrator. Reading were obtained in mV DC and this was converted to photons using the equation 10mV = 6

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[1] Model QS, Delta-T Services Ltd, Cambridge

x 10^{23} photons. The intensity of the supplementary light was measured under conditions of natural darkness.

There were 1.3 cubicles/cow, each of 2.1 x 1.2 m and bedded with chopped straw. Passageways were scraped daily. Cows were group fed a complete diet *ad libitum*, at 11 a.m. daily, using a mixer wagon with load cells[2]. The diet contained (g/kg freshweight) 790 grass silage, 90 rolled barley, 90 wheat distillers' pellets and 30 mineral and vitamin mix. The chemical composition, determined according to MAFF (1986) was 292 g DM/kg freshweight and (g/kg DM) crude protein 166, MAD fibre 232 and digestible matter 674. Refusals were weighed and removed weekly, and individual intakes estimated from the ME output of each cow (Taylor and Leaver, 1984). Cows were milked twice daily and milk yield was measured once weekly and samples taken for the analysis of fat, protein and lactose (MAFF, 1986).

Cows were weighed weekly and an estimate made of their fat reserves in the region of the pin bones (Lowmann et al., 1976). Blood samples were taken from each cow before the experiment started, after two weeks and at the end of the experiment. They were collected from the tail vein into heparin-coated vacutainers 90 minutes after milking, the cows being held in the weigh crush with minimum stress. Samples were analysed for β-endorphin and cortisol by radioimmunoassay, with binding percentages of 35 and 30, inter-assay variation of 13.9 and 9.7 % and intra-assay variation of 9.8 and 7.5 %, respectively. Blood plasma was also analysed for nitrogen constituents (total protein, albumin, globulin and urea) and the glycogenic hormone alanine aminotransferase by Greiner G400 Analyser. Saliva samples were obtained from six cows in each treatment for the analysis of immunoglobulin A content by an enzyme-linked immunosorbant assay (ELISA) (Mirbahar et al. 1994).

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[2] Keenan Easifeeder, Richard Keenan and Co Ltd, Borris, Eire

Figure 4.1 cubicle building

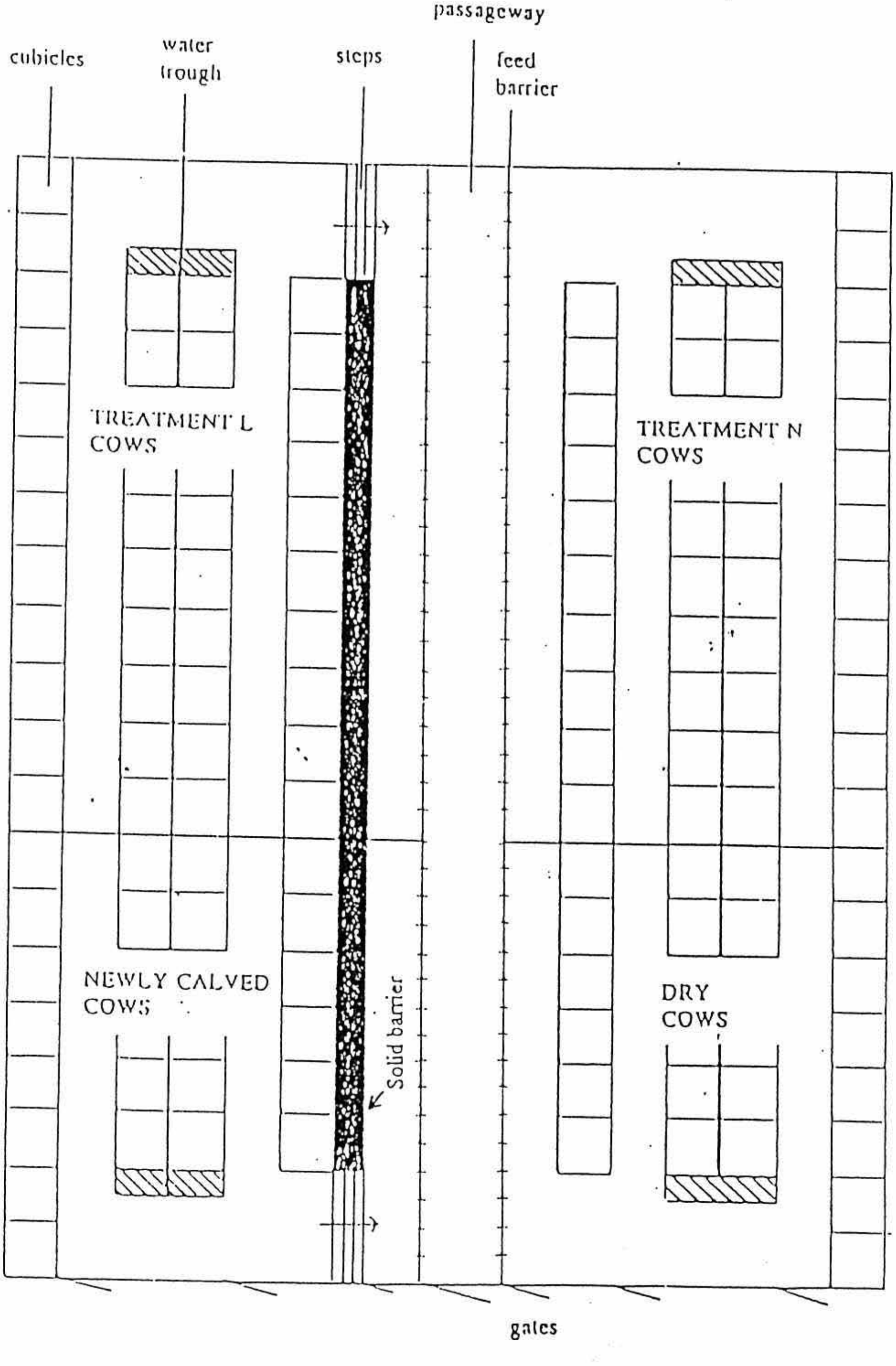
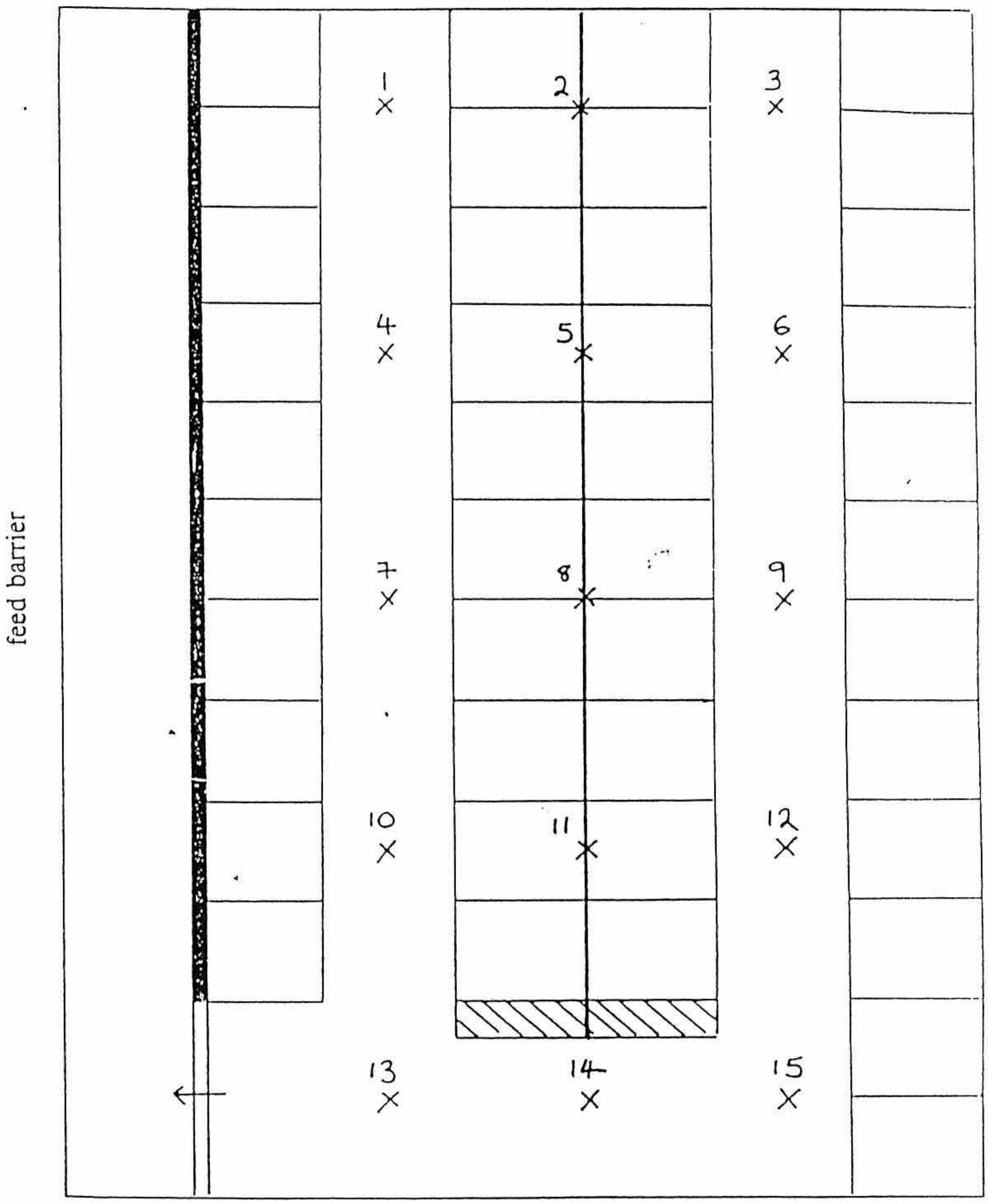


