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ECOLOGY AND MANAGEMENT OF ARTHROPOD PESTS OF POULTRY

R. C. Axtell and J. J. Arends

Department of Entomology, North Carolina State University, Raleigh, North Carolina 27695

PERSPECTIVES AND OVERVIEW

The growth in poultry production worldwide has been striking in recent years. The developed countries now have 26% of the human population but produce 48% of the world's poultry and 67% of the world's eggs (131). Per capita consumption of poultry meat is increasing in the developed countries while consumption of red meats is static or declining (163). Economics plays a large role in these changes, since in developed countries the efficiency of feed conversion of poultry has been steadily increased through selective breeding and improved management so that a feed conversion ratio of 2.0 or less is now common (109). The marketing of improved breeds throughout the world is making poultry production more efficient in all countries. To meet the needs of the increasing human populations, poultry production will rapidly expand in underdeveloped countries. Production has been increasing worldwide for several years (163), and the increases have been in large operations, using high densities of animals, financed and managed by large companies. These man-made production systems present challenges and opportunities for arthropod management as a subsystem of the total production management system (13). The production management systems are highly structured and sophisticated, and under the control of the parent company ("integrator") who owns the feed mills, hatcheries, processing plants, transportation, and some poultry houses (primarily breeder flocks). The integrator contracts with individual producers who raise the poultry, with young birds and feed supplied by the integrator. The producer is paid on a per unit basis (number of eggs, weight of birds). The threat of arthropod pest outbreaks is serious; proper pest

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management programs are necessary to avoid economic losses. For further information on the variety of poultry pests and associated diseases, see Hofstad et al (79) and Williams et al (169), and for chemical control measures see Drummond et al (47).

This review focuses on the major arthropod pest problems in modern integrated poultry production and ignores the minor pest species known to occur in small "backyard" flocks. Worldwide in modern high-density poultry production facilities, the major arthropod pests are: (*a*) ectoparasites: mites, lice, and bedbugs, and (*b*) habitat pests: litter beetles and filth flies (house fly and other species). Integrated arthropod pest management programs must address all of these pests. The major arthropod pest species of concern and the pest management strategies vary with the housing and production systems.

HOUSING AND PRODUCTION SYSTEMS

Modern poultry production uses fully integrated production techniques that allow for the production of a large number of eggs, or birds for meat, on a small amount of land. This change in management systems from low to high bird densities has completely changed the environment in which the birds are reared and the stressors that can alter growth and production. In these high density production systems, management of the arthropod pests is directly related to the type of product being produced (meat or eggs), housing type, feed and water equipment, manure disposal, and the environmental quality within the house. For each type of poultry produced, there are specific requirements for temperature, air quality and movement, feed, and housing for maximum production at the least cost. Pest management strategies must be compatible with the poultry management and production requirements.

The ecology of the arthropod pests is tied to the artificial environment in which they and the birds exist, and changes in the environment that affect arthropods can only be made if they are not detrimental to the birds. Because the environments of the various types of production facilities differ, the complex of arthropod pests differs among the systems. As examples, flies (the house fly and related filth flies) are a major problem in caged-layer and breeder houses but are rarely a problem in broiler facilities. Northern fowl mites are a problem in caged-layer and breeder flocks but are rare in broilers which are in a house for too short a time (about 8 weeks) for a detrimental mite population to develop.

Although the details vary to meet climatic and geographic needs, the facilities and techniques for modern poultry production are basically the same worldwide (for illustrations and descriptions of poultry housing see Refs. 14, 119, and 123).

ECTOPARASITES

The impact of arthropod ectoparasites of poultry involves the stressing of the bird, feeding on the bird, and/or vectoring of disease organisms. Pests that are not ectoparasites may lower the quality of the bird's environment and thereby cause stress to the birds.

Stress

In poultry, responses to stress are elevated levels of corticosteroids (33, 55). Freeman (55) stated that some of the consequences of increased levels of corticosteroids are: (*a*) reduction in food consumption, (*b*) decreased gonadal activities, (*c*) cardiovascular changes, (*d*) lower immunological reactions, and (*e*) increased susceptibility to disease. Stressors may cause only localized reactions (e.g. mosquito bites), and the bird will adapt to the stress or the stress may cause death (e.g. insect-vectored disease organisms). Arthropod ectoparasites of poultry would be "hostless" if the stress they placed upon the host were great enough to cause death.

In low stress environments, increased corticosteroid levels have been shown to increase resistance of birds to bacteria but to decrease their resistance to viruses and mycoplasma (72, 73). Birds with high levels of corticosteroid may have lower levels of northern fowl mites than do birds with low levels of corticosteroid (74, 75). However, birds can be genetically selected for corticosteroid level (27). Field observations of mite infestations indicate that the strain of bird is important in determining the level of infestation and the inherited levels of corticosterone can be more important than stress-induced levels (75).

Many stressors, in addition to arthropods, may affect poultry, including feed quality, environment, temperature, humidity, ammonia levels, light, social interactions, age, and strain and type of bird. Each production system has its own built-in stressors. The impact of the arthropod pest may be tempered or increased by the other stressors within the production system.

