OFFICIAL

NORTHEAST MULTI-STATE RESEARCH PROJECT

PROJECT NUMBER:	NE-127 (revised)
TITLE:	Biophysical Models for Poultry Production Systems
DURATION:	October 1, 1999 - September 30, 2004

STATEMENT OF THE PROBLEM:

Rapid growth of the poultry industry combined with the move to controlled environments for production has challenged the producer to manage a system rather than the flock. In an environmentally controlled production system, optimal production can only be obtained when the important environmental conditions have been defined and interactions with other components understood. This requires a multidisciplinary, collaborative approach to be followed by generation of multi-factor, dynamic models to be used to define production environments. Current problems in poultry production such as mortality losses due to heat stress, ascites, respiratory complications, and leg/bone deformation have a physiological basis and are modified by other factors in the environment.

JUSTIFICATION:

Poultry production has increased and intensified over the last several decades to meet the increased demand for poultry products, with new production technologies relying more heavily on climate controlled environments. Concurrent advances have been made in the efficiency of production of poultry meat and eggs through genetic selection and refined nutritional programs. It has become increasingly critical that management strategies optimize efficiency of production, minimize losses from environmental and housing stresses and maximize animal well-being — areas of major concern to producers. A multi-disciplinary, collaborative approach to understanding how best to achieve these goals is necessary because of the enormous complexities of animal-environment interactions.

It is unfortunate that the very efficiency that has led to increases in poultry production has also been its nemesis: the rapid growth of broiler chickens and the egg production capability of modern layers are themselves sources of stress in the animal. As examples, rapid broiler growth is implicated as a cause of ascites and leg deformities, and egg production results in metabolic bone disease in layers. All three disorders are exacerbated by environmental extremes.

Producers and consumers alike have become increasingly concerned about the negative effects imposed by high production levels and current housing practices on animal well-being and environment. Animal-environment interactions are complex and require multi-disciplinary research efforts to define and alleviate unfavorable conditions. To address producer and consumer concerns, several critical questions have been identified as the focus of the proposed project: 1) What physiological mechanisms are disrupted by stress episodes of various duration; 2) How are those mechanisms affected by environmental manipulations; 3) What management technologies are suggested by answering questions 1 and 2; and 4) Can any or all of these events be predicted reliably by mathematical models generated from research data accumulated in attempting to do so? Specifically, the NE-127 research effort would focus on physiological responses to the following environmental conditions - temperature, air quality, and light.

In recent years there have been such significant changes in the characteristics of modern poultry and their housing that it is imperative that information used in the design of housing and equipment be updated, and that behavior and well-being taken into consideration. For instance, while it once required 10 weeks to rear a broiler to a four-pound body weight, it now only requires six weeks. Similarly, most heat production data used in building design are at least 20 years old and recent studies show substantial discrepancies with past literature.

Methods of evaluating and assessing information on a systems basis are needed more than ever for use in decision-making, and are available through artificial intelligence and operations research methods. It is also important that physiological stress be defined and that modifications be made to current environmental control recommendations that optimize animal well-being, maximize the efficiency of safe food production and minimize environmental impact. This enormously challenging task exceeds the capabilities of individual research laboratories or even single universities.

It is the complexity of this task that dictates the need for the continuation of this regional research project. The unique character of this project lies in the combined efforts of physiologists, nutritionists, agricultural engineers and economists that form an excellent vehicle for the multi-disciplinary, interdependent collaborations necessary to address the issues facing the poultry industry. In addition, highly specialized facilities at several stations are available for collaboration, including spectraradiometers (CT), hypo/hyperbaric chambers (TX), convective calorimeters (IL), large-scale indirect calorimeters (IA), single-bird calorimeters with infrared cameras and computerized data acquisition equipment (NE), and environmentally regulated production facilities for simulating field testing (MD, AR). These facilities are too costly to duplicate, but provide a significant resource for collaborative research.

RELATED CURRENT AND PREVIOUS WORK:

Research conducted under the aegis of Regional Research Project NE-127 ("A Systems Approach to the Evaluation of Environmental Constraints Affecting Poultry Production" [1989-1994] and "Biophysical Models for Poultry Production Systems" [1994-1999]) has provided many significant contributions to understanding of the effects of the physical environment on poultry physiology and productivity.

Current Work: Results of the CRIS search

A CRIS search identified 12 regional research projects including NE-127 that are working on similar or related areas of research with poultry (see Appendix I). Much of our proposed research deals with the effects of thermal environment on poultry. Therefore this area of the current research will be discussed first.

In addition to NE-127 and the stations involved, the following stations and ARS units were identified to have currently active projects related to the thermal environment of poultry production facilities: AL, FL, GA, KY, MS (ARS), NC, SC, and TN. All these stations are involved in the Southern Regional Research Project S-261 "Interior Environment and Energy Use in Poultry and Livestock Facilities". While both NE-127 and S-261 share the common goal to improve production profitability of poultry operations, there exist numerous distinctive and complementary natures between the two projects. These distinctions and complementation include:

a) Committee Profile and Work Thrust: The S-261 committee consists of primarily agricultural engineers, and its main thrust is to develop and/or evaluate building ventilation and environmental control components or systems that lead to improved interior environment and energy efficiency. By comparison, the NE-127 committee has much greater diversity of disciplines and focuses on establishing the fundamental database for development of the optimal housing and environmental control systems by characterizing physiological, behavioral and performance responses of poultry to critical environmental factors.

b) Project Scope: S-261 encompasses all farm animal species (cattle, dairy, swine, and poultry). The poultry aspect of its work scope focuses primarily on broilers, the major poultry industry for the Southern region. NE-127 is devoted entirely to poultry and its work scope covers all the poultry species of broilers, layers, and turkeys, all of which have a major role in the agricultural economy in the Northeast and/or Midwest.

Thus, we see the efforts by both projects as being highly complementary with each having its own, equally important uniqueness. In fact it has been proposed that the two committees exchange annual reports to enhance prompt information dissemination and avoid unnecessary duplication of efforts.

No projects were identified to systematically quantify the heat and moisture production of modern poultry and their housing systems except those from participants of NE-127. Limited studies have recently been conducted at IA with young turkeys (Xin et al., 1998), breeder chicks (Xin and Harmon, 1996; Han and Xin, 1997), and market-size broilers (Xin et al., 1996).

With regard to ongoing research in behavior and leg problems, no other station was identified as currently active in this topic. Different stations are working on leg problems but focusing on effects of nutrition (AL, AK, MS), physiological and biochemical aspects of leg problems (MI, AK), etiology and pathology of osteomyelitis-synovitis (AK), biomechanical properties of the musculo-skeletal system (GA) and effects of slats flooring systems on leg problems in broiler breeders(GA). Only one station (WA) has an active project in behavior that is focused on cannibalism in laying hens.

