ELSEVIER

Bioresource Technology **61** (1997) 229–237

0960-8524/97 $17.00

PII:S0960-8524(97)00005-9

A FARM-SCALE STUDY ON THE USE OF CLINOPTILOLITE ZEOLITE AND DE-ODORASE® FOR REDUCING ODOUR AND AMMONIA EMISSIONS FROM BROILER HOUSES

Marko Amon,[a] Martin Dobeic,[a] Robert W. Sneath,[b]* V. Roger Phillips,[b] Tom H. Misselbrook[c] & Brian F. Pain[c]

[a]*Veterinary Faculty, University of Ljubljana, Gerbičeva 60, 61000 Ljubljana, Slovenia*
[b]*Silsoe Research Institute, Wrest Park, Silsoe, Bedford MK45 4HS, UK*
[c]*Institute of Grassland and Environmental Research, North Wyke, Okehampton, Devon EX20 2SB, UK*

(Received 1 January 1996; revised version received 6 December 1996; accepted 12 December 1996)

Abstract

Intensive poultry farms are frequently the subject of odour complaints and are also known emitters of ammonia. In this paper an experiment is described which compared the effectiveness of two abatement compounds, clinoptilolite and De-Odorase®, when used in broiler production. Two sites were used which had almost identical buildings, each with two rooms, and the same strain of bird. Clinoptilolite was used on one site and De-Odorase® on the other. Once a week ventilation rate, ammonia concentration and odour concentration were measured, to determine the effects of the additives. We also measured temperature, relative humidity and carbon dioxide concentration to confirm that the control and test rooms had similar micro-climates. In the room treated with clinoptilolite the ammonia concentration was statistically significantly higher than in the control and the total mass of ammonia emitted was 50% greater. In the De-Odorase® experiment the mean ammonia concentration in the treated room in the final week was 38% lower than in the control and the total mass of ammonia emitted from the treated room was 50% lower. There was no statistically significant reduction in the odour concentration or odour emission rate for either of the additives used. © 1997 Elsevier Science Ltd.

Key words: Chickens, broilers, additives, odours, ammonia, yucca extract, zeolite.

INTRODUCTION

Odours from intensive livestock buildings in the UK cause large numbers of complaints (Institution of Environmental Health Officers, 1992), while ammonia emissions from such buildings are believed to represent a serious environmental risk (van Breemen *et al.*, 1982; Hartung & Phillips, 1994). Many other countries, including Slovenia, have similar problems and the use of chemical additives is often recommended as a means of odour abatement. High levels of ammonia in the building can also not only be a health risk to stockmen but can also reduce the performance of the animals, (Donham, 1987; Charles & Payne, 1966).

Natural zeolite minerals may have the potential to reduce odour and ammonia emissions; in particular the clinoptilolite form of zeolite which is extracted at Zaloska Gorica in Slovenia and is sold commercially both in Slovenia and abroad.

A comprehensive review of aerial ammonia in poultry houses was published by Carlile (1984). She summarized the findings of Nakaue *et al.* (1981), who used clinoptilolite both as a broiler-feed additive and as an additive to broiler litter. 'Experiment 1' by Nakaue *et al.* (1981) showed that surface application on clean wood shavings was more effective at reducing aerial ammonia at 28 days bird age than at 21 days. An application rate of 5 kg/m^2 on the 21st day reduced aerial ammonia concentration by 15%, while 5 kg/m^2 applied on the 28th day reduced it by 35%. 'Experiment 2' by Nakaue *et al.* (1981) showed that incorporating clinoptilolite in the feed at the 10% level throughout the lifetime of the birds reduced aerial ammonia concentrations significantly (by an average of 8%).

The ammonia and ammonium absorption properties of zeolites have been reported in detail by Bernal & Lopez-Real (1993), who suggest that aerial ammonia is adsorbed at a rate of between 6 and 14 g/kg of zeolite.

Carlile (1984) also summarized the findings of Johnston *et al.* (1981) on 'yucca saponin' (which is presumably a major constituent of De-Odorase®), used with broilers raised on a litter of wood shavings. Yucca saponin was added to their ration at

*Author to whom correspondence should be addressed.

63 ppm, but no significant reduction in aerial ammonia concentrations was found.

De-Odorase® (Alltech Biotechnology Center, 3031 Catnip Hill Pike, Nicholasville, KY 40356, USA), a commercial powder preparation based on an extract of *Yucca shidigera*, may have the potential to reduce these odour and ammonia emissions. According to the manufacturers, De-Odorase® contains selected glycocomponents from the *Yucca shidigera* plant. These components are said to bind ammonia and other noxious gases, which would otherwise be released from manure.

Brick and concrete-built broiler houses with two (or three) identical storeys are common on private farms in Slovenia and these gave a good opportunity for farm-scale experiments to test the performance of the two additives with broilers.

An equivalent experiment with pigs has already been reported (Amon *et al.*, 1995).