Northern Fowl Mite

The northern fowl mite, *Ornithonyssus sylviarum,* is an ectoparasite of domestic and wild birds throughout the world, although it may be replaced by *O. bursa* in tropical regions. It is the primary ectoparasite of chickens (38, 40, 105, 162). The mite is common on wild birds, which readily introduce it into poultry production facilities. The biology and control of the northern fowl mite have been reviewed by Lemke & Kissam (96). The entire life cycle of the mites occurs on the host, with the eggs laid in masses at the base of the feathers, primarily in the vent area. Only two (protonymph and adult) of the five life stages feed on the host. The life cycle is short (5 to 12 days), and large populations can develop rapidly on the birds. The mites can survive off the host for a week or more, and this ability enhances the chances for transmission (43).

Even though biosecurity is high in modern facilities, northern fowl mites continue to be a problem. In addition to movement of the mites by wild birds, the mites are carried on rodents and contaminated egg trays and flats. In a North Carolina breeder farm with birds infested with northern fowl mites, the egg crates were found to be infested. The crates delivered to a second farm after being emptied at the hatchery had an average of 19 mites per case (personal observation). While some authors consider that wild birds or domestic birds are the major means of mite dissemination (96), we believe that the main means of transmission from farm to farm is contaminated equipment (mostly egg flats, cases, and chicken crates) and people.

In a breeder flock, the roosters generally have higher populations of northern fowl mites than do the hens, and the roosters will spread the mites among the hens (96). In caged-layer houses, the hens caged alone or in pairs generally have higher mite infestations than do those housed at greater numbers per cage (11, 75). Consequently, in monitoring birds for mite infestations, the roosters in a brooder flock should be examined at a 2:1 ratio to the hens, and in caged-layer houses, preference should be given to examining the birds that occur one or two per cage. The mites are generally more abundant near the vent (95, 96) and spread to other locations (breast, thigh, back) as the populations increase. Mites tend to be more uniformly distributed over the entire body of roosters; this may be related to the contour of rooster feathers (74, 89). Some strains of birds as well as individual birds are resistant to the establishment of mites; the specific reasons are not clear (29, 96).

Attempts to examine the immune responses of chickens to northern fowl mites have given variable results (29, 41, 96). Although the production of antibodies as a result of mite infestations have been detected, there is no way to use this information to quantify the level of infestation or predict its impact. A vaccine to give the birds immunity to mites has not been developed. Immunological research has been slowed by the lack of an efficient method for rearing the mites off the host (34, 35, 54, 96).

Economic losses due to northern fowl mites have been reported as decreased egg production, anemia, loss of condition, and death (96). Loss data about laying hens conflict (39, 97, 106). Matthysse et al (106) and DeVaney (39) found that losses may be greater if the birds are under other stresses at the same time that they suffer the mite infestation. Future research should take into account normal stress encountered in the production environment; the birds should not be placed in an "ideal" environment with no outside stress (such as inadequate air movement, poor quality feed and water, crowded cages). The genetics of commercial caged-layer hens has changed in recent years, and old data may not be relevant to today's genetic stocks.

In the competitive marketplace of poultry production, any increase in production costs is significant. Previous attempts to examine losses due to mites did not consider the feed consumption, though this is the single largest production cost. In breeder flocks, Arends et al (6) found that losses due to mites resulted both from fewer eggs per bird and from increased consumption that was equivalent to 1 to 6 cents per dozen eggs. In poultry production feeding levels are commonly increased if the production has decreased for unknown reasons. Augmenting feed per bird increases the production costs but does not overcome the impact of the mites (6). Eventually mite control is instituted and the cost of treatment incurred, while the delay in treatment has increased the possibility of mite transmission to more birds in the house and even to other houses.

Control of northern fowl mites in a modern integrated poultry production company requires changes in management procedures. Monitoring all of the flocks weekly or bimonthly is vital to detect infestations early. Prevention of movement of mites (by contaminated birds, people, or equipment) into a house (cultural control) is the most important method of control. Fumigation of egg flats and cases is effective (44) but inconvenient and costly. Wild birds should be excluded by screening, and rodents must be controlled in and around the poultry houses. Detailed records of all flocks should be maintained so that facilities with repeated mite infestations can be given special attention to prevent the spread of mites to other farms within a company.

Chemical control of northern fowl mites becomes necessary when these cultural measures fail. Since the risk of mites from a few birds in a house to the remainder of the birds is great, at least part of the birds must be treated as soon as any mites are found in the routine monitoring. No chemical feed additives are registered for poultry ectoparasite control, owing mainly to problems of residues in the meat and/or eggs (4, 40). The most effective treatment is with high pressure, high volume sprays, and this is very difficult. Most chemical "failures" are due to inadequate treatment of the birds. This may be due to inappropriate formulations, poor application equipment, and inability of the spray to reach the birds due to limited access in cage operations and the difficulties in herding the free birds in breeder houses. Mite resistance to chemicals has been reported for malathion, carbaryl, and stirofos (12, 47, 96). Permethrin, a synthetic pyrethroid, is widely used for mite control, and to date there is no evidence of resistance (10). Due to the lack of ovicidal action and the chances that some birds were missed in the initial spraying of large flocks, respraying is advisable after 7–10 days. Dipping the birds (45) and feather clipping (42) give excellent control, but are impractical and stressful to the birds. Insecticide-impregnated strips and tubing are effective in caged-layer houses (76, 77, 88), but the cost and difficulties in their installation make them impractical.