There are currently no projects that study all three aspects of the light environment: spectral quality, intensity and duration of light/dark cycles. However investigators in OH, TN, and PA are looking at photoperiod schedules, such as intermittent lighting, to improve layer or broiler production. Other researchers at FL and ARS-Beltsville are looking at light attractants to kill flies in poultry facilities. The FL team is also looking at the effect of UV light from these fly attractants on bird performance.

A CRIS search of the literature shows a paucity of information concerning the use of artificial intelligence and operations research methods in poultry management systems. The poultry work involving Operations Research and Artificial Intelligence noted in the CRIS research came from PA (Roush et al., 1996, 1997; Roush and Cravener, 1997) and the University of Georgia (Patel et al., 1996).

Related work: Studies in thermoregulation

The negative impacts of warm environmental temperatures or heat stress on poultry production have been well documented. Less defined are the physiological mechanisms and strategies to reduce the negative impacts. An increase in environmental temperature decreases feed consumption and growth of meat type poultry (Deaton et al., 1978; Reece et al., 1972; Reece and Lott, 1983; Suk and Washburn, 1995). Heat stress alters the rate of thermal panting and blood flow patterns. Depressed gastrointestinal blood flow may impair energy assimilation and contribute to poor performance.

In layers, increased environmental temperature reduces egg mass and shell quality, but much remains to be elucidated about how egg production is disrupted. Homeostasis of calcium metabolism, as well as of the reproductive hormones (LH; progesterone, P4; estradiol, E2) is disrupted within 24h of onset of acute HS in unacclimated birds (Mahmound et al., 1996; Novero et al., 1990). Progesterone release by ovarian granulosa cells is inhibited by heat stress even with challenge by the releasing hormone (LH). Heat shock proteins (hsp) may alter progesterone release.

Hsp90 is of particular interest for its role intracellular transport and possible activation of avian progesterone receptor function (Kost et al., 1989) as well as possible involvement in activation of other steroid receptors (Carson-Jurica et al., 1989). Increases in hsp90 in response to heat stress could flood progesterone receptors, making activation of the receptors more difficult and resulting in the decreased ability of granulosa cells to produce and secrete progesterone following heat stress of the hen (Novero et al., 1991).

The main cooling mechanism in the fowl is convective heat transfer to the skin surface, but because of the great insulatory properties of the feathers, vasodilatation is only likely to achieve substantial heat losses in the comb, shanks, and undersurface of the wings (Hutchinson and Sykes, 1953; Appleby et al., 1992a). Recent research indicated that local peripheral tissue cooling during heat stress can shift visceral and peripheral circulatory patterns and improve production. At high temperatures the birds' feet provide a site to modulate heat dissipation through conductive heat loss (Muiruri and Harrison, 1991a; Reilly et al., 1991) and several other physiological mechanisms (Hillman et al., 1982; 1985). For example, access to a cooled roost improved egg production during heat exposure (Staten et al., 1986; Flynn et al., 1984).

As air temperature rises, animals increasingly rely on latent heat loss. When high air temperatures are combined with high humidity, the effects can be devastating. In order to assess the relative effects of temperature and humidity, temperature-humidity indices (THI) have been developed and used by researchers for several species (ASHRAE, 1981). For poultry, THI's have been developed for laying hens (Zulovich and DeShazer, 1990); turkey hens (Xin et al., 1992); and growing male turkeys (Brown-Brandl et al., 1997). No THI's have been developed for broilers, which suffer heavy losses during periods of acute heat mortality stress annually.

Research-based data are also meager on the effective environmental temperature (EET) for poultry that integrates the combined effects of air temperature, humidity, velocity, and possibly radiation, although tunnel ventilation (to increase air velocity and thus convective heat dissipation of the birds) has been routinely used in the industry to cool the birds. Timmons et al. (1995) proposed a new control algorithm that uses a time integrated thermal history of the birds as opposed to the conventional, instant thermal conditions, to better recover the heat stress accumulated during the hot period of the day. One critical issue that remains to be further investigated regarding this approach is the optimal time interval of integration, which will likely depend upon animal species, age, and acclimation history.

Current literature data on moisture production have a major limitation in that they represent only the latent heat loss from the birds. Although the data were appropriate for evaluation of bird thermoregulation, they would be incomplete as a database for building ventilation designs where heat and moisture from both the birds and their surroundings must be considered. The partition of total heat production into sensible and moisture modes is undoubtedly affected by the housing components (e.g., open trough drinker vs. nipple drinker), waste handling system (liquid vs. solid manure; belt vs. litter), and management schemes (e.g., manipulation of photoperiod). For instance, a recent study on young tom turkeys during 5-week brooding/growing period (Xin et al., 1998) revealed a 4% (for body mass= 0.1 kg) to 282% (for body mass = 1.0 kg) higher moisture production and a corresponding 2% to 107% lower SHP for the current study, as compared with those in the ASAE Standard (EP 270.5) (1998). Consequently, the discrepancy in the minimum ventilation requirement for moisture control ranged from 55 to 457% between the values based on the current moisture production data and the values of the literature recommendations (MWPS, 1990).

Related work: Studies related to the aerial environment

Aerial ammonia in poultry facilities is usually found to be the most abundant air contaminant. Ammonia concentration varies depending upon several factors including temperature, humidity, animal density and ventilation rate of the facility. Maghirang et al. (1991) concluded that overall air quality was poorest at locations furthest from the exhaust fans with significant differences in air temperature and NH_3 levels and that ventilation rate appears to be the most important factor influencing indoor air quality. Xin et al. (1996) showed that 8 to 9 times the normal minimum ventilation rate, i.e., for new bedding was required for NH_3 control on the first day of brooding for broiler houses using old litter.

The effect of aerial ammonia on bird performance has been widely studied. Birds exposed to ammonia showed reductions in feed consumption, feed efficiency, live weight gain, carcass condemnation, and egg production (Charles and Payne, 1966a; Quarles and Kling, 1974; Reece and Lott, 1980; Xin et al.,1987). High ammonia exposure was found by Xin et al. (1987) and Charles and Payne (1966b) to reduce respiratory rate by 7 to 25% in layers. The reduction of egg production under heat stress may have been related to the altered respiratory pattern (Xin et al.,1987).

Studies on the effects of dust in animal housing generally indicate potential for adverse effects on the health, growth and development of animals (Janni et al., 1985; De Boer and Morrison, 1988; Feddes et al., 1992). Respirable aerosol particles within poultry housing have been shown to decrease bird growth (Butler and Egan, 1974), increase disease transfer within flocks (Hugh-Jones et al., 1973; Beaseley et al., 1970; Simensen and Olson, 1980), and increase condemnation of meat at processing plants (Hugh-Jones et al., 1973). Dust might affect the health and the growth rate of livestock in four ways: 1) as a physical irritant of the respiratory tract; 2) as a carrier of toxic chemicals and odors; 3) as a carrier of pathogenic microorganisms; and 4) as a carrier of commensal, non-pathogenic bacteria (Harry, 1978). The size and shape of the dust particles determines the extent of penetration and deposition of the particles into the respiratory system. Dust helps to concentrate the non-pathogenic microorganisms to very high levels, which may interfere with normal function and predispose the animal to further health problems. In addition, dust absorbs and carries gases and moisture (Day et al., 1965; Burnett, 1969; Scott et al., 1983; Donham et al., 1986; Hinz and Krause, 1987) and can thus transport gases such as ammonia deep into the lungs (Hillman et al., 1988). Dust plays an important role in the transport of trace gas and odors inside and outside the animal building. Dust can also carry toxins (Attwood et al., 1987).