METHODS

The broiler houses

Two separate broiler houses were used, Fig. 1, (one having two storeys and the other three, of which only two were used in the experiment), one for each of the two additives studied. The floor area, ventilation schemes, etc., were the same in each of the two houses. The ventilation was cross-flow and each room had seven air inlets, all 0·6 m below the ceiling, in one side wall, and seven fans, all 0·6 m above the floor, in the opposite side wall. Each of the four rooms, which had a floor area of approximately 480 m^2, held about 8000 birds, all of the same strain and stocked on the same day. The litter was wood shavings in all cases. From 1 day old to 7 days old, all the chicks received a starter ration; and from then on a grower ration. For the first 3 days the chicks received antibiotics and vaccine in their

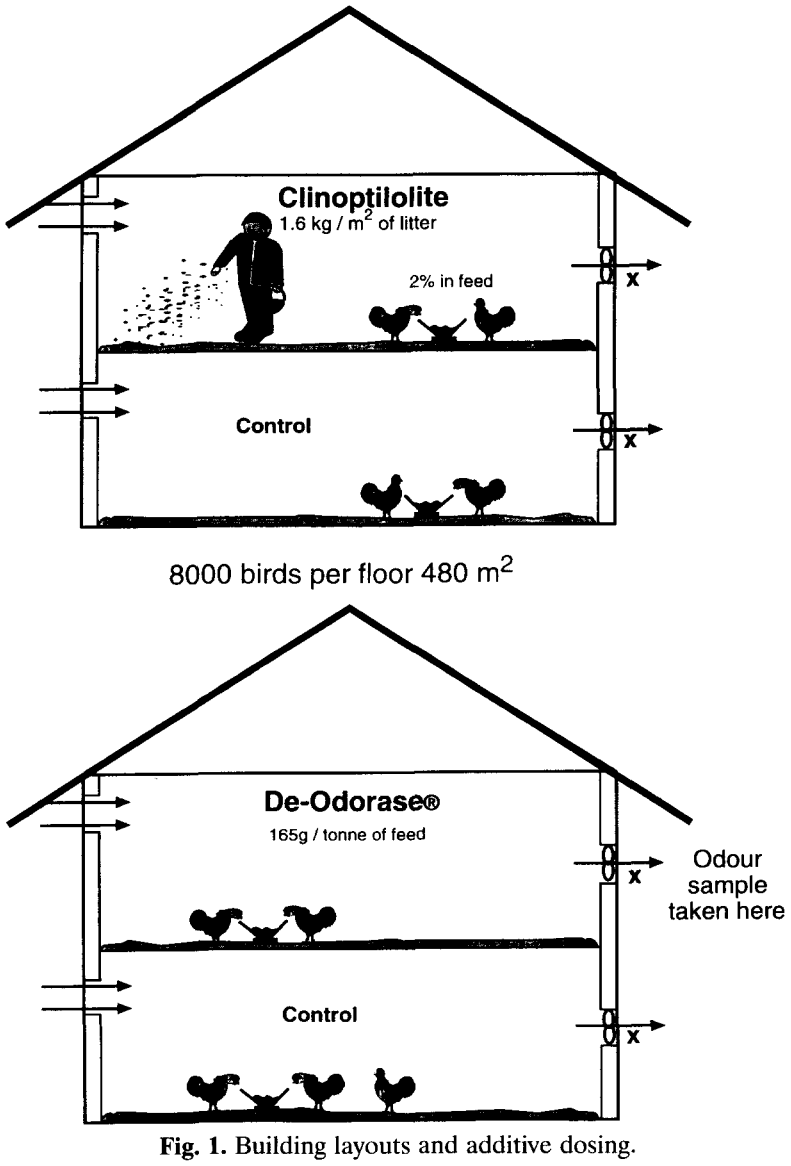

Fig. 1. Building layouts and additive dosing.

water. The subsequent veterinary treatment depended on specific health problems.

The air temperature was held at 33–35°C for the chicks' first week but was then progressively reduced so that by their fourth week it was down to 18–21°C.

Use of the additives

In both broiler houses the birds in the upper room were treated with the additive while the birds in the lower room received no treatment. The clinoptilolite treatment, as recommended by the supplier, consisted of both adding 2% by weight clinoptilolite (granule size 300 μm nominal) to the feed ration, and a total dose of 1·6 kg clinoptilolite (granule size 2000 μm nominal) spread per m^2 of litter surface. Of this dose spread on the litter, 0·7 kg/m^2 was spread in the first week and then 0·3 kg/m^2 was spread in each of weeks 4, 5 and 6.

The De-Odorase® treatment consisted of adding the dose rate advised by the supplier, namely 165 g of De-Odorase® to each tonne of feed.