Figure 4.2 measurements of light intensities



Key X=position of intensity measurement

4.3.1.2 Behaviour recording

All animals were identified with large numbers painted on the back and side. Cows in each treatment were observed separately for all 24 h of the day, once in the first, fourth and eight week periods of the experiment 3 (referred to subsequently as period 1, period 2 and period 3 respectively). In each period there were two observations, each of 12 h. At 15 minute intervals, the most frequent behaviour of each animal (i.e. the behaviour that occupied the most time) was identified and classified in the following mutually exclusive categories: feeding, standing, standing ruminating, lying, lying ruminating or sleeping. A 1.5 W handtorch was used to aid cow identification in the dark.

4.3.1.3 Statistical analysis

The data was examined for normal distribution before being tested by analysis of variance using Genstat V (LAT, 1980). Treatment alone was included as factors in the model. Both plasma cortisol and β-endorphin values were converted to natural logarithms in both experiments to normalise the data, before analysis of variance could be carried out.

4.3.2 Experiment 4. Declining daylength

4.3.2.1 Animal Management

Sixty-four cows, with a mean calving date of 26 August were allocated to the same treatments, diet and management as in (section 4.3.1.1) experiment 3. The experiment was conducted between 3 November and 30 December. Mean natural daylength was 8.8 h, declining from 9.7 h at the start to 8.0 h at the end. After 28 days, since it was apparent that feed intake and milk yield were substantially reduced in treatment L, lights were positioned in the feeding passage for this treatment. For this purpose, two 400 W halogen lights were positioned at either end of the feeding passage, providing an illumination level of 1.0 x 10^{18} photons at cow standing height. Experiment 4 therefore comprised two periods of 28 days, Period 1 with supplementary light in the cubicle area only for treatment L, and Period 2 with supplementary light provided in the cubicle and feeding areas for this treatment.

Milk yield and composition and cow weight and body condition were recorded weekly as in (section 4.3.1.1) experiment 3. Blood samples were obtained on the day before the experiment began, and the last day of each period.

4.3.2.2 Behaviour recording

All animals were individually identified as in (section 4.3.1.2) experiment 3. The major behavioural activities of the cows were examined in two 24-h observations. The first observation was taken in the first week of the experiment (referred to subsequently as period 1). The second observation was taken 4 weeks after the first one (referred to subsequently as period 2). Both treatments were observed separately. In each period there was one observation for a continuously 24-h of recording. At 15 minute intervals, the behaviour of each animal was identified and recorded as in experiment 3. A 1.5 W handtorch was used to aid cow identification in the dark and was not expected to influence behaviour since cattle are not particularly sensitive to small changes in light intensity (Phillips and Weiguo,

1991) and the animals used in this study were well accustomed to the presence of the observer.