Ammonia and dust also interact to worsen the air quality impact. Results of air quality monitoring in commercial turkey grower barns have indicated that ammonia and dust are significant contributors to the incidence of air sacculitis and resulting condemnation in tom turkeys (Janni et al., 1984; Janni et al., 1985; Janni and Redig, 1986).

There are three basic methods used in an attempt to control air contaminant levels in poultry facilities: 1) Reduce contaminant production at the source; 2) Remove contaminants from the air; and/or 3) Reduce gas contaminant concentration by dilution (ventilation). The most effective method is to reduce release of contaminants from the source, or to at least intercept and remove them before they reach the workers and animals.

Sprinkling small quantities of vegetable oil on floors every day has reduced dust concentration by more than 80 percent in swine facilities (Zhang, et al., 1996). High animal activity levels release large quantities of particulates into the air, so management strategies to reduce agitation of animals are helpful. Electrostatic precipitators or room air filters can reduce dust problems and air scrubbers have the capability to remove gases and particulates, but practical, economical systems need to be developed.

Reducing ammonia generation might be obtained through the use of litter additives that affect ammonia release or by decreasing the amount of available substrate (organic nitrogen) through diet manipulation.

Litter pH has been shown to be a critical component in the control of ammonia release in floor rearing management conditions (Carr et al., 1980). Chemical additives which decrease litter pH appear to be most effective (Hulet, 1998). Recent research has emphasized alum application (Moore et al., 1995). Effectiveness appears to be influenced by other environmental conditions such as litter moisture and temperature. Developing predictive ammonia models with consideration of litter additives and including economic considerations is needed for making recommendations to producers.

Decreasing diet protein levels has the potential to decrease nitrogen excretion. Recent research at Kentucky (Ferguson et al., 1998a, 1998b) showed lowered litter nitrogen concentrations when broilers were fed diets with reduced protein content. However, some reduction in body weight was observed which could be corrected with supplemental lysine. Waibel (unpublished, University of Minnesota) has indicated the potential to reduce diet protein content in turkey diets to 50% of the NRC (1994) recommended levels with appropriate amino acid supplementation. The next step is to demonstrate the degree of reduction in nitrogen excretion and ammonia generation.

Related work: Studies related to the light environment and photoperiod

Several studies have shown that energy efficient compact fluorescent lamps do not adversely affect bird performance for layers (Darre and Spandorf, 1985; Darre, 1991a; Widowski, et al. 1992), or broilers (Zimmerman, 1986; Andrews and Zimmerman, 1990; Scheideler, 1990).

Longer lamp life along with energy and monetary savings have been shown to outweigh the initial cost of the lamps (Darre, 1986; Darre, 1991b; Darre and Rock, 1995). Other types of lamps, including high and low pressure sodium lamps, have been tested with broilers without adverse results (Zimmerman, 1986). More recently a variety of alternative lighting programs have been compared to 23 hours of light: 1 hour of dark for broilers with the observation that intermittent lighting schedules resulted in heavier body weights (Buyse et al. 1996). Gordon (1997) reported that reducing the hours of light provided to growing broilers also reduced mortalities due to sudden death and ascites. Classen et al. (1991) found programs with increasing photoperiod were superior to near continuous light for the health of growing broilers.

Studies on the quality of wavelength have been conducted in both laying hens (Pyrzak et al., 1986, 1987) and broilers (Prayitno et al. 1997) showing that birds will respond to all wavelengths of light, but broilers may be more active under red light than under blue or green, but grow to slightly heavier weights under green lights. Widowski et al. (1992) showed that laying hens prefer compact fluorescent lamps over incandescent lamps. What is lacking in the literature are studies defining the interaction of wavelength, intensity and duration on layer performance or broiler growth and the use of newer energy efficient lighting devices, such as the electronic lamps, electronic ballasts for CF lamps and high pressure sodium lamp dimming devices.

Related work: Leg disorders, perch design and behavior

Leg disorders in broilers are due to a large number of bone, muscle and tendon deformations of different pathology and are often of multi-factorial origin (Nairn and Watson, 1972; Riddell, 1981; Pierson and Hester, 1982; Classen, 1992; Edwards, 1992; Leach and Lilburn, 1992). Important factors contributing to the high incidence of leg abnormalities are genetic selection and the use of high-energy diets for rapid growth (Rizk et al., 1980; Nestor, 1984; Edwards and Sorensen, 1987; Lilburn et al., 1989; Leterrier, 1992). Other factors, such as environmental quality (for review see Hester, 1994), and the level of exercise of the birds (Newberry et al., 1988; Farm Animal Welfare Council, 1992; Kestin et al., 1992; Elson, 1993) may also play a very important role in the incidence of leg abnormalities.

Leg weakness and lameness can have immediate results such as decreased food and water consumption and litter eating (Rowland, 1989; Kestin et al., 1992). Increasing the level of activity in broilers might be one of the most cost-efficient and practical management procedures to reduce leg abnormalities (Hester, 1994). In fact, many positive results obtained with different lighting programs (Hester et al., 1983; Classen and Riddell, 1989; Renden et al., 1991), and feed restriction programs (Rizk et al., 1980; Lilburn et al., 1989) may be due to the higher level of activity of the birds under those conditions (Hester et al., 1983; Lilburn et al., 1989; Hester, 1994).

Although there are several methods to increase the level of exercise of the birds such as to increase availability of space (Estevez et al., 1997), perches have been used extensively in different avian species to increase exercise. Perch use has been shown to increase laying hen bone strength (Hughes and Appleby, 1989; Knowles and Broom, 1990; Appleby and Hughes, 1990; Duncan et al., 1992), increase trabecular bone volume (Appleby et al., 1992b) and increase tibial mass (Hughes et al., 1993). Perches improve the health and well-being of laying hens (Appleby et al., 1992a; Appleby, 1994; Duncan et al., 1992).

Despite the potential benefits of perch use by broilers, few studies have examined its application in the production of broilers (Hughes and Elson, 1977; Simpson and Nakaue, 1987; Reilly et al., 1991, 1992; Newberry and Blair, 1993; Newberry et al., 1995) or broiler breeders (Muiruri et al., 1990, 1991, Muiruri and Harrison, 1991a, 1991b). Perches reduced wing flapping during catching prior to transport, which could reduce injuries (Newberry and Blair, 1993). Perches also improve growth rate and might play an important role in reducing heat stress if their design is adequately combined with a cooling system (Muiruri et al., 1990; Reilly et al., 1991).