Lice

The chicken body louse, *Menacanthus stramineus*, is the most common species of louse found in modern poultry production facilities (4, 14, 40, 105, 162). The entire life cycle occurs on the host. The eggs are glued to the base of the feathers in dense clusters. The eggs hatch in 4–7 days into nymphs, which develop through three instars. The life cycle requires 2–3 weeks. The data on economic losses caused by lice is conflicting, with reports of no losses (156, 166) and other reports (37, 48, 70) of an economic effect from louse infestations. The birds used in the older trials were not the same genetically as today's birds, and so it is difficult to draw any conclusions relevant to current poultry production.

Lice are introduced into poultry houses by people, wild birds, infested equipment (especially egg flats), and rodents (46). After introduction, the lice spread from bird to bird by contact and the activities of rodents, people, and wild birds. Normally, mixed infestations of lice and other ectoparasites are not found, partly because the lice eat barbs and barbules (37); this makes the feathers less suitable for mites.

DeVaney (37) reported that louse infestations result in decreased hen weight, clutch size, and feed consumption, and that the older birds are at the time of infestation the more severe the impact. The reason for the age-related response is unclear; however, the older bird is declining in productivity, and the added stress of ectoparasites may accelerate this decline. In modern production, caged-layers are the group most likely to have a louse infestation (R. C. Axtell, J. J. Arends personal observation).

Control of lice requires regular weekly or bimonthly monitoring and cultural measures to prevent introductions, a process described above for northern fowl mites. It is essential to exclude wild birds, to control rodents, and to ensure that only clean equipment and personnel enter a house. If an infestation is detected, chemical treatment by high-pressure, high-volume spraying, like that described for northern fowl mite control, is necessary. In addition, before a previously infested house is restocked, it must be cleaned of all feathers that may contain egg masses and a residual insecticide applied to the structure. To eliminate lice established on a farm is difficult unless all houses are emptied of birds at the same time and thoroughly cleaned and sprayed. There are no reports of lice being resistant to insecticides. Although malathion, carbaryl, and stirofos are used for lice control, permethrin is most widely used because of its long-term effectiveness.

Chicken Mite

The chicken mite, *Dermanyssus gallinae,* is also known as the red mite and roost mite. Like bedbugs, the chicken mite is on the bird only to feed (mostly at night) and spends the rest of the time in cracks and crevices in the cage structure. Its eggs are laid in the hiding places and hatch into a six-legged larvae in 2–3 days. The larvae molt into nymphs without feeding, and the two nymphal stages and the adult mites each feed on a bird. Adults are able to live off the host without feeding for up to 34 weeks. The chicken mite causes feeding lesions, most likely to be seen on the breast and lower legs of the birds. Economic losses due to chicken mites have not been quantified, but the mites can cause anemia, transmit diseases, lower production, and increase feed consumption (90, 173, 174). These mites are most likely to be a problem in breeder houses.

Chicken mites are transmitted from house to house by the same means as northern fowl mites and lice, described above. Consequently, control requires cultural measures to prevent infestations. Because the mite spends most of its time off the host and the eggs are laid off the host, great attention must be given to the environment (i.e. the structure and equipment). When an infestation is detected, not only the birds, but also all of the structure and equipment must be sprayed, with particular attention to the slats and nest boxes in breeder houses. Spray application of the chemicals used for control of northern fowl mites and lice are also effective against chicken mites; there is no evidence of resistance (174).

Bedbug

The bedbug, *Cimex lectularius,* is a blood-feeder attacking humans and poultry worldwide. Its occurrence in modern poultry production facilities is sporadic, but an infestation of breeder houses is a serious problem. People working in the houses may carry the bedbugs back to their homes where infestations can become established. The bedbugs, like chicken mites, are on the birds only to feed (mostly at night). All stages of the bedbugs (eggs, nymphs, and adults) are found concealed in cracks and crevices in the house, especially in the slats and nest boxes in breeder houses. The eggs hatch in about 6 days, and each of the five nymphal instars takes a blood meal. The nymphs may withstand starvation for 70 days, and adults can live without feeding for up to 12 months. The feeding, which usually occurs at night, takes only 10 minutes for full engorgement. Since the bedbugs require harborage, the broiler breeder houses provide a suitable environment in the raised slats and the straw of wood shavings of the nest boxes. Birds raised on litter or in cages are rarely infested because protective sites are lacking. Although bed bugs have been reported as pests of poultry for more than 40 years, economic losses from them have not been quantified. Damage from bedbugs has been reported as allergic reactions of the growers, egg spots due to fecal deposits, lower production, and increased feed consumption (92). Bedbugs transmit various disease organisms in the laboratory (50), but epidemiological significance for transmission of any pathogen by bedbugs has not been demonstrated in the field. Because only a short time is spent on a host, the spread of bedbugs from farm to farm by wild birds or other hosts is minimal. The main means of dispersal are egg cases and flats transported by the integrators from infested farms to the hatchery and then to other farms for reuse (R. C. Axtell, J. J. Arends personal observation).

To monitor for bedbugs is difficult due to their hiding and nocturnal feeding. Evidence of a bedbug infestation are fecal spots (on posts, nest boxes, and other surfaces) and lesions on the breast and legs of the birds. Possible hiding places should be examined in the same manner as described above for chicken mites.