Air sampling and measurements

At each weekly visit three samples of air were collected [in 50 litre FEP or Tedlar bags using stainless-steel pumps (Metal Bellows Co., Sharon, Massachusetts, USA)] from alternate fans in each room from outside the building, for olfactometric measurements. The total flow of air exhausted from each room was computed from the cross-sectional area of each fan outlet and the average velocity of the air emerging from each: the velocity was calculated from 12 measurements made with a hot wire anemometer at different points in each cross-section. Each room had three internal air-sampling positions equally spaced along a diagonal: at these points weekly measurements of temperature, relative humidity, ammonia and carbon dioxide were made at bird height. Temperature, relative humidity and air velocity were measured by a Solomat apparatus (Solomat Co., Ottery St Mary, Devon, UK) and ammonia and carbon dioxide concentrations were measured on each visit using Dräger tubes (Dräger GmbH, Lübeck, Germany).

A sample of 20 birds was weighed on each visit to the farms to assess weekly weight gain and calculate the feed conversion ratio.

The air samples were taken to the Veterinary Faculty, University of Ljubljana, and their odour concentrations were measured, always within 24 h, using two 'Olfaktomat' dynamic dilution olfactometers (Project Research bv, Amsterdam, The Netherlands), with a forced-choice method of sampling presentation to a panel of 8–10 assessors using the methods prescribed in the Dutch pre-standard NVN2820.

Six dilutions of each sample, differing from each other by a factor of two, were presented to the panel three times. Dilutions were made using odour-free air supplied by a compressor fitted with activated carbon filters and an air dryer. Each olfactometer had two sniffing ports, one delivering the diluted sample air and the other odour-free air. For each presentation, panel members indicated, via a keyboard, which port delivered the odorous air. The mean threshold value of the panel, expressed as odour concentration (odour units per cubic metre, ou/m^3), for each sample was calculated using the method of Dravnieks & Prokop (1975).

Statistical methods

Analysis of variance of the ammonia and odour concentration data on the natural scale assumes that the difference due to the treatment is the same each week. In contrast, transforming the concentration data by taking logs assumes that the relative proportions are the same from week to week. This is the more natural and realistic assumption and so this approach was adopted. In addition to this, the assumption of constant variance on the log scale is more true.

RESULTS AND DISCUSSION

Parametric tests and analyses of variance, for significant differences between treatments and control were, except for ammonia concentration in this clinoptilolite experiment, unsuccessful in establishing differences.

Over the 7 weeks of the trial each of the measured variables could be followed for the complete broiler crops in both buildings (Figs 2 and 3). The points plotted on all graphs are averages of three measurements. Error bars on the graphs for odour and ammonia concentration are standard errors calculated from the residual mean squares from the appropriate analysis of variance table, applied to the means on the log scale and then back transformed to the natural scale. Non-parametric tests including the Kolmogorov–Smimov test also failed. The power of both types of test would have been greater had a greater number of observations been made. The minimum number of observations needed is of the order of eight on each occasion with the variability in the measurements observed in these experiments.

Neither of the two additives had any effect on feed conversion ratio or on live weight gain. Total broiler live-weight in each room of each building each week was calculated as the product of number of birds and average bird live-weight.

There was no visual difference in the average total live-weight over the 7 week period between treated rooms and control rooms of each building. The average bird weight in each building was 2·03 kg at the end of the experiment. There was no evidence that the additive increased the rate of live-weight

gain of feed conversion ratio in either building, but birds in both the rooms of the De-Odorase® experiment had an improved feed conversion ratio of 2·046 compared with 2·13 for birds in the clinoptilolite building.

Litter conditions varied in much the same way in both buildings. Between weeks 2 and 7, litter nitrogen content increased from about 20 g/kg to 40 g/kg in the control and up to 30 g/kg in the clinoptilolite treated room. The pH of the litter remained acidic until the last 2 weeks, when that of the treated litter alone rose to 7·5. The litter moisture content remained below 30% in both cases but the treated-room litter became slightly wetter in the last 2 weeks. Wet (greater than 30% mc) and alkaline litters have previously been associated with high ammonia and odour emissions (Clarkson & Misselbrook, 1991). In the De-Odorase® building, litter nitrogen content and litter pH varied similarly in both rooms in this experiment and their variation with time reflected the increasing ratio of excreta to original litter.

Carbon dioxide concentration began and ended at similar levels in both buildings but the treated rooms had higher concentrations on three occasions.

Conditions of temperature and ventilation rate were similar in the treatment and control rooms in each comparison. Temperature was automatically controlled, the set point being reduced each week from 30°C. There was a slight difference between rooms in the spot measurements made (see Figs 4 and 5).

Odours

Clinoptilolite added to the litter and the feed gave no measurable reduction of the odour concentration or odour emission rate, at week 4 the odour concentration was significantly higher in the treated-room air than in that from the control room (Fig. 4). The mean odour concentration over the period showed an increase in both rooms, from 430 to 2480 ou/m^3 for the clinoptilolite treatment, with a high value of 4460 at week 4. Odour concentration in the air from the control room increased from 500 in week 2 to a

