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Welfare and environmental benefits of integrating commercially viable free-range broiler chickens into newly planted woodland: A UK case study

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Abstract

The commercial, welfare and environmental impacts of rearing small colonies of free-range chickens in newly planted woodland at two sites in the UK, during the first 2 years of the enterprise, were investigated. Newly planted rather than established trees were used so that commercially viable species could be planted in a way that would suit the management of the chicken enterprise, and small colonies were used so that farmers wishing to diversify could buy into the system progressively. It was anticipated that marketing a high specification product would provide an immediate income, whilst waiting for the future investment in trees to grow.

A split plot design was used at each site to investigate the effect of tree provision compared to conventional pasture plots on a range of production and welfare variables. The design also allowed for comparison of two chicken densities. Our measures of welfare included chicken mortality and morbidity, leg health and ranging behaviour, whilst production measures included growth rate, feed conversion and cost of production. Environmental impacts were investigated by examining the effects of chicken presence and density on the growth of the trees, the existing vegetation and groundwater quality. Results for the first 2 years of tree growth showed that the presence of young trees did not improve the measured welfare or production variables at either site compared to pasture range. Tree growth was acceptable by commercial standards and was not affected by chicken presence. Chicken presence and density had inconsistent effects on the composition of the vegetation, but did not result in significant changes to the amount of bare ground at either site. There were no significant changes in the concentration of nitrate, ammonium and phosphate in surface or ground waters attributable to the presence of chickens at the population densities used in the experiment. The experiment yielded important information on the wider aspects of management and production of free-range broilers, including the effects of season, weather conditions and leg health on ranging patterns. It is likely that an impact of trees on welfare and production will become apparent over the next 3–5 years of the enterprise with the increased growth of trees.

Keywords: Broiler chickens; Free-range; Trees; Welfare; Environmental impact

1. Introduction

Housing and confined living conditions were the primary concern of people asked about farm animal welfare (Bennet, 1996), with 62% of respondents altering their

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purchasing behaviour to include products (particularly eggs) from free-range production systems. One can assume therefore that consumers of premium poultry products would like to see chickens ranging outside. The use of outdoor areas in free range poultry systems however is often poor, with less than 15% of commercial flocks observed outside the house and then mostly located near the house (Hegelund et al., 2005; Dawkins et al., 2003; Bubier and Bradshaw, 1998).

A number of factors have been reported to affect the ranging behaviour of poultry. Climatic conditions and season are of prime importance, with more broiler chickens observed outside the house on warm overcast days and in summer (Dawkins et al., 2003), and under an optimum temperature of 17 °C for laying hens (Hegelund et al., 2005). Genetic strain is also important, with slower growing broiler strains ranging more (Nielsen et al., 2003), and significant differences existing between different laying hen strains (Kjær and Isaksen, 1998). Ranging increases with age (Keeling et al., 1988); Mirabito and Lubac (2001) observed 11% of Label Rouge broilers ranging at 7 weeks of age and 23% ranging at 11 weeks. Ranging follows a diurnal rhythm, with most birds out of the house after sunrise and before sunset (Dawkins et al., 2003), and tends to decrease with increasing laying hen flock size (Hegelund et al., 2005; Bubier and Bradshaw, 1998).

The quality of the outdoor environment, which is often an open pasture field, and its attractiveness to chickens must be questioned. Ranging in laying hens increased marginally by providing artificial cover outdoors (Hegelund et al., 2005; Grigor and Hughes, 1993), whilst the distribution of chickens on the range was improved by providing roofed shelters with sand for laying hens (Zeltner and Hirt, 2003) and a functional feeding trough for broilers (Weeks et al., 1994) at the furthest point from the house. Broiler chickens however, were shown to prefer habitat consisting of trees and bushes rather than short grass (Dawkins et al., 2003), and Mirabito et al. (2001) showed that established trees encourage ranging at all ages. In their study, 65.7% of the flock (at week 12) ranged when given access to a pear tree orchard, compared to 39% given access to pasture plots.

It is not surprising that birds prefer tree and thicket cover in which to range, considering the home of their ancestors, the Red Junglefowl of South East Asia (Collias and Collias, 1967). It is likely that trees are multifunctional in their provision for chickens; they provide shelter from wind and rain, and shade from the sun; cover from predators, and areas of contrasting light. Trees encourage ranging, but can the provision of trees measurably improve the health and welfare of the birds?

To date, health comparisons have largely centred on free range versus indoor systems. Free-range birds have been reported to have low rates of pathological lesions compared to standard birds (Herenda and Jakel, 1994) and free range laying hens have higher bone breaking strength than birds in cages (Leyendecker et al., 2001). There may, however, be increased risk from helminth infection (Permin et al., 1999), Salmonella (Hoop and AlbeckerRippinger, 1997) and other diseases (Sommer and Vasicek, 2000).

In this paper we describe the results from an investigation of the commercial, welfare and environmental impacts of rearing small colonies of free-range chicken in newly planted woodland at two sites in the UK, during the first 2 years of the enterprise. Newly planted rather than established trees were used so that commercially viable varieties could be planted in a way that would suit the management of the chicken enterprise. Small colonies were used to mimic the commercial enterprise of farmers undergoing progressive diversification and/or of enterprises slowly increasing the number of arks and chickens reared. It was anticipated that marketing a high specification product would provide an immediate income, whilst waiting for the future investment in trees to grow. We asked whether the enterprise could be commercially viable, was welfare truly improved by planting trees and encouraging the birds to range, were the chickens good for the trees by contributing fertilizer to their base and eating competitive vegetation, and what would be the environmental impact of such a system; would there be problems with nitrate leaching or loss of biodiversity?

2. Methods

Two sites in the UK, Wytham (SP47092235) and Northmoor (SU551934) were used in the study. Each site had eight experimental plots in a split-plot design incorporating two replicates of four plots in approximately a north–south field direction. The experimental plots comprised areas with chickens (Wytham 45.2 m × 36 m, 1617 m^2; Northmoor 50.8 m × 32 m, 1625.6 m^2) and areas without chickens (32 m × 36 m, 1152 m^2). Half were planted with broadleaf and conifer tree varieties and half were not. Each plot was individually fenced and the trial sites were surrounded by a seven wire electric fence to protect against predation. Fig. 1 gives a diagrammatic representation of the experimental layout of both sites, which is further described below.

