ZEOLITES - DO THEY HAVE A ROLE IN POULTRY PRODUCTION ?

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SUMMARY

Literature on the application of natural and synthetic zeolites for poultry production is reviewed. A total of 66 experiments were cited involving the application of zeolites to poultry production. Areas where zeolites have potential use are: as a feed additive to improve poultry performance for layers and broilers; to assist in manure and litter management; and to assist in controlling air quality in poultry house environments. These are discussed in detail, including a brief discussion on the general structure and fundamental properties of zeolites. Some of the data reviewed is often incomplete and sometimes inconsistent, and this paper indicates areas where research is needed to clarify current findings, and to indicate new areas which are in need of research. Guidelines for the character isation of zeolites in agricultural research are presented and discussed.

INTRODUCTION

Zeolites were discovered in 1756 by Freiherr Axel Fredrick Cronstedt, a Swedish mineralogist. Since that time, over 45 distinct natural species of zeoli tes have been recognised, and more than 100 species having no natural counterparts have been synthesised in the laboratory. Since the discovery of large mineable deposits in the U. S.A, Soviet Union, Japan and other countr ies, interest in natural zeolites has grown steadily, including Australia. In recent years an increasing amount of effort has been directed towards natural zeolites and their potential applications in industrial and agricultural technology. The potential areas of use for natural zeolites include animal feeds, odour control, horticulture and water treatment and pollution control. A total current market potential for natural. zeolites of 13,000-41,000 tonnes per annum in New South Wales and 33,000-96,000 tonnes per annum in Australia has been estimated (Holmes and Pecover, 1987).

The purpose or this paper is to review the potential use of both natural and synthetic zeolites as they apply specifically to poultry production. The paper will highlight areas where information is lacking and indicate those areas where future research should focus.

CRYSTAL STRUCTURE AND PROPERTIES OF ZEOLITES

Any discussion on the application or potential application of both synthetic and natural zeolites requires an initial discussion on their fundamental physical and chemical properties. It is not the intention of this review to discuss in detail the chemistry and properties of zeolites, since this has been covered and reviewed adequately elsewhere (Mumpton 1984; Holmes and Pecover , 1987), but to indicate and discuss those properties of zeolites which can be exploited and are important in applications for poultry production.

Zeolites are crystalline, hydrated aluminosilicates of alkali (Na^+, K^+, Rb^+, Cs^+) and alkaline (Be^{+2}, Mg^{+2}, Ca^{+2}, Sr^{+2}) earth cations, having infinite, three-dimensional structures. They are further characterised by an ability to lose and gain water reversibly and to exchange constituent cations without a major change in structure. Each zeolite species has its own unique crystal structure, and hence, its own set of physical and chemical properties.

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Crystal structure

Mumpton (1984) describes in detail the structure of zeolites. Similar to quartz and the feldspar mineral, zeolites are tektosilcates, that is, they consist of three-dimensional frameweorks of SiO_4^{-4} tetrahedra, wherein all four corner oxygen ions of each tetrahedron are shared with adjacent tetrahedra. This arrangement reduces the overall oxygen:silcon ratio to 2:1, and if each tetrahedron in the framework contains Si as its central cation, the structures are electrically neutral, as is quartz (SiO_2). However, in zeolite structures, some of the quadrivalent silicon (Si) are replaced by trivalent aluminium (Al), giving rise to a deficiency of positive charge in the framework. This charge is balanced by mono- and divalent cations, such as Na^+, K^+, Ca^{2+}, and Mg^{2+}, elsewhere in the structure.

Most zeolite stuctures can be visualised as SiO_4 and AlO_4 tetrahedra linked together in simple geometrical forms. The geometry of the structure is more easily seen by considering only lines joining the midpoints of each tetrahedron, as shown in figure 1 and are called sodalite units. Individual sodalite units may be connected in several ways; for example, by double four-rings of oxygens as shown in figure 2 the framework structure of synthetic zeolite A.

Generally, cations substitute freely for one another in the exchangeable cation sites in zeolites, the only restriction being overall charge balance. Loosely bound molecular water is also present in the structures of all zeolites as they occur in the natural state or as they are synthesised, and surrounds the exchangeable cations in the large pore spaces of the structure,

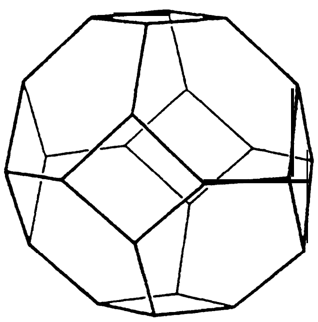

Fig 1. Line drawing of truncated sodalite unit. (From Meier, 1968)

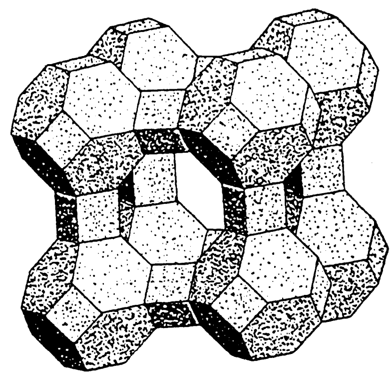

Fig 2. Sodalite units connected by double 4-rings in structure of synthetic zeolite A

Fundamental properties

Mumpton (1984) describes in detail the fundamental properties of zeolites, All agricultural applications of both natural and syntheic zeolites are basically dependent on one or more of the following physical or chemical propeties: absorption and related molecular sieving and hydration-dehydration (a special type of absorption), cation exchange, and extensive properties of the mineral aggregates or rock particles, such as size, shape, porosity and hardness.

As previously indicated, the large cavities and entry channels are generally filled with water molecules that form hydration spheres around the exchangeable cations. If the water is removed molecules having effective cross-sectional diameters small enough to fit through the entry channels are readily absorbed on the inner surfaces of the dehydrated central cavities. Molecules too large to fit through the entry channels are excluded and pass around the outside of the zeolite particle, giving rise to the well known *molecular sieving' property, of most crystalline zeolites. The surface area available for adsorption ranges up to several hundred square meters per gram, and some zeolites are capable of adsorping as much as 30% by weight of a gas on a dry weight of the zeolite. A more detailed discussion on the adsorption properties of zeolites are found in Mumpton (1984) and Flanigen (1984).