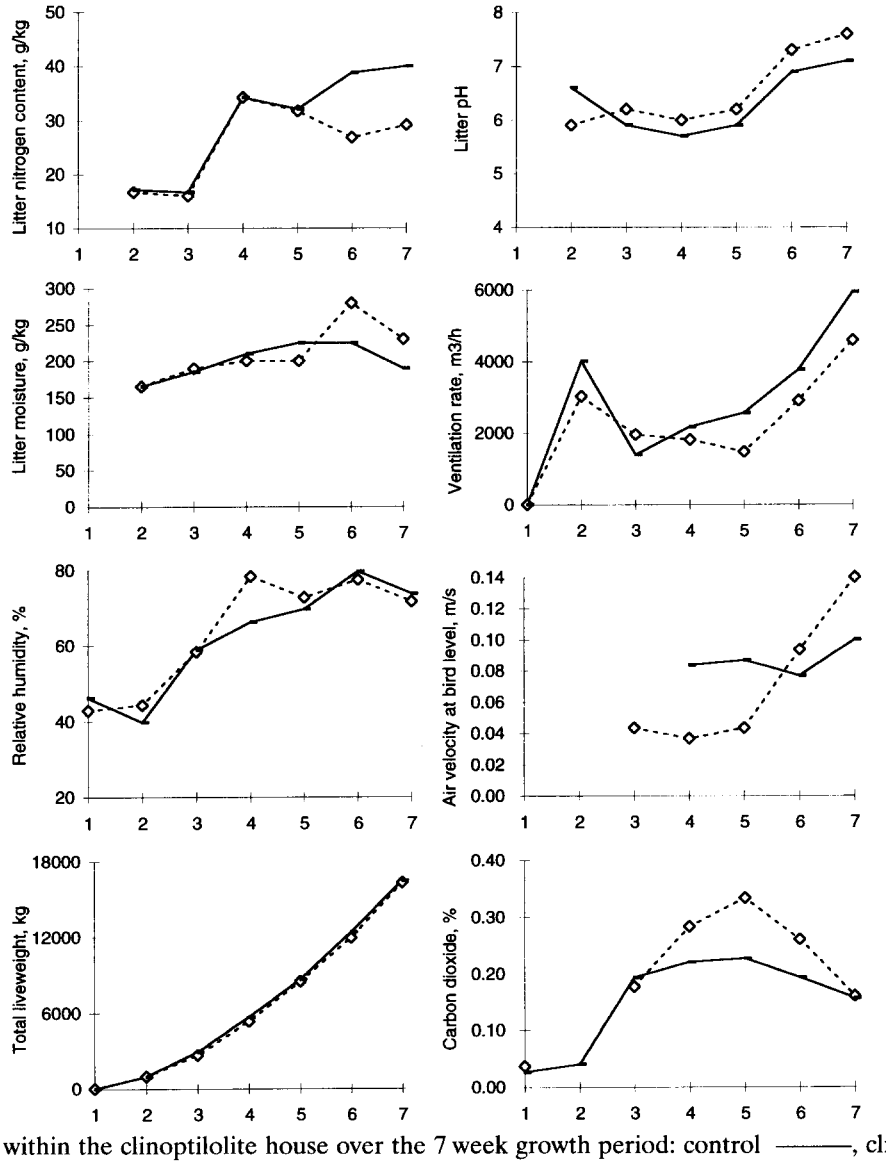

Fig. 2. Conditions within the clinoptilolite house over the 7 week growth period: control ———, clinoptilolite – ◇ –.

maximum of 2080 in week 6. In both cases the odour concentration was lower in week 7 than in week 6, but these differences were small and not statistically significant. The measured values of odour concentration agree well with the range of values measured in broiler houses in the UK by Clarkson & Misselbrook (1991).

De-Odorase® likewise had no measurable effect either on the odour concentration or on the odour emission rate when added to the feed at the recommended rates. The mean odour concentration (Fig. 5) over the period showed an increase in both rooms from 360 to 2490 ou/m^3 for the De-Odorase® treatment and from 310 to 2300 ou/m^3 for the control room. The two highest values occurred in week 6 in both cases, but these values showed no significant difference between the two rooms.

Ammonia concentration and emission

Clinoptilolite

The aerial ammonia concentrations, Fig. 4, in the clinoptilolite-treated room increased in the last 4 weeks of the experiment by between 600% and 42% of the concentration in the air in the untreated control. Ammonia concentration within the rooms increased over the period, with the larger increases occurring after week 4. The increases were lower and began later in the control room than in the clinoptilolite-treated room. The average concentrations in the clinoptilolite room over the 7 week period ranged between 1 ppm and a maximum of 29 ppm in week 6, but fell to 21 ppm in the last week. In the control room, the ammonia concentration rose from 1 to 14 ppm over the period. Again these values agree well with measurements made in the UK, but there it was observed that mean ammonia concentrations within a building can vary between 10 and 40 ppm during a 24 h period (Sneath *et al.*, 1996). The ammonia concentrations in the clinoptilolite-treated room were statistically significantly higher ($P<0{\cdot}05$) than the concentrations in the control room, Fig. 4. Observations of the litter condition over the period confirm that higher ammonia emissions were likely, e.g the pH of the