Current work: Pulmonary hypertension syndrome (PHS, ascites)

Any one or more of the following general factor categories can cause PHS: genetics, nutrition, management, environment, incubation, and disease. The specific factors that appear to be most important include: inadequate environmental conditions during incubation (Odom, 1993), limit oxygen uptake by the blood in the lung (i.e., respiratory disease, high altitude), inadequate house ventilation (ammonia, dust, or carbon monoxide build-up), or factors that increase the need and use of oxygen, such as an increase in basal metabolic rate with cold exposure, and rapid somatic body growth (for an excellent review, refer to Julian, 1993 and Wideman et al., 1995).

Interactions between the general and specific causative factors may lead to a similar endpoint in this disease (i.e., PHS). Chronic pulmonary hypertension as a physiological consequence of interactions has been suggested by researchers (Huchzermeyer and DeRuyck, 1986; Julian, 1993; Maxwell et al., 1986; Peacock et al., 1989) as being the primary causative factor.

In mammal research, it has been shown that the production of vasoactive compounds such as synthesis of nitric oxide (NO, the endothelium derived relaxing factor, Palmer et al., 1987; Palmer et al., 1988) and synthesis of endothelin-1 (ET-1, a powerful endothelium-derived vasoconstrictor, Yanagisawa et al., 1988) participates in the regulation of vascular function (Rees et al., 1989). Furthermore, the biosynthesis of NO occurs within endothelial cells via L-arginine (L-arg) and synthesizes the formation of L-citrulline and NO. Under certain conditions, treatment *in vitro* and *in vivo* with L-arg attenuated the constriction and augmented the relaxation of blood vessels (Eddahibi et al., 1992; Imaizumi et al., 1992). These results suggest that the basal endothelial synthesis of NO from L-arg and/or the release of NO, contribute to normal vascular tone (Eddahibi et al., 1992; Imaizumi et al., 1992; Palmer et al., 1987; Palmer et al., 1988).

Additionally, researchers have suggested that the availability of endogenous L-arg is an important limiting factor for NO synthesis (Eddahibi et al., 1992; Imaizumi et al., 1992; Kuo et al., 1992; Palmer et al., 1988). In some diseases such as pulmonary and essential hypertension and atherosclerosis (Kuo et al., 1992; Panza et al., 1993) or in experimental models of acute and chronic hypoxic pulmonary hypertension (Adnot et al., 1991; Eddahibi et al., 1992; Johns et al., 1989; Liu et al., 1991), the synthesis of NO may be reduced because of a lack of L-arg substrate or another flaw in the NO signaling cascade. The precise mechanisms of the endothelial cell impairment remain to be fully established.

L-arg is an essential amino acid for avian species. Birds lack the enzyme carbamoyl phosphate synthase (Tamir and Ratner, 1963a; Tamir and Ratner, 1963b) required for L-arg synthesis. Therefore, the bird has to ingest, absorb and circulate dietary arginine for normal endothelial cell NO production. Supplementing L-arg in the chicken diet at levels higher than required for adequate growth rate may allow synthesis of more NO in the chicken and may influence disease resistance (Dietert et al., 1994; Taylor et al., 1992) especially to PHS (Wideman et al., 1995).

Current work: Modeling technical and economic responses

The scientific effort is directed toward the end of predicting via the means of understanding. Its superstructure is built on the faith that causal relationships are inherent in all phenomena. Therefore, the charge of the scientist is to systematically proceed toward discovery, revelation and utilization of these intrinsic properties. Modeling is a methodology that assists in accomplishing this charge by abstracting from reality in a manner that maintains the essential inherent causal relationships but reduces complexity enough so that explanatory and thereby inference powers are enhanced.

Rahn (1977) presented a way that strategic planning models can be used to make economic-based decisions that incorporate both physical relationships and market conditions. Also, since both physical relationships and market conditions are time related, dynamic economic models typically need to consider investments in assets that will yield flows of services over more than one time period, likely have an impact on income tax considerations as well as explicit time value of money considerations. Rahn (1978) presented a modeling procedure that can be used to appropriately appraise capital expenditures and their associated net revenue streams. Both of these techniques are complementary to other project activities focused on discovering and characterizing causal relationships of poultry to environmental factors and are crucial in ascertaining their economic merit and commercial adoption prospects.

Artificial Intelligence and Operations Research Methods offer systematic methods of distilling information for making prescriptive decisions. Collaborative studies carried out between AR and PA have shown that artificial neural network models can be developed based on physiological inputs and outputs for diagnosis of ascites in broilers (Roush et al., 1996, 1997).

It is interesting to note that the Edelman prize for Management Science Achievement (given by the Institute for Operations Research and the Management Sciences) was given to Sadia, a poultry company in Brazil. Using the principles of operations research, the company saved over $50 million over a three year period as a result of (1) better conversion of feed to live bird weight, (2) improved utilization of birds to produce more than 300 products classified by weight range, taking into account weight variation between and within flocks; (3) almost 100 percent fulfillment of daily production plans with increased output of higher value products; (4) greater flexibility and reduced lead time in meeting market demand; and (5) timely and wide ranging studies of different price and demand scenarios (Taube-Netto, 1996). The limited application of Operations Research/Management Science application in poultry science research in the USshould give cause for concern for poultry scientists.

OBJECTIVES:

1. To characterize physiological and behavioral responses of poultry to critical environmental factors.
2. To develop dynamic models of these responses for optimizing technical and economic aspects of poultry production systems.

PROCEDURES:

Objective 1: Characterize physiological and behavioral responses of poultry to critical environmental factors

Thermal Environments

The effects of hot environments on poultry well-being and production are well documented. As ambient temperature increases above thermoneutrality, feed consumption and growth rate decrease and abrupt extreme thermal stress produces significant losses in all production settings. As temperature rises, animals increasingly rely on latent heat loss; when high temperatures are combined with high humidities, the effects can be devastating. These adverse effects include elevated mortality, reduced growth rate, reduced egg production and quality, and disrupted physiological and behavioral equilibrium.

In the following protocols, various techniques and or technologies developed under the current NE-127 will be used. Calorimeters were designed at **NE** and built jointly by **NE** and **MD**; and others were built at **IA** and **IL**. Each of these calorimeters was designed to evaluate a specific animal-environment interaction and their uses are mutually complementary. Cool roosts were initially experimented with at **IL** and their use and applicability were tested in cooperation with **MD**.

Specific Experimental Protocols:

1) **NE** and **MD**, in collaboration with **IL** and **IA** will determine the relative effects of air temperature (T) (25-40°C), relative humidity (RH) (40-80%), and velocity (V) (0.2-2.0 m/s) in broiler chickens at 5, 6, 7 and 8 weeks of age (after they reach homeothermy). Four identical indirect calorimeters (1.2x1.5x1.5 m) will be used and modified as needed to generate the T-RH-V conditions. They are located within a 3.6x7.2x3.6 m environmental chamber that provides preconditioned air. Each bird will be exposed to a T-RH-V combination for 2 hours or until the body core temperature reaches 43°C. A PC-based, automatic measurement and data acquisition system will be used to continuously collect the following physiological response variables of the birds: respiration rate, core body temperature, CO_2 production rate, O_2 consumption rate, and moisture production rate. The procedures detailed above will be applied in subsequent studies to broiler chickens of the same ages under the same T-RH-V conditions, but with modification of the **NE** calorimeters to provide cool roosts for perching and for use as a heat sink. This study will also contribute data to development of temperature-humidity index (THI) at various air velocities for broilers as described in objective 2.

