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Increased winter growth in male red deer calves under an extended photoperiod

J. R. Webster, I. D. Corson, R. P. Littlejohn and J. M. Suttie

AgResearch, Invermay Agricultural Centre, Private Bag 50034, Mosgiel, New Zealand

Abstract

The growth of male red deer slows during the first winter of life before increasing again during spring. This study aimed to determine if this period of slow growth could be minimized using artificial photoperiods during autumn and winter (10 April (week 1) to 11 September (week 23), southern hemisphere). Four groups of deer (no. = 10) were housed indoors as follows. Two groups were placed on a winter solstice photoperiod (8·5 light (L) : 15·5 dark (D)) and given either a natural increase in photoperiod to 11·25L : 12·75D (WSN) or held on 8·5L : 15·5D for 7 weeks followed by an abrupt increase to 11·25L : 12·75D (WSH). One group was exposed to a summer solstice photoperiod of 16L : 8D (SS) and one group exposed to a natural photoperiodic pattern (IC). A fifth group of deer (no. = 10) was maintained outside on a gravelled enclosure under natural changes in photoperiod (OC). All groups were given a diet containing 160 g protein per kg and 11·0 MJ metabolizable energy per kg dry matter (DM) ad libitum. *All animals were weighed weekly and group food intake recorded daily. Metatarsal length was measured at weeks 3, 17 and 22 from the start of treatments.*

The major differences occurred between SS and the other groups. After a period of slower growth (weeks 1 to 5, SS = 88 g/day v. 168 g/day other groups, s.e.d. 31·2, $P < 0.05$*), SS grew more rapidly from week 10 (*$P < 0.01$*). As a result, SS was heaviest from week 17 (*$P < 0.05$*) until the end of the experiment (*$P < 0.01$*). The mean growth rate of SS animals from weeks 10 to 23 was 346 g/day compared with 173 g/day (s.e.d. 15·3;* $P < 0.001$*) for the other groups. Over the whole experiment, SS animals gained 42·3 kg live weight, compared with 31·1 kg for WSN, 26·6 kg for WSH, 25·1 kg for OC and 23·7 kg for IC (s.e.d. 2·08 kg,* $P < 0.01$*). The DM intake of SS from week 9 until the end of the experiment averaged 2·04 kg DM per head per day compared with 1·48 (s.e. 0·041) kg DM per head per day for the mean of the other groups. Metatarsal length increased more in SS than the other groups (*$P < 0.001$*) between weeks 3 and 17 and was longest in SS at weeks 17 and 22 (*$P < 0.01$*). Exposure to a 16L : 8D photoperiod during winter advanced the rapid growth of red deer calves normally associated with spring and summer. This response may be used to advance slaughter dates for venison production.*

Keywords: *food intake, growth rate, photoperiod, red deer.*

Introduction

The growth of male red deer (*Cervus elaphus*) has a seasonal pattern typified by rapid growth during spring and summer followed by very slow growth in autumn and winter (Kay, 1979; Fennessy, 1982; Suttie *et al.*, 1983). This slow winter growth is undesirable in a venison production system where continuous rapid growth to an acceptable slaughter weight is preferable. A major cause of the low winter growth rate is a drop in appetite rather than the seasonal unavailability and decreased quality of food, or higher energy costs due to cold weather, as deer supplied with constant quality food *ad libitum* and maintained indoors under a natural photoperiod also undergo this pronounced seasonal growth pattern (Suttie, 1980; Fennessy, 1982). Housing animals during their first winter in an attempt to reduce maintenance energy costs failed to increase live-weight gain during this period (Webster *et al.*, 1997). However appetite can be altered by changing the photoperiod (Simpson *et al.*, 1983/84; Suttie *et al.*, 1984a; Suttie and Simpson, 1985) indicating that photoperiodic manipulation may be a possible way to increase winter growth rate.