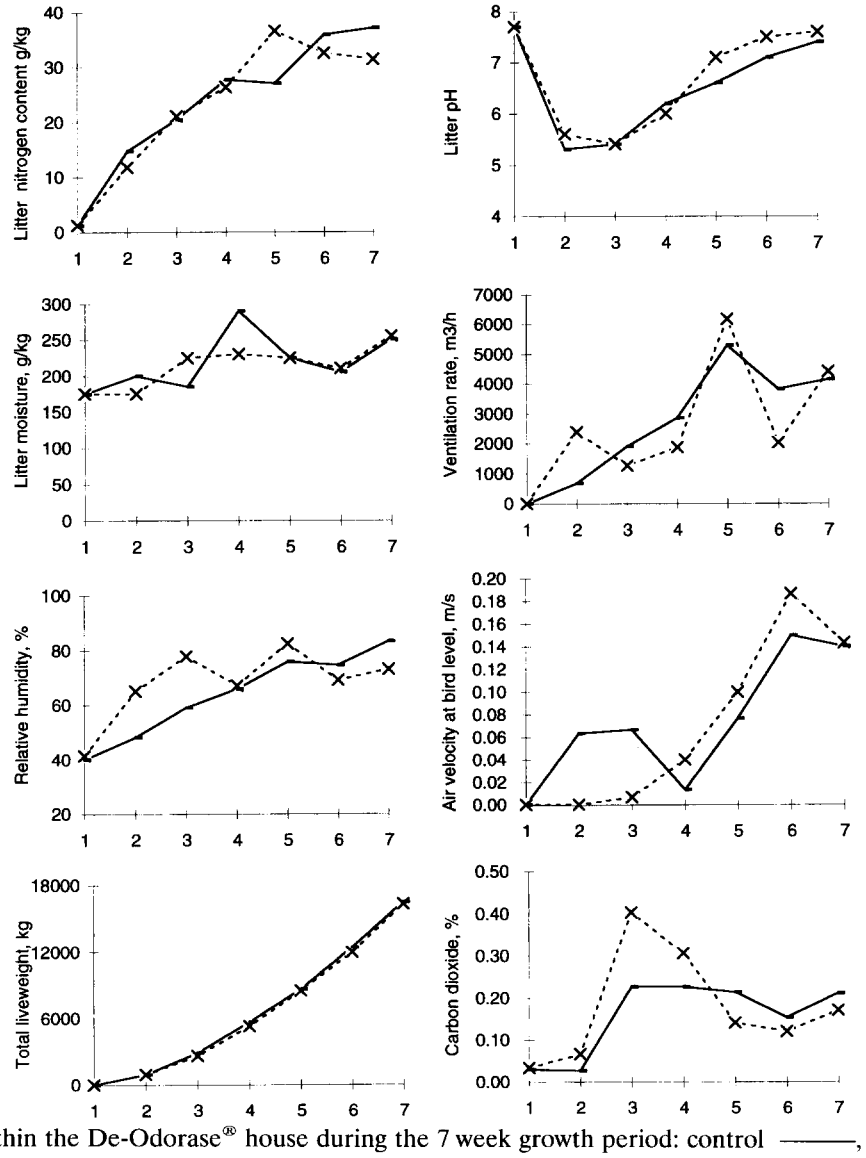

Fig. 3. Conditions within the De-Odorase® house during the 7 week growth period: control ———, De-Odorase® – × –.

litter in the treated room was higher than the control room for the last 5 weeks, which would increase the potential volatilization of ammonia. Moreover, the litter nitrogen content in the clinoptilolite room fell below the level measured in the control room, suggesting that nitrogen had been lost (in the form of ammonia) to the air.

The total quantity of ammonia emitted from the clinoptilolite-treated room over the 7 week period was 66 kg, 50% greater than that from the control room at 44 kg. The ammonia and ammonium absorption properties of zeolites have been reported by Bernal & Lopez-Real (1993) and imply that this aerial ammonia load in the untreated room could theoretically be adsorbed completely by between 3140 and 7300 kg of clinoptilolite, depending on type. Since the total quantity of clinoptilolite added to the test room, according to the suppliers' recommendations, was 766 kg in the feed ration and 281 kg added to the litter, the sum of these appears to be a sufficient quantity to adsorb only about, at best, 40% of the emission from the control room, given 100% efficiency of absorption.

As with ammonia concentrations, ammonia emissions expressed per 500 kg live weight show the control room to have had a lower emission rate. The actual mechanism that led to emissions from the control building being less than emissions from the treated room remains unclear, but all the observations made indicate that this was indeed the case.

Literature sources do not describe the total mechanism of sorption of ammonia when the zeolite minerals are used in this application, but it appears that the conditions in broiler litter may inhibit the sorption process or even reverse it, causing extra ammonia volatilization. There would appear to be a need for research in this area to gain an understanding of the mechanisms in real conditions.