2) **MD,** in collaboration with **IL** and **NE,** will investigate the effects of conductive heat transfer on the incidence of leg problems in broilers during periods of heat stress. Cold water perch systems of various designs and at various locations within pens will be evaluated.

3) **NE** and **IA** will address basic and applied aspects of laying hen responses to thermal stress; basic mechanisms will be investigated at **NE** and applied commercial evaluations at **IA**. In addition, **IA** and **NE** will jointly evaluate the efficacy of the low pressure sprinkling versus high pressure fogging developed at **IA** versus cool roosts in alleviating heat stress in hens. **IA** will develop the control algorithm and collect data on production and the environment; **NE** will investigate hormonal, immunological and cellular affects of heat stress, including samples from hens in the **IA** studies. **IA**, in collaboration with **IL** and **NE** will evaluate the various

cooling methodologies on physiological responses in simulated laboratory heat stress conditions.

4) **IA**, in collaboration with **IL**, will systematically measure heat production (HP) and moisture production (MP) data for modern poultry strains reared under current housing and management systems. Precise data are critical for proper design and operation of ventilation systems. Lab-scale measurements will be conducted to differentiate HP and MP of the bird from those of the system. Field measurements will also be conducted to verify partitioning of total heat production (THP) into sensible heat production (SHP) and MP. These new data will be used to update the literature and ventilation recommendations.
5) The data collected in the above studies will be analyzed for their economic ramifications by **MI** (see Objective 2).
6) Nonlinear models will be developed by **PA** with artificial intelligence tools, of temperature and humidity relationships to biological responses from the above studies (see Objective 2).

Expected Outcomes:

Broiler responses to temperature-humidity combinations change with age and body size. The cool roosts are expected to decrease the effect of humidity, reduce panting stress, and reduce incidence of leg problems. Laying hen experiments will provide a better understanding of basic mechanisms disrupted by heat stress. The efficacy of the high-pressure fogging and the low-pressure sprinkling systems as cost-effective alternative(s) for air quality control in caged layer houses will be demonstrated. If proven technically desirable, guidelines on the system design and operation will be established. An updated HP and MP database will be established for more precise design and operation of environmental control systems.

Aerial Environment

Ammonia and dust are major factors affecting both flock performance and worker health. In addition as production units concentrate in small areas, release of ammonia and dust becomes an environmental concern. Effective strategies need to be identified to abate gas and dust emissions in order to improve flock health and lessen worker exposure.

Specific Experimental Protocols:

IL and **MN** will investigate the application of vegetable-based oils to manure and litter. An initial study will be done by **IL** to determine the potential of spraying a small amount of vegetable oil onto manure surfaces on alternate days for reducing dust and gas emissions in laying hen facilities. Individually caged hens will be placed in the **IL** Convective Calorimeter and Mass Gas Generation Chamber (I-CAG) for periods of about two weeks. Each test will run for about two weeks. Environmental conditions in the chambers will be controlled to operate at thermoneutral conditions. The manure will accumulate and undergo anaerobic decomposition by the second week. Data collected will include: ammonia levels, hydrogen sulfide levels, dust levels, oxygen consumption, carbon dioxide production, and water production. **MN** will extend oil application to litter based housing systems for turkeys in anticipation of production times most likely to result in high levels of dust from bird activity (e.g., loadout for marketing) and during times of low relative humidity (e.g., the winter season). Dust will be measured and comparisons will be made between a control and various oil application regimens.

IA will examine the efficacy of fogging and sprinkling water inside commercial high-rise layer houses on reduction of aerosols, especially ammonia and dust. For aerosol suppression, water application rate and application intervals will be determined by monitoring the dynamic profiles of the aerosols following each application.

MD, MN, NE, and **IA** will collaborate to collect data and develop/refine models of ammonia release from broiler litter and turkey litter. Ammonia levels will be measured in chambers or production units with different temperatures and relative humidity, litter moisture, pH and ventilation rates. Litter additives, such as alum, ferrous sulfate or other sulfur-based compounds, will be used as recommended by the manufacturer. Combinations of litter additives and ventilation rates will be tested. Weekly manure analysis of the litter base for N, P, K and other minor elements will be determined at **MD**. Bird performance, processing, feed and non-feed data and water use data will also be collected.

MN will collaborate with **IA** to determine the effect of feeding reduced diet protein on ammonia production in turkey facilities. Previous research has been conducted to determine the extent of dietary protein reduction that can be accomplished with utilization of supplemental amino acids. Intact protein diet series will be compared with a reduced protein diet supplemented with appropriate amino acids expected to provide adequate growth. Turkeys will be acclimated to chambers and diets prior to determination of total nitrogen balance.

Economic assessment of the results will be made with the collaboration of **MI**.

Expected Outcomes:

Results from these synergistic studies will provide a database for *Objective 2* in developing predictive models on ammonia generation. They will provide practical alternatives and recommendations for ammonia and dust control under commercial conditions.

Responses to Physical Environment

Perch Design

Leg problems in broilers cause financial losses of $80 to $120 million per year because of poor feed conversion, culling and high mortality. Lack of physical activity is directly related to increased incidence of leg problems. One of the most effective and widely used methods for increasing activity levels without increasing available floor space is to provide the birds with perches.

Specific Experimental Protocols:

MD and **IL** will collaborate to study reduction of leg disorders by increasing level of activity and exercise using perch designs adapted to the physical conditions of broilers throughout their life (e.g. horizontal vs. perches at an angle). Potential benefits of perch availability on leg disorders at high rearing densities will also be studied.

Expected Outcomes:

Data generated from these studies will be used to formulate recommendations for perch design and application to poultry systems for improved bird performance and well-being.

Light Environment

Spectral quality, intensity and duration of light/dark cycles are primary concerns in poultry production, but cost effectiveness is a primary factor in the adoption of energy-efficient lighting devices by poultry producers. As new devices come on the market, there is a hesitancy to be the first to use it on a commercial poultry farm. Sound research data is required to encourage adoption of these lamps by producers.

Specific Experimental Protocols:

CT, **MD** and **NE** will collaborate on studies of the effects of light environment on chickens. The studies will examine the light sensitivity of poultry to various sources of illumination: incandescent, fluorescent (miniature and circular types), mercury vapor, and high- and low-pressure sodium lamps. These studies will examine the behavior, growth and production of different strains of layers and broiler exposed to different sources and intensities of illumination. Data analysis using artificial neural network will predict the proper lighting levels and or types for different strains of birds. Economics of the lighting systems will be evaluated in collaboration with **MI**.