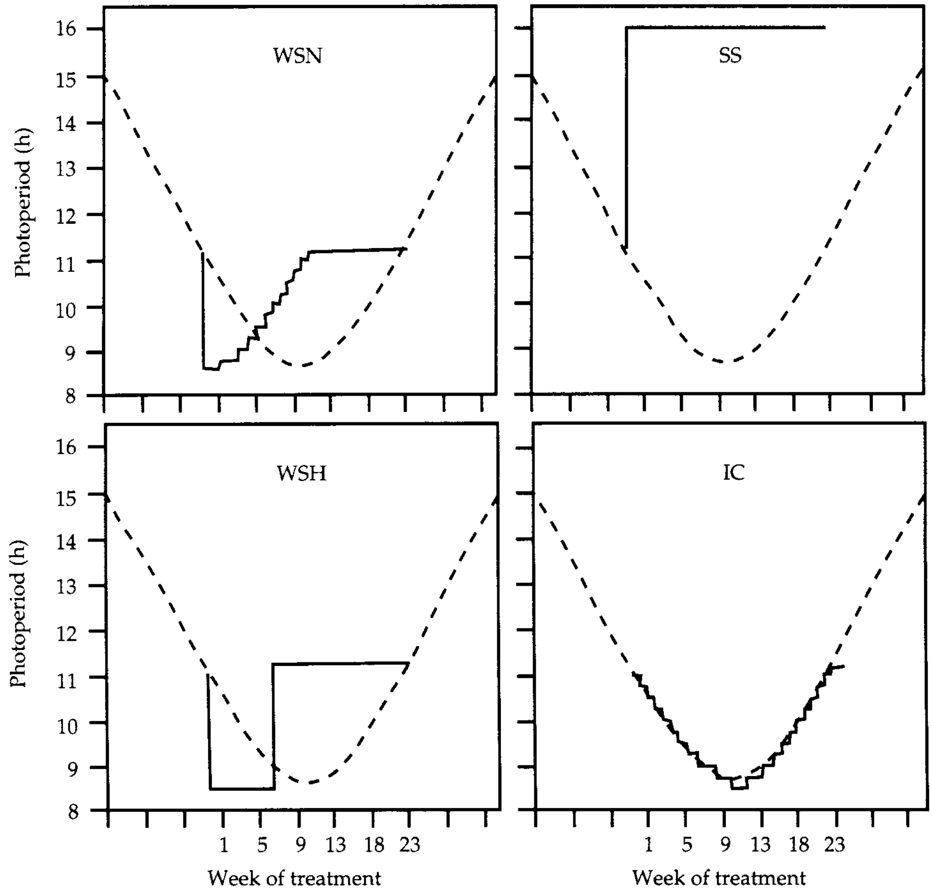

Figure 1 Experimental design depicting the photoperiodic treatments applied to five groups (no. = 10) of young male red deer beginning 10 April (week 1) and ending on 11 September (week 23). The broken line is the natural change in photoperiod at Invermay (45° 52'S). WSN = simulated natural increase in photoperiod from that of the winter solstice (8·5L : 15·5D) to 11·25L : 12·75D. WSH = 8·5L : 15·5D for 7 weeks followed by an abrupt increase to 11·25L : 12·75D. SS = summer solstice photoperiod of 16L : 8D. IC = control group inside, exposed to a simulated natural photoperiodic pattern. OC (not shown) = control group outside, exposed to natural changes in photoperiod (dashed line) during the treatment period.

In the present study we tested the ability of various photoperiodic regimes to reduce the seasonal depression in food intake and growth rate during winter and therefore result in heavier animals in spring. To do this, during autumn and winter we measured the live weight and food intake of male red deer calves that were exposed to a range of artificial photoperiods normally associated with the faster growth phase of spring and summer.