Two chicken densities were tested. High density plots accommodated 1340 chickens in two arks providing an area of 1.2 m^2/bird on the range, equivalent to free-range requirements. Low density plots accommodated 670 chickens in one ark and provided 2.5 m^2/bird on the range, equivalent to organic production requirements. Each week approximately 1340, 24 day old birds, were transferred from the brooder house to the field arks in a predetermined 12 week rotational order of the experimental plots (see Fig. 1 for rotation). One week's intake therefore accommodated either one high density plot (1 flock) or two low density plots (2 flocks). Chickens were grown for a commercial market to a target ~2.28 kg at 56 days, with a maximum stocking density inside the ark of 27 kg/m^2.

Tree plots were planted in October 2002 with commercial conifer (western red cedar *Thuja plicata*, Douglas fir

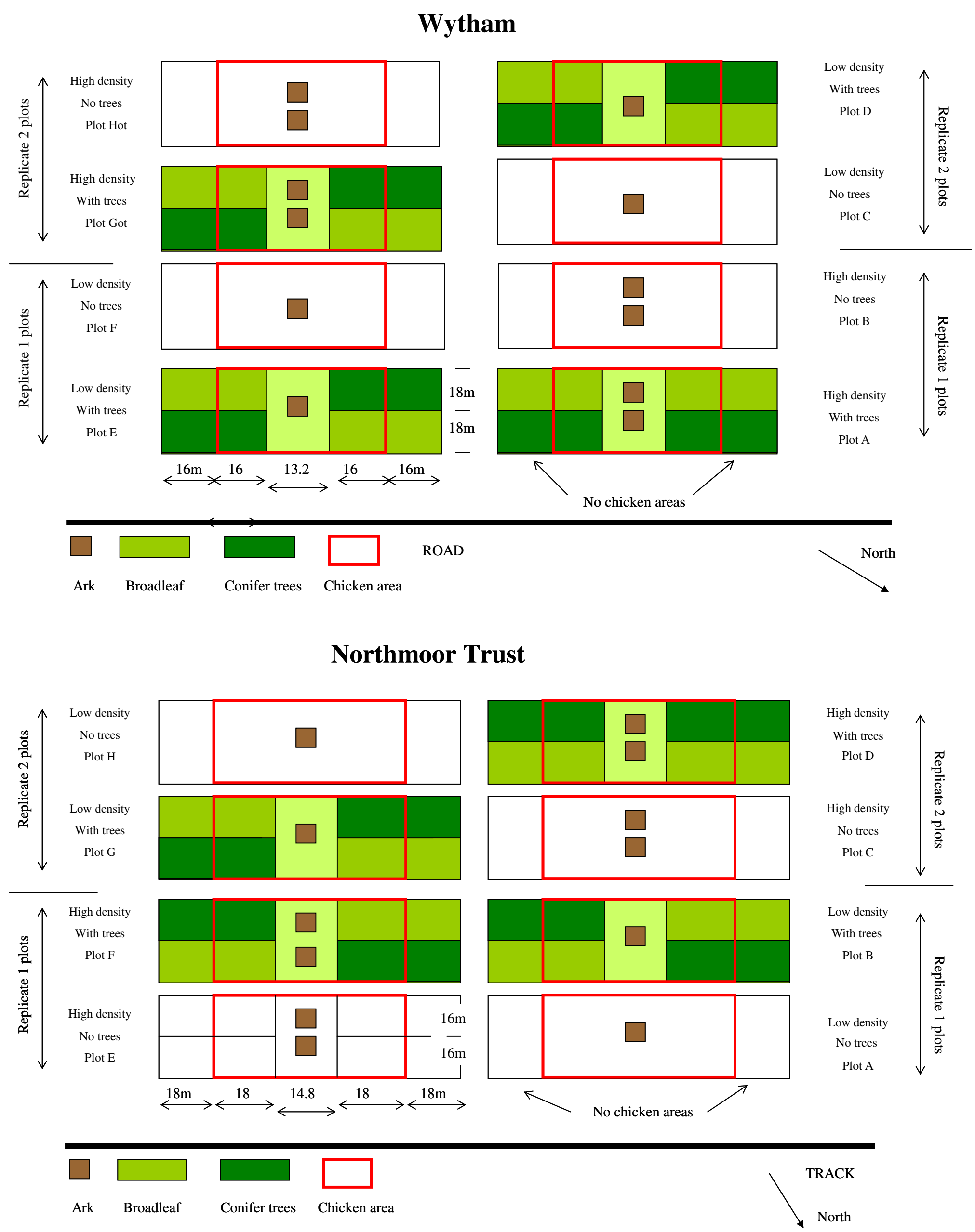

Fig. 1. The experimental layout at the Wytham and Northmoor sites (indicating plots with and without trees, and low and high chicken density; areas with and without chickens, and sub-plots with broadleaf and conifer tree varieties). Each site is spilt into two replicates (north–south of the field) of four plots. Chicken flocks were transferred to the field on an 12 week rotational cycle of plots; week 1 Wytham plot A, week 2 Wytham H, week 3 Wytham E and C, week 4 Northmoor F, week 5 Northmoor C, week 6 Northmoor B and H, week 7 Wytham plot B, week 8 Wytham G, week 9 Wytham F and D, week 10 Northmoor E, week 11 Northmoor D, week 12 Northmoor B and H. Plots were free of chickens for 7 weeks between successive flocks and adjacent plots (e.g. plots A and B) shared arks to maximise their use.

Pseudotsuga menziesii and Corsican pine *Pinus nigra* var. *maritime*), and broadleaved species (ash *Fraxinus excelsior*, silver birch *Betula pendula*, wild cherry *Prunus avium* and pendunculate oak *Quercus robur*). Plots without trees were left to pasture; at Wytham cocksfoot *Dactylis glomerata*, timothy *Phleum pratense* and red fescue *Festuca rubra* were dominant, whilst at Northmoor Italian ryegrass *Lolium multiflorum* and red clover *Trifolium repens* were dominant.

In year 1 we used ‘as-hatched’ Sherwood White chickens, initially developed for the free-range 56 day market. However, due to health problems in the limited parent flocks available, and because we needed to change breed quickly, we switched breed to a female Ross 308 in year 2; males were not used as their high bodyweight at 56 days precluded them from this market. Chickens were fed commercial free-range broiler diets based on wheat; growth promoters, digestive enhancers and coccidiostats were excluded. The following vaccination programme was adopted: Paracox 5 Coccidiosis on feed (day old), Infectious Bronchitis H120 spray (day 13), Gumbro Bursine in water (day 20).