4.3.2.3 Statistical analysis

The data in experiment 4 was examined for normal distribution before being tested by analysis of variance using Genstat V (LAT, 1980). Treatment, period and the interaction between treatment and period were included as factors in the model. Both plasma cortisol and β-endorphin values were converted to natural logarithms in both experiments to normalise the data, before analysis of variance could be carried out.

4.4 RESULTS

4.4.1 Experiment 3

4.4.1.1 Feed intake, milk production and blood composition

DM intake was reduced by the supplementary light (Table 4.1). Milk yield was not significantly affected, but milk fat content was reduced. There were no significant effects on milk fat, protein or lactose yields ($P > 0.05$) or on liveweight gain and condition score.

Blood plasma protein concentration was increased by supplementary light, and this was essentially an increase in globulin concentration. There were, however, no differences in salivary Ig A concentration between treatments. Plasma albumin and urea concentrations were not affected by treatment. β-endorphin concentration was decreased after two weeks and cortisol after nine weeks Table 4.1.

Table 4.1 Effect of supplementary light on DM intake, milk production and blood composition of cows in Experiment 3

Treatment	N	L	s.e.d.	P
DM intake (kg/d)	16.5	15.4	0.09	0.05
Milk yield (kg/d)	19.5	20.1	1.02	0.53
Milk composition (g/kg)				
Fat	42.8	40.0	1.37	0.05
Protein	32.6	32.4	0.53	0.68
Lactose	46.4	46.4	0.36	0.96
Liveweight gain (kg/d)	0.35	0.30	0.09	0.60
Condition score gain (units x 10^{-4}/d)	4.3	2.9	7.1	0.78
Blood composition				
Total protein (g/l)	73.9	76.2	1.22	0.01
globulin (g/l)	39.1	41.6	1.50	0.02
albumin (g/l)	34.8	34.6	0.59	0.69
Urea (mmol/l)	4.38	4.29	0.19	0.47
ALAT[3] (U/l)	17.9	19.9	1.29	0.03
β-endorphin ($\log_e$ pmol/l)				
Week 2	4.77	4.64	0.042	0.05
Week 9	4.69	4.61	0.045	0.17
Cortisol ($\log_e$ nmol/l)				
Week 2	4.04	3.82	0.196	0.39
Week 9	4.35	3.41	0.184	0.06
Salivary immunoglobulin A (nm)	0.30	0.30	0.054	0.73

[3] Alanine aminotransferase

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[3] Alanine aminotransferase

4.4.1.2 Cow behaviour

Supplementary light did not affect the time that cows spent feeding, but it reduced the time that cows spent ruminating (Table 4.2). This was mainly a reduction in standing ruminating, with more time being spent standing not ruminating to compensate. There was no effect of supplementary light on the time that cows spent lying down, but it reduced the time that cows spent asleep.

Table 4.2 Time (min./day) spent in different behaviours in Experiment 3

Treatment	N	L	s.e.d.	P
Feeding	370	388	13.5	0.20
Standing ruminating	267	235	17.2	0.06
Other standing	228	251	9.7	0.02
Lying ruminating	319	306	16.3	0.44
Lying asleep	21	16	2.5	0.02
Other lying	235	250	13.3	0.27
Total lying	554	556	23.1	0.93
Total ruminating	586	541	11.3	<0.01

Mean light intensities in the cubicle area are presented in Table 4.3.

Figure 4.3 Mean light intensity in the cubicle area

Position	**Light intensity at standing height (1.30m) in photons**	**Light intensity at lying height (0.50) in photons**
1	2.1×10^{18}	1.2×10^{18}
2	1.2×10^{18}	7.8×10^{17}
3	2.52×10^{18}	1.32×10^{18}
4	2.88×10^{18}	1.68×10^{18}
5	1.62×10^{18}	1.2×10^{18}
6	2.52×10^{18}	1.62×10^{18}
7	2.58×10^{18}	1.62×10^{18}
8	1.62×10^{18}	1.2×10^{18}
9	2.22×10^{18}	1.32×10^{18}
10	2.28×10^{18}	1.32×10^{18}
11	1.2×10^{18}	7.8×10^{17}
12	2.22×10^{18}	1.02×10^{18}
13	1.98×10^{18}	1.02×10^{18}
14	1.32×10^{18}	7.8×10^{17}
15	1.98×10^{18}	7.8×10^{17}
Mean	**2.02×10^{18}**	**1.18×10^{18}**

4.4.2 Experiment 4

4.4.2.1 Feed intake, milk yield and composition and blood composition

The DM intake was reduced by supplementary light, especially in Period 1 (Table 4.4). Milk yield was also reduced by supplementary light, and even though the interaction with period was not significant the reduction tended to be greater in period 1. Milk composition was not affected by treatment in either period. As in experiment 1, milk constituent yields were not affected by treatment ($P > 0.05$). In period 1 cows in treatment L lost weight and body condition, whereas those in treatment N gained both weight and body condition. In period 2 there were no differences between the two treatments in weight or body condition change.

Plasma protein fractions were not affected by treatment, but in period 1 supplementary light reduced urea concentrations. ALAT and β-endorphin concentrations were not affected by treatment, but cortisol was increased by supplementary light in period 1.

Table 4.4 The milk production and blood plasma composition of cows during the declining of daylength

	Period 1		Period 2		Treatment effect		Treatment x period interaction	
Treatment	N	L	N	L	s.e.d.	P	s.e.d.	P
DM intake (kg/d)	17.5	13.2	15.3	12.7	0.36	<0.001	0.50	0.03
Milk yield (kg/d)	18.1	16.9	17.0	16.4	0.42	0.04	0.60	0.45
Milk composition (g/kg)								
Fat	39.5	39.9	39.6	39.7	0.84	0.65	0.56	0.79
Protein	32.0	32.4	32.3	32.2	0.24	0.52	0.33	0.30
Lactose	46.9	46.7	48.3	48.7	0.27	0.60	0.38	0.31
Liveweight gain (kg/d)	0.62	-0.22	-0.26	-0.13	0.09	<0.001	0.122	<0.001
Condition score gain (units x 10^{-4}/d)	20.7	-8.8	0.0	0.0	5.73	0.01	5.73	0.01
Blood composition								
Total protein (g/l)	74.0	75.0	74.3	74.5	0.69	0.36	0.97	0.59
globulin (g/l)	38.9	39.4	38.5	39.0	0.68	0.47	0.96	0.99
albumin (g/l)	35.1	35.6	35.8	35.5	0.29	0.63	0.29	0.21
Urea (mmol/l)	5.28	4.73	4.41	4.63	0.11	0.14	0.15	0.001
ALAT[4] (U/l)	17.6	18.6	14.6	15.4	0.94	0.38	1.34	0.96
β-endorphin ($\log_e$ pmol/l)	4.40	4.09	3.99	3.96	0.29	0.13	0.41	0.23
Cortisol ($\log_e$ nmol/l)	1.60	1.92	1.80	1.79	0.156	0.06	0.221	0.05

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[4] Alanine aminotransferase

4.4.2.2 Cow behaviour

As in Experiment 3, supplementary light did not affect the time cows spent feeding. It reduced the time that they spent ruminating, but this could not be definitely ascribed to a change in standing or lying ruminating. The time cows spent lying down was increased by supplementary light, and the cows in this treatment tended to spend longer asleep. The results of the cow behaviours are presented in Table 4.5.