Material and methods

Experimental design

Male red deer calves aged approximately 6 months (mean live weight 42·4 (s.e. 0·8) kg) were randomly allocated to five groups (no. = 10) and each exposed to a different photoperiod (Figure 1) during autumn and winter beginning on 10 April (week 1) and ending on 11 September (week 23). Four groups remained indoors, housed on a deep litter of sawdust in separate pens which measured 7·5 m by 4·5 m, with overhead lighting designed to produce >300 lux 1 m from the ground. As spring growth normally begins in early September, it was decided to test whether the change in photoperiod from the winter solstice (8·5 light (L) : 15·5 dark (D) at 45° 52'S) to that of September (11·25L : 12·75D) was a stimulus for growth. Thus, groups WSN and WSH were immediately shifted onto the winter solstice photoperiod and then given either a natural increase in photoperiod, changed in 15-min increments, to 11·25L : 12·75D or held on 8·5L : 15·5D for 7 weeks followed by an abrupt increase to 11·25L : 12·75D, respectively. After reaching 11·25L : 12·75D, both groups remained on this photoperiod until 11 September. To determine whether the longer photoperiod of the summer solstice would stimulate growth during winter, group SS was exposed to an abrupt increase to 16L : 8D on 10 April and remained on this photoperiod until 11 September. As an indoor control, group IC were exposed to a photoperiod that was changed in 15-min increments to follow the natural photoperiodic pattern outside. The fifth group of deer (OC) served as a control group outside and therefore experienced natural changes in photoperiod. This group was maintained on a gravelled enclosure (25 m × 15 m). All groups were given an identical barley-based, pelleted diet containing 160 g protein per kg and 11·0 MJ metabolizable energy per kg dry matter (DM) *ad libitum*. A small amount of lucerne hay (100 to 200 g per animal per day) was also offered. Fresh water was available at all times.

Measurements
All animals were weighed weekly and food intake of each group was recorded daily. Daily food refusals were maintained at proportionately about 0·10 of food offered. The length of the metatarsal bone, from the tip of the calcaneum to the junction between the fused metatarsi and the phalanges was measured with a flexible plastic tape at weeks 3, 17 and 22 from the start of treatments.

Data analysis
Live weights for each week were analysed by ANOVA, assuming independence of individuals within groups and fitting treatment with a covariate adjustment for the three previous weeks live weight for each animal. This was based on testing the order of antedependence (Kenward, 1987). The full live weight dataset to 21 weeks was also analysed using the model of Diggle (1990), with a quadratic trend over time for each treatment; the correlation structure for each animal's live weight profile included parameters for measurement error (ϕ_1), variation between animals (ϕ_2) residual variance (σ^2), with serial correlation given by the linear model corr (μ) = 1 − $\beta\mu$ for lag μ. This model was fitted by maximum likelihood.

Results

Live weight
Mean live weights of the five groups of deer are illustrated in Figure 2. The covariate adjusted live weight showed significant differences between SS and the other groups at week 5 ($P < 0{\cdot}05$), when SS had the lowest mean live weight, and from week 10 onwards ($P < 0{\cdot}01$), when mean live weight of SS increased at a faster rate than the other groups. As a result (unadjusted) live weight was greater for SS than the other groups at week 17 ($P < 0{\cdot}05$) and each succeeding week until the end of the experiment ($P < 0{\cdot}01$). The low live weight of SS at week 5 was preceded by a slow growth rate over weeks 1 to 5 of 88 g/day compared with 168 g/day (s.e.d. 31·2, $P < 0{\cdot}05$) for the other groups combined. In contrast, from weeks 10 to 23 the mean growth rate of SS was 346 g/day compared with 173 g/day (s.e.d. 15·3; $P < 0{\cdot}001$) for the other groups. Over the whole experiment, SS animals gained 42·3 kg, compared with 31·1 kg for WSN, 26·6 kg for WSH, 25·1 kg for OC and 23·7 kg for IC (s.e.d. 2·08, $P < 0{\cdot}01$). The overall pattern of growth was well described by the variance component/quadratic trend model (estimated parameters are given in Table 1). The rapid growth of SS after week 10 resulted in a strong positive quadratic trend ($P < 0{\cdot}001$). WSH also showed a slight positive quadratic curvature ($P < 0{\cdot}01$), suggesting an increased growth rate towards the end of the experiment. In contrast OC had a negative quadratic curvature ($P < 0{\cdot}01$) indicating that growth rate slowed.