Control of bedbugs, like that of mites, is based on cultural measures taken to prevent introductions. If an infestation is found, thorough chemical treatment with special attention to the equipment and structure is required. As with control of chicken mite, control of bedbugs can be satisfactory only if all houses on a farm are cleaned and sprayed at the same time. The chemicals used for other ectoparasites are effective as sprays against bedbugs; permethrin is used frequently (143). There is no documented resistance to these chemicals.

Ectoparasite Management

The development and implementation of management programs for poultry ectoparasites is a continuing problem. The strategies and techniques must evolve as new strains of birds, new feeding systems, different housing, changed environmental control systems, and different production goals are adopted by the industry. The fundamental goals of the ectoparasite management program that must be met for the program to be successful in the field are: (*a*) Ectoparasites must be controlled economically, and (*b*) the program must fit into the everyday poultry management practices. The basic components of an ectoparasite management program are cultural control (exclusion of the arthropod), chemical control (spray applications of insecticides), and ectoparasite population monitoring.

Monitoring the ectoparasite populations in a poultry house and setting economic thresholds for treatment are important aspects of a pest management program. While evidence suggests that ectoparasites must reach certain levels before economic losses will occur, the data are limited and often conflicting. Usually the data do not include losses related to increased feed consumption. Consequently, we cannot presently define economic thresholds for poultry ectoparasites. Although in theory, treatment should be recommended only when the ectoparasite level reaches an economic threshold, in modern poultry production facilities, other concerns must be included in the decision of whether to treat. A major concern is the transport of the ectoparasites from one house to another, and from one farm to another, under the operation of one company. Although the ectoparasite population in one house may seem minor, in the total picture it may present a serious threat. The cost of treating one house or a part of a house must be weighed against the potential cost of treating many houses. Given current biosecurity practices in the poultry industry, the operators are not successful in isolating infested flocks and preventing the rapid expansion of ectoparasite populations to other flocks managed by the same company. If the ectoparasite population in a house is allowed to reach a certain level before treatment is used, the risk of ectoparasite movement is higher than if treatment is carried out earlier.

Consequently, the practical treatment level (rather that economic threshold) for poultry ectoparasites is the detection of a single parasite, i.e. treatment is recommended if any ectoparasites are detected by the monitoring program. If northern fowl mites or lice are found on caged birds, it may be necessary to treat only the sections of cages where ectoparasites are detected rather than all of the birds in the house. It is obviously easier to spray a few hundred birds in a few cages than to treat thousands of birds in an entire house or eventually in many houses if the infestation spreads. With breeder flocks, the entire infested house must be treated, but this is preferable to waiting and risking the need to treat many houses due to the spread of the ectoparasites.

Effective and practical chemical treatments for ectoparasite control in modern poultry operations are difficult. Liquid sprays are most widely used because dust formulations are difficult to apply, irritating to the birds, and often ineffective. Caged-layers are difficult to spray due to the closeness of the cages and limited access to the birds. It is impossible to direct the spray at the birds from several directions and coverage is spotty; some birds are even missed by the spray. Presently, spraying at 75–125 psi with a solid stream (disc nozzle) from the front of the cages is most commonly recommended. Before spraying, the feed conveyors are emptied and the eggs retrieved. In breeder houses reaching all of the free-moving birds with a spray is difficult, and care must be taken to avoid excessive crowding of the birds, which may cause injury or death. Also, it is difficult to treat the nest boxes, under the slats, and in the cracks and crevices. At the time of spraying in breeder houses, the water and feed equipment should be raised to prevent contamination; fortunately that equipment is normally installed on cables so that it can be elevated readily. If any type of house is sprayed while birds are absent, spray should not be left standing in the feed equipment because subsequent rust will interfere with feed delivery and shorten the life of the equipment.

HABITAT PESTS

In confined poultry housing, a diversity of insects and mites will be found in the accumulated poultry manure (in caged-layer houses and beneath the slats in breeder houses) and litter (feces mixed with wood shavings or other plant materials in broiler and turkey grow-out houses and portions of breeder houses). These arthropods are mainly species of beetles (Coleoptera), flies (Diptera), and mesostigmatid mites (2, 9, 80, 94, 103, 127).

Litter Beetles

The two major pest species of litter beetles are *Alphitobius diaperinus* (Tenebrionidae), the lesser mealworm, and *Dermestes maculatus* (Dermestidae), the hide beetle. Other species in those genera may occur but apparently are rare.

LESSER MEALWORM The life history and bionomics of *Alphitobius diaperinus* have been described (128, 144, 157, 171). The eggs are laid in clusters in the manure or litter and develop through a variable number of larval instars (6 to 10 or more) requiring 40–60 days, depending upon the conditions. Pupation occurs in suitable portions of the manure or litter and in the soil beneath (the preferred site). Under conditions that are not fully understood, the late-stage larvae often move upward and pupate in the insulation in the building. The pupal stage lasts 7–12 days, and the adults are long-lived (up to a year). Extremely large populations of all stages of these beetles can be found in some poultry houses, especially in the litter of broiler and turkey growout houses. The beetles often aggregate in areas of higher temperature, suitable moisture (especially around waterers), and nutrients (mainly spilled chicken feed). Consequently, greater numbers of insects may be found under and around feeders and waterers in broiler and turkey growout houses, and in areas of spilled feed in accumulated manure under caged-layer hens. In addition to feeding on chicken feed and other organic matter, the beetles (adults and late-instar larvae) will prey on smaller arthropods, including other lesser mealworm larvae; they also consume dead or moribund chicks.