Expected Outcomes:

Lighting equipment and programs will be recommended to save electrical energy, increase production efficiency of the birds, and improve their well-being.

Pulmonary Hypertension Syndrome (Ascites)

Research by TX has suggested that pulmonary hypertension can be underscored by an unbalanced pulmonary vascular arterial tone and is consistent with the theory that inadequate synthesis and or release of nitric oxide may contribute to an additional impairment with hypoxia (due to an inequality between rapid somatic growth and cardio pulmonary function).

Specific Experiment Protocol

TX will elucidate the role of the vascular endothelium responses using an invasive (isolated vessel assay) and non-invasive techniques (electrocardiograph and echocardiography) to study PHS. Diet supplements will be developed toward the prevention of PHS. AR will examine the role of air quality in PHS development in broilers.

Expected Outcomes

Certain specifications for environmental conditions to prevent ascites in broilers will be established.

Objective 2: To develop dynamic models of these responses for optimizing technical and economic aspects of poultry production systems

1) Broiler THI model

Data from Objective 1-1 will be used in a multi-dimension rotatable composite design (Montgomery, 1991), with data analyzed by RSREG regression procedure of SAS (1985), using the following equation:

$$y = c_0 + c_1 T + c_2 H + c_3 V + c_4 T^2 + c_5 H^2 + c_6 V^2 + c_7 TH + c_8 TV + + c_9 HV + c_{10} THV + e$$

where

y = physiological response variable

T = dry bulb temperature, °C
H = relative humidity, %
V = air velocity, m/s
c_i = independent coefficients
e = random error

Calculation of the THI at each air velocity will be based on the following equation:

$$y = c_0 + c_1 T_{db} + c_2 T_{wb}$$

where

y = dependent physiological variable
c_i = independent coefficients
T_{db} = dry-bulb temperature
T_{wb} = wet-bulb temperature

$$THI = \frac{c_1}{c_1 + c_2} T_{db} + \frac{c_2}{c_1 + c_2} T_{wb} \qquad \text{(Xin } et\ al.\text{, 1992)}$$

2) Ammonia emission models

Data from Objective 1 will be used to build a predictive model for ammonia release from poultry facilities. Physical factors such as ventilation rate, litter pH, chamber temperature, humidity, and litter moisture will be used to confirm a previously developed model (Carr et al., 1987) and will be modified to include performance responses.

3) Economic models

Partial budgeting models will be specified and utilized to estimate – using representative and standardized market values – the potential receipt and expenditure stream changes implied by the performance results observed in the studied thermal environment states. These net receipt streams will be incorporated into discounted cash flow budgeting procedures and the financial attractiveness of the investments associated with each thermal environment evaluated and compared.

4) Artificial Intelligence and Operations Research Models

Artificial Intelligence and Operations Research Methods offer systematic methods of distilling information for making prescriptive decisions. Artificial neural network models can be developed based on physiological inputs and outputs.

Expected Outcomes:

The THI will change over time. Assuming that to be true, relating body surface area to mass might allow the generation of one THI that could be used for all ages tested. Whether one equation or four are generated, the predictive value of the equation(s) will be of benefit to the broiler industry in anticipating periods of critical T/RH combinations and their effects on health and survivability of birds. The availability of cool roosts will significantly alter the THI, because the birds will be able to dissipate considerable heat through conductive transfer to the roosts. Ammonia emission models will aid industry in management of the poultry house to improve production conditions, and provide data for improved sensor development. Economic model assessments of the investigated environmental modifications will provide an indication of the monetary benefits associated with their adoption and thus, their commercial viability.

Overall Expected Outcomes:

1. Increased knowledge of basic physiological processes in poultry.
2. Identification of more empirically meaningful environmental factor relationships and their associated economic ramifications.
3. Development of astute biophysical models that minimize variance and maximize economic return in poultry through enhanced management decision-making and action-taking initiatives

Organization:

The Technical Committee is responsible for the planning and supervision of the NE-127 Regional Research Project. The membership of this committee shall consist of an Administrative Advisor, a technical representative of each participating agency or experiment station, and representative of the USDA Cooperative States Research Service. Each participating agency or experiment station is entitled to one vote.

The Technical Committee shall be responsible for review and acceptance of contributing projects, preparation of reviews, modification of the regional project proposal, and preparation of an annual report. Annual written reports will be prepared by each technical committee member and distributed at the annual meeting. Annual reports will be complied and distributed to Technical Committee members and Agricultural Experiment Station Directors.

The Technical Committee will meet yearly and conduct an election for the office of Junior Executive. The position will alternate between Poultry Scientists and Agricultural Engineers. In odd numbered years Poultry Scientist(s) will be nominated; in even number years Agricultural Engineer(s) will be nominated. The person elected to serve as Junior Executive will rotate through the remaining offices of Senior Executive, Secretary and finally serving as Chair in the fourth year. All voting members of the Technical Committee are eligible for office.

The Chair prepares the meeting agenda and presides at meetings. The Chair is responsible for preparation of the annual report. The Secretary records minutes and assists the Chair. The Senior and Junior executives help with policy decisions and nominations.

The Technical Committee functions as a unit with sub-committees formed as necessary. i.e., preparing nominations for elections.

SIGNATURES:

Regional Project Title: Biophysical Models for Poultry Production Systems

Administrative Advisor
AA- William Saylor (DE) for AA

Aug 16, 1999
Date

Chair, Regional Association of Directors

Aug 16, 1999
Date

Administrator, Coperative State Research,
Educa tion and Extension Service

8/26/99
Date

REFERENCES:

Adnot, S., B. Raffestin, S. Eddahibi, P. Braquet, and P. Chabrier. 1991. Loss of endothelium-dependent relaxant activity in the pulmonary circulation of rats exposed to chronic hypoxia. J. Clin. Invest. 87:155-162.

Andrews, D. K. and N. G. Zimmerman. 1990. A comparison of energy efficient broiler house lighting sources and photoperiods. Poultry Sci. 69:1471-1479.

Appleby, M.C. 1994. Modified cages for laying hens: Future prospects. In: C.M. Sherwin (Editor), Modified Cages for Laying Hens. Proceedings of a Symposium held at Nobel House, London on 18th January 1993. Universities Federation for Animal Welfare, Potters Bar, Herts, pp. 95-98.

Appleby, M.C., Hughes, B.O. and Elson, H.A. 1992a. Poultry Production Systems: Behavior, Management and Welfare. CAB International, Wallingford, Oxon, UK.

Appleby, M.C., Smith, S.F. and Hughes, B.O. 1992b. Individual perching behavior of laying hens and its effects in cages. British Poultry Science, 33:227-238.

Appleby, M.C. and Hughes, B.O. 1990. Cages modified with perches and nests for the improvement of bird welfare. World's Poultry Science Journal, 46:38-40.

ASAE Standards Engineering Practices Data. 1997. Design of ventilation systems for poultry and livestock shelters. ISBN 0-929355-50-4. ASAE: St. Joseph, MI.