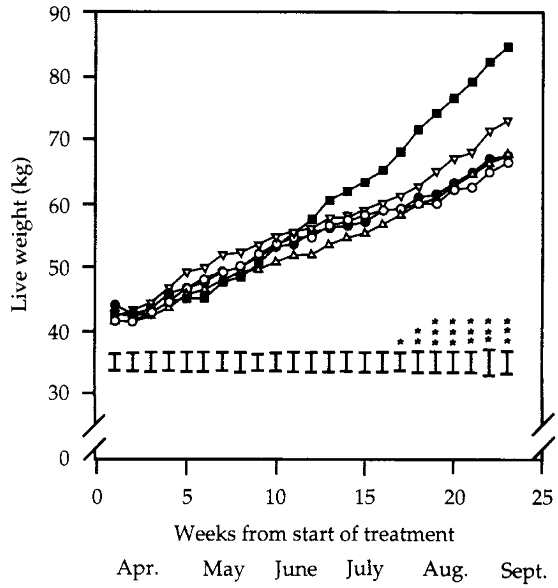

Figure 2 Mean live weight of groups (no. = 10) of young male red deer exposed to various photoperiods beginning 10 April (week 1) and ending on 11 September (week 23). The pooled s.e.d. is shown by the bars at the bottom of the graph with the significance level denoted by asterisks: WSN = ∇; WSH = Δ; SS = ■; IC = ●; OC = ○ (abbreviations defined in Figure 1).

Table 1 *Parameters obtained from the variance components/quadratic trend model of analysing live weight of young male red deer exposed to various photoperiods beginning 10 April (week 1) and ending on 11 September (week 23)*

Group†	Constant (kg) Parameter	s.e.	Linear (kg/week) Parameter	s.e.	Quadratic (kg/week^2) Parameter	s.e.
WSN	40·8	1·99	1·34	0·134	−0·0020	0·0055
WSH	40·2	1·99	0·85	0·134	0·0146	0·0055
SS	41·5	2·10	0·55	0·141	0·0603	0·0058
IC	42·1	2·10	0·93	0·141	0·0068	0·0058
OC	39·2	1·99	1·55	0·134	−0·0209	0·0055
Variance components						
$\Phi_1=0{\cdot}21\pm0{\cdot}93$	$\Phi_2=7{\cdot}76\pm4{\cdot}17$		$\beta_1=0{\cdot}072\pm0{\cdot}030$		$\sigma^2=4{\cdot}32\pm1{\cdot}829$	

† Photoperiods of each group were: WSN = winter solstice with natural increase; WSH winter solstice held and followed by abrupt increase; SS = summer solstice; IC = indoor control; OC = outdoor control. See **Material and methods** section for details.

Food intake
The DM intake of SS increased from week 9, corresponding to the period of faster growth in this group (Figure 3). From this time until the end of the experiment the average DM intake of SS animals was 2·04 kg DM per head per day compared with the average of the other groups which was 1·48 (s.e. 0·041; d.f. = 3) kg DM per head per day. There was very little difference between the food intake of the control groups (although the group nature of these data prevents a statistical comparison) with IC consuming on average 1·45 kg DM per head per day and OC consuming 1·59 kg DM per head per day.

Metatarsal length
At week 3 there was no significant difference in metatarsal length between the groups (Table 2). Between weeks 3 and 17, the mean metatarsal length of the SS group increased significantly more than the other groups ($P < 0{\cdot}001$) and was longer for SS than for the other groups at weeks 17 and 22 ($P < 0{\cdot}01$).