Arks were mobile, and moved between adjacent plots after flock depletion to maximize their use. The floor area was 52 m^2, and the arks were naturally ventilated via adjustable side inlets and roof outlet vents, and equipped with roof insulation, 16 Dutchman pan feeders, 60 Dutchman low pressure nipple drinkers, ~5 cm deep woodshave/straw mix litter and dawn-dusk light simulation. Lights and feeders were battery operated, recharging from wind and solar power. Pop holes on the side of the arks, with ramps to the ground, allowed chickens access to the range in daylight hours after 28 days of age. Ramp design differed between sites. At Wytham ramps were made of plastic and there was a 30 cm drop from the edge of the ark to the ramp; birds were not able to sit under the ramp. At Northmoor ramps were wooden with horizontal cleats; they ran directly from the ark, and allowed birds to sit underneath.

Each plot was occupied by seven flocks throughout the study period and in total 112 flocks (108,827 chickens) were included, representing the system during the first 2 years of tree growth. A wide range of behaviour, welfare, production and environmental variables were measured, and are detailed below.

2.1. Behaviour and welfare measures

The number and location of chickens outside the ark was recorded at 52 days of age and three observation times (morning ~9.30 a.m., early afternoon ~1.30 p.m., and late afternoon ~4.30–5.30 p.m.) for each flock. Location was defined as (i) within the central ride (area around arks), (ii) near left or right of the range (up to 8 m from central ride at Wytham, 9 m at Northmoor) and far left or right of the range (>8 m from central ride at Wytham, >9 m at Northmoor). The percentage of chickens outside the ark and in each location on the range was calculated from actual numbers in the arks on that day. Depending on plot rotation, this ranging behaviour was also recorded at 45 days of age (half of the high and all low density plots $n = 79$ flocks) and 38 days (low density plots only $n = 48$ flocks). Maximum and average wind speed (altitude anemometer) and direction (relative to the ark), light levels (ISO tech ILM 350), and temperature (Huger digital probe) were also recorded. In addition, at day 52, focal chickens were chosen at random from inside and outside the ark and all behaviour recorded for a 10 min period, in the morning and afternoon; in total four birds were chosen from high density plots (two inside and two outside the ark), and two birds from low density plots ($n = 523$ birds). Chickens were followed between the ark and range and observations were terminated if the chicken moved out of view or if the bird's behaviour was affected by the observer in any way. Missing data occurred if no birds were outside the ark and during holiday periods.

At day 53, walking ability and leg health was inspected and scored according to the definitions given in Table 1. Walking ability was recorded for 30 chickens per ark; 10 chickens at three designated points were enclosed in a small frame and allowed to walk out one by one. The ease with which the birds walked was scored after observing 10 walking paces ($n = 4675$). A further 30 chickens per ark were examined for foot pad dermatitis, hockburn, and angular leg deviations ($n = 4631$); they were again enclosed in groups of 10, lifted by both legs with support under the breast during foot pad and hock inspection, and inverted with the feet away from handler and held with the thumb at the hock joint during inspection for angular leg deviation. The percentage incidence of each score for each condition was calculated. The latter birds were also individually weighed (Welltech digital weigh and sling) and growth rate over the 53 day period calculated.

In year 2, temperature and relative humidity (RH) (Tiny Talk data loggers at 60 cm height) inside the field arks were recorded hourly. Average weekly temperature and RH were calculated along with the percent of time above and below certain levels, for example <18 °C temperature and >70% RH.

The experimental unit was the flock. Outcome variables included percent birds out of the ark (ranging) and in location (i), (ii) and (iii), percent incidence of gait, pad and hock scores 0, 1, 2, and percent incidence of angular leg deviations. Behavioural variables included the percent of

Table 1
Scoring system for gait (walking ability), hockburn, pad dermatitis and angular leg deviation

Leg health measure	Score		
	0 Best	1 Moderate	2 Severe
Gait	Bird walks with ease, has regular and even strides and is well balanced	Bird walks with irregular and uneven strides and appears unbalanced	Bird is reluctant to move, is unable to walk many strides before sitting down
Hockburn	No discoloration or lesions	<10% hock with lesion	>10% hock with lesion
Pad dermatitis	No lesions	<5 mm lesion on pad	>5 mm lesion on pad
	Absent	Present	
Angle-in	Legs straight	Inward bow at inter-tarsal joint so that the two legs meet >22°	
Angle-out	Legs straight	Outward twist at inter-tarsal joint with =30° between the legs	
Rotation	Legs straight, pads facing away from handler	Rotation of the tibia shaft so that pads face each other >15°	

time chickens spent standing or lying, the percent time spent in various activities such as feeding, drinking, resting (with eyes closed), and rates of activities such as steps taken when walking, shaking head, pecking ground. Outcome variables were subjected to an analysis of variance General Linear Model (ANOVA, GLM) in Minitab version 13.0. The experimental model included the fixed effects of site, replicate nested within site, chicken density, presence or absence of trees and the interaction between chicken density and tree presence or absence. Data were tested for normality of residuals and transformed where appropriate; generally, proportional data (e.g. ranging, time spent feeding, etc.) was arcsine square root transformed and frequency data (e.g. incidents/minute of ground pecking) was square root transformed. In order to maintain normality in the focal behaviour data, the fixed factor 'inside/outside' the ark was added to the model to test for behavioural differences of birds that started the observation period either inside the ark or outside on the range.

A more detailed analysis of the outcome variables was then conducted by including season as a fixed factor in the model and any continuous variables (e.g. ambient temperature or % time <18 °C or other outcome variables, such as % gait score 1) with highly significant ($p < 0.001$) correlation to the outcome variable. Factors that best explain the observed variation in the outcome variable are given along with the percent variation explained (R^2) for important outcomes. Significant effects of categorical and continuous predictors were further examined by post hoc Tukey comparison and regression analysis (fitted line model), respectively. Year 1 and year 2 data were analysed separately.

Subsequently, paired students *t*-test were used to compare ranging behaviour between times of day and location on the plot. Finally, during the summer of year 3, 38 flocks of different ages were observed on sunny days and the position of the birds outside the ark recorded according to; in the shade next to the ark, in the shade of trees, and in the open. The ranging behaviour of chickens in plots with trees was then compared to that in plots without trees by single factor ANOVA.

2.2. Production measures

The following were recorded by the stockman for each flock in the brooder house and field ark separately: number of birds placed, daily numbers found dead, numbers culled due to leg problems and other culls, feed (kg) placed each day, and number of pop holes open (field ark only). Each flock was sampled and tested for Salmonella at day 49, as standard procedure. Outcome variables included calculated percent mortality, feed efficiency (kg of feed required for each kg gain in body weight), and cost of production, as well as average flock growth rate from the previous section. The cost of production formula included general fixed costs and labour, and feed cost and mortality across each flock. Analysis was by ANOVA (GLM) as described above.