The lesser mealworms are reservoirs for a wide variety of pathogens including several that are threats to poultry production (79). They harbor fungi *(Aspergillus)*, bacteria *(Escherichia, Salmonella, Bacillus, Streptococcus)*, and viruses causing leukosis (Marek's disease) and infectious bursitis (Gumboro disease). A variety of other viruses, including the agents causing fowlpox, Newcastle disease, and avian influenza, have been recovered from the beetles although other arthropods are considered to be more important vectors. Avian coccidosis, a major disease of poultry caused by protozoans

(*Eimeria* spp.) is a poor survivor in poultry litter but survives as oocysts ingested by beetles which may then be ingested by the birds (133). The cysticercoids of helminths (*Choanotaenia* and *Raillietina*) which affect poultry have been recovered from *A. diaperinus* demonstrating its role as an intermediate host (51, 71).

In addition to the potential for spreading poultry disease pathogens, the lesser mealworms are detrimental to the poultry by providing an alternate food for the birds that may result in lesser weight gains compared to those of birds feeding normally on the nutrient-balanced feed. It has been suggested that the insect may cause lesions on the birds (22), and the scratching activity of the birds seeking the beetles in the litter may increase the susceptibilities of the birds to disease agents, owing to the irritation of the respiratory tract from the resulting dust (103). Humans may become allergic to *A. diaperinus* (145).

For modern poultry production facilities, the most serious impact of *A. diaperinus* is the structural damage (84, 96a, 120, 142, 161, 165). The migration of the beetle larvae into the insulation for pupation results in extensive damage, to the extent that the insulation must be replaced after a few years. All types of insulation (especially polystyrene and polyisocyanurate) are damaged. Some tunneling into soft wood may occur. The loss of insulating value due to the holes and tunnels results in greater heating costs as well as lowered feed conversion efficiency of the birds due to the lack of adequate temperature control in the houses. Although adult beetles are found in the insulation, most of the damage is from larvae that have migrated there and pupated. Some adults will move into the holes caused by the larvae and use the insulation as an oviposition site. This problem is greatest in broiler and turkey growout houses because of the proximity of the heavily infested litter to the walls and ceiling. The problem also exists in high-rise caged-layer houses even though the larvae have greater distances to move to reach the insulation (36, 154).

Most of the climbing by the later-instar larvae and adults is at night. The larvae initiate the holes and tunnels in the insulation, and the adults follow. Although other factors may be involved, the major stimulus to larval climbing is the need for pupation sites when the litter is not adequate. With large populations of larvae this happens as the underlying soil sites for pupation becomes insufficient (57). The degree of climbing increases when the birds are removed from a house (57, 144). Adult flight occurs at night and is affected by the light: dark cycle (57, 58). When poultry manure containing beetles is spread on fields, the flying adults often move to nearby houses and businesses and create a serious annoyance problem to the inhabitants.

Methods to control *A. diaperinus* in poultry houses are only partially successful. Thorough cleaning of the houses and then leaving them empty and unheated for a prolonged period in a cold climate will reduce the rate of beetle population increase in subsequent flocks, but these measures do not eradicate the infestation (3, 68). Application of insecticides to the structure (including the soil floor) after cleaning assists in lowering the beetle survival, but mixing insecticides with disinfectants, although a common practice, is risky due to a loss of both germicidal and insecticidal effectiveness (62). A variety of organophosphate, carbamate, and synthetic pyrethroid insecticides and borates are toxic to the beetles as residues on the structure or in the litter, but although effective in laboratory tests, they yield only temporary population reductions in the field (3, 164). Likewise, insect growth regulators (IGRs), juvenile hormone analogues, and avermectin have effects in laboratory tests but have not been demonstrated effective in the field (49, 108, 167). In broiler and turkey growout houses insecticides are most effective when applied to the soil after cleanout and before adding new litter; this causes death of the late instar immatures when they move into the soil to pupate.

Biological control is an attractive concept, but few agents have been investigated. Steinernematid and heterorhabditid nematodes infect larvae, pupae, and adults of *A. diaperinus* in laboratory tests (61), but field tests with *Steinernema feltiae* gave only slight reductions in the rate of beetle population increases in broiler and turkey houses, apparently due to lack of persistence in the underlying soil under the relatively high temperatures (56, 59). Other strains and species of nematodes may be effective; Cycles and crashes of beetle populations in some houses which are otherwise inexplicable suggest the existence of pathogens that could be identified and exploited as biocontrol agents.

Monitoring beetle populations in poultry houses is necessary in order to carry out limited control measures, and the use of tube traps (corrugated cardboard inside a section of plastic pipe) is recommended, although their placement is critical (142, 154). A large number of traps and consistent placement of them are required owing to the aggregation behavior of the larvae and adults. Aggregation pheromones probably exist, but this has not been investigated. Secretions (benzoquinones) from abdominal glands have been identified (160) and are presumed to be defensive.