De-Odorase®

The only statistically significant result from the De-Odorase® experiment was in week 4, when the ammonia concentration in the treated room was twice that in the control room. There were no statistically significant differences, although the total quantity of ammonia emitted from the room where De-Odorase® was used was 50% less than that emitted from the control room. Ammonia concentration within the rooms increased over the period, with the larger increases occurring beyond week 4. The increases were smaller in the De-Odorase®-treated

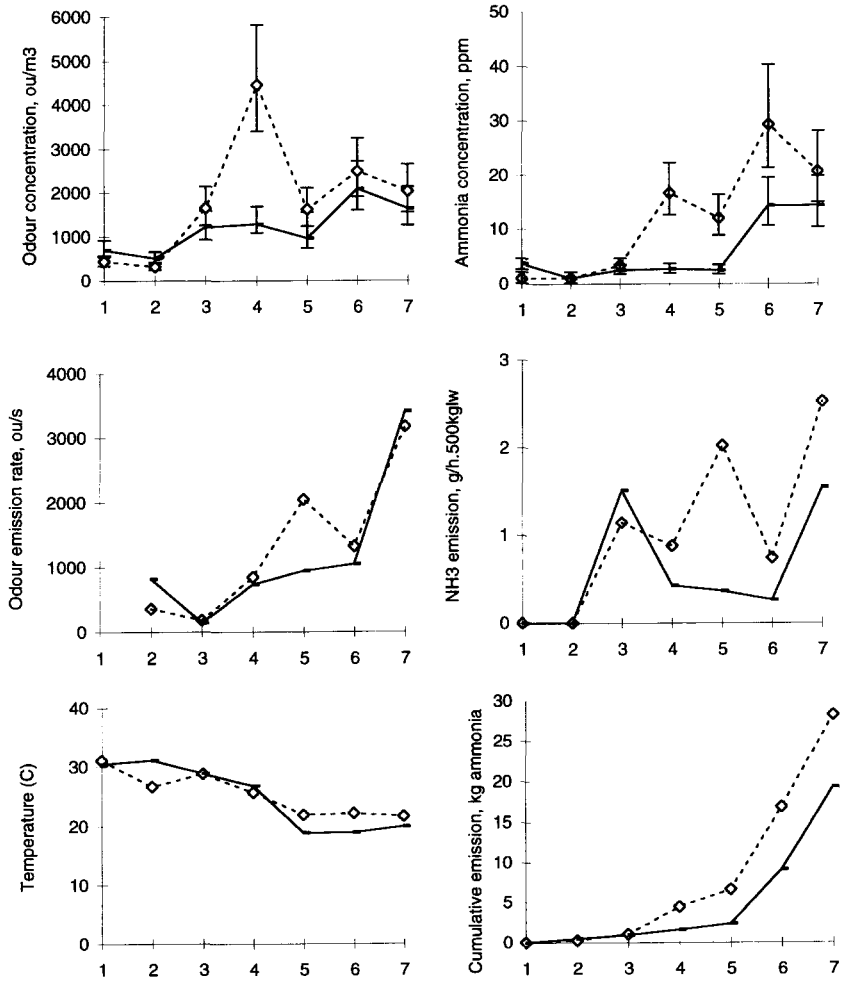

Fig. 4. Changes with time (week No.) in temperature, odour concentration and emissions, ammonia concentrations and cumulative ammonia emission for clinoptilolite: control ———, clinoptilolite – ◇ –.

room than in the control room, with average concentrations over the 7 week period of between 1 ppm and 24 ppm for De-Odorase® treated and between 1 and 39 ppm for the control.

However, when the total quantity of ammonia emitted was calculated, the De-Odorase®-treated room emitted 44 kg, 67% of the 66 kg emitted from the control room. Ammonia emissions expressed per 500 kg live weight again show the control room to have had a higher emission rate during the last 2 weeks.

Measurements of ammonia emission rates from broiler houses have been made in other European countries by several groups of workers and these are compared with emission rate measurements from this work, in Table 1. Measurements in the UK were carried out over periods of between 24 and 48 h in a set of experiments in four buildings, with birds aged about 4 weeks, visited in summer and in winter (Wathes *et al.*, 1997; Sneath *et al.*, 1996); those reported by Oldenburg (1992) relate to measurements in Germany. Dutch government data (MVROM, 1993) have been converted from annual emissions per bird by assuming average live weights and building occupation times. Müller (1994) made measurements in a naturally ventilated building, the maximum emissions reported were measured at the beginning of the crop and minimum rates reported