2.3. Environment measures

Tree survival was assessed in the September of year 1 and the August of year 2. All dead trees were replaced during the winter of year 1 and herbicide applied to trees in the areas without chickens only; in year 2 herbicide was applied to all trees. Counts of live trees were converted to percentages and arcsine transformed. Tree growth was measured for the central 25 trees within each sub-plot to avoid edge effects. Height was measured (to the nearest centimetre) at time of planting, and during assessment of tree survival in both years. Height increment was calculated for individual trees, whilst plot means were used as the experimental unit. Data for tree survival, height (years 1 and 2) and height increment were analysed in Genstat (version 7.1) using ANOVA (GLM). The experimental model included the fixed effects of site, replicate nested within site, presence or absence of chickens, chicken density and tree species nested within chicken presence and the interaction of chicken density and tree species again nested within chicken presence. Initial tree height was included as a covariate in the model for the response variables tree height and height increment.

Plant species richness and bare ground percentage were assessed in plots with trees at Wytham and Northmoor in the spring of both years. Each tree plot was divided into eight sub-plots (four with and four without chickens evenly matched for coniferous and broadleaf trees). Six permanent quadrats (1×0.5 m sub-divided into eight cells) per sub-plot (48 quadrats per plot) were recorded for rooted frequency of plants and an estimate of bare ground. Proportional data were arcsine square root transformed and analysed using ANOVA with density, distance from ark and tree type as factors (SAS, 1989). Additionally, assessments were made before and after chickens were introduced to the plot over one cycle, so that the effect of chickens was investigated. These data were analysed using a repeated measures analysis of variance (ANOVA–GLM procedure) with density as a factor and pre and postchicken sampling as the repeated measures factor.

Ground and surface water quality were measured at the Northmoor site only. Weekly visits were made from November 2002 to June 2004 during which a total of 336 water samples were collected from lysimeters and wells; on average seven samples were available per visit during winter and three in summer, reflecting the seasonal rainfall-evapotranspiration pattern and groundwater levels. Lysimeters (1 m^2), which collect rainwater that has passed through a set volume of soil, were installed in the chicken plots ($n = 16$, two per plot) and no-chicken plots ($n = 4$, two in with-tree plots, two in no-tree plots) at a depth of 300 mm. Additionally, 11 wells were installed in selected areas, at 1.0–1.6 m depth, penetrating the groundwater of the underlying sand and gravel, allowing monitoring to continue as groundwater levels dropped in summer. Water samples from lysimeters, wells, drainage ditch and stream were analysed for nitrate, soluble reactive phosphate

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(SRP), ammonium, pH, and electrical conductivity. The analytical resolution for each parameter allowed data to be compared by simple descriptive statistics.

3. Results

There was no effect of the presence of young trees or chicken density on ranging behaviour, focal chicken behaviour, leg health or production.

3.1. Behaviour and welfare measures

Table 2 summarises the ranging behaviour of chickens in relation to the number of birds outside the ark, their location on the plot (distance from the ark), and differences between sites. Across sites and year, only 11% of birds on average were observed out of the ark at 52 days, the variation between flocks was high however with some flocks achieving just over 50% ranging and others virtually none. There was a diurnal pattern in the ranging with most birds observed out of the ark in the morning and least in the early afternoon. Fewer birds ranged at a younger age and most birds were observed near the ark within the central ride. At 52 days, higher levels of ranging were observed at the Northmoor site than at Wytham.

Ranging results in the third year of tree growth are given in Table 3. On sunny days, significantly more birds were observed outside the ark where there was tree provision (22.4% compared to 16.3%). There was no difference in the percent of birds observed in the shade of the ark or out in the open between tree and no tree plots. Consequently, more birds were observed in the shade (ark plus trees) in plots with trees than plots without trees.

Table 4 summarises the incidence of moderate and worst walking ability, hockburn, and pad dermatitis and the presence of angular leg deviations. Overall the total incidence of angular leg deviations was low at 6.5%, whereas moderate gait and pad dermatitis levels were relatively high (around 20–25%) and moderate hockburn at an intermediate level (∼12%).

Further analysis of the results explained much of the variation observed in ranging, walking, foot and hock health of the birds, as summarised in Table 5. Most birds ranged in the summer and autumn months and flocks with higher levels of moderate gait difficulty ranged less (adding 8.5% to the total variation in ranging explained, subsequently referred to as the partial R^2). Birds ranged further from the ark in the summer months (partial R^2 16.7%). Flocks with heavier birds were observed to range

Table 3
The percent of chickens in the flock outside the ark, in the shade of the ark and trees and in the open, according to tree provision on sunny days during the summer months in the third year of tree growth

Percent of flock, %	With trees, %	Without trees, %
Outside ark	22.4^a (6–40.8)	16.3^b (3.1–30.5)
In shade of ark	10.2 (4.1–18.7)	12.8 (3.1–26.1)
In shade of tree	9.5 (0–23.7)	n/a
In open	2.7 (0–8.3)	3.5 (0–11.5)
In shade (tree + ark)	19.7^a (5.5–36.8)	12.8^b (3.1–26.1)

Values with different superscripts in same row are significantly different; a > b, $F = 4.7$, $p < 0.05$, R^2 11.5%; c > d, $F = 7.2$, $p < 0.01$, R^2 16.5%.

Table 4
The incidence of moderate and worst (scores 1 and 2) gait (walking ability), hockburn and pad dermatitis, and the presence of angular leg deviations (% of birds sampled)

	Mean, %	St. dev	Range
Moderate gait	25.6	10.8	5.0–56.7
Worst gait	5.8	4.9	0–20.0
Moderate hock	12.3	10.4	0–50.0
Worse hock	1.0	2.2	0–10.0
Moderate pad	21.5	15.8	0–66.7
Worse pads	4.3	7.0	0–36.7
Inward angular deviation	2.4	2.8	0–13.3
Outward angular deviation	0.7	1.6	0–10.0
Rotation	3.4	3.4	0–16.7

Table 2
The percent of chickens in the flock outside the ark on days 52, 44, and 37, with their location on the experimental plot during the morning of day 52, and site differences in ranging

Measure	Observation	Mean % birds	St. dev	Range % birds
1. Chickens outside the ark	Day 52 Morning	11.1^{a,d}	9.2	0.2–51.4
	Day 52 early afternoon	6.1^b	5.2	0.2–25.9
	Day 52 early evening	8.6^c	8.4	0–47.8
	Day 44 morning	9.5^{d,e}	8.8	0–40.3
	Day 37 morning	8.2^e	7.3	0–30.9
2. Chicken location, day 52 morning	Central ride	9.4^j	6.9	0.2–31.0
	Near left (i)	0.6^k	1.2	0–7.8
	Near right (i)	0.9^l	1.6	0–9.5
	Far left (ii)	0.1^m	0.3	0–1.6
	Far right (ii)	0.2^m	0.5	0–3.9
3. Site effects, day 52 morning	Wytham	8.6^x	7.5	0.2–29.0
	Northmoor	14.0^y	10.2	1.6–51.4

Values with different superscripts within measure (1–3) are significantly different (a > c > b at least paired $t = 4.3$, $p < 0.001$; d > e paired $t = 2.7$, $p < 0.01$; j > k, l, m at least $t = 14.0$, $p < 0.001$; l > k paired $t = 2.0$, $p < 0.05$; l and k > m at least paired $t = 5.0$, $p < 0.001$; x < y, $F = 9.8$, $p < 0.01$).