HIDE BEETLE *Dermestes maculatus* is generally less abundant than lesser mealworms in poultry houses, but on occasion it may be a serious pest, especially in high-rise (deep-pit) caged layer houses where *Dermestes lardarius* also has been reported as a pest (31, 86, 154). In high-rise houses, *D. maculatus* populations can be monitored with tub traps placed on the surface of the accumulated manure (154). The behavior and economic significance of *Dermestes* are very similar to those of the lesser mealworm in that the beetles bore into the insulation and wood, presumably seeking pupation sites. The hide-beetle eggs are deposited in clusters in the manure or litter, and the larvae develop through a variable number of instars (5–7) requiring 20–30 days. The entire life cycle from egg to adult requires 30–40 days (32, 158). Poultry manure by itself is not adequate for development, but spilled chicken feed provides suitable nutrients (32).

Effective control measures for *D. macalatus* in high-rise poultry houses are not known, though a variety of organophosphate, carbamate and synthetic pyrethroid insecticides and insect growth regulators are toxic to the adults and larvae in laboratory tests (31). No biological control agents are known. Pheromones may have a thus-far-unexplored potential in the control of hide beetles. Aggregation pheromones have been demonstrated in the feces of adult *D. maculatus* (85, 129, 130), and evidence exists for a sex pheromone (147). Overall, the biology and control of *Dermestes* in poultry houses has been investigated very little compared to that of the more common litter beetle *A. diaperinus*.

Filth Flies

Worldwide the species of flies and other arthropods breeding in poultry manure are very similar, and their relationships to housing and poultry management schemes are basically the same. By far the greatest populations of flies occur in the caged-layer houses that are widely used for commercial egg production. In the narrow caged-layer houses manure is in close contact with the outside environment; this facilitates invasion and movement of the flies and their natural enemies. In wide-span houses with several walkways and rows of tiered cages, less contact occurs between the manure and the outside environment. In both the narrow and wide-span houses, the manure may accumulate, with removal only once or twice a year; opportunity then exists for a diverse, heterogeneous manure fauna to develop. Alternatively, a scraper or a flushing system may be used to remove the manure daily into a lagoon; in which case there is little or no fly breeding (unless a malfunction of the equipment results in an accumulation of manure). Disposal of the manure into lagoons creates a mosquito problem, however (136, 140). The wide-span houses may have open sides with adjustable curtains, or they may be enclosed with fans used for ventilation and temperature control (environmentally controlled houses). The high-rise or deep-pit caged layer houses are essentially the same type as the wide-span houses, except that the high-rise house is two-story with the birds on the top story; manure is allowed to accumulate on the first floor (on soil or concrete) for as long as 2 to 4 years. These houses may have curtain sides, or they be environmentally controlled. The condition of the manure and hence the heterogeneity of the fauna are greatly influenced by the amount of manure accumulation and the environmental conditions created in the "pit."

The second place fly breeding occurs prolificly is in the manure accumulated under the slats in breeder houses. Since the feeders and waterers are positioned on the slatted portions in these houses, most of the manure and fly breeding occur there, and very little take place in the drier litter in the center of the houses. The manure under the slats accumulates for the life of the flock (12–18 months) and contact is limited between the manure and the external environment.

In the broiler and grow-out houses used to feed chickens and turkeys to market weight, little or no fly breeding occurs because the entire floor is covered with relatively dry litter. The litter is usually removed after 3–6 flocks and replaced with new wood shavings or other dry material. Some fly breeding may occur in wet litter around the waterers, but this is usually a minor problem.

Excessive numbers of filth flies (especially the house fly) in poultry facilities are unacceptable because the flies annoy workers, may disperse to nearby residences and businesses (engendering disputes and lawsuits), and often constitute a violation of local public health laws and regulations. Also, the flies by defecation and regurgitation cause spotting on the structure and equipment, on light fixtures (reducing illumination levels), and on eggs (presenting potential for transmission of pathogens into the freshly laid egg). Flies also provide a reservoir for a wide variety of pathogenic organisms affecting humans as well as poultry.

Because the fly problem is greatest in the types of caged-layer houses with accumulated manure under the cages and in breeder houses with accumulated manure under the slats, discussion of the ecology and management of flies applies to those production systems. Relevant reviews and surveys of manure-inhabiting arthropods have been published (9, 14–17, 20, 80–82, 94, 127). The housing environment relevant to fly control has been described (7, 8, 152).

FLY SPECIES The house fly, *Musca domestica,* is usually the most abundant and pestiferous fly species in poultry houses (2, 15, 17), and it is the primary object of most fly management and control programs. The house-fly life cycle in poultry manure requires 6–10 days in warm housing. The eggs are deposited in batches in manure that has the most attractive odor and moisture level (53). Aided by their anterior sensory receptors (30), the larval stages move through the manure though usually not very deeply, owing to the anaerobic conditions. When there is no alternative, the larvae can tolerate rather liquid conditions. Pupations occurs in the drier portions near the surface and edges of the manure. Other muscoid flies (2,150) common in poultry manure include *Fannia canicularis, F. benjamini,* and *F. femoralis*. In some locations *F. canicularis* and/or *F. benjamini* may be major pests for part of the year, but usually their populations decline quickly at high temperatures.