Table 4.5 Time (min./day) spent in different behaviours in Experiment 4

Treatment	N	L	s.e.d	P
Feeding	433	415	17.2	0.30
Standing ruminating	289	279	23.1	0.66
Other standing	231	212	12.6	0.13
Lying ruminating	295	281	20.0	0.50
Lying asleep	25	32	3.8	0.10
Other lying	162	222	12.0	<0.001
Total lying	457	503	25.8	0.08
Total ruminating	584	560	19.9	<0.01

4.5 DISCUSSION

Providing the supplementary light in the cubicle area only reduced feed intake, which has not been recorded before when light has been provided to the entire housing area. This reduction in intake was more pronounced in the first period of experiment 4 than in experiment 3, probably because the natural daylength was shorter in Experiment 3. Cows prefer not to feed in the dark (Phillips and Leaver, 1986) and when consuming silage-based diets they normally have small meals that are well dispersed over the day. Probably cows in treatment N experienced less stress when feeding at night because their eyes would have been adapted to the dark, whereas for those in treatment L it would have taken them 5-10 minutes before their rods were active and 20 minutes before full adaptation to the dark had occurred (Piggins, 1992). Nevertheless, although feed intake was decreased by supplementary light, feeding time was not, suggesting that the rate of intake was decreased. It is likely that this decrease occurred at night, since vision is an important cue in feed selection and was probably impaired for cows that had just entered the dark.

The greater reduction in feed intake in experiment 4 suggests that either the shorter natural daylength (9.3 compared with 11.6 h in experiment 3) or the fact that daylength was declining in this experiment exacerbated the stress of feeding in the dark for cows in treatment L. Photoperiod perception is relative rather than absolute, and it is reasonable to suppose that both factors may have been involved in producing the stress associated with visiting the feeding barrier. Plasma cortisol concentrations demonstrated that cows were stressed before the lights were installed in the feeding passage but not after (Table 4.4). In the first experiment both cortisol and β-endorphin concentrations suggested that the supplementary light was reducing stress to the cows. Phillips (1992) has argued that supplementary light can reduce stress on the evidence of longer lying times in light-supplemented female cattle (Phillips and Schofield, 1989; Phillips et al., 1997). Although the hormonal evidence in experiment 3 suggests that stress may be reduced in light-supplemented cattle, the behavioural evidence suggests that it is not connected with the time spent lying since lying time tended to be reduced in experiment 4 not 3. Probably in experiment 4 the cows were both stressed by having to fed in the dark and encouraged to lie down for longer because of the lights in the cubicle area.

An additional factor that may have caused the cows in treatment L to be more stressed during feeding in the second experiment was the longer time that they spent feeding (7.1 hours, compared with 6.3 in experiment 3). In experiment 4, the cows would have had to spend 86 % of their available daylight hours feeding (allowing one hour for the afternoon milking), if they did not want to feed in the dark, whereas in experiment 3 they only needed to spend 59 % of their available daylight hours feeding.

The reduction in milk fat concentration in Experiment 3 has been reported previously (Stanisiewski et al., 1985, Phillips and Schofield, 1989) , but the aetiology was unclear. It is unlikely that this relates to the reduced rumination observed in this study, since this was reduced in the same proportion as feed intake. In the absence of changes in the composition of the feed, rumination time is directly related to feed intake (Balch, 1971). A more likely explanation relates to the recent observation that in short days cattle growth contains a greater proportion of fat and less lean (Phillips et al., 1997). Since supplementary light reduces fat accretion in both heifers and steers (Petitclerc et al., 1984; Zinn et al., 1986b; Phillips et al., 1997), it is logical to suppose that in adult cows lipogenesis will also be reduced and those fatty acids that are synthesized *de novo* will have reduced concentrations in the milk. The functional significance of increased lipogenesis in short daylength may have been to insulate cattle during winter, or in the case of lactating cows to provide a more nutritious food supply for their calves.

The increase in plasma globulin concentration with supplementary light in experiment 3 suggests that the immunological status of the cows was improved. This was not observed in IgA analysis and was probably IgG. Yurkov (1982) and Yurkov and Kartushin (1984) have reported improved disease resistance in calves exposed to high light intensity, with increased IgG among other indicators of immunocompetence. This may be due to the animal's ability to avoid contaminated areas when visibility is improved or may relate to changes in corticosteroids (Varner and Johnson, 1983).

4.6 CONCLUSION

It is concluded that providing supplementary light in the cubicle area during short and declining photoperiod restricts the feed intake of dairy cows, leading to reduced milk production. In longer and increasing photoperiod the reduction in feed intake is less and milk production may not be adversely affected, although milk fat concentration is consistently reduced. Under such conditions stress hormones may be reduced in the blood, but this does not appear related to increases in lying times with supplementary light.

CHAPTER VI

EXPERIMENT FIVE

EXPERIMENT FIVE

THE PREFERENCE OF INDIVIDUALLY-PENNED CATTLE TO CONDUCT CERTAIN BEHAVIOUR IN THE LIGHT OR THE DARK

5.1 ABSTRACT

Previous reports indicate that cattle prefer to spend just over half their time in the light, but it is unclear whether this arises from a strong desire to perform certain behaviours in the light or a weak preference for a lit environment at all times. An experiment was conducted where individually-penned cattle were able to switch lights on and off and their behaviour was recorded over a five day period. The cattle showed only a weak preference to feed in the light and to be in the light when they were standing or lying doing nothing. They showed no clear evidence of preferring to sleep or ruminate in the light or dark. It is concluded that the provision of artificial light for individually-penned cattle cannot be recommended on the basis of behavioural needs.