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Table 5
The effect of season and other factors on ranging, and moderate walking ability, pad dermatitis and hockburn in year 2

Variable	Model + season + covariates	Total R^2
Day 52 ranging, morning % flock	Greatest in summer ($F = 6.7$, $p < 0.01$) • Summer: 17.7% (4.8–51.4) • Winter: 3.1% (0.5–6.9), Spring: 6.9% (1.7–13.0) Negative with moderate gait, score 1 ($F = 7.4$, $p < 0.01$, $r = -0.56$)	60.9
Day 52 morning far right of plot % flock	Greatest in summer ($F = 4.3$, $p < 0.05$) • Summer: 0.5% (0–4.0) • Winter: 0, Spring: 0.01% (0–0.2)	27.7
Day 52 early afternoon % flock	Positive relationship with % birds out in morning ($F = 4.9$, $p < 0.05$, $r = 0.74$) Negative relationship with body weight ($F = 12.0$, $p < 0.01$, $r = -0.51$) Chicken density × tree provision interaction ($F = 4.5$, $p < 0.05$)	77.8
Day 37 ranging afternoon % flock	Positive relationship with ambient temperature ($F = 40.6$, $p < 0.001$, $r = 0.56$) Effects of site ($F = 20.6$, $p < 0.001$) and tree provision ($F = 5.7$, $p < 0.05$)	91.3
Year 2 moderate gait %	Positive relationship with % time ark temperature <18 °C ($F = 12.0$, $p < 0.001$, $r = 0.41$), positive relationship with moderate pad dermatitis ($F = 9.2$, $p < 0.05$, $r = 0.47$)	53.9
Year 2 moderate pad dermatitis %	Negative relationship with best gait (score 0) ($F = 14.5$, $p < 0.001$, $r = -0.53$)	33.9
Year 2 moderate hockburn %	Least in summer ($F = 8.4$, $p < 0.001$) • Summer: 5.0% (0–20.0) • Winter: 16.7% (3.5–36.7), Spring: 16.7% (0–38.3)	40.8

Effects of season are described and correlation relationship with covariate factors given. Total R^2 is the total variation explained by the model + season + covariate factors.

less in the early afternoon (partial R^2 14.0%), whilst ranging in the morning encouraged ranging in the early afternoon (partial R^2 16.2%), and ranging at a young age (day 37) increased with increasing ambient temperature (partial R^2 76.1%). Moderate gait difficulties increased when ark temperatures were below 18 °C (partial R^2 35.9%) and with increased levels of moderate pad dermatitis in the flock (partial R^2 18.0%). The incidence of pad dermatitis and moderate gait difficulties were strongly linked (partial R^2 26.8%) and hockburn was least in summer (partial R^2 28.7%).

Examples of focal bird behaviour according to whether the chickens were inside the ark or outside on the range at the start of the observation period, are given in Table 6. Chickens were more active outside the ark, standing for almost three quarters of the observation period. They were occupied with walking and pecking at the ground or grass and drinking from puddles. Body movements such as shake head and wing flap were also performed more outdoors. Indoors the birds stood for only one fifth the observation period and were occupied with feeding, drinking from nipples, resting, and comfort behaviours such as preening. They panted indoors (particularly in summer) and were jostled more. Indoors, chickens pecked at the litter less than birds outdoors pecked at the ground.

Chickens in small arks with access outdoors were subjected to a wide range of temperatures (average weekly range 4.1–28.3 °C) and RH (average weekly range 44.1–92.9%) which were affected by season; Figs. 2 and 3 show average temperature and RH, respectively by week, season and site. Arks were coldest in winter and spring when humidity was highest, and were warmest in summer.

3.2. Production measures

In year 2 chickens grew at an average 37.6 g/d to produce a 2.0 kg chicken (at 53 days) at a cost of £1.03/kg. Production figures are summarised in Table 7, along with significant factors contributing to the explanation of variation in each variable. Field mortality in the first year (particularly summer) was high and partly due to health problems in the parent flock which contributed to higher rates of dead birds, large variation in bird size and the vice behaviour of vent pecking (in the summer months). Field mortality was reduced to 3.2% in the second year as production moved away from the Sherwood White to the Ross 308 female. Predation (by foxes and crows) accounted for 132 deaths at Wytham (0.24% mortality) and 43 deaths at Northmoor (0.08% mortality).

Heavier flocks were associated with moderate gait difficulties (partial R^2 15.3%) and hockburn (partial R^2 8.3%), and flocks with high growth rates were also associated with moderate hockburn (partial R^2 26.8%). Flocks that grew faster were more efficient at converting feed (partial R^2 42.0%) and were cheaper to produce (partial R^2 46.2%). Both feed conversion and cost of production were less efficient in summer, and there was some evidence that feed efficiency was reduced the more a flock ranged (partial R^2 1.8%). It is essential that costs are minimised as sale price from the farm was £1.30/kg. Encouragingly, flocks remained *Salmonella* free throughout the study period.