ASAE D270. 1986. Design of ventilation systems for poultry and livestock shelters (Data). Standards, 1986. American Society of Agricultural Engineers, SL Joseph, MI.

ASAE Standards Engineering Practices Data. 1997. Design of ventilation systems for poultry and livestock shelters. ISBN 0-929355-50-4. ASAE: St. Joseph, MI.

ASHRAE Handbook. Fundamentals. 1997. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA. pp10.1.

ASHRAE Handbook. Fundamentals. 1997. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA. pp10.1.

Attwood, P., R. Brouwer, P. Ruigewaard, P. Versloot, R. De Wit, D. Heederik, and J. S. M. Boleij. 1987. A study of the relationship between airborne contaminants and environmental factors in swine buildings. Am. Ind. Hyg. Assoc. 48:745-751.

Beaseley, J.N., L.T. Patterson and D.H. McWade. 1970. Transmission of Marek's disease by poultry house dust and chicken dander. Am. J. Vet. Res. 31(2):339-344.

Brown-Brandl, T.M., M.M. Beck, D.D. Schulte, A.M. Parkhurst, and J.A. DeShazer. 1997. Evaluation of temperature and humidity effects on physiological responses of tom turkeys from 6-21 weeks. Trans. ASAE 40:1:203-209.

Burnett, W.E. 1969. Odor transport by particulate matter in high density poultry houses. Poul. Sci. 48:182-185.

Butler, E.J. and B.J. Egan. 1974. Unidirectional air flow isolators: a review. World's Poultry Sci. 30:32-41.

Buyse, J., P.C.M. Simons, F. J. G. Boshouwers and E. Decuypere. 1996. Effect of intermittent lighting, light intensity and source on the performance and welfare of broilers. World's Poultry Science J. 52:121-130.

Carr, L.E., F. W. Wheaton and L.W. Douglass. 1987. Empirical models to determine ammonia concentrations from broiler chicken litter. ASAE Paper No. 87-4007. ASAE. SL Joseph MI.

Carr, L.E., J. L. Nicholson and J.P. Donohoe. 1980. Control of ammonia release in broiler litter. ASAE paper No. 80-451 1. ASAE. SL Joseph, MI.

Carson-Jurica, M.A., A.T. Lee, A.W. Dobson, O.M. Conneely, W.T. Schrader and B.W. O'Malley, 1989. Interaction of the chicken progesterone receptor with heat shock protein (HSP) 90. J. Steroid Biochem. 34:1-9.

Charles, D. R and C. G. Payne. 1966a. The influence of graded levels of atmospheric ammonia on chicks. I. Effects on the performance of laying hens. Brit Poultry Science. 7:177-187.

Charles, D. R. and C. G. Payne. 1966b. The influence of graded levels of atmospheric ammonia on chicks. II. Effects on the performance of laying hens. Brit Poultry Sci. 7:189-198.

CIGR. 1992. 2nd Report of Working Group on Climatization of Animal Houses, 2nd Ed. Gent, Belgium: Center for Climatization of Animal Houses - Advisory Services, Faculty of Agricultural Sciences, State University of Ghent. pp18-19.

Classen, H.L , 1992. Management factors in leg disorders. In: Whitehead, C.C (ed.) Bone Biology and Skeletal Disorders in Poultry. Carfax Publishing Co., Oxfordshire, England, pp. 195-211

Classen, H.L., and C. Riddell, 1989. Photoperiodic effects on performance and leg abnormalities in broiler chickens. Poultry Sci., 68:873-879.

Classen, H.L., C. Riddell and F.E. Robinson. 1991. Effects of increasing photoperiod length on performance and health of broiler chickens. Poultry Science 32: 21-29.

Darre, M. J. 1991a. Light management for growing pullets. Poultry Digest 50(6) 10-12.

Darre, M. J. 1991b. Lumen maintenance of energy efficient compact fluorescent lamps under commercial poultry farm conditions. Poultry Sci. 70(Suppl 1):33.

Darre, M. J. 1986. Energy efficient fluorescent lights reduce electric bills for poultrymen. Poultry Digest 44(528): 108-113.

Darre, M. J. and A. H. Spandorf. 1985. Energy efficient cost effective lights for use with poultry. Poultry Sci. 65 (Suppl. 2):85

Darre, M. J. and J. S. Rock. 1995. Lumen maintenance and lamp life of compact fluorescent lamps under commercial poultry house conditions. J. Appl. Poultry Res.. 4:105-108

Day, D.L., E.L. Hansen and S. Anderson. 1965. Gases and odors in confinement swine buildings. Trans. of the ASAE 8(1):118-121.

De Boer, S. and W.D. Morrison. 1988. The effects of the quality of the environment in livestock buildings on the productivity and safety of humans, a literature review. Dept. of Animal Science, University of Guelph, Guelph, Ontario.

Deaton, J.W., Reece, F.N. and McNaughton, J.L. 1978. The effect of temperature during the growing period on broiler performance. Poultry Science, 57:1070-1074.

Dietert, R.R., K.A. Golemboski, and R. E. Austic. 1994. Environment-immune interactions. Poultry Sci. 73:1062-1076.

Donham, K.J., L.J. Scallon, W. Poppendorf, M.W. Treuhaft and R.C. Roberts. 1986. Characterization of dusts collected from swine confinement buildings. Am. Ind. Hygiene Assoc. 47(7):404-410.

Duncan, E.T., Appleby, M.C. and Hughes, B.O. 1992. Effect of perches in laying cages on welfare and production of hens. British Poultry Science, 33:25-35.

Eddahibi, S., S. Adnot, C. Carville, Y. Bloquit, and B. Raffestin, 1992. L-arginine restores endothelium-dependent relaxation in pulmonary circulation of chronically hypoxic rats. Am. J. Physiol. 263:L194-L200.

Edwards, H.M., Jr. 1992. Nutritional factors and leg disorders. In: Whitehead, C.C. (ed.). Bone Biology and Skeletal Disorders in Poultry. Carfax Publishing Co., Oxfordshire, England, pp. 167-193.

Edwards, H.M., Jr., and P. Sorensen. 1987. Effect of short fasts on the development of tibial dyschondroplasia in chickens. J. Nutr., 117:194-200.

Elson, A., 1993. Housing systems for broilers. The IV European Symposium on Poultry Welfare, pp. 177-184.

Estevez, I, Newberry, R.C, and Arias de Reyna, L. 1997. Broiler chickens: A tolerant social system. Etologia (In Press).

Estevez, I. (1994). Efecto del tamano de grupo y de las condiciones demanejo en el comportamiento y uso del espacio de pollos broiler (Gallus gallus). Unpublished Ph.D. Thesis, University of C"rdoba, Spain.

Farm Animal Welfare Council. 1992. Report on the Welfare of Broiler Chickens. FAWC, Tolworth Tower, Surbiton, Surrey.