5.2. INTRODUCTION

At pasture cattle are largely diurnal, even though the duration of sleep is short compared to other mammals, about 3-4 hours a day (Ruckebusch, 1972). Feeding is largely confined to daylight, unless there are insufficient daylight hours, in which case a short meal is introduced about midnight (Phillips and Denne, 1988). Some other behaviours, such as agnostic interactions and drinking, which involve the animal moving around and potentially exposing themselves to predators, are also largely confined to daylight hours, whereas behaviours that can be performed while the animal is lying down, such as ruminating, are largely performed at night.

While it is clear that cattle prefer to perform certain behaviours during the light or dark when they are at pasture, it is unclear to what extent these preferences are maintained when the cattle are confined indoors. Both individually-penned (Baldwin and Start, 1981) and group-housed (Weiguo and Phillips, 1991) cattle prefer to spend slightly more time (67 and 58 % receptively) in the light than dark each day (Baldwin and Start, 1981; Weiguo and Phillips, 1991), but it is unclear whether this indicates a weak preference for light or a strong preference for certain behaviours to be performed in the light. This could perhaps be resolved by making the animals work to obtain the reward (Baldwin and Meese, 1977), but this has many complications of creating and interpreting an objective test. One of these is that the work e.g. breaking a beam of light or getting up to press a lever, is likely to interact with the reward, light, which may in itself alter the behaviour pattern in the animal. It is also difficult to establish how important the work is to the animal, or how different rewards can be equated (Baldwin and Meese, 1977).

An alternative approach is to investigate whether cattle consistently prefer to perform some behaviours in the light (or the dark). If they do, this would strengthen the argument that light (or dark) is very important for certain behaviours, and not just weakly preferred to darkness. An experiment is described where cattle in a controlled environment were given the opportunity to control whether their chamber was lit or unlit, and their preference for performing certain behaviours in the light or dark was recorded by video camera.

5.3 MATERIALS AND METHODS

5.3.1 Animal management and behaviour recording

In the winter of 1990 four Friesian bullocks of approximately 2 years of age were kept in stalls in an artificially ventilated building without windows. A division separated the building into two chambers of 6 x 4m, each with two stalls of 1.5 x 2m, so that bullocks in both the test chamber and the holding chamber were in pairs to avoid isolation. Natural light was completely excluded from the test chamber, and one of the stalls was fitted with a switch by which a bullock could turn on artificial lights in the chamber in either the lying or standing position. Artificial light was provided by two 80 W fluorescent tubes. A small room was located at the rear entrance to the test chamber so that attendants could enter without exposing the animals to natural light.

Natural light was allowed to enter the test chamber for 20 minutes at 09.30 h and 16.00 h, while the bullocks were fed and the stalls cleaned. The outside door to the holding chamber was left open to provide this area with artificial light. The feed provided was chopped grass hay offered *ad libitum* and water was also available *ad libitum*. After the food was delivered the lights in the test chamber were left either on or off, according to their state when the chamber was first entered to commence feeding. The stall fitted with the light switch was continuously recorded by a wall-mounted, infrared sensitive video camera (Panasonic WV-1450 B), with an infrared light mounted just below the camera. Initially each bullock was trained to be able to turn the light on and off using their muzzle, with confirmation that the animal was using the device being obtained from video records. After two weeks the bullock was video recorded for five consecutive days at 1 frame/15 seconds. During replay of the tapes the activity of each bullock was classified as feeding, standing, standing ruminating, lying, lying ruminating and sleeping at two minute intervals. Additionally a continuous record was made of whenever the light was switched on or off.

5.3.2 Statistical analysis

A hierarchical log linear model was employed for the analysis of the repeated measures data, using the SPSS statistical package. The complete model contained the following terms: light (on or off), behaviour, bullock, day (1-5) and all the two and three way interactions. The significance of individual terms was calculated by adding them to the model and determining the resultant change in Pearson's chi-square statistic and the degrees of freedom.