Table 6
Examples of behavioural differences in chickens inside the ark (In) or outside on the range (Out)

Variable	In Out	Mean	SE	Range		R^2
Stand %	In Out	21.8 71.6	2.4 3.4	0–100 0–100	Stand more outside: $F = 150$, $p < 0.001$	43.5
Walking strides (No.)	In Out	7.2 98.4	1.3 10.1	0–125 0–431	Walk more strides per walking bout outdoors $F = 80.8$, $p < 0.001$	29.4
Peck ground rate[a]	In Out	1.0 9.9	0.5 1.1	0–39.0 0–52.0	Peck ground more if outdoors during whole of observation period $F = 126$, $p < 0.001$	39.0
Drink–puddle %	In Out	0.0 4.0	0.0 1.1	0–1.7 0–87.4	Drink from puddle more if outdoors during whole of observation period $F = 23.0$, $p < 0.001$. Drink more at Northmoor (3.3% vs 0.5% $F = 9.1$, $p < 0.01$)	15.3
Shake head rate	In Out	0.1 0.4	0.0 0.1	0–1.6 0–3.4	Shake head more outdoors $F = 47.6$, $p < 0.001$	21.8
Wing flap rate	In 0ut	0.1 0.3	0.0 0.1	0–0.8 0–3.4	Wing flap more outdoors $F = 12.7$, $p < 0.01$	17.5
Feed %	In Out	2.6 0.5	0.7 0.2	0–63.2 0–16.6	Feed more if indoors during whole of observation period F=11.3, $p < 0.001$	7.1
Drink–nipple %	In out	6.4 1.8	1.2 0.6	0–59.0 0–40.2	Drink from nipple more if indoors during whole of observation period $F = 11.3$, $p < 0.001$. Drink more at Wytham (6.0% vs 2.5% $F = 9.1$, $p < 0.01$).	12.0
Rest %	In Out	12.1 4.5	1.5 1.1	0–71.7 0–50	Rest more inside ark $F = 30.9$, $p < 0.001$	15.1
Preen %	In Out	2.6 0.3	0.5 0.2	0–26.8 0–16.7	Preen more indoors $F = 24.1$, $p < 0.001$	12.3
Pant %	In Out	5.8 0.0	1.6 0.0	0–73.3 0	Pant indoors only and more at Northmoor (4.2% vs 1.4% $F = 4.6$, $p < 0.001$)	12.6
Jostled rate	In Out	0.2 0.1	0.0 0.2	0–0.9 0–1.7	Jostle more indoors $F = 35.2$, $p < 0.001$ and at Wytham (0.2 vs 0.1 $F = 55.7$, $p < 0.05$).	10.0
Peck litter rate[b]	In out	2.3 0.1	0.6 0.1	0–46.9 0–3.2	Peck litter more if indoors during whole observation period F=47.3, $p < 0.001$	20.1

Site differences are also given.
% = Percent of observation period engaged in activity. Rate = incidents of behaviour per minute of observation. a > b: Birds indoors peck at the litter less than birds outside the ark peck at the ground ($t = -6.2$, $p < 0.001$).

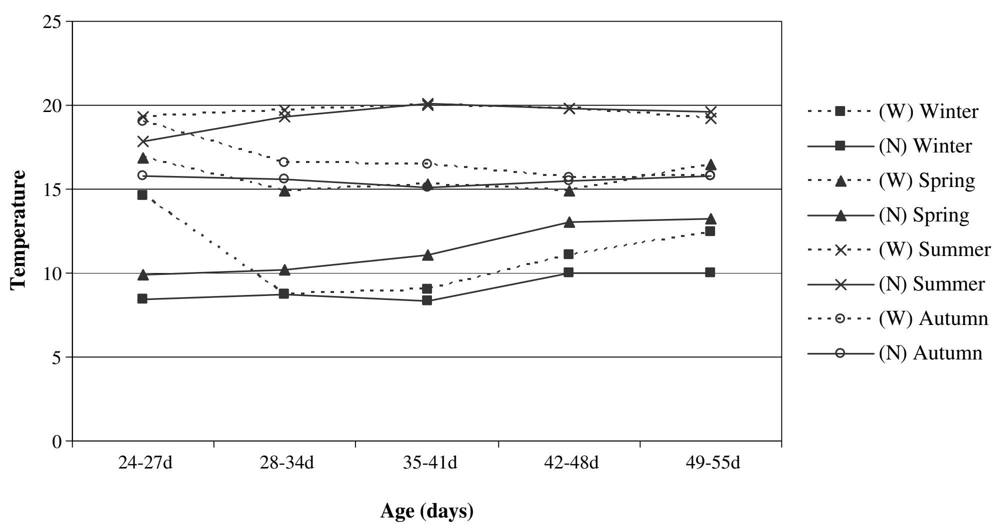

Fig. 2. Average temperature (°C) inside the ark according to chicken age, and by site, Wytham (W) and Northmoor (N), and season. Ark temperature was higher at Wytham than Northmoor up to 41 days (at least $F = 7.6$, $p < 0.01$). Wytham: From 28 days to 41 days, ark temperature was lowest in winter and highest in summer (at least $F = 10.0$, $p < 0.001$), whist from 42 days temperature was highest in summer months (at least $F = 4.5$, $p < 0.01$). Northmoor: Up to 41 days, ark temperatures were lower in winter and spring (at least $F = 13.0$, $p < 0.001$). From 42 days, ark temperature was lowest in winter and highest in summer (at least $F = 28.5$, $p < 0.001$).

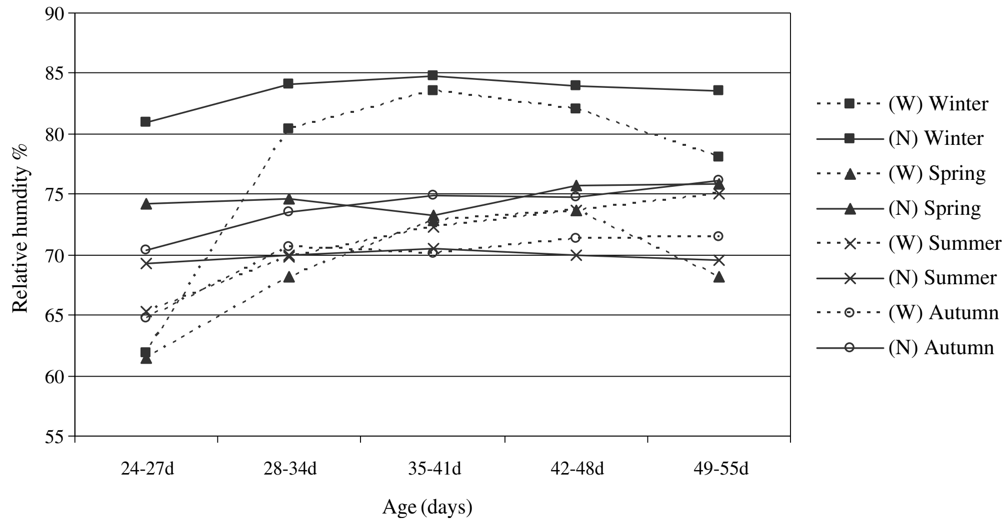

Fig. 3. Average relative humidity (%) inside the ark according to chicken age, and by site, Wytham (W) and Northmoor (N), and season. Relative humidity inside the ark was lower at Wytham than Northmoor at 24–27 days ($F = 19.9$, $p < 0.001$). From 28 days onwards, humidity was higher in the winter months (at least $F = 7.5$, $p < 0.001$).