Ophyra leucostoma, O. aenescens, and *O. capensis,* the so-called black garbage flies or dump flies, are sometimes abundant. They have basically the same life cycle and behavior as the house fly, except that the larvae of *Ophyra* prey on other arthropods as well as feed on the manure. Another muscid, *Muscina stabulans,* occasionally is abundant, and its larvae also prey to a limited extent on other fly larvae. The only larva of a blood-sucking muscid found in poultry manure is *Stomoxys calcitrans.*

The soldier fly, *Hermetia illucens* (Stratiomyidae), is common in poultry manure in some regions and may be especially abundant in high-rise houses. The robust larvae churn the manure and physically render the habitat less suitable for the house fly and other muscids (18, 148). Large numbers of soldier fly larvae in the manure also may inhibit oviposition by the house fly (26). The soldier fly oviposits (25) on the drier portions of the manure (up to a thousand eggs per mass). Larval development (5 instars) is slow (2 weeks or more), and the pupal stage lasts 2 weeks or more. A complete life cycle from egg to adult in poultry houses requires 40–60 days and consequently larvae can become very abundant. The adults are slow flying, and although they may be found resting on vegetation around the house where they feed on plant pollen, they do not readily disperse in sufficient numbers to cause problems in nearby residences or businesses. Although the soldier fly larvae provide the benefit of discouraging house fly and *Fannia* development, the larvae cause the manure to become so liquified that it is difficult to remove and may flow onto walkways or undermine foundations of the poultry house. In breeder houses, the liquified manure may flow from beneath the slats and adhere to the feet of the hens; this results in manure adhering to the surface of the eggs as they are laid in the nest boxes and, consequently, a risk of pathogens entering the egg through the moist shell at time of laying. Such pathogens can cause decreased hatch and chick growth.

The *Ophyra* flies breeding in poultry houses have a slighly longer life cycle than that of house flies, but the larvae occupy the same microhabitats in the manure (87). *Ophyra* larvae prey on house fly larvae and often become the dominant fly species. An *Ophyra aenescens* larva may destroy 20 house fly larvae per day (63). The use of *Ophyra aenescens* as a biocontrol agent against the house fly has been suggested (117), and its limited dispersal from poultry houses has been reported (118). However, in the mid-1970s *O. aenescens* was accidentally introduced from the New World into Europe, where it is rapidly becoming a new pest, along with *O. capensis* and *O. leucostoma,* in poultry production facilities as well as in refuse dumps (1; 115, 116, 150, 155). In Africa, *O. capensis* is the most common *Ophyra* in poultry facilities (80, 81, 121). *Ophyra* flies appear to leave fecal and regurgitation spots on the structure, light fixtures, equipment, and eggs in a manner similar to that of house flies.

FLY PREDATORS, PARASITES, AND PATHOGENS Although the diverse fauna in accumulated poultry manure includes a variety of minor predators, worldwide the major, most abundant predators on the eggs and first-instar larvae of the house fly (and other muscids) are the mite *Macrocheles muscaedomesticae* (Macrochelidae) and the beetle *Carcinops pumilio* (Histeridae). In some regions *Carcinops troglodytes* may replace *C. pumilio* (82). Other common mite predators are *Fuscuropoda vegetans* (Uropodidae) and *Poecilochirus* spp. (Parasitidae). These major predators and *Ophyra* larvae may destroy up to 40 house fly immatures per predator per day (58, 63, 64, 170, 172).

The mite and beetle predators of the house fly immatures are most effective in manure that is properly managed so that it is not too wet and accumulates in a distinct pile ("cone formation"). The distribution of *C. pumilio, M. muscaedomesticae,* and *F. vegetans* in accumulated poultry manure has been well documented (23, 65, 66, 151, 170); those predators are most abundant at and near the crest and slightly beneath the surface, in the areas most likely to have house fly eggs and first-instar larvae.

The parasitids are more active than the other mites and rapidly run around on the surface of the manure mostly near the crest. These predators feed on nematodes and other small arthropods as well as immatures of the house fly and other Diptera. Larvae of Sphaeroceridae (Diptera) are common food for *Carcinops* (67). The mites exhibit a succession as manure accumulates and ages, with the *Poecilochirus* invading early, followed by *Macrocheles*, and subsequently *Fuscuropoda*. The mites exhibit phoresy (52, 83), with the house fly the most common carrier, which is regulated by olfactory responses to the flies and the aging manure; this is a mechanism for dispersal to the most favorable fly breeding areas.

Hymenopterous parasites (Ptermolalidae) are a major factor in destroying fly pupae in poultry facilities (as well as in other confined livestock operations). The extensive literature on this topic is summarized by Axtell (17), Patterson & Rutz (124), and Rueda & Axtell (135). Naturally occurring parasite populations are often substantial and apparently contribute significantly to fly control (104, 107, 113, 134, 138, 141) although it is difficult to quantify the impact (124, 126). Augmentative releases of *Spalangia* and *Muscidifurax* have successfully reduced the abundance of house flies in poultry facilities (93, 110, 122, 124, 137, 139, 149). Naturally occurring parasite populations may be large, and these are enhanced by dry manure, which provides areas where the house fly pupae are readily accessible to the parasites. Although parasites are important limiting factors to fly populations and are even offered for sale as biocontrol agents, many questions remain unresolved concerning the most effective species or combination of species, how to evaluate the degree of parasitism, how to time augmentative releases, and how to integrate parasites into a total fly management program (124, 126). These questions are presently resolved empirically while awaiting the results of further research and population modelling (17, 20, 168).