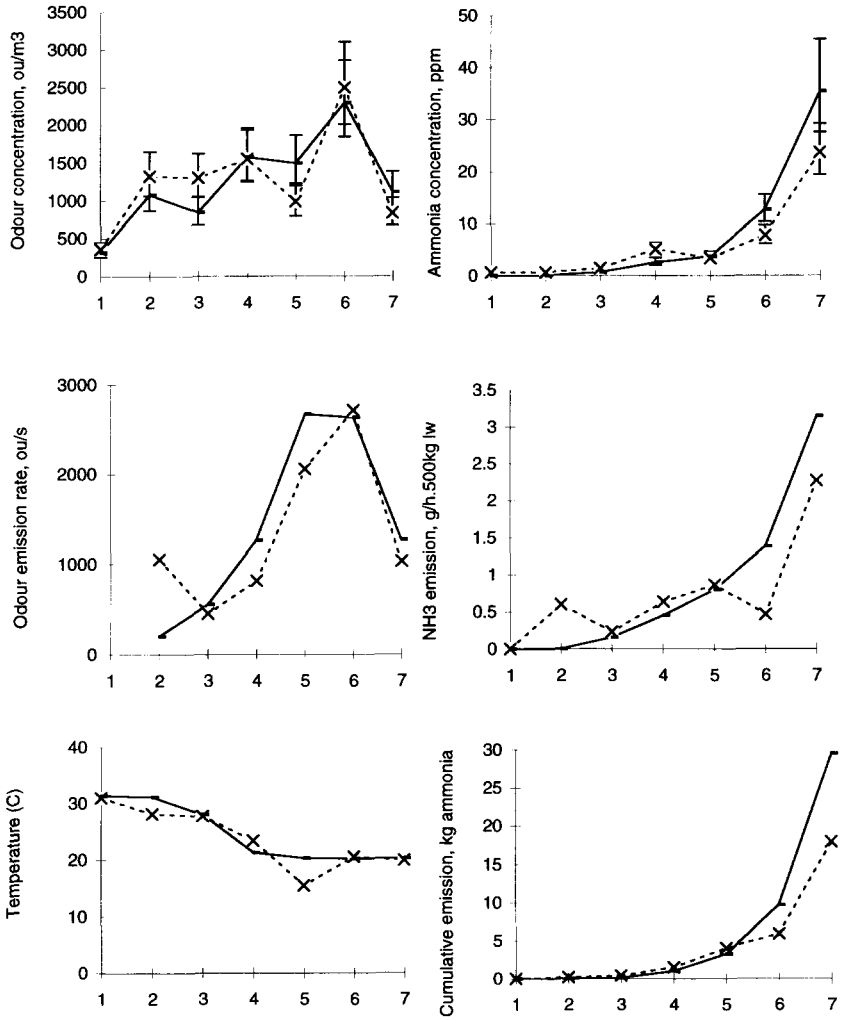

Fig. 5. Changes with time (week No.) in temperature, odour concentration and emissions, ammonia concentrations and cumulative ammonia emission for De-Odorase®: control ———, De-Odorase® – × –.

Table 1. Range of mean ammonia emission rates expressed as g/h/(500 kg live weight) compared with values from other studies

Building	Slovenia (present study)	UK (Wathes *et al.*, 1997)	Oldenburg (1992)	MVROM (1993)	Müller (1994)
Broiler, minimum	0.6	6.4			2.7
Broiler, maximum	8.1	14.2	7.6	4	82

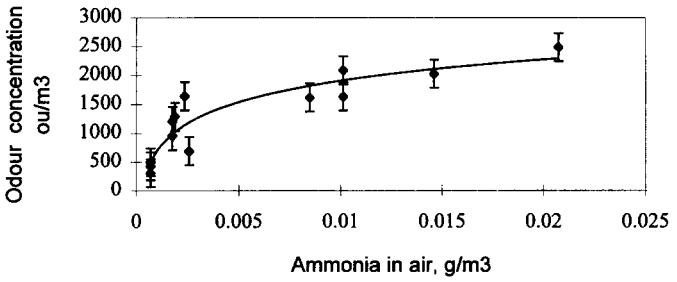

Fig. 6. Relationship of ammonia concentration to odour concentration in the clinoptilolite building.

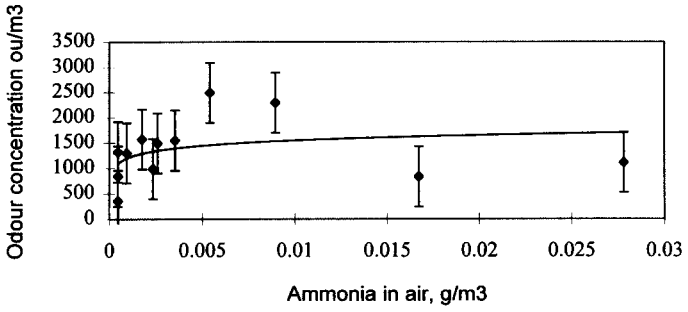

Fig. 7. Relationship of ammonia concentration to odour concentration in the De-Odorase® building.

refer to emissions at the end of the crop during the summer.

Relationship between ammonia and odour

There is often a desire to relate the odour concentration to a parameter that can be measured instrumentally and ammonia concentration is usually chosen.

Ammonia concentration and odour concentration correlated well in the clinoptilolite-treated room In Fig. 6 odour concentration is plotted against the ammonia concentration. The relationship between them is given by

$$\text{Odour conc. (ou/m}^3) = 530.\ln (NH_3, \text{ g/m}^3)+4347$$

$$(P<0{\cdot}01, r^2 = 0{\cdot}851)$$

The data collected from the De-Odorase® room did not confirm this relationship. The relationship between them in this case (Fig. 7) is given by

$$\text{Odour conc. (ou/m}^3) = 149.\ln (NH_3, \text{ g/m}^3)+2234$$

$$(P = 0{\cdot}29, r^2 = 0{\cdot}1173)$$

Large variations in concentration and emission rate have been shown to occur in broiler houses by this and other studies, therefore more intense monitoring is recommended in order to reduce standard deviations and thus demonstrate other statistically significant differences between treatments.