Table 7
Field mortality (years 1 and 2) and year 2 body weight, growth rate, feed conversion and cost of production figures, with significant factors affecting each variable

Variable	Mean	St. dev	Range	Model + season + covariates	R^2
Field mortality % year 1	6.0	6.2	0.3–38.6	{Greatest in summer}, negative relationship with pink hocks ($F = 5.1$, $p < 0.05$, $r = -0.4$), greater at Wytham (6.5% cf 4.6%, $F = 5.4$, $p < 0.05$), density effect ($F = 5.9$, $p < 0.05$)	44.5
Field mortality % year 2	3.2	1.5	0.5–7.0	Positive relationship with best hocks ($F = 8.0$, $p < 0.01$, $r = 0.39$)	31.4
Body weight, kg	2.0	0.2	1.6–2.3	{Season}, positive relationship with moderate gait ($F = 5.8$, $p < 0.05$, $r = 0.56$) and hockburn ($F = 5.2$, $p < 0.05$, $r = 0.56$)	50.6
Growth rate, g/d	37.6	3.3	30.1–43.9	Positive relationship with moderate hockburn ($F = 14.2$, $p < 0.001$, $r = 0.54$)	35.9
Feed conversion	2.5	0.4	1.6–3.6	Less efficient in summer ($F = 3.6$, $p < 0.05$) • Summer: 2.7 (2.1–3.6) • Winter: 2.3 (1.9–2.7); Spring: 2.3 (1.6–2.9) Negative relationship with growth rate ($F = 28.7$, $p < 0.001$, $r = -0.82$), positive relationship with total % birds out day 52 ($F = 7.9$, $p < 0.01$, $r = 0.64$)	76.9
Cost of production, £/kg	1.03	0.1	0.9–1.25	Greatest in summer ($F = 9.8$, $p < 0.01$) • Summer: £2.08 (0.95–1.25) • Winter: £0.98 (0.88–1.08), Spring: £1.00 (0.92–1.19) Negative relationship with growth rate ($F = 101$, $p < 0.001$, $r = -0.87$)	85.4

{ } Indicates where season drops out of the expanded model with inclusion of other covariates.

3.3. Environment

3.3.1. Tree survival and growth

The effects of site, chicken presence and tree type on tree survival and height are summarised in Table 8. Overall tree survival was 94% at the end of the second growing season, and was significantly less at Northmoor; there was no effect of chicken presence or tree type on tree survival.

Trees at Northmoor were significantly taller than those at Wytham (by 20 cm) and trees in plots without chickens were taller than in plots with chickens (by 15.5 cm). Broadleaf species were 200% taller than conifer species. There

Table 8
Plot means for tree survival, tree height and height increment, growth, (year 1–year 2) at both sites and by chicken presence or absence and tree type

	Overall	Site		Chicken presence		Tree type (chickens present)	
		Northmoor	Wytham	Present	Absent	Broadleaf	Conifer
Mean survival (%)	94.4	90.4[a]	98.4[b]	95.0	93.2	94.8	95.3
Mean height (cm)	88.5	98.6[c]	78.3[d]	83.3[e]	98.8[f]	106.0	52.9
Mean tree growth (cm)	16.7	19.3	14.2	13.7	22.8	18.9	6.7

Values with different superscript are significantly different: a < b and e < f, $p < 0.01$, c > d and g > h, $p < 0.001$.

was no effect of site, chicken presence or tree type on tree growth (height increment) in year 2.

3.3.2. Plant species richness

Effects on vegetation and bare ground cover were inconsistent between sites and differed in the direction and extent of effects with site and year, as summarised in Table 9.

At Northmoor and in year 2, plant species richness and percent bare ground were greater in plots without chickens (year 2 $F = 20.1$ and 14.9, both $p < 0.001$), and in chicken plots at high density (both years). There was greater species richness in year 2 before chickens had access to the range ($F = 8.8$, $p < 0.01$).

At Wytham, plant species richness was significantly greater in plots with chickens than without chickens (year 1 $F = 6.9$, $p < 0.001$), after chickens had been on the plot (year 1 $F = 7.3$, $p < 0.01$), and at low density (year 2 $F = 4.3$, $p < 0.05$). Percent bare ground was greater in low density plots (year 1 $F = 12.7$, $p < 0.001$) and plots without chickens (year 2 $F = 31.1$, $p < 0.001$).

3.3.3. Water quality

Ammonium concentrations and SRP were initially considered prime indicators of pollution from chickens, but levels remained low through out the study period, below 5 mg/l ammonium-N and 3 mg/l as PO_4, respectively, and were not affected by the presence of chickens. Electrical conductivity and pH were also not affected by chickens.

Nitrate levels before the introduction of chickens remained below 10 mg/l N, but increased and showed a wide variation after the introduction of chickens and trees, with some wells exceeding 100 mg/l N. Plots without chickens had a nitrate mean of 10.3 mg/l N (95% confidence range of 6.9–13.7 mg/l N), and plots with low density chickens had a nitrate mean of 7.5 mg/l N (95% confidence range 5.1–9.9 mg/l N). Plots with high density chickens, however, had a nitrate mean of 4.8 mg/l N (95% confidence range 3.6–6 mg/l N), indicating lower levels than plots without chickens, at the 95% confidence levels. Mean nitrate concentrations in plots with and without trees were 8.4 mg/l N (95% confidence range 5.8–11.0 mg/l N) and 7.4 mg/l N (95% confidence range 5.4–9.3 mg/l N), respectively, indicating no effect of tree presence on nitrate levels. Finally, nitrate-N concentrations were consistently lower in the deeper wells than the shallower lysimeters, and were attributed to soil nitrate denitrification and beyond the scope of this study.

Table 9
Plant species richness (mean number of plant species per quadrant, standard errors in parentheses) by site and study year, for plots with or without chickens, and before or after chicken placement

	Mean number of plant species/quadrat			
	Year 1		Year 2	
	With chickens	Without chickens	With chickens	Without chickens
Northmoor				
Before chickens	$4.1(0.2)^{a,x}$	$4.0(0.2)^{a}$	$3.4(0.2)^{a,y}$	$4.4(0.2)^{b}$
After chickens	$3.9(0.2)^{a,x}$	$3.8(0.2)^{a}$	$3.0(0.1)^{a,x}$	$3.9(0.2)^{b}$
Wytham				
Before chickens	$5.7(0.2)^{b,x}$	$5.2(0.1)^{a}$	–	–
After chickens	$6.2(0.2)^{b,y}$	$5.4(0.15)^{a}$	$5.9(0.2)^{a}$	$5.8(0.2)^{a}$

Different superscripts in same row and year are significantly different and b > a at least $p < 0.01$; different superscripts in same column, site and year are significantly different and y > x, at least $p < 0.01$.