5.4 RESULTS

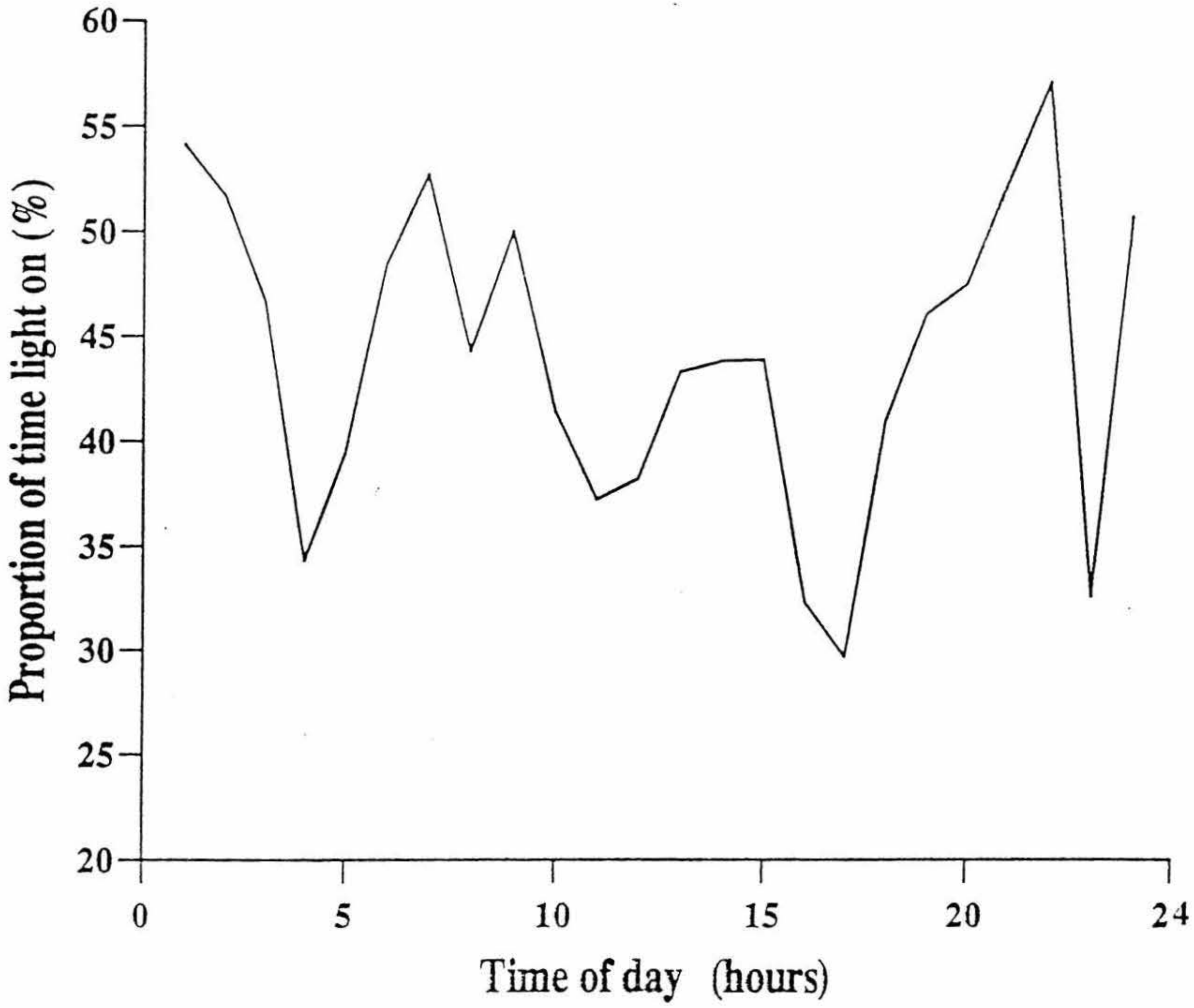
On average animals kept the light on for 54% of the day. There were four main periods when the lights were switched on, concentrated around midnight, 07.00 h, midday and 20.00 h. (Figure 5.1). Whilst several factors were included in the statistical model (section 5.3.2) only the interaction between behaviour and light is presented here. There was a significant difference between behaviours in the proportion of time that each behaviour was performed in the light ($P<0.001$) (Table 5.1). The bullocks' relative preference to perform the behaviour in the light was: Feeding > standing = lying > sleeping > standing ruminating > lying ruminating. For feeding and to a lesser extent standing and lying there was a weak preference to perform the behaviour in the light, but for sleeping and ruminating there was no preference to perform the behaviour in the light or dark.

Table 5.1 The time (min./day and %) that each behaviour was performed in the light and the dark

Behaviour	Light	%	Dark	%	Total For Each Behaviour
Lying Ruminating	183	23.6	179	26.9	362.5
Standing Ruminating	63.5	8.2	60	9	123.5
Feeding	150	19.4	114	17.1	264
Standing	140	18.1	117	17.6	257
Lying	212.5	27.5	174	26.1	386.5
Sleeping	24	3.1	21.5	3.2	45.5
Column Total	773.5 53.7%		666.5 46.3%		1440 100%

Chi-square statistic for this ditribution was 1084 ($p<0.001$) with 20 degree of freedom

Figure 5.1 Circadian changes in the proportion ot the time that bullock had the light on



5.5 DISCUSSION

The proportion of time that the cattle in this experiment preferred the light to be on (54%) was similar to the proportion of time that a group of cattle spent in a lit area when given the choice between a lit and unlit housing area (58 %, Weiguo and Phillips, 1991), but less than the 67 % of time that individually penned cattle chose to light their pen in the study of Baldwin and Start (1981). There was some evidence of a complex circadian rhythm to the bullocks' preference for a lit environment, which did not resemble the biphasic circadian rhythm of natural light that the animals had previously experienced.

The behaviour that the cattle preferred most to perform in the light (feeding) involves the most activity. It therefore appears that there is a preference, even if it is not a strong one, for housed cattle to feed during the light. Lighting the feeding area in a dairy cow barn stimulates the intake of feed (Lomas, 1994). The next most preferred behaviours in the light were standing and lying, in both of which the animal is alert, compared with sleeping and ruminating when the animal is resting. It has been postulated that rumination substitutes for quiet sleep in cattle, and its stereotyped nature may benefit cattle in confined conditions that they find aversive (Phillips, 1993). Most rumination takes place at night and in the day it is voluntarily ceased when cattle are stressed, e.g. when they are being walked down a track or pass through a milking parlour. The fact that, along with sleeping, there was no clear evidence that the cattle preferred to ruminate in the light suggests cattle do not feel a need for visual awareness while performing these behaviours.

The results of this experiment relate to cattle in individual pens only. In a group housing situation, cattle might show a greater preference to perform certain behaviours in the light because they perform them collectively and there is a need to be aware of the behaviour of other individuals. Phillips and Weiguo (1991), for example, found a stronger preference in group-housed cattle to lie down in the lit area than was evident in this experiment. Lying is a synchronised behaviour and the distance between individual animals is carefully regulated (Phillips, 1993).

5.6 CONCLUSION

It is concluded that individually-penned cattle show some preference for a lit environment when they perform behaviours in which they need to be alert. This is not a strong preference, however, which suggests that there is not a major need for lighting under these conditions.

CHAPTER VII

GENERAL DISCUSSION

GENERAL DISCUSSION

In discussing the effects of photoperiod on the behaviour and performance of cattle, it must be remembered that if the main utilisation of photoperiodic cues by animals is to synchronize rhythms of activity, then the effects obtained: (a) will depend on the stage of the annual cycle the animal is at, (b) will depend on previous photoperiodic information the animal has registered, and (c) will be gradual rather than precipitous in effect.

Five experiments were carried out in Bangor and Stratford-on-Avon, to verify whether photoperiod alteration would change behaviour and increase the efficiency of cattle productivity. It is important to remember that commercially manipulation of photoperiod is easy to achieve, economical and free of potentially harmful residues of exogenous chemicals in the food chain. These experiments were motivated by the research of Tucker who found that long days in winter may affect growth rate and will influence carcass composition in heifers (Tucker et al., 1984), and more recently by Phillips and Schofield's (1989) work at Bangor, University College of North Wales, who found that extending the daylength for cattle housed in the winter reduces their activity and increases their lying time. They also reported an increase in milk production by 7-10% when cows were supplemented with 4-8 h light. Their results, however, highlighted the need for studying the effect of photoperiod on the general aspects of cattle behaviour.