Discussion
Exposure of young male red deer to a 16L : 8D photoperiod during autumn and winter increased food intake and growth above that of animals under simulated natural or natural photoperiods. By the end of the experiment in spring these animals had a live-weight advantage of approximately 17 kg over animals exposed to the natural photoperiodic pattern. This difference would place the treated animals approximately 7 weeks ahead of control animals in terms of growth at that time.

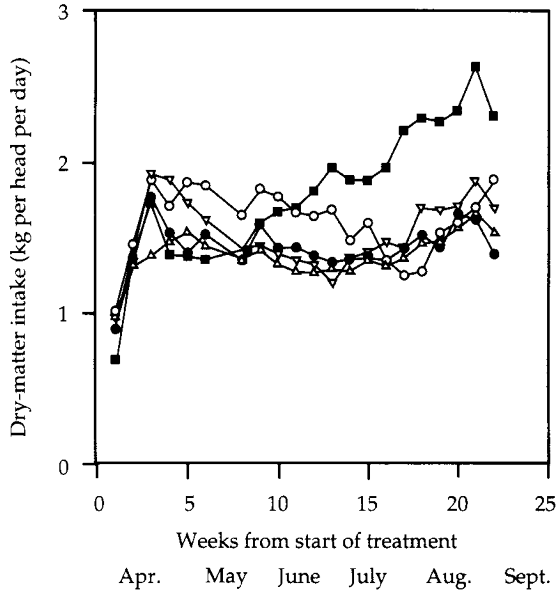

Figure 3 Dry-matter intake in kg per head per day calculated from the daily group (no. = 10) food intake of young male red deer exposed to various photoperiods beginning 10 April (week 1) and ending on 11 September (week 23): WSN = ▽; WSH = Δ; SS = ■; IC = ●; OC = ○ (abbreviations defined in Figure 1).

It has been recognized for some time that growth of sheep and cattle and deer is higher during longer, e.g. 16L : 8D, than shorter photoperiods (Peters *et al.*, 1978; Forbes *et al.*, 1979). Red deer have a seasonal appetite cycle which is more pronounced than domestic sheep and follows artificial photoperiod cycles very closely (Kay, 1979; Simpson *et al.*, 1983/84; Suttie *et al.*, 1984a). Red deer are particularly well suited for manipulation with artificial light to stimulate growth for commercial purposes. A 16L : 8D photoperiod has been reported to stimulate

Table 2 *Metatarsal length and standard error of the difference in centimetres of groups (no. = 10) of young male red deer at weeks 3, 17 and 22 after the onset of various photoperiods during winter*

Group†	Week 3	Week 17	Week 22
WSN	34·4	37·3	38·4
WSH	34·1	36·8	37·4
SS	34·7	38·4	39·2
IC	34·1	36·8	37·8
OC	34·3	36·7	37·4
s.e.d.	0·41	0·47	0·46

† See Table 1 footnote.

growth rate during winter in young male reindeer (Suttie *et al.*, 1991), red deer (Davies *et al.*, 1995) and fallow deer (Vigh-Larsen, 1993). It should be noted however that a high food intake does not continue under constant long photoperiod as the animals become refractory and appear to revert to a circannual rhythm (Loudon and Brinklow, 1992) as is the case with the reproductive neuroendocrine function in the ewe (Karsch *et al.*, 1989). Therefore advantages from using artificial light during winter must come from the fact that the phase of seasonal rapid growth is shifted to occur earlier, rather than any additional growth occurring *per se*. This feature also has important consequences with regard to selecting the optimal slaughter date of animals exposed to 16L : 8D. If slaughtered at 85 to 90 kg live weight, the present experiment indicates an advancement of slaughter date of around 7 weeks. It would be interesting to see if this advancement can be increased with a longer time under 16L : 8D, by either starting treatment earlier or extending it further. However with increasing time under this constant light regime the animals may become refractory to the photoperiod, growth would slow and control animals would begin to catch up in terms of live weight. Moving the 16L : 8D animals outside before slaughter at any time other than the summer solstice would effectively expose them to a drop in photoperiod and it would be predicted that this may stimulate a return to a winter, slow growth state. It is obvious that further work is needed on this aspect to develop a practical system for using 16L : 8D to enhance returns from venison production.

The summer solstice photoperiod of 16L : 8D was the only treatment to produce a significant stimulation of growth, suggesting that photoperiods in excess of 11L : 13D are required for stimulation of spring growth during winter. However in the natural situation spring growth has resumed by the time photoperiod has reached 11L : 13D indicating that animals may normally be anticipating the increasing photoperiods of spring.

The longer metatarsal length of SS group indicates that a more rapid skeletal growth formed a component of the increased live weight under 16L : 8D. As metatarsal length is relatively unaffected by nutritional restriction (Suttie *et al.*, 1984b) it is therefore a more stable indicator of the underlying growth state of the animal than live weight.

In mammals which inhabit temperate and arctic regions, seasonal cycles are thought to be kept entrained to the environment via photoperiod and melatonin secretion (Arendt, 1986). The effects of artificial photoperiod or melatonin treatments on seasonality can therefore be thought of as a re-entrainment process. Thus, in the present experiment the deer responded to the summer solstice photoperiod in winter by undergoing spring growth early and re-synchronizing their growth cycle with the prevailing, artificial photoperiod. There are two important features of this response which must be considered if 16L : 8D is to be used as a management tool to increase winter growth rate and advance slaughter date. Firstly, the re-synchronization of the growth cycle to photoperiod takes some time, for the animal must change its physiology from a state of winter growth stasis to one of rapid growth. In the present experiment, it appeared to take around 9 to 10 weeks before appetite and growth rate increased. This delayed effect may have a similar basis to the lag between a photoperiodic change (Fraser and Laing, 1969; Ducker *et al.*, 1970) or melatonin treatment (Asher, 1990) and the response of the reproductive axis in sheep and deer. If this is the case then, as in the above studies, the duration of this lag period may change, depending upon the date when treatment commences. The work of Davies *et al.* (1995) suggests that the lag period may also be altered by diet quality, with a high quality diet reducing the response time for rapid growth under 16L : 8D. A characteristic of this lag period in the present experiment was an initial stage when growth was slowed. The slow growth period seemed especially pronounced between weeks 4 to 6 from the start of treatment. One possible explanation for this may be that the various components of the growth axis which need to be altered to enable rapid growth, may be shifted at different rates by the photoperiod change. This would cause a period when the components are desynchronized with each other and growth may actually slow as a result.

Secondly, once into this rapid growth state, sufficient quantity and quality of food must be provided to enable the high growth rates, at a time when low quality conserved foods are normally used to maintain animals over winter. The DM intake during the rapid growth period under 16L : 8D in the present experiment was proportionately around 0·25 more than that of control groups. It is important that this extra DM intake must supply the energy and protein to support the more rapid growth, as there is obviously a physical limit to the amount of DM that can be eaten.

There were no significant differences between the indoor and outdoor control groups in total growth, and the mean food intake outdoors was only slightly more than indoors suggesting that there is no major saving of food consumption to be gained by housing animals during winter, as has been found previously under the climatic conditions here at Invermay

(Webster *et al.*, 1997). The only difference found between control groups was a slight negative curvature of the outdoor group due to a slowing in growth between weeks 12 and 18. This appeared to be due to a drop in food intake of outdoor animals. The reason for this short-term drop in food intake is unknown.

In conclusion this study has demonstrated that exposure to a 16L : 8D photoperiod during winter offers considerable potential as a practical means to advance the slaughter date of young male red deer.

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