4. Discussion

We found that the presence of newly planted trees during their first two year's of growth had yet to demonstrate a benefit to chicken welfare compared to access to pasture range, in terms of enhanced ranging, behavioural repertoire, leg health or production. However, trees in their third year of growth did encourage more birds out of the ark and into the shade created by them on sunny days in the summer months. Tree growth and survival was promising, particularly for the broad leaf species (31 cm above tree guards). We estimate that average tree heights by year 5 (2007) will be 2 m in the broadleaved plots, with tree canopy providing 50% coverage of the area. This should provide very different ranging conditions for the chickens, with potentially significant consequences for bird welfare. Chickens were initially successfully marketed through the Tesco '*Finest*' range label; the success of the product subsequently led to the inclusion of trees as standard practice for all Tesco free-range poultry production.

Despite the lack of treatment effects on our measured welfare and production variables we have been able to explain much of the variation in some of the outcome variables, and thus point the way for future improvements. Site had a large effect on ranging late in the growth cycle, with more birds out of the ark and further from the ark at Northmoor. This site may have benefited from the following: (1) ramp design: ramps attached to the ark and there was access underneath for up to 20 birds to shelter; at Wytham there was a big drop from the ark to the ramp and no access underneath. (2) Shelter from hedges: hedges in close proximity to the trial plots afforded some protection from the wind and certainly provided shade from the sun which was attractive to the chickens. (3) Vegetation: chickens grazed on the clover/grass mixture, and when tall this vegetation was less dense than at Wytham and allowed chickens to create pathways through during ranging. (4) Orientation: The site was angled so that the sun moved further to the right of the arks, providing more sun shade in the late afternoon, when site effects on ranging were greatest.

Season was a major influence on ranging, leg health, mortality, and production efficiency. There was least ranging in winter and spring and this was directly related to outside temperature. Additionally, the chickens were exposed to cold and damp conditions inside the arks and this affected their gait (through leg stiffness and foot pad dermatitis) which in turn was also linked to lower ranging.

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Production efficiency was least in the summer months; this was partly exacerbated in the first year through health problems in the parent flock, and linked to increased mortality (primarily through vent pecking or culling for size), poor growth, and feed wastage (as birds spent long periods of time throwing feed on the floor). Panting levels were high on hot still days, and this probably contributed to reduced feed intake and growth. Fans were subsequently installed in the brooder house in an attempt to improve temperature control in the summer months. However, further monitoring and analysis is required to investigate the effects of temperature, RH and wind on the welfare of free range chickens, particularly in small arks which are subjected to a wide range of environmental conditions. As with intensive production systems, a major route of this welfare protection is deemed to be through the level of climatic control we are able to attain (Dawkins et al., 2004). Subsequent to our 2 years of monitoring reported here, the marketable product shifted to a higher specification; this required a change of breed to a slower growing (Hubbard) bird that will be processed at 81 days and at 3.0 kg, and sold under a more 'Traditional Free Range' label. It is hoped that this bird will be able to cope better with wide extremes of temperature and humidity than the highly selected Ross 308. In that favour, the new birds will be housed in the brooder house until day 35 and let out on the range on day 40.

Overall though, it is encouraging that, given the right climatic conditions, this study has shown the modern broiler to be active outdoors, ranging extensively and exhibiting natural behaviours of ground pecking, ground scratching and grazing. The motivation to drink from puddles or troughs is high, with large numbers of birds flocking out of the house after a rain shower to do so.

Although some significant effects of chickens on our measured environmental parameters were detected, it is too early to say whether the presence of chickens will have a negative effect on tree growth or plant species richness over the longer term. Under some circumstances it may be possible that the presence of chickens could help to reduce levels of competing vegetation at the tree base and assist with tree growth; in our study we did not find this to be a significant effect, but our results may have been confounded by the residual effects of tree transplant and the year 1 herbicide application. Whilst the effects of chickens on plant species richness were inconsistent across treatments and sites, it was encouraging that, at the stocking densities used in the experiment, there was no evidence for a profoundly negative impact of chickens on the natural vegetation over the first 2 years of the enterprise.

Nutrient concentrations in surface and groundwater were low before and after the introduction of chickens and trees, and were comparable with expectations for *low intensity* agriculture or where most manure is removed from site (see DEFRA, 2002 and ADAS, 2002 for general summaries; Formosa and Singh, 2002; Pitcairn et al., 2002). Groundwater nitrate was the only water quality parameter change attributable to the introduction of chickens, and unexpectedly, plots with high chicken density had a lower mean nitrate concentration than plots without chickens. Nitrate concentrations increased as groundwater flowed across the site, indicating a diffuse effect which may extend beyond the immediate experimental plots.

Finally, we have developed various practical solutions to problems encountered during the development of the commercial system. Removal of litter from the ark after flock depopulation was facilitated by use of plastic sheeting (two sections per ark) under the litter. The sheet could be dragged out of the ark with a telescopic loadall, and the litter emptied into a trailer and removed from site. Moving arks on heavy clay soil was achieved with a timber winch. Wind and solar technology supported the system, and it is likely that the power would be sufficient to support some form of semi-mechanical automation for pophole opening, but insufficient to run fans in summer months. Attention should be paid to heat conservation in winter and spring, by opening popholes and vents away from prevailing winds and closing them before it gets dark and cold, and maximising heat loss in the summer, by opening popholes and vents very early and leaving some popholes open at night – a mesh grid can be inserted in the hole to protect against predators. The electric fence excluded all but the largest male foxes, but needed to be maintained and fully powered to be effective. Our losses due to predation at one site were greater than the average reported for free-range farms in the South West of England (average 0.08%, Moberley et al., 2004), but well within the range reported.

5. Conclusions

The small colony concept is commercially viable with continued product and market development meeting the needs of a higher specification table chicken. We found that newly planted trees did not have a significant impact on the welfare of the chickens, in terms of reduced mortality and better ranging, compared to access to pasture, over the first 2 years of the enterprise. However, the presence of trees did encourage the numbers of birds on the range on sunny days in the summer of year 3. Chicken colonies did not have a significant impact on the majority of our environmental variables. Ranging was highly variable between flocks and largely dependent on season, temperature and time of day, with large proportions of birds observed outdoors in the summer months, whilst ranging over a larger ground area. Further monitoring is required to show whether a welfare benefit will develop as the trees grow, when we predict that they will provide a local microclimate and habitat more suited to the needs of the birds.

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