Little attention has been given to fly pathogens in poultry production facilities except for fungi and evaluation of nematodes as possible biocontrol agents. The fungus *Entomophthora muscae* is a common pathogen of the house fly and other filth flies; perhaps ways can be found to exploit it (91, 114), but it has been investigated in only a few locations. Several steinernematid and heterorhabditid nematodes are infective to house-fly larvae in the laboratory but rapidly die when in poultry manure. Hence they have little value as filth fly control agents in poultry houses (60, 69, 111, 112, 132).

FLY MANAGEMENT Control of the house fly and other filth flies in poultry houses requires a management approach using cultural, biological, and chemical techniques, with appropriate monitoring of the fly populations (14–16). Although details will vary with the type of housing, the manure handling system, and climatic situation, the principles of fly mangement are universal.

Cultural methods are primary and basically involve keeping the manure as dry as possible. This is accomplished by proper building design and ventilation to maximize air flow over the manure, by provision for drainage of water away from the house, and by careful maintenance of the bird watering system to minimize leaks. To conserve part of the heterogeneous manure fauna, especially fly predators and parasites, the manure should not be totally removed in one brief span of time (125). Whenever possible, portions of the manure should be removed in a staggered schedule, preferably during the cooler months when there is low fly activity; a base of old manure should be left to provide absorbancy for the fresh manure as well as harborage for beneficial arthropods. These cultural manure management practices are the basis for biological control, which consists of encouraging a heterogeneous population of predators and parasites that occur naturally and suppress the fly population. Augmentation by parasite releases is a future avenue for biological control, but quantitative guidelines for augmentation are presently lacking.

Chemical methods of fly control are proven supplements to cultural and biological methods. Unfortunately most insecticides effective against house flies and other filth flies are also toxic to predators and parasites. Consequently, routine larviciding of the poultry manure is incompatible with maintainence of the beneficial arthropods. Spot treatment of small areas containing unusually high numbers of fly larvae is acceptable. Using cyromazine as a feed additive or in direct application to the manure is acceptable because that chemical is relatively nontoxic to predacious mites and beetles (19). Some selectivity of chemicals can be achieved by the choice of application method. The use of fly baits and selective application of fly control chemicals to the interior upper portions of the poultry house where flies rest are compatible with biological control agents. Aerosol and mist applications for temporary adult fly control are sometimes needed in crisis situations, and if their use is limited, these should have little effect on the populations of predators and parasites (146). House flies develop resistance to insecticides very rapidly, and few effective chemicals for control are available. Even with the newer synthetic pyrethroids and cyromazine, some indications of fly resistance have been reported (24). Consequently, chemical control of flies should be only a supplement to cultural and biological control methods.

A major problem in managing fly populations is monitoring to evaluate the potential for reinvasion as well as fly dispersal. Practical monitoring methods focus on the adult fly; a variety of techniques have been used, including resting counts, grid counts, sticky ribbons, baited jug traps, and spot cards (21, 28, 153). The baited jug traps and spot cards are the most thoroughly researched and are related to actual fly numbers; the cards provide a simple, practical method for use in the poultry industry (98–101). Inconsistencies of results using the various monitoring methods in different situations have been reported, and each method has its advantages and disadvantages. Uniform, consistent application of a method at frequent intervals during a fly season will provide a measure of changes in fly abundance that is superior to erratic subjective impressions and will establish a basis for decision-making in regard to fly control measures. Also, a body of quantitative monitoring data by a proven method is required in case of lawsuits of other actions under public health laws.

SUMMARY

The worldwide spread of modern, high-density confined poultry production systems under the direction of integrators has intensified the importance of a select number of arthropod ectoparasites and habitat pests. This concentrated production of poultry provides artificial ecosystems that are sometimes ideal for the development of large populations of arthropod pests. At the same time the systems are amenable to integrated pest management involving a multipest and multimethod approach to reducing or eliminating arthropod pests. Since rodents are major pests, they should be included in an integrated pest management program to make the program most cost-effective and attractive to the integrators and producers (5).

Quantitative data are scarce on economic effects, and the concept of economic thresholds is difficult to apply either to ectoparasites or to habitat pests. The risk of transporting ectoparasites among flocks is difficult to evaluate and necessitates treatment after early detection of the arthropods.

Flies and litter beetles present a threat of disease transmission and the potential for lawsuits from neighbors or public health agencies that are factors not subject to easy cost estimates. The monetary losses of a flock devastated by disease or a farm forced to close are so great that the risks are unacceptable. Production losses from lowered feed conversion ratios and insulation damage are likely to be detected by the sophisticated record-keeping of the integrators. Minimal use of pesticides and other chemicals on poultry and in poultry housing is an objective of the integrators and, consequently, an integrated pest management (IPM) approach that reduces the need for pesticides is attractive.

The key to further development of effective arthropod management programs for poultry is the implementation of pest and disease monitoring programs for the complete system. Improvements in arthropod sampling methods and more attention to monitoring the biosecurity systems to minimize ectoparasite dispersal are needed. The integrators have servicemen who regularly visit the production facilities and can be trained to perform monitoring functions and to instigate and supervise integrated pest management measures. With the increasing use of computers by the integrators, the prospects for utilizing the monitoring data in predictive computer simulation models for pest management decision-making justify more efforts to develop such tools (64, 102, 168). Future poultry pest managment programs must be based on sound data, which presently is too limited, and must be flexible enough to adjust rapidly to evolving pest problems in rapidly changing production systems.

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CONTENTS