It has been suggested that there are obvious commercial benefits. Indeed many Americans close their articles by putting their findings in cash terms - for example, Stanisiewski (1985) says the equipment pays for itself in 120 days. Every consumer wants cheaper meat or milk and the public may view extra lighting as less controversial than hormone injections or food supplements. There is, therefore, a great desire to believe that long days stimulate growth and milk yield despite any inconsistencies in the evidence. The extension of natural daylength with artificial lighting under commercial conditions has, however, not so far shown any consistent benefit in growth (Forbes, 1982).

The five experiments, involving a total of 246 animals, were carried out at two locations (ADAS, Drayton in Stratford on-Avon and University of Wales, Bangor, College Farm, Aber) and the range of animal studied included steers, heifers, dairy cows and bullocks. All experiments on these animals involved comparisons between treated and control animals.

The results of experiments 1 and 2 showed that supplementary light did not affect the overall final liveweight gain or daily liveweight gain of steers or heifers. The overall result, however, that daylength did not affect weight gain of the steers or feed conversion efficiency agrees with Roche and Boland (1980). The reduction in Feed Conversion Ratio over the first 70 days may relate to an increased lean content of the carcases, which was evident both in experiment 1 at slaughter and in the autumn in experiment 2. Bourne et al. (1984) found that heifers on extended photoperiod gained more weight in the second half of the experiment while heifers on natural daylength grew significantly faster than those on 16L:8D photoperiod in the first half.

In contrast to my results and the results of Roche and Boland (1980) and Bourne et al. (loc. cit), Peters et al, (1978 ; 1980) found that supplementary light of 16L:8D increased growth rate of 10-17% in Holstein heifers. The initial better performance by the control animals obtained in experiment 1, may have been due to the sudden change in daylength experienced by the 16 hour animals. It suggests that this variation in responses comes from two sources. Firstly, the previous exposure to a given photoperiod may affect the response of the animal to the present pattern of photoperiod (Moore Ede et al., 1982). Secondly, the rate of change of light intensity at dawn and dusk may affect the growth response to light.

Both experiments demonstrated that long days increase carcase fatness. Carcase fatness was reduced in winter in light-supplemented heifers, but this effect had disappeared by the spring. In steers carcase fatness was reduced in light-supplemented steers at the time of slaughter in spring. Previous researchers have found reductions in body fatness of postpubertal heifers with long days (Zinn et al., 1986; Petitclerc et al., 1984), but results from the present study suggest that the time of analysis in relation to natural photoperiod will determine whether body fatness is increased or not. This conclusion has important implications for the optimum time of slaughtering heifers. Extending the day length in autumn or winter will reduce the fat class or allow the heifers to be taken to a heavier weight. Thus, it would be in the farmers' interest to maximize the profit margin per kg of lean meat via reduced fat by the means of introducing artificial lighting in the early part of the winter season.

In experiment one, supplementary light significantly increased prolactin levels ($p<0.05$) in steers throughout the experiment, while heifers respond initially to supplementary light, with maximum response being achieved between 2 to 4 weeks, in accordance with results obtained by (Peters et al, 1981; Newbold et al, 1991). The increase in prolactin levels in both experiments was declining as the experiment progressed, and Stanisieski et al, (1988) on observing the same phenomenon suggested that the pituitary gland becomes refractory to increased daylength. It has also been suggested that the response is not to photoperiod *per se* but the change in photoperiod (Zinn et al, 1988), which would concur with the increase in prolactin diminishing after shortest day.

The results of these two experiments, when considered over the whole winter, demonstrated that supplementary light did not significantly influence the behaviours of either steers or heifers compared with natural daylight. The first experiment indicated that supplementary light did not affect time spent feeding but increased ruminating time. This agrees with Phillips (1992) who reported that total feeding time is not significantly affected by photoperiod. In the second experiment a reduction in feeding time and increase in ruminating time was observed. The trend for supplementary light to increase lying time has been reported by Phillips and Schofield (1989), and Weiguo and Phillips (1991). Their results are in agreement with the results obtained in both experiments one and two. These results suggest that the reduced effects of supplementary light on feeding time in experiment two could be due to the fact that animals were more disturbed during the course of feeding or may be attributed to the greater aggressive behaviour by dominant animals, with the aid of supplementary light to see the subordinates.

Steers receiving supplementary light increased the incidence of grooming others but not themselves and reduced the incidence of licking objects, this agrees with results obtained by Phillips and Schofield (1989) and Weiguo and Phillips (1991). These results suggest that giving steers extra light could reduce their individual space and create a more complex environment where animals become more aggressive and tend to be groomed more often by subordinates animals than grooming themselves.

In the second experiment the incidences of grooming (self and other) were similar in both treatments, except during the winter season when supplementary light tended to increase the incidence of grooming self. Biting objects was increased in supplemented heifers compared to unsupplemented ones.

The results of these two experiments demonstrated that an activity response to a supplementary light does not occur under all conditions, as the reviews of Phillips and Schofield (1989) and Weiguo and Phillips (1991) on this subject show. Many of the factors that have been suggested as possible moderators of the response were similar in these two experiments - time, duration of supplementary light, temperature, feeding level and age. They were therefore, unlikely to have been responsible for the variable response to supplementary light reported in these two studies. The major difference between the two experiments was that steers were used in experiment one, while heifers were used in the second experiment and the recording method employed was different.

These results confirms that photoperiod can have an effect on the behaviour of growing cattle, which in turn may affect their performance, but that the effects are inconsistent. This suggests there is a genuine need for further research into the mechanisms of response to photoperiod by cattle.

It can be concluded that the capital economic benefit of extended photoperiod for growing cattle is the reduction in carcass fatness, permitting the producer to rear cattle to a heavier weight before slaughter at certain times of the year. To a certain extent this could be offset in heifers by earlier puberty in light supplemented cattle.

Experiments three and four compared the effects of an extending photoperiod on the behavioural changes during conditions of increasing and declining natural daylength, respectively. These experiments examined whether the response to supplementary light changed over the winter period during which cattle are housed.

The results of experiment three indicated that supplementary light increased the time spent feeding, reduced ruminating and sleeping time but there was no significant difference in lying time from that exhibited in natural daylength.

The importance of supplementary light in experiment three demonstrated that there was a decrease in ruminating and feeding times with the most pronounced effect observed in the first period of the experiment. This increase in rumination time was reduced as the experiment progressed. The reduction in ruminating time with supplementary light was consistent with the observed reduction in milk fat contents (Lomas, 1994).