Feddes, J.J.R., B.S. Koberstein, F.E. Robinson and C. Ridell. 1992. Misting and ventilation rate effects on air quality, and heavy tom turkey performance and health. Can. Agric. Eng. 34:177-181.

Ferguson, N.S., R.S. Gates, J.L. Tarabo, A.H. Cantor, A.J. Pescatore, M.L. Straw, M.J. Ford and D.J. Burnham. 1998a. Effect of dietary protein and phosphorus on ammonia concentration and litter composition in broilers. Poultry Sci. 77:1085-1095.

Ferguson, N.S., R.S. Gates, J.L. Tarabo, A.H. Cantor, A.J. Pescatore, M.L. Straw, M.J. Ford and D.J. Burnham. 1998b. Effect of dietary crude protein on growth, ammonia concentration and litter composition in broilers. Poultry Sci. 77:1481-1487.

Flynn, B.M., P.C. Harrison, H. W. Gonyou, and F. E. Staten. 1984. Effect of ambient and roost temperature on hen production. Poultry Sci. 63(Suppl) :101-102

Gates, R.S., D.G. Overhults, and S.H. Zhang. 1996. Minimum ventilation for modern broiler facilities. Trans. of the ASAE 39(3):1135-1144.

Gordon, S. H. 1997. Effect of light programmes on broiler mortality with reference to ascites. World's Poultry Sci J. 53:68-70.

Han, T. and H. Xin. 1997. Performance and energetics of neonatal chicks as influenced by intermittent "in-transit" lighting regimens. Proc. of the 5th International Livestock Environment Symposium, May 29-31, 1997, Minneapolis, MN, pp948-953.

Hansen, K. and M. M. Beck. 1997. Heat stress, estrogen implants and calcium uptake in duodenum of hens. Poultry Sci. 76(Suppl.):26.

Harry, E.G. 1978. Air pollution in farm buildings and methods of control: a review. Avian Pathology 7:441-454.

Hester, P., 1994. The role of environment and management on leg abnormalities in meat-type fowl. Poultry Science, 73:904-915.

Hester, P.Y., R.G. Elkin, and P.M. Klingensmith. 1983. Effects of high density step-up and low-density step-down lighting programs on the incidence of leg abnormalities in turkeys. Poultry Sci., 62:887-896.

Hillman, P.E., K.G. Gebremedhin and R.G. Warner. 1988. Ventilation system to control airborne bacteria, dust, and ammonia in intensive calf housing. In: Proceedings of the 3rd Livestock Environment Symposium, 25-27 April, Toronto, Ontario, Canada, ASAE Publication 1-88. St. Joseph, MI.

Hillman, P.E., Scott, N.R. and A. van Tienhoven. 1985. Physiological responses and adaptation to hot and cold environments. Ed, M.K. Yousef. In: Stress Physiology in Livestock, vol. 3 Poultry:1-71. CRC Press. Boca Raton, Florida.

Hillman, P.E., Scott, N.R. and A. van Tienhoven. 1982. Vasomotion in chicken foot: dual innervation of arteriovenous anastomoses. Am. J. Physiol., 242:R582-R590.

Hinz, T. and K. Krause. 1987. Emission of respiratory biological- mixed aerosols from animal houses. In: Environmental aspects of respiratory diseases in intensive pig and poultry houses, including the implications to human health. J.M.Bruce and M.Sommer (eds.), pp.81-89. Commission of the European Communities Report EUR 1O82OEN. Luxembourg.

Huchzermeyer, F.W. and A.M.C. DeRuyck. 1986. Pulmonary hypertension syndrome associated with ascites in broilers. Vet Rec.119:93.

Hughes, B.O. and M. C. Appleby. 1989. Increase in bone strength of spent laying hens housed in modified cages with perches. Veterinary Record, 124:483-484.

Hughes, B.O. and H. A. Elson. 1977. Use of perches by broilers in floor pens. British Poultry Science, 18:715-722.

Hughes, B.O., Wilson, S.C., Appleby, M.C. and S. F. Smith. 1993. Comparison of bone volume and strength as measures of skeletal integrity in caged laying hens with access to perches. Research in Veterinary Science, 54(2):202.

Hugh-Jones, M., W.H. Allan, F.A. Dark and G.J. Harper. 1973. The evidence for the airborne spread of Newcastle disease. J. Hygiene 71:325-339.

Hulet, R. M. 1998. Strategies to control ammonia in poultry facilities. In Proceedings 14th Minnesota Poultry Service Workshop, pp. 11-12. University of Minnesota, St. Paul, MN.

Hutchinson, J.C.D. and A. H. Sykes. 1953. Physiological acclimatization of fowls to a hot humid environment. Journal of Agricultural Science, 43:294-322.

Imaizumi, T., Y. Hirooka, H. Masaki, S. Harada, M. Momohara, T. Tagawa, and A. Takeshita. 1992. Effects of L-arginine on forearm vessels and responses to acetylcholine. Hypertension 20:511-517.

Ingram, D.L. 1964. The effect of environmental temperature on body temperature, respiratory frequency, and pulse rate in the young pig. Res. Vet. Sci. 5(3):348-356.

Janni, K.A. and P.T. Redig. 1986. Factors affecting the occurrence of aspergillosis in turkeys. Paper No. 86-4533. ASAE, St. Joseph, MI.

Janni, K.A., P.T. Redig, J.R. Mulhausen and J.A. Newman. 1985. Turkey grower barn monitoring results. Paper No. 85-4527. ASAE, St. Joseph, MI.

Janni, K.A., P.T. Redig, J.A. Newman and J.R. Mulhausen. 1984. Respirable aerosol concentrations in turkey grower buildings. Paper No. 84-4522. ASAE, St. Joseph, MI.

Johns, R.A., J.M. Linden, and M.J. Peach. 1989. Endothelium-dependent relaxation and cyclic GMP accumulation in rabbit pulmonary artery are selectively impaired by moderate hypoxia. Circ. Res 65:1508-1515.

Julian, R.J. 1993. Ascites in poultry. Avian Pathol. 22:419-454.

Kestin, S.C., Knowles, T.G. Tinch, A.E. and N. G. Gregory. 1992. Prevalence of leg weakness in broiler chickens and its relationships with genotype. Veterinary Record, 131:190-194.

Knowles, T.G. and D. M. Broom. 1990. Limb bone strength and movement in laying hens from different housing systems. Veterinary Record, 126:354-356.

Kuo, L., M. J. Davis, M.S. Cannon, and W.M. Chilian. 1992. Pathophysiological consequences of atherosclerosis extend into the coronary microcirculation. Circ. Res. 70:465-475.

Leach, R.M., Jr., and M.S. Lilburn. 1992. Current knowledge on the etiology of tibial dyschondroplasia in the avian species. Poultry Sci. Rev. 4:57-65.

Leterrier, C. 1992. Etude des deformations osseuses du membre inferieur du poulet lors du syndrome pattes tordues. Ph.D. Thesis, Universite Claude Bernard-Lyon I, France.

Lilburn, M.S., T.J. Lauterio, K. