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Reviews

Environmental control for layers

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Light patterns have less effect on numbers of eggs laid by current stocks than on those of forty years ago, but the principles have not changed. Ovarian activity is stimulated by increasing photoperiods and suppressed by decreasing photoperiods. The light pattern used during rearing can still have large effects on age at 50% lay, even for modern stocks. Early sexual maturity maximises egg numbers but gives smaller eggs. Late maturity maximises egg size at the expense of numbers. The relationship between egg output (g/hen d) and age at first egg is curvilinear, with maximum yield occurring in flocks maturing in about the centre of their potential range. Fancy patterns of increasing daylength after maturity are probably not justified. A flock held on a constant 14h day will lay as many eggs as one given step up lighting.

Intermittent lighting saves about 5% of feed consumption with no loss of output, provided that the feed has adequate amino acid content to allow for the reduced feed intake. Producers with light-proof laying houses should be taking advantage of intermittent lighting.

The recommended light intensity for laying houses is still 10 lx, although the physiological threshold for response to changes in photoperiod is closer to 2 lx. Very dim (0.05 lx) light filtering into blacked out houses will not stimulate the hypothalamic receptors responsible for photo-sexual responses, but may affect the bird's biological clock, which can alter its response to a constant short photoperiod.

Feed intake shows a curvilinear dependence on environmental temperature. At temperatures below the panting threshold, performance can be maintained by adjusting the feed so as to maintain an adequate intake of critical amino acids. Above the panting threshold, the hen is unable to take in enough energy to maintain normal output. There is no dietary modification which can effectively offset this problem.

Diurnally cycling temperatures result in feed intake and egg production equivalent to that observed under a constant temperature equal to the mean of the cycle. When the poultry house is cooler at night than by day, it helps to provide light so that the birds can feed during the cooler part of the cycle.

Keywords: lighting; photoperiod; light intensity; temperature

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Introduction

This paper, like its companion (Morris, 2003), looks back at ideas that were first published many years ago but which still seem relevant today. The principles of photoperiodism and responses to environmental temperature are not complicated, but their application in practical poultry production has sometimes been misunderstood. It seems worthwhile, therefore, to go over some old ground, pointing out as we go some of the lessons that seem not to have been fully applied in practice.

We shall first consider photoperiodism under the headings 'lighting patterns', 'intermittent lighting' and 'light intensity' and then turn our attention to temperature. The engineering side of environmental control will be ignored and some specialised aspects of lighting, such as colour (reviewed by Lewis and Morris, 2000) and non-24-hour (ahemeral) cycles, will be omitted for want of time. For those interested in ahemeral cycles and what they can tell us about the mechanisms of follicular development and ovulation, an introduction has been provided by Morris (1973), but an important afterthought is contained in Shanawany *et al.* (1993). For those with light-proof laying houses who wish to exploit ahemeral cycles for practical purposes and are not prevented from doing so by Welfare regulations, a 27 h or 28 h cycle of bright light and dim light still provides the best way of simultaneously improving both egg output and shell quality towards the end of the first laying year (*Table 1*).

Table 1 Data from Shanawany *et al.*(1993) showing that a light-dark cycle >24 h used late in the laying year (61 - 71 weeks of age) can increase egg size and improve shell thickness without reducing rate of lay (L = h of light; D = h of darkness: * = significant differences). Note that Yannakopoulos and Morris (1979) reported a significant reduction in rate of lay when using a 28 h cycle from 66-74 weeks, but observed a much greater increase in shell thickness (7.5 mg/cm^2). Note also that, if using alternating bright and dim lighting instead of light and dark, an illuminance ratio of 10:1 is sufficient to entrain oviposition in a 27 h cycle, but 30:1 is required for a 28 h cycle (Morris and Bhatti, 1978).

Light-dark cycle	Rate of lay %	Egg weight g	Shell thickness mg/cm^2
16L:8D (24 h cycle)	81.6	75.1*	77.4*
12L:16D (28 h cycle)	81.8	78.5	78.4

Lighting patterns

Early studies were concerned to explain the influence of natural daylength on the performance of laying fowls and led to the proposition that birds are influenced more by change in daylength than by the amount or duration of illumination at any one time (Whetham, 1933; Morris and Fox, 1958). Transferring pullets from long to short days tends to suppress ovarian development or activity, whereas transfers from short to long days stimulate ovarian activity. A 10 h day can act either as a long day, when it follows a period of shorter days, or as a short day when it follows a period of longer days (*Table 2*). This makes the point that it is the contrast between the current and the preceding photoperiod which is important. We know that these responses are the result of changes in FSH secretion from the pituitary gland (Lewis *et al.*, 1999b) which in turn depend upon changes in secretion of gonadotrophin-releasing hormone from the hypothalamus. How the hypothalamus is hard-wired is still a mystery. Sharp (1993) has summarised the view, popular amongst zoologists who long ago discovered that *gradual* changes in daylength are not required to elicit gonadal responses, that the bird makes a specific response to prevailing daylength, but that this is modified by the physiological state of the bird at the time. Pullets held on long days for a protracted period are described as "photorefractory" and need a period of short days before they can again respond to long days. The difference between this way of describing things and the view that the bird is more sensitive to change in photoperiod than to current level is largely semantic, but there are two difficulties with Sharp's synthesis. Firstly, modern laying strains do not appear to show photorefractoriness. Pullets of these strains mature at about the same age whether reared on constant short (8 h) days or constant long (18 h) days (Lewis *et al.*, 1998) but are nevertheless highly sensitive to changes in photoperiod during development (Lewis *et al.*, 1997). Broiler parents, incidentally, do exhibit photorefractoriness when reared on constant long (16 h) days (Lewis *et al.*, 2003) but Pekin ducks do not (Cherry, 1993). When in lay, pullets of high producing strains give much the same yield whether held on medium (11 h) or long (14 h) days or given a programme of delayed increases in photoperiod designed to obviate photorefractoriness (*Figure 1*). Secondly, Sharp's presentation does not lead directly to quantitative predictions of the response to be expected from a defined pattern of photoperiods, whereas Lewis *et al.* (2002, 2003) have shown that age at first egg can be reliably predicted from knowledge of the initial photoperiod and changes in photoperiod during rearing.

Table 2 Data from Lewis *et al.* (2002) showing that a 10 h day can act as a short day or as a long day, depending on the preceding photoperiod (L = h of light; D = h of darkness).

	Rearing photoperiod	Mean age at first egg (d)	Change in age at first egg
Experiment 5	10L:14D constant	154.5	
	18L: 6D from hatching reduced abruptly to 10L:14D at 8 weeks of age	180.5	+ 26.0 d
Experiment 12	8L:16D constant	146.6	
	8L:16 D from hatching increased abruptly to 10L:14D at 9 weeks of age	133.6	- 13.0 d

For practical purposes, the usual advice is to avoid any increase in daylength for growing pullets (because it induces precocious sexual development) and to avoid any decrease in daylength for laying birds (because it is liable to induce a moult). Given light-proof housing these precepts can easily be followed. If egg-type pullets are to be exposed to natural daylight at some stage, the best plan is to use supplementary lighting so as to provide a constant photoperiod throughout the birds' lives. Although earlier work indicated that yield could be increased by using a short day during rearing and stepping up during lay (Morris, 1967) it is doubtful whether the high-producing stocks now available will lay any more eggs if given a fancy pattern of light during lay.

In the growing stage, there is a choice between stimulatory lighting patterns which will maximise egg number to a fixed age (more eggs are laid because of the earlier start, not because of a higher peak rate) and those patterns which delay maturity and consequently maximise egg size (*Figure 2*). Egg number and egg size both show linear dependence on age at 50% lay, but with slopes in opposite directions (*Figure 3*). The regression estimates are −1.2 % rate of lay and +1.3 g egg weight for each 10 days' delay in sexual maturity. Lewis *et al.* (1997), using more prolific stocks, obtained estimates of −1.9 % rate of lay and +1.3 g egg weight for each 10 days' delay in maturity due to lighting. Since the slopes for rate of lay and egg weight are in opposite directions, it follows that egg output (g/hen day) which is the product of the two traits must show a curvilinear dependence on age at 50% lay (if $y = a-cx$ and $z = b+dx$ then $yz = ab + (ad-bc)x - cdx^2$). Thus, when egg income is closely related to the total mass of eggs produced (as in most European markets), pullets should be reared to mature roughly in the middle of their potential range of maturities (as influenced by lighting). However, when there is little or no premium for larger eggs and income is closely related to egg number, early maturity is a desirable trait, provided that the stock does not suffer from prolapse of the oviduct as a consequence. Higher laying house mortality used to be a common feature of precocious flocks, but seems not to be a problem in current stocks which generally have much lower mortality rates whatever lighting pattern is used.

Having chosen a pattern of lighting for rearing, designed to bring the flock into lay at the optimum age for the stock and egg market concerned, it is relatively unimportant what pattern of lighting is used in the laying house. Of course, daylength must not be reduced at point of lay and this is particularly important when pullets are reared with exposure to natural daylight and then moved to a light-proof laying house: but whether the flock is given a constant daylength, an abrupt increase or a step up pattern of lighting in the laying house makes no discernible difference to total yield and has remarkably small influence on the shape of the laying curve. A slightly higher peak can be obtained by stimulating the flock as it comes into lay, but this will be at the expense of eggs laid later when egg size is greater (*Figure 1, Figure 4*).

Intermittent lighting

Intermittent lighting does not increase egg yield but offers a saving in feed consumption, related to the amount of darkness (*i.e.* resting time) inserted into the working day. There are three categories of intermittent light programmes for layers: asymmetrical patterns, symmetrical patterns with full light and symmetrical patterns with restricted light. Biomittent lighting (15 min light and 45 min darkness repeated for 15 h, then 15 min light, 30 min dark and 15 min light, followed by 8 h darkness) is an example of an asymmetrical pattern. This will save some electricity and, more importantly, saves about 5% of feed consumption without any alteration in rate of lay or egg size (Midgley *et al.*, 1988) and can be used in imperfectly blacked out houses. Since feed intake is lower with Biomittent lighting, it is important to ensure that the diet contains sufficient protein to allow for this reduction (*Figure 5*). Symmetrical patterns, when used in light-proof houses, allow the ovulation rhythm to run free of the 24 h pattern of natural days and this results in increased egg size but causes a proportional reduction in rate of lay. Egg output (g/hen d) is unaltered but shell thickness is improved (*Table 3*). If the symmetrical pattern uses 12 h light in the cycle (*e.g.* 3 h light 3 h dark, repeated) there is no saving in either electricity or feed. However, repeated cycles of 15 min light and 45 min dark use only 6 h of light in 24 h and so give reduced feed consumption with no reduction in egg output whether compared with Biomittent lighting (*Table 3*) or with a conventional step up programme (*Table 4*). European Union Welfare Codes do not allow the use of the Reading system because it does not provide the bird with 8 h of uninterrupted darkness, but there is no rational basis for this limitation. The evidence shows that mortality rates are actually lower for those intermittent lighting systems which deliver less light than the controls with which they are compared (Lewis *et al.*, 1996). In countries not limited by these arbitrary constraints, intermittent lighting should be used routinely as a means of saving feed and electricity costs.

Table 3 Comparison of three systems of intermittent lighting applied to laying pullets from 23 to 72 weeks of age (* = significantly different from Biomittent). Data from Morris and Butler (1995).

Lighting system	Biomittent [15(0.25L:0.75D): 0.25L:0.50D:0.25L:8D] (asymmetric)	French 4(3L:3D) (symmetric, full light)	Reading 24(0.25L:0.75D) (symmetric, restricted light)
Rate of lay, %	73.9	72.1*	72.3*
Mean egg weight, g	62.1	63.6*	63.5*
Egg output, g/hen d	49.5	49.4	49.5
Feed intake, g/hen d	109	112*	108
Shell thickness at 65 weeks (mg/ cm^2)	79.3	82.3*	81.5*

Table 4 Comparison of the Reading System of intermittent lighting with the Step Up lighting programme recommended by the breeder. Both groups were reared on constant 8L:16D. The Step Up was from 8 h at 18 weeks to 15 h at 27 weeks. The Reading system (24(0.25L:0.75D)) was introduced abruptly at 20 weeks (* = significant difference). Data from Morris and Butler (1995).

Lighting system	Step Up	Reading System
Rate of lay, %	80.9	78.2*
Mean egg weight, g	63.8	65.1*
Egg output, g/hen d	50.5	50.3
Eggs per hen housed	299	292
Feed intake, g/hen d	123	116*

Light intensity

Early studies (Morris and Owen, 1966) indicated that a minimum intensity of about 10 lx was needed to support normal egg production but that, above this level, there was no effect of intensity on performance. Lewis and Morris (1999) subsequently showed that rate of lay exhibits a curvilinear response to illuminance and that 5 lx probably gives the optimal balance between lighting cost and egg income. A more recent study with growing pullets indicates a photoperiodic threshold at around 2 lx (*Figure 6*). This experiment is particularly useful in defining the threshold since pullets in the top tier of cages in one room (mean illuminance 2.2 lx) came into lay at an average of 106 days of age whereas those in the bottom tier in the same room (mean illuminance 0.75 lx) were 21 d later on average in laying their first egg. Although the threshold for maximum stimulation is therefore close to 2 lx, 3-5 lx is a good practical range of intensity for rearing houses whilst 10 lx is still a sensible value to recommend for laying houses because it is convenient for working and allows for some variation in intensity in different parts of the house.

Light filtering into blacked-out houses may have the effect of supplementing the intended artificial daylength inside the house. If stray light is above 2 lx, measured where the birds are, they can be expected to respond to the natural daylength that they can see and not to the artificial pattern provided. However, even at intensities below 2 lx there can be an influence of stray light on performance. *Figure 6* shows that pullets reared on 8 h light (at 10 lx) followed by 16 h of total darkness matured at 135 d whereas those getting the 8h light plus 6 h of very dim light (0.05 lx, 3 h before and 3 h following the main photoperiod) matured 10 d earlier. A possible explanation is that the very dim light, although not enough to activate hypothalamic receptors responsible for photoperiodic responses, was able to advance the position of "dawn" on the biological clock by 3 h. The bird would then "read"

8 h of normal lighting as an 11 h photoperiod. However, the data in *Table 5* indicate that it makes no difference whether the exposure to dim light occurs before or after the main photoperiod, which casts doubt on this interpretation based on a shift in the biological clock. The message is that one has to be careful when rearing pullets on short days to ensure that the house is thoroughly blacked out if one is to avoid unintended consequences. This is yet another argument for simplifying life by rearing layer-strain pullets on a constant daylength of 12 or14 h.

Table 5 The effect of placing 8 h of dim (0.1 lx) lighting before or after a main photoperiod of 8 h (at 7 lx) on mean age at first egg. Pullets were reared on 8L:16D to 10 weeks of age and then transferred to one of the four treatments. Data from Lewis *et al.*, (2001).

	8L:16D	16L:8D	8Dim: 8L:8D	8L:8Dim:8D	SEM
Age at first egg (d)	141	102	134	135	2.1

Temperature

It comes as no surprise to a South African audience to hear that high temperatures reduce feed intake and also depress egg production. The general relationship between ambient temperature and feed intake for laying hens held at constant temperatures is shown in *Figure 7.* Although all the publications summarised in this figure reported a linear dependence of feed intake on ambient temperature (within the range investigated), it is clear that the true relationship is a curve. The equation of the curve is given in Marsden and Morris (1987).

Much has been written about dietary modifications designed to allow hens to perform normally at high temperatures. Of course, a higher concentration of limiting amino acids will be required to offset the lower feed intake, but once ambient temperature is above the panting threshold, no amount of extra protein will enable the hen to maintain a normal rate of egg production (*Figure 8*). The point at which the bird is obliged to pant varies with breed, feather cover and acclimatisation but is around 29-31 C.

The problem for animals that are continually panting is that they cannot take in enough ME to sustain normal output. Some have suggested that it might help to feed a higher energy diet in these circumstances, but this misses the point. A higher energy diet merely depresses feed intake further, without increasing ME intake. Another suggestion is that the diet should be modified so as to deliver more of the energy in the form of fat, rather than starch, since the heat increment from metabolising fat is lower than that from carbohydrate. Experiments have been done to test this proposition but no clear conclusion has emerged. The reason for this is probably that the effect looked for is too small to detect in a production trial. It has been calculated that substituting 20% of the carbohydrate energy in a diet with lipid energy (keeping ME/kg constant) produces a theoretical saving in metabolic heat production about equal to the effect of lowering the dry bulb temperature by 1 C. If that is all that can be achieved with a large addition of dietary fat, it is hardly worth the bother.

Cycling temperatures

All the results summarised in *Figure 7* come from experiments in which temperature was held constant for each treatment. In practice, of course, temperature inside a laying house can only be held constant during temperate weather, when thermostatically controlled fans will adjust the ventilation rate to maintain the set temperature. In hot weather, fans will run at maximum speed day and night and there will be a temperature cycle inside the building. Very little work has been done on the bird's response to cycling temperatures, but the data in *Table 6* indicate that performance of hens exposed to a diurnal cycle is the same as that of hens maintained on a constant temperature equal to the mean of the cycle. There must be some limits to this proposition, since a 15 C/45 C cycle is lethal whereas a constant 30 C is not.

Table 6 Comparison of performance on constant and cycling temperatures. Means for three breeds of pullets held on 12L:12D from 38 to 47 weeks of age (* = significantly different from constant 27 C treatment). Data from Marsden (1981).

	Constant temperatures			Warm days, cool nights	Hot days, warm nights
	21 C	27 C	30 C	24 C in light 18 C in dark (mean 21 C)	30 C in light 24 C in dark (mean 27 C)
Feed (g/bird d)	113*	102	90*	108	98
% lay	77.1	78.5	70.9*	75.8	77.0
Egg weight (g)	61.8*	60.6	58.8*	61.5	59.7

A more important point about cycling temperatures is that birds cope better if they are allowed or encouraged to eat during the cooler part of the cycle. Providing light during the cool of the night or the very early morning is therefore helpful (Grizzle *et al.*, 1992).

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