Cation-exchange capacity is primarily a function of the degree of Al substitution for Si in the framework structure; the greater the substitution, the greater the deficiency of positive charge and the greater the number of alkali or alkaline cations required for electrical neutrality. In practice however, cation-exchange capacity depends on a number of other factors. In natural zeolites, the zeolite as mined will contain a mixture of Na^+, K^+, and Ca^{2+} in exchangeable positions in its structure, and, despite whatever pretreatments that may have been performed on it by the supplier, will not be a pure, homoionic species. Secondly, the environment (soil, animal intestinal tract) will contain significant amounts of other cations which may compete with the cation of interest (e.g. NH_4), and which may also enter into exchange reactions with the the zeolite. These ions therefore compete with cation of interest for exchange sites within the zeolite. The net result is that cation of interest will exchange onto only apart of the available sites within the zeolite.; other sites will be occupied by the competing cations.

The framework of a crytalline zeolite dictates its selectivity towards competing ions. The small amount of Al in the framework of clinoptilolite, for example, results in relatively low cation-exchange capacity (about 50-220 meq/100g); however its cation selectivity is: Cs > Rb > K > NH_4 > Ba > Sr > Na > Ca > Fe > Al > Mg > Li (Ames, 1960). Thus clinoptilolite has definite preference for larger cations, and its selectivity for NH_4 can be exploited commercially. This inherent selectivity for specific cations influences the effective cation-exchange capacity of a zeolite.

The extensive properties of zeolite aggregates are those of the natural particle of rock and are directly related to the manner in which the minerals are formed in nature. The ideal natural zeolite ore for both cation-exchange and adsorption applications should be rich in the zeolite of interest, mechanically strong to resist abrasion and disintegration, highly porous to allow liquids and gases to diffuse in and out of the grain with ease, and soft enough to be crushed to the desired particles size. Not all of these properties are commonly found in the same zeolite ore. Synthetic zeolites which are produced with uniform, small (2-10 micron) crystal sizes, bound into high porous pellets do contain contaminants from the manufacturing process which may or may not influence their usage for certain applications.

CHARACTERISATION OF ZEOLITES IN AGRICULTURAL RESEARCH

One of the major problems encountered in reviewing the literature on the application of zeolites to agriculture was the reporting of the full details on the characteristics of the zeolites used in agricultural experiments. This deficiency has contributed to difficulties in interpreting and reproducing experimental results, and therefore has led to some degree of scepticism on the part of many consuming industries. This is in addition to the natural conservatism that alreading exists in the testing of new products. This same problem was also highlighted by Shepherd (1984) and Fredrickson (1987). Both these sources stress the importance of careful detailed chemical characterisation of zeolitic samples under investigation in agricultural experiments.

Shepherd (1984) lists and discusses ten criteria that is adequate or desirable for the characterisation of zeolitic material and which should be reported in agricultural experiments. These are as follows:

1. Name of the zeolite mineral species.
2. Supplier's name and address and product or sample code.
3. Location of the deposit as to the country, state, town from which the material was mined.
4. Mesh or particle size.
5. Mineralogic composition of the zeolitic material.
6. Chemical composition zeolitic material and the constituent zeolite material.
7. Homogeneity of the zeolite material.
8. Crystallite size of the zeolite.
9. Cation-exchange and/or adsorption properties, where appropriate.
10. Description of any modifications made to the as-mined material.

POTENTIAL USE OF ZEOLITES IN POULTRY PRODUCTION

Fredrickson (1987) summarises the potential uses for both synthetic and natural zeolites. Other detailed discussions of the various applications can be found (Mumpton, 1977; Sand and Mumpton, 1978; Pond and Mumpton, 1984).

The three areas of application where zeolites have potential use in poultry production are:

1. As a feed additive to improve poultry performance for layers and broilers.
2. To assist in manure and litter management.
3. To assist in controlling air quality in poultry house environments

USE OF ZEOLITES AS FEED ADDITIVES IN DIETS FOR POULTRY

The use of both natural and synthetic zeolites as feed additives for poultry, have been treated separately. The reason for this is because both their physical and chemical characteristics are total different for one another. One critical difference is the ratio of silicon:aluminium which is approx 1:1 for the synthetic zeolite, sodium zeolite A (SZA, ETHACAL, Ethyl Corporation, Baton Rouge, LA 70820), and for the natural zeolite clinoptilolite, about 2.5-5: 1. This lower ratio of Si:Al in synthetic sodium zeolite A is responsible for its higher cation-exchange capability due to the presence of more negative charges. This ratio also affects the stability of zeolites under different pH conditions. In general, the lower the Si:Al ratio the more unstable the zeolite will be under conditions of low pH. Synthetic sodium Zeolite A is therefore less stable at lower pH than the natural zeolite, clinoptilolite. The stability or instability will influence the mode of action of the particular zeolite have when it is fed and when it comes in contact with the variable pH that exists in the gut of the bird. Although not proven as yet, SZA may become unstable and breakdown in the gut, with subsequent effects such as aluminium (Al) injected into the gastro-intestinal tract (GIT) and loss of cation-exchange capacity (less material available), whilst the more stable natural zeolites remain intact. This may or may nor be an advantage in certain circumstances.

The cation-exchange capability will also influence the exchange of cations in the gut of the bird and therefore the mode of action. These characteristics have been taken into account by the various researchers and is contrasted in the levels of inclusion between the synthetic and natural zeolites in experimental poultry diets. Inclusion levels for synthetic zeolites are generally much lower (< 2%) than the natural zeolites (up to 10%).

The consistency of the chemical composition of the zeolite and its associated material may influence the effects that zeolites have on poultry performance. The injection of the various cations and other trace minerals into the gut of the bird may influence poultry performance. Natural zeolites are more variable than synthetic zeolites and this can influence the interpretation of the results obtained. On the other hand, synthetic zeolites do also contain contaminants from their manufacture, such as sodium hydroxide in SZA manufacture, which is a strong alkali and which may influence the pH of the gut. The effects of these synthetic and natural contaminants is unknown. The balancing of diets for protein (amino acids), energy and minerals is critical to ensure that the true charcterisitics of the zeolites are evaluated and not confounded with dilution effects and effects from imbalanced minerals.

Use of natural zeolites in the diets of laying hens

Ten experiments were cited where natural zeolites had been included in diets for laying hens. In all cases description of the zeolite used was inadequate and in two of the experiments the zeolite used was not even named. In all of the experiments where the zeolite was named, clinoptilolite was used, with the exception of one experiment where mordenite was used as well. In many of the experiments no information was supplied on the mesh or particle size, mineralogical composition, chemical composition including exchangeable cations, homogenicity, crystalite size, cat ion exchange and adsorption properties or any modification that may have been made to the zeolite. The importance of describing the natural zeolite material can not be over emphasised, and it is unfortunate that from these ten experiments very little can be deduced as to what characteristics of the zeolites are responsible for the results observed. Questions such as how important is the cation and absorption properties, particle size, the type of cation present initially in the zeolite can not be answered from the data presented in these experiments.