ACKNOWLEDGEMENTS

We thank the Slovene Ministries of Science and Technology, and of Research, and the UK Ministry of Agriculture, Fisheries and Food for funding the project; the British Council for travel grants (Academic Links and Interchange Scheme) to allow the UK staff to travel with equipment to Slovenia and vice versa; and the owners of the two farms for their kind cooperation. We gratefully acknowledge advice from R. P. White, Silsoe Research Institute, on statistical analysis of the data.

REFERENCES

Amon, M., Dobeic, M., Misselbrook, T. H., Pain, B. F., Phillips, V. R. & Sneath R. W. (1995). A farm-scale study on the use of De-Odorase for reducing odour and ammonia emissions from intensive fattening piggeries. *Biores. Technol.*, **51**, 163–169.

Bernal, M. P. & Lopez-Real, J. M. (1993). Natural zeolites and sepiolite as ammonium and ammonia adsorbent materials. *Biores. Technol.*, **43**, 27–33.

van Breemen, N., Burrough, P. A., Velthorst, E. J., van Dobben, H. F., de Wit, T., Ridder, T. B. & Reijnders, H. F. R. (1982). Soil acidification from atmospheric ammonium sulphate in forest canopy throughfall. *Nature*, **299**, 548–550.

Carlile, F. S. (1984). Ammonia in poultry houses: a literature review. *World's Poultry Sci. J.*, **40**, 99–113.

Charles, D. R. & Payne, C. G. (1966). The influence of graded levels of atmospheric ammonia on chickens. II. Effects on the performance of laying hens. *Brit. Poultry Sci.*, **7**, 189–198.

Clarkson, C. R. & Misselbrook, T. H. (1991). Odour emissions from broiler chickens. In *Odour and Ammonia Emissions from Livestock Farming*, ed. V. C. Nielsen, J.

H. Voorburg & P. L'Hermite. Elsevier Applied Science, London, pp. 194–202.

Donham, K. J. (1987). Human health and safety for workers in livestock housing. In *Latest Developments in Livestock Housing. Proc. Commission Internationale du Génie Rural*, Section 2 Seminar, 22–26 June 1987, Illinois, pp. 86–95.

Dravnieks, A. & Prokop, W. H. (1975). Source emission odour measurement by a dynamic forced choice triangle olfactometer. *J. Air Poll. Control Assoc.*, **25**(1), 28–35.

Hartung, J. & Phillips, V. R. (1994). Control of gaseous emissions from livestock buildings and manure stores. *J. Agric. Engng Res.*, **57**, 173–189.

Institution of Environmental Health Officers (1992). *Environmental Health Statistics 1990–1991*. IEHO, London.

Johnston, N. L., Quarles, C. L., Fagerberg, D. J. & Caveny, D. D. (1981). Evaluation of yucca saponin on performance and ammonia suppression. *Poultry Sci.*, **60**, 2289–2295.

Misselbrook, T. H., Clarkson, C. R. & Pain, B. F. (1993). Relationship between concentration and intensity of odours for pig slurry and broiler houses. *J. Agric. Engng Res.*, **55**, 163–169.

Müller, H.-J. (1994). Rates of odour and pollutant gas emission from animal housing. Measurement and analysis (Geruchs- und Schadgasemissionsstrome aus Tierhaltungen) (translated by S. H. Jones, Silsoe Research Institute). *Landtechnik* **49**(6), 360–361 (1995).

MVROM, (1993) (Ministry of the Environment, The Netherlands) *Green Label Guidelines for Low Emission Livestock Buildings* (in Dutch).

Nakaue, H. S., Koelliker, J. K. & Pierson, M. L. (1981). Studies with clinoptilolite in poultry: II. Effect of feeding broilers and the direct application of clinoptilolite (zeolite) on clean and reused broiler litter on broiler performance and house environment. *Poultry Sci.*, **60**, 1221–1228.

Oldenburg, J. (1992). Ammonia emissions from animal houses. In *Baltic Sea Environmental Proc. No. 44:. Nitrogen and Agriculture International Workshop*, Schleswig, Germany, 9–12 April 1991.

Sneath, R. W., Holden, M. R., Phillips, V. R., White, R. P., Wathes, C. M. (1996). An inventory of emissions of aerial pollutants from poultry buildings in the UK. In *Proc. Int. Conf. on Air Pollution from Agricultural Operations*, 7–9 February 1996, Kansas City, Missouri, USA.

Wathes, C. M., Holden, M. R., Sneath, R. W., White, R. P., Phillips, V. R. (1997). Concentrations and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in UK broiler and layer houses. *Brit. Poultry Sci.*, **38**, 14–28.