The results are in agreement with the work of Peters et al. (1978) who reported that cows responded rapidly to an initial period of light supplementation, with the maximum response being achieved in 10 to 20 days, but that the response after a change-over in mid winter is much less pronounced.

It is, therefore, concluded that providing housed dairy cattle with an extra period of artificial lighting during the declining in daylength in winter is recommended for the period following the initiation of light supplementation of approximately 2 to 4 weeks. However, keeping the lighting thereafter would probably minimize the margin of profit and could end with expenditure. But, also it is probably important to eliminate the extra lighting gradually along with the extending of natural daylength.

In experiment four cows receiving supplementary light in the conditions of declining daylength showed a reduction in time spent feeding and time spent ruminating. This reduction was associated with a reduction in milk yield. The reasons for the poor performance exhibited by cows in this period of experiment 4 can be attributed to the poor visibility in the unlit feeding area. Lack of visual information may have made the cows very disturbed, especially as they were forced into close vicinity to other animals. Therefore, the feeding passage was illuminated with two halogen lamps in the second period of this experiment. Illuminating the feeding passage increased the cows' feeding time by approximately 15-21 min./day. This increase supports the results in experiment 3 and provides some evidence that supplementary light can increase feeding time in housed dairy cows and was associated with the observed reduction in ruminating time. The reason for the reduction in ruminating time could be due to the disturbance caused by the presence of human behaviour recorder when the cow was ruminating. Cows with supplementary light significantly increased their lying time compared with those without supplementary light ($P<0.001$). This finding was also reported by Phillips and Schofield (1989).

It is clear from the results of the milk yield obtained in experiments three and four that on this occasion the increase in milk yield due to the use of supplementary light was so insignificant that it could not even offset the cost of electricity to provide the extra lighting. The lack of result probably is because lights were in the cubicle area only. Van Soest (1982) and Church (1991) provide evidence that lying is an energy saving practice. In these two studies cows with supplementary light were lying down without ruminating more and were therefore lying down ruminating less. These observations have important practical implications and require further investigation.

The ability of bullocks to regulate their behaviour when given a choice of light or darkness was examined in experiment five. The results of this experiment demonstrated that the proportion of time that the bullocks preferred to perform a certain behaviour was longer in the light hours rather than in the darkness. The most dominant behaviour exhibited when the light was on, was feeding behaviour. Other types of behaviour follow in the following order: standing > lying > sleeping > standing ruminating > lying ruminating. The results confirm the finding of Baldwin and Start (1981) that sheep spent an average of 77% while calves spent an average of 67% of each 24 h in light. However, the higher proportion obtained by Baldwin and Start (1981) compared with the result in this study is probably due to the fact that the animal was rewarded every time they interrupted the infrared beam used in their study whereas no reward was offered to the animal in this study. This may be the reason why the bullocks left the light off or on for prolonged periods. In the only known comparison of activity levels between cattle types in the same environment, Hall (1989) found that bulls had a higher ratio of standing to lying than cows, in accordance with the results obtained in this experiment. The only surprising result is that bullocks tended to sleep for longer when the light was on. This may be due to the increased level of fearfulness during the dark hours.

The results obtained in experiment five show that it is possible to assess the environmental preferences of farm animals objectively. Such information should be of use in the design of husbandry systems. However, under farm conditions, animals often live in groups and social behaviour may influence environmental preference. It would, therefore, be advantageous to develop suitable methods for determining the environmental preferences of groups of cattle.

Research into the effects of photoperiod on animal performance and production has generally been characterized by a conflict of ideas and findings. One major rift has been the divide over whether photoperiod does or does not affects production. As discussed earlier some researchers have adduced evidence to the effect that light supplementation does produce tangible effects on animal performance and behaviour. Others, however, have maintained that such effects are either negligible or not present.

Some of the results reported in this thesis present further evidence to support the view that supplementary light affects animal performance and behaviour positively. However, this conclusion does not encompass all aspects of animal performance and behaviour.

The extended photoperiod experiments demonstrated that the problems of finding spaces can be lessened by supplementary light. Feeding time increased in dairy cows (Exp. 3 and 4), and in bullock (Exp. 5), but not in growing cattle. Supplementary light was also shown to increase the time the animal spends lying, suggesting that the resting behaviour of dairy cows housed with cubicles can be increased by a long photoperiod, but that for growing heifers in a straw yard changes in age dominate behaviour pattern, and photoperiod does not affect behaviour. The results obtained by many researchers on the effect of photoperiod on animals behaviour and performance are varied and can be attributed to the environmental conditions used in their experiments. As Broom (1986) defines welfare as 'an individual's state as regards its attempts to cope with its environment', better performance may be directly or indirectly related to the welfare of the animal. This work reported in this thesis has demonstrated that the provision of supplementary light can improve the welfare of housed cattle.

Lorenz (1965) suggested that the environment for a farm animal should not only minimize discomfort, stress, fear and frustration, but positively promote behavioural satisfaction. Progress towards this ideal depends on an improved understanding of the animal's own perception of its environment. Analysis of an animal's behaviour in terms of external and internal motivating forces requires a knowledge of physiology and ethology to design environments that are more in tune with those patterns of behaviour which the animal deems important (Spedding, 1988).

It is, therefore, clear that work is still needed to establish the optimum duration of artificial lighting and its intensity, particularly in relation to behaviour and production. Moreover, research findings about the optimum duration and light intensity used may have beneficial effects on cattle welfare.

Given more resources better experiments could have been designed. For example, using a reward mechanism in experiment five would have produced a clearer pattern of results, reducing thereby the amount of uncertainty in the data. The pattern of results obtained in experiment three and four can only explained by the poor visibility in the feeding area due to the poor design of the experimental environment, which might have been responsible for the reduction in the time spent ruminating and milk yield.

CONCLUSIONS

The principle conclusions to be drawn from this work are:

1. Extending the photoperiod for cattle in winter reduces body fatness in both steers and heifers and increases the time heifers spend lying down, but that there are no major effects on growth rate or feed intake.

2. Providing supplementary light only in the lying area of dairy cows will have adverse effects on their production and welfare in decreasing, but not increasing daylength.

3. Provision of artificial light for individually-penned cattle cannot be recommended on the basis of behavioural needs.

CHAPTER VII

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