Out of the 10 experiments cited, two were conducted on birds that were early in lay (16 to 35 weeks), two mid lay (35 to 65 weeks) and two late in lay (over 65 weeks). Four did not indicate the age of the birds. Inclusion levels of zeolite varied from 0% to 10% and in half of the experiments, inclusion was by direct substitution for another feed ingredient, usually grain. In only one experiment was the diet isonitrogenous, only one was isocaloric, and three were both isonitrogenous and isocaloric. Of these three, two were balanced for minerals as well. The balancing of diets for protein (amino acids), energy and minerals is critical to ensure that the true characteristics of the zeolites are evaluated and are not confounded with dilution effects and effects from imbalanced minerals.

(i) Effect on body weight and growth rate. Out of the 10 experiments, only three reported information on growth rate (Kvashali et al, 1980; Kvashali & Mikautadze, 1980; Nakaue & Koelliker, 1981) and four reported information on body weight (Nakaue & Koelliker, 1981; Olver, 1986; Vest & Shutze, 1984, experiments 1 & 2),(3 different). In all cases there was no difference between zeolite and control diets, except in two experiments where one experiment reported an higher growth rate for zeolites but supplied no data details for verification (Kvashali et al, 1980), and in one experiment where the increased growth rate was observed in diets where the zeolite was included in granular form (1 to 2.5 mm) rather than as a powder (Kvashali & Mikautadze, 1980).

(ii) Effect on egg production. Eight of the 10 experiments reported information on egg production. Four reported no difference between zeolite and control diets (Roland, 1988; Szabo et al, 1983; Berrios et al, 1983; Vest & Shutze, 1984, experiment 1), two found a positive effect due to zeolites (Merabishvili et al, 1980; Olver, 1986) and two found a negative effect due to zeolites (Nakaue & Koelliker, 1981; Vest & Shutze, 1984 in experiment 2), although Nakaue & Koelliker (1981) reported inconsistent results, with egg production being depressed at 2.5% and 5% but not at 10% zeolite inclusion.

(iii) Effect on egg weight, egg mass and internal egg quality. Five out of the 10 experiments reported information on egg weight (Nakaue & Koelliker, 1981; Roland, 1988; Szabo et al, 1983; Berrios et al, 1983; Olver, 1986) and one of these five (Olver , 1986) reported information on egg mass and three of these 5 (Nakaue & Koelliker, 1981; Roland, 1988; Olver, 1986) reported information on internal egg quality as well. In all of these experiments there was no influence of zeolites on egg weight, egg mass or internal egg quality.

(iv) Effect on feed consumption. Out of the 10 experiments, five only reported information on feed consumption. Two reported no difference between control and zeolite diets (Roland, 1988; Berrios et al, 1983), one reported an increase in feed consumption as zeolite level increased (Nakaue & Koelliker, 1981), but this was clearly a dilution effect. Where diets were balanced for protein and energy, one experiment reported an increase in feed consumption as the zeolite increased (Olver, 1986) and one reported a slight decrease in feed consumption with the zeolite diet (Vest & Shutze, 1984).

(v) Effect on feed efficiency. Seven out of the 10 experiments reported information on feed efficiency. In five of these seven experiments (Kvashali, 1980; Kvashali & Mikautadze, 1980; Berrios et al, 1983; Olver, 1986; Vest & Shutze, 1984 experiment 2) feed efficiency was improved by zeolites and in one of these cases feed efficiency was better when zeolites were included as a granule (1 to 2.5 mm) rather than in powdered form (Kvashali & Mikautadze, 1980). One experiment gave no difference between control and zeolite diets (Vest & Shutze , 1984 experiment 1) and one gave a negative response (Nakaue & Koelliker, 1981). The experiment which gave a negative response was confounded by an energy dilution effect resulting in a significant increase in feed consumption. In this experiment the diets were balanced for protein.

(vi) Effect on mortality. Of four experiments, two reported a reduction in mortality with zeolites but gave no details as to the extent of the reduction, (Kvashali et al, 1980; Merabishvili et al, 1980) and two showed no difference (Nakaue & Koelliker, 1981; Vest & Shutze, 1984 experiment 1).

(vii) Effect on shell quality. Seven out of the 10 experiments reported information on shell quality. Five of these experiments showed no difference in shell quality. Three of these five experiments measured shell quality by specific gravity of eggs, (Nakaue & Koelliker , 1981; Roland, 1988; Szabo et al, 1983), one experiment used an unspecified shell resistance measurement, (Berrios et al, 1983), and another experiment used shell thickness measurement to measure egg shell quality, (Olver, 1986). Two experiments by Vest & Shutze, 1984, experiments 1 and 2, gave conflicting results. In experiment 1 the zeolite diet (2% clinoptilolite) improved shell quality as measured by a deformation evaluation method, but showed no difference in specific gravity or % cracks observed; and in experiment 2 the zeolite gave poor shell quality as measured by the same deformation evaluation method, but showed no difference in specific gravity, although specific gravity tended to be better on the zeolite diet.

(i) Effect on body weight and growth rate. Out of the 19 experiments only one reported information on growth rate (Roland et al, 1985 experiment 2), which showed no effect due to SZA and seven reported information on body weight. The results are conflicting, with four experiments showing no effect on body weight due to SZA (1.0% & 1.5%), (Ingram et al, 1987c; Ingram et al, 1987a; Ingram et al, 1987d; Ingram et al, 1987b experiment 2); one showed a decrease in body weight due to SZA (0.75%, 1.5%) (Roland et al, 1985, experiment 1); one showed an increase in body weight due to SZA (1.5%) (Ingram et al, 1987b experiment 1) and one showed that SZA reduced the effect of high temperatures (heat stress) on body weight loss. Birds which had experienced a body weight loss (the group with no SZA) due to heat stress recovered this body weight loss when placed on a diet with SZA at 1.5%.

(ii) Effect on egg production. Seventeen of the nineteen experiments reported information on egg production. Thirteen experiments reported no difference between control and SZA diets with inclusions of 1.0% SZA (Roland et al, 1985 experiments 1 & 2; Miles et al, 1986; Ingram et al, 1987a; Ingram et al, 1987d; Roland, 1988a experiments 1 to 4; Skinner et al, 1988; Roland, 1988b; Ingram, 1987b experiments 1 & 2). Seven of these experiments showed no effect on egg production at levels of up to 1.5% SZA (Roland et al, 1985, experiments 1 & 2; Roland, 1988a, experiments 1 & 3; Skinner et al, 1988; Ingram et al, 1987b experiments 1 & 2), but two showed a reduction in egg production at the 1.5% SZA inclusion (Miles et al, 1986; Roland, 1988a experiment 2) and one showed a reduction at the 1.5% level only when the calcium level was low (2.75%) (Roland, 1988a experiment 4). One of these experiments only showed an effect on egg production due to SZA (1.0%) when the total phosphorus (P) level in the diet was below 0.43% (Roland, 1988b). Above a total P of 0.43 up to 0.7% P, SZA up to 1.0% did not affect egg production. Two experiments showed a linear reduction in egg production as the the level of SZA increased (Littleton, 1988; Roland, 1988a experiment 5;). However, birds subjected to heat stress (two experiments), benefited from the inclusion of SZA (1.5 & 1.0%) in their diets (Ingram et al, 1987c experiments 1 & 2). The adverse effects of heat stress were reversed when control birds which had experienced a drop in egg production were switched to SZA diets and bird feds diets containing SZA prior to heat stress and which were continued on these diets did not experience an egg production drop when subjected to heat stress.

(iii) Effect on egg weight and egg mass. Fifteen of the experiments reported information on egg weight. Thirteen of these fifteen experiments showed no effect on egg weight due to SZA. (Roland et al, 1985 experiments 1 & 2; Ingram et al, 1987c experiment 1; Ingram et al, 1987a; Ingram et al, 1987d; Littleton, 1988; Roland, 1988a experiments 1, 3, 4 & 5; Roland, 1988b; Ingram et al, 1987b experiment 1 & 2). One showed no effect on egg weight up to 0.75% but decreased egg weight at 1.5% (Miles et al, 1986), and another showed a decrease in egg weight two weeks after birds were placed on a diet containing 1.0% SZA (Harms & Miles, 1987). One experiment which showed no significant effect on egg weight, showed a trend to reduced egg weight as the level of SZA increased up to 1.5% (Littleton, 1988). In this same experiment, the only experiment that reported on egg mass, showed no significant effect on egg mass, but again the trend was for egg mass to decrease as the level of SZA increased.

(iv) Effect on feed consumption. Three experiments with broiler breeder hens had their feed consumption fixed. Of the remaining 16 experiments, 13 recorded information on the effects of SZA on feed consumption. Eleven experiments showed no effect on feed consumption due to SZA (Roland et al, 1985 experiments 1 & 2; Miles et al, 1986; Ingram et al, 1987c, experiment 2; Ingram et al, 1987a; Ingram et al, 1987d; Littleton, 1988; Roland, 1988a, experiments 1 to 4) and two showed a significant decrease on feed consumption as the level of SZA increased (Roland, 1988a, experiment 5; Roland 1988b). Of the eleven experiments that showed no effect on feed consumption, three showed a trend to reduced feed consumption as SZA increased in the diet, but this was not significant (Littleton, 1988; Roland, 1988a, experiments 3 & 4) and one showed a significant decrease in feed consumption at the 1.5% inclusion rate, but not at the 0.75% level (Miles et al, 1986).

(v) Effect on feed efficiency. Three experiments reported information on feed efficiency. One experiment found no effect of SZA (levels up to 1.5% SZA) on feed efficiency (Littleton, 1988), although there was a trend for feed efficiency to deteriorate as the level of SZA increased. One experiment reported an improvement in feed efficiency at the 1.5% inclusion level but not up to the 0.75% level (Miles et al, 1986). In this experiment the diet was balanced for protein, energy and minerals. Another experiment reported an improvement in feed efficiency at a 2% SZA inclusion rate (Roland & Dorr, 1987), unfortunately information on whether the diet was balanced or not was not repor ted.

(vi) Effect on shell quality. All nineteen experiments cited reported information on shell quality. In all of the experiments shell quality was determined using specific gravity of the eggs as the measure. In seventeen of the nineteen experiments SZA increased specific gravity (Roland et al, 1985, experiments 1 & 2; Miles et al, 1986; Ingram et al, 1987c experiments 1 & 2; Harms & Miles, 1987; Ingram et al, 1987a; Ingram et al, 1987d; Roland & Dorr, 1987; Littleton, 1988; Roland, 1988a experiments 3, 4 & 5; Roland, 1988b; Ingram, 1987b experiment 1 & 2). In one experiment where specific gravity was not generally improved by SZA, balancing the chloride level with hydrochloric acid did allow SZA to improve specific gravity. Where balancing was done with other chloride salts, SZA had no effect on specific gravity compared to control diets (0% SZA) (Roland, 1988a experiment 1). However, in another experiment, regardless of how chloride was balanced, SZA did not improve specific gravity (Roland, 1988a experiment 2). The improvement in specific gravity was generally better in diets containing reduced calcium (2.75%) (Roland et al, 1985) and where the trend for low specific gravity eggs was observed, (Ingram et al, 1987d). In one experiment, the improvement in specific gravity was reflected in a decrease in the number of cracked eggs (29%), a reduction in egg breakage (28%) and a reduction in the number of egg body checks (44%) (Roland & Dorr, 1987). Where specific gravity was adversely affected due to heat stress, SZA reduced the effects of the heat stress by maintaining the specific gravity of the eggs. The levels of SZA used were 1.0 and 1.5% (Ingram et al, 1987c experiments 1 & 2). It should be pointed out however, that despite these positive observations on specific gravity by using SZA, one would have to question whether these improvements in specific gravity are economical. Specific gravity in most of the experiments was reasonably good (above 1.080), both in control and SZA diets. Only one experiment reports information on actually shelldefects and breakage.

(vii) Effect on mortality. Only two experiments reported information on mortality in layers, and this was done on birds exposed to heat stress. Under heat stress conditions diets containing 1.5% SZA reduced mortality associated with the heat stress, (Ingram et al, 1987c experiment 1), but not when SZA was included at 1% of the diet, (Ingram et al, 1987c experiment 2).

(viii) Effect on plasma calcium and phosphorus levels. Three experiments measured Ca plama levels (Roland et al, 1985 experiments 1 & 2; Miles et al, 1986) and one of these measured plasma P as well (Miles et al, 1986). In all experiments SZA did not influence plasma Ca or P levels.

Information was not reported in any of the 19 experiments on water consumption, internal egg quality, moisture or ammonia levels in manure, influences on GIT microflora or effects on nutrient utilisation.

Use of natural zeolites in the diets of broilers

Twenty five experiments were cited in which natural zeolites had been included in diets for broilers and young chickens. Seventeen experiments cited clinoptilolite as the natural zeolite and eight did not report the zeolite used. In all cases description of the zeolite used was inadequate. Sixteen of the experiments were conducted on birds beginning at less than one week of age, seven did not report the age of birds and two were conducted on birds 3 weeks of age. In twenty two of the experiments where meat chickens were used, all except one, were taken to marketable ages i.e. between 7 to 12 weeks of age, depending on strain. Inclusion levels of zeolite varied from 0% to 10%, with the majority of experiments having inclusion levels between 1% and 5%. Only two of the experiments balanced dietary nutrients; one balanced protein and the other balanced protein and energy. Fifteen experiments did not balance dietary nutrients, but substituted the zeolite for grain or feed. Two exper iments , balancing was not applicable and six did not report.

(i) Effect on growth rate and body weight. The results were conflicting. Twenty one experiments reported information on growth rate or body weight. Four experiments reported an increase in growth rate on zeolite diets compared to controls, (Onagi, 1966; Dzhen Sun Din, 1987; Lon-Wo et al, 1987; Kempton, 1988). Six experiments reported an increase in market body weight, (Chung et al, 1978; Hatieganu et al, 1979; Nestorov, 1983; Vest & Shutze, 1983; Karadzhyan & Chirkinyan, 1986; Karelina, 1985); two experiments reported a decrease in body weight, (Zavadsky et al, 1985; Lenkova, 1985), one at levels of 7% and 10% inclusion levels only, (Lenkova, 1985); six reported no difference in body weight, (Nakaue et al, 1981; Dion & Carew experiments 1 & 2; Waldroup et al, 1984 experiments 1 & 2; Dion & Carew 1984, experiments 1 & 2); one experiment reported an increase in body weight at 3 weeks but this disappeared at market age (7 weeks) (Hayhurst & Willard, 1980); and another reported no difference at 3 weeks but an increase in body weight at market age (7 weeks) for one source of zeolite (K type), but not for another source (Na type) (Willis et al, 1982). For those experiments where zeolite supplementation improved body weight the improvement was from 1% to 16%. For those experiments where a decrease in body weight was reported, the extent of the decrease was not reported.

(ii) Effect on feed consumption. The results were conflicting. Seven exper iments repor ted information on feed consumption. In two experiments zeolite diets depressed feed consumption (Hayhurst & Willard, 1980; Lon-Wo, 1987). Three experiments reported an increase in feed consumption on zeolite diets compared to controls (Dion & Carew, 1983 experiment 1; Dion & Carew, 1984 experiment 1; Zavadsk et al, 1985), and two experiments reported no differences in feed consumption, (Lenkova, 1985; Kempton, 1988). One of these two did have depressed feed consumption at the higher levels of zeolite inclusion (7% & 10%) (Lenkova, 1985). It appears that where levels of zeolite are 7% or greater, feed consumption is depressed, whilst on lower levels (< 7%) zeolite tended not to influence or increase feed consumption,

(iii) Effect on feed efficiency. Twenty experiments reported information on feed efficiency, Feed efficiency in all these experiments was reported after the dilution effect of the zeolite had been taken into account, Ten experiments reported an improvement in feed efficiency on zeolite diets (Onagi, 1966; Arscott, 1975; Chung et al, 1978; Hayhurst & Willard, 1980; Dion & Carew, 1984 experiment 1; Fisinin et al., 1985; Karadzhyan & Chirkinyan, 1986; Karelina, 1985; Dzhen Sun Din, 1987; Lon-Wo et al, 1987); six experiments reported no difference in feed efficiency (Nakaue et al, 1981; Willis et al, 1982; Dion & Carew, 1983 experiment 2; Waldroup et al, 1984, experiment 1 & 2; Kempton, 1988); one experiment reported a deterioration in feed efficiency (Zavadsky et al, 1985); and one experiment reported a improvement in feed efficiency in males and a deterioration in females (Vest & Shutze, 1983).

(iv) Effect on nutrient utilisation. Four experiments reported information on nutrient utilisation. One experiment, (Chung et al, 1978), made a general statement that zeolite improved utilisation of nutrients in general as reflected in a greater proportion of nutrients being retained as tissue growth. However, no details were supplied. One experiment (Hayhurst & Willard, 1980) reported an improved utilisation of the organic component of the diet (68.7% vs 57.6%). Calcium utilisation also increased with the zeolite diet, (86.7% vs 33.9). Another experiment (Hatieganu et al, 1979) showed an improvement in nitrogen utilisation as the level of zeolite in the diet increased, (39.1%, 48.4% & 51.9% for 0%, 5% & 10% zeolite respectively). Dion and Carew, 1984 experiment 2 reported and improvement in metabolisable energy (ME) of the diet (6.9%) for birds fed zeolite at 20-24 days of age but not for birds at 7-14 days of age. The level of zeolite was 5%.

(v) Effect on chick mortality. Eleven experiments reported information on chick mortality. In seven of these experiments chick mortality was lower on zeolite diets than controls (Arscott, 1975; Fisinin et al, 1985; Karadzhyan & Chirkinyan, 1986; Karelina, 1985; Dzhen Sun Din, 1987; Lo-Wo et al, 1987; Kempton, 1988). In many of these experiments the general health and vitality of the chickens was reported to be better on the zeolite diets than the controls. Four experiments reported no difference in chick mortality between zeolite diets and controls (Nakaue et al, 1981; Willis et al, 1982; Vest & Shutze, 1983; Dion & Carew, 1983 experiment 2).

(vi) Effects on litter or manure. Five experiments reported information on litter condition. Two experiments reported a reduction in the moisture content of the litter and the litter appeared less odoriferous from bird fed diets containing zeolite (Onagi, 1966; Hayhurst & Willard, 1980). In both these experiments the zeolite level in the diet was 7.5% and 10% respectively. In three of the experiments no difference in litter moisture or condition was observed. In one of these experiments the zeolite level was 10%, (Nakaue, 1981), but in the other two experiments the zeolite level was a maximum of 3%, (Willis et al, 1982; Vest & Shutze, 1983).

(vi) Effect on water consumption. Two experiments reported information on water consumption. In both experiments water consumption declined by about 8% in birds fed zeolite diets (Onagi, 1966; Dion & Carew, 1983 experiment 1). In one of the experiments this may have been the reason for the reduced litter moisture content observed (Onagi, 1966).

No information was reported on the incidence or severity of tibial dyschondroplasia and other leg disorders, and no information was reported on GIT microflora.

Use of synthetic zeolites in the diets of broilers

Nine experiments weres cited where synthetic zeolites had been included in diets for broilers. Eight of these experiments used (SZA) from Ethyl Corporation and one used a hydrated sodium, calcium aluminium silicate from Kaiser Chemicals, Cleveland, USA. Again description reported on the zeolites was poor (see previously).

Zeolite levels in all experiments did not exceed 1% for SZA and 0.5% for HSCAS. These are contrasted with levels of inclusion for natural zeolites which not uncommonly reach levels as high as 5% and 10% in broiler diets.

All experiments fed birds from one day-old to a maximum of 16 days of age. No experiment took birds to a market age, which is normally 6 to 7 weeks, No more than 240 birds were used in any experiment, although 2 experiments did not report the number of birds used.

Six out of the nine experiments did not report whether the diets were balanced for protein, energy or minerals. It appears that probably four of these six experiments substituted the zeolite for maize in the diet. The three remaining experiments reported that substitution of the zeolite was at the expense of maize. Therefore not one experiment balanced the diets.

(i) Effect on body weight and growth rate. Two experiments reported information on growth rate, which showed no effect due to SZA, (Ballard & Edwards, 1988 experiment 1; Ballard & Edwards, 1988 experiment 4) and six reported information on body weight. One experiment reported no effects due to SZA, (Ballard & Edwards, 1988 experiment 3), the remaining five reported lowered body weight with SZA but 4 of the responses were qualified by an interaction with dietary phosphorus (P) in three of the experiments (Edwards, 1988 experiments 1,2,3), and an interaction with vitamin A in another (Ballard & Edwards, 1988 experiment 2). Birds fed diets with P levels less than 0.5% had much greater reductions in body weight than those on higher dietary P levels (> 0.7%) when fed in conjuction with SZA. SZA had an unexplained interaction with vitamin A in one experiment, increasing body weight at low levels of vitamin A (0 IU/kg, normal vit A supplementation via premix) and reducing body weight at high vitamin A levels (45,000 IU/kg in addition to normal levels in premix).

(ii) Effect on feed efficiency. Seven out of the nine experiments reported information on feed efficiency. Five of the seven experiments reported no difference in feed efficiency between zeolite diets and controls (Ballard & Edwards, 1988 experiments 1 to 4; Edwards, 1987) . One of these however had a tendency for reduced feed efficiency on the zeolite diet (Edwards, 1987). Two experiments reported a reduced feed efficiency on zeolite diets (Edwards, 1988 experiments 1,2).

(iii) Effect on tibial dyschondroplasia (TDP). Eight of the experiments reported information on the incidence and severity of tibia1 dyschondroplasia (TDP), (Ballard & Edwards experiments 1 to 4; Edwards, 1988 experiments 1 to 3; Edwards, 1987). In all experiments except two (Ballard & Edwards, 1988 experiment 4 ; Edwards, 1988 experiment 2) SZA reduced the incidence of TDP. In all experiments except one (Edwards, 1988 experiment 2), SZA reduced the severity (score #3) of TDP. Although in experiment 2, Edwards (1988) the incidence and severity of TDP tended to be lower on the SZA diet. In experiments 1 and 2, Edwards (1988) there was an interaction between zeolite and dietary phosphorus level. At the low phosphorus level (0.5%) the incidence and severity of TDP was much less than than at the high dietary level of phosphorus (0.75%). The addition of SZA to the diets reduced the incidence and severity of TDP at both levels of P, but more so at the low P level, reducing the incidence of TDP to almost zero. There was no interaction between Ca and SZA as reported by Edwards (1987) on the incidence of and severity of TDP. However, there was a Ca effect with high levels of Ca (1.58% & 1.81%) and low levels of Ca (0.65% & 0.88%) increasing the incidence and severity of TDP, but Ca levels in the middle of these extremes (1.11% and

1.34%) had incidence and severity of TDP of almost zero. This Ca effect was the same whether the birds were fed SZA or not.

(iv) Effect on tibia bone ash. Eight of the nine experiments reported information on tibia bone ash. The results are conflicting with three experiments reporting an increase in bone ash with SZA, (Ballard & Edwards, 1988 experiment 1,2,3), one experiment reporting no difference, (Ballard & Edwards, 1988 experiment 4), three reporting a decrease in bone ash with SZA when the dietary P level was low (0.5%), (Edwards, 1988 experiments 1,2,3), and one reporting a decrease in bone ash with SZA at medium to high dietary levels of Ca (1.11% to 1.81%) but not low levels of Ca (.65% to .85%), (Edwards, 1987). These results indicate there is little relationship between the incidence and severity of TDP and bone ash and is similar to that reported by Leach and Nesheim (1965), and Edwards and Veltmann (1983) where no correlation was observed between TDP and bone ash.

(v) Effect on calcium absorption and calcium and phosphorus retention. Four of the nine experiments reported information on Ca and P absorption or retention. In one experiment, (Ballard & Edwards, 1988 experiment 4), calcium adsorption was studied using radioactive ^{47}Ca via oral and muscular injection routes. The rate of absorption was the same for oral and muscular injection routes and SZA increase the absortion of ^{47}Ca. However, in another experiment (Edwards, 1988 experiment 2) found that SZA did not affect adsorption when compared with controls. In this same experiment high dietary P (0.75%) increased ^{47}Ca absorption and there was no P X SZA interaction. In two experiments (Edwards, 1988 experiment 3; Edwards, 1987) Ca retention was reduced with SZA and this was especially so at low levels of dietary P (0.5%) (i.e significant P X SZA interaction). Both P and phytate P retention was reduced with SZA, but phytate P retention was particularly reduced, and in the second of these experiments (Edwards, 1987) phytate P was reduced to virtually zero. In both of these experiments as the dietary level of Ca increased the retention of Ca was reduced.

SUGGESTED MODE OF ACTION OF ZEOLITES AS A FEED ADDITIVE IN POULTRY DIETS

The mode of action of zeolites when fed to poultry as a feed additive is speculative and nothing as yet has been proven. From this it appears that natural zeolites have a different mode of action to synthetic ones. There appears to be four possible modes of action which may be responsible for the effects observed in the above review. The first relates to the stability of the crystal structure of the zeolite; the second relates to the cation-exchange capacity of the zeolite; the third relates to influence zeolites have on rate of passage of digesta in the GIT, particularly at high levels of dietary inclusion; and the fourth relates to the influence on gut microflora.

As previously discussed the synthetic zeolite (SZA) has a low Si:Al ratio (1:1) which may reduce its stability under conditions of low pH. On the other hand the natural zeolite, clinoptilolite, has a much higher ratio of Si:Al (2.5-5:1) and therefore is much more stable in conditions of low pH. The ability of the zeolite to maintain or not maintain its stability in the gut of the bird, particularly early in the GIT in the proventriculus, may affect the mode of action of the zeolite.

It could be speculated that SZA might breakdown in the proventriculus and even the gizzard under conditions of low pH. The consequences of this is that aluminium (Al) would probably be injected into the GIT. An experiment by Hayhurst & Willard (1980) measured aluminiurn content in lung, brain, skeletal muscle, liver and kidney but found no difference between zeolite diets and controls. These assays were conducted based on the statement made by Breck (1974) who indicated that zeolitic aluminium can be leached out of the zeolite structure when subjected to an acidic environment. This result was not unexpected since Street (1942) demonstrated that when a soluble form of Al is fed to young rats in amount equal to the phosphorus content of the diet, there is nearly a complete precipitation of phosphorus in the intestinal tract. It is also unlikely that the natural zeolites would not break down as readily and that the small amount of Al that was injected into the GIT would be precipitated out by the P without too much affect on the total P in the diet, Again this is speculative. Work done by a number of researchers (Deobald & Elvehjem, 1936; Street, 1942; Williams and Rodbard, 1957; Storer & Nelson, 1968; Harmon et al, 1968), has shown that aluminium in the GIT can combine with dietary P to form insoluble aluminium phosphates which are then excreted in the faeces.

There is some evidence that this might be the case in experiments conducted by Ballard and Edwards (1988) and Edwards (1988). In these experiments the inclusion of the zeolite, SZA, modified the response to dietary P (P X SZA interaction) and in the experiment by Edwards (1988) reduced the retention of P and phytate P by the bird. Effects appeared to be more pronounced in diets containing low dietary P (0.5%), indicating a possible P deficiency. The influence of SZA was not as great at the higher levels of dietary P (0.75%). In laying hens, high levels of dietary P have been responsible for adverse effects on egg shell quality (Hunt & Cancey, 1970; Singh et al, 1971; Connor & Barram, 1972; Charles & Jensen, 1975; Ingram et al, 1976; Hamilton & Sibbald, 1977; Scott et al, 1976; Reichmann & Connor, 1977; Goto et al, 1978; El Boushy, 1979; Outerhout, 1980). The removing of P from the GIT by aluminium from the breakdown of SZA could partly explain the improvements in shell quality (specific gravity) when SZA is fed in diets for laying hens, No information as yet has been reported on the effects of natural zeolites with different levels of dietary P and this could be a subject for future research.

Zeolites have the ability to reversibly ion-exchange cations into and out of its framework structure, providing their structure remains intact in the GIT of the bird. The most common cat ions involved in these exchanges include Na, K, Mg, Ca and NH_4^+. Zeoli tes therefore may play a role in electrolyte balance and one suggested mechanism of action for clinoptilolite in the GIT is that the zeolite reversibly ion-exchanges Ca into its stucture thereby maintaining this calcium in an available form (Hathurst & Willard, 1980). However, it does not appear that this explanation may altogether be true in practice. If this were the case then one might expect a much more positive effect on shell quality in natural zeolites than was observed. In seven of the experiments which reported information on shell quality with natural zeolites, five experiments did not show a response to clinoptilolite. Only one showed a response to the zeolite by a deformation method but showed no difference in specific gravity or the percentage of cracks observed, (see previously). Electrolyte balance has been shown to play a major role both in egg shell quality (Harms, 1982; Hamilton & Thompson, 1980; Austic & Keshavarez, 1984; Hughes, 1988) and leg abnormalities in chickens, (Mongin & Sauveur, 1977). The ability of zeolites to exchange Na, K and Ca in and out of their framework structure may modify this electrolyte balance. This is a subject for future research.

One experiment alluded to the possibility that natural zeolites may slow the rate of passage of digesta through the GIT (Lo-Wo et al, 1987). The implication of this is that it may explain partially the improvements in feed efficiency that were observed, in general, in birds fed on natural zeolites. Ten of the twenty experiments cited using natural zeolites in broilers found an improvement in feed efficiency and five out seven experiments cited using natural zeolites in layers also found an improvement in feed efficiency. In all of these experiments feed efficiency was determined after the dilution effect of the zeolite was taken into account. In contrast to these findings, the synthetic zeolite (SZA) gave variable results on feed efficiency, but in general did not show a difference in feed efficiency between SZA and control diets, (five of the seven experiments cited with broilers and one of three experiments cited with layers), or showed a reduction in feed efficiency (two of the seven experiments cited with broilers and one of three experiments cited with layers). This difference between natural and synthetic zeolites may be related to the higher inclusion levels traditionally used for natural zeolites. The improvements in nutrient utilisation (organic content of diet, Ca, nitrogen and ME) observed both in broilers (four experiments) and layers (one experiment) when fed natural zeolites may be responsible for the improvements seen in feed efficiency on natural zeolites and may be related to the rate of passage of digesta. No experiments have been conducted on the effect of varying levels of natural or synthetic zeolite on rate of passage of digesta in the GIT and is a subject for future research. Similarly the information on the effects of zeolites on nutrient utilisation, in particular, protein, energy and minerals is limited and is also a subject for future research.

One experiment (Olver, 1986), did report information on GIT microflora. In this experiment the proximal and distal colony counts were significantly lower in layers fed natural zeolites. In this experiment it was difficult to determine the significance of this finding since no mortality was observed. However, in other experiments where natural zeolites had been fed, seven of eleven experiments in broilers and two of four experiments in layers, reported improvements in chick livability and general health. In no experiment did zeolites have an adverse effect on chick livability or health, The significance of these findings is the subject for future research.

The importance of using raw material and feed additives in poultry diets that are of consistent quality is a problem that the feed, pig and poultry industries face everyday. One of the major concerns about the use of zeolites in poultry diets is the inconsistency in 'quality' that these products appear to have. Natural zeolites are more inconsistent than synthetic ones, since batches of zeolite can vary substantially from one mining site to another and within a mining site. It is not surprising therefore that the results when fed to poultry are variable and sometimes inconsistent. Future research is required to better understand effects of natural zeolites with different initial cations, that is, are there differences between K and Na type clinoptilolites. Further research effort is required to identify contaminants in natural zeolites which may or may not have beneficial effect on poultry product ion.

Synthetic zeolites too suffer from contaminants of manufacture. Sodium hydroxide, a strong alkali, is used in the manufacture of SZA, and some of this remains in the product after manufacture. The level of inclusion of SZA in broiler and layer diets is generally kept to below 1.0%. Inclusion levels above this have shown to reduce egg production and produce conflicting results on market weights in broilers. One could pose the question, what would the effect be of adding hydroxyl ions to the GIT of the bird ? One could speculate that the pH would increase in the proventriculus due to neutralisation of the acid. Again the question could be asked what would be the subsequent effects on protein digestion and other acid-dependent functions in the GIT. This may be one explanation for adverse effects on egg product ion at high levels of inclusion of SZA and certainly should be the subject for future research.

USE OF ZEOLITES IN MANURE AND LITTER MANAGEMENT

Two of the major properties that the natural zeolite, clinoptilolite, possesses is its ability to absorb water and to preferentially exchange its alkaline and alkali cations for the ammonium (NH_4^+) ion. These two properties can be exploited to assist in manure and litter management.

Clinoptilolite can be used to manage manure or litter in an indirect way through the feed or by direct application to the litter or manure. Seven experiments, (five broiler, two layer), reported information on manure or litter condition after zeolites were included in diets. Four of these experiments (two broiler, two layer) found a reduction in the manure moisture content and the manure appeared less odoriferous. One possible reason for a reduction in manure moisture level could be due to a decrease in water consumption (about 8%) which was observed in two experiments when clinoptilolite was fed to broilers. Ammonia retention in the manure was measured in one experiment, but the results are inconsistent, with ammonia retention being greatest in the 2.5% and 5% zeolite diets and no difference in the 0% and 10% diets (see previously). Further research is required in this area to assess the benefits of feeding zeolite on manure and litter condition.

The direct application of zeolite to broiler litter has been shown to reduce faecal moisture and ammonia levels. The direct application of 2.5 and 5.0 kg/m^2 of clinoptilolite on unused broiler litter from 21 days of age until the end of a 50 day production cycle reduced the ammonia level from 9 ppm by 9% and 19% respectively (Nakaue et al, 1981). Delaying application of the zeolite until day 28 reduced the ammonia concentration by about 35%. -At the end of the production cycle the pens that recieved 5 kg/m^2 clinoptilolite had litter moisture contents 9% less than the controls. The incidence of foot pad burns also decreased markedly on the zeolite-treated litter (10% vs 53%). Economic parameters of bird mortality, feed conversion and final live weight were not different between controls and zeolite treatments. This same findings of reduced ammonia when clinoptilolite was applied to broiler litter at 5kg/m^2 was also confirmed by Lon-Wo et al (1986). Dust levels in the sheds in experiments by Nakaue et al (1981) increased by 12% and 50% above controls for the 2.5 and 5.0 kg/m^2 applications respectively. The application of clinoptilolite at the same rates on reused litter at 30 days of production, however, did not produce any significant reductions in litter ammonia (Nakaue et al, 1981). Further research is required in this area to confirm application rates, particularly on reused litter.

USE OF ZEOLITES IN CONTROLLING AIR QUALITY IN POULTRY HOUSE ENVIRONMENTS

Again, the two properties of water adsorption and preferential cation-exchange for ammonium ions of the natural zeolite, clinoptilolite, have been used to improve the air quality in poultry house environments. Koelliker et al (1980) describe a small air-scrubbing device which was constructed to examine the use of clinoptilolite as a means of removing ammonia and possibly moisture from the air of a poultry laying house. Both single layer and multi layer zeolite-packed trays were investigated. Details are not included here but can be found in that paper.

The single-layer scrubber demonstrated that clinoptilolite has the ability to absorb ammonia- from the air of the poultry laying house. Although there was considerable variation in the measurements, the concentration of NH_3-N in the air leaving the scrubber was consistently less than that entering it. The average NH_3-N concentration of the air entering the scrubber was 2.4 mg/m^3 vs 1.6 mg/m^3 for air leaving it. Thus 0.8 mg/m^3, or about one third of the NH_3-N that entered was removed by the scrubber. Based on the average flow rate of 31 dm^3/sec, the scrubber should have removed about 35g of NH_3-N over the 16.5-day experiment. The zeolite as received contained almost no detectable NH_3-N, whereas after use in the scrubber the material contained an average of 6.7 mg/g. Therefore, clinoptilolite trapped 31g of NH_3-N, in close agreement with the calculated amount above.

The multilayer scrubber during an 18-day experiment reduced the percentage of NH_3-N at a linear rate. Initially the reduction in NH_3-N was about 45%, but by the end of the run, it had dropped to only 15%. The decrease in efficiency of the scrubber paralleled a decrease in air flow rate. The air flow was 47 dm^3/sec at the start of the test, but as the zeolite bed became clogged with dust filtered from the incoming air, it decreased considerably. After seven days the air flow rate had dropped to about two-thirds of its initial value, and at the end of the test the rate was slightly less than half the initial rate. These data indicate that the NH3-N concentration of air passing through the multilayered scrubber decreased by 1.2 md/m^3. Thus, on the basis of an estimated 5.2 X 104 m^3 of air passing through the scrubber during the 18-day test, an estimated 63g of NH_3-N was trapped in the clinoptilolite.

Such a clinoptilolite air scrubber could be useful in both layer and broiler houses, particularly in winter where ventilation is usually reduced in poultry houses to conserve heat and which results in a build up of ammonia and moisture. Further research is required in this area in commercial type sheds.

CONCLUSIONS

Zeolites, both natural and synthetic appear to have a role in poultry product ion. Some of the data presented in this review is incomplete and conflicting. Most of this conflicting data is the result of the lack of control over the consistency of the zeolite materials, and the types of contaminants present in the zeolite material used in the experiments reported. Further research is certainly needed, but in future experiments control needs to exercised more over the 'quality' of the zeolite material involved. There needs to be a more concerted effort to balance diets used in zeolite experiments to remove the effects of dilution, particularly for natural zeolites which have such high levels of inclusion, and to ensure only the characterisitcs of the zeolites are tested.

In addition to areas of future research alluded to in the review, future research is required in determining the effects of zeolite particle size when fed in poultry diets and also when applied directly to manure or broiler litter. The importance of the initial cation in natural zeolites needs to be evaluated. There is some evidence that in the same zeolite, but with a different cation, that is a K or Na type, may influence the cation capability of the zeolite. For example, clinoptilolite has greater affinity for K^+ than either Na^+, Ca^{+2} or NH_4^+. A K^+ type zeolite, in the gut of the bird, might prefer to hang onto its K^+ rather than exchange it for another ion. Clinoptilolites have been shown to have an affinity for heavy metals (Sato, 1975; Fujimori and Moriya, 1973; Chelishchev et al, 1974; Semmens & Seyfarth, 1978). This ability might be exploited to reduce the accummulation of heavy metals in flesh of farmed animals and fish when fed certain raw materials containing such metals. Fish meal is such a raw material which has been found from time to time to contain elevated levels of heavy metals and which is used consistently in diets for poultry, pigs, ruminants and fish. The use of synthetic zeolites (SZA) in reducing heat stress in layers alluded to in the review is promising and needs further study.

ACKNOWLEDGEMENTS

I wish to thank the Poultry Research Council for their financial support by way of a Junior Research Fellowship to allow this work on zeolites to be undertaken. I also wish to thank my supervisor, Associate Professor David Farrell, for his discussion and advice on this review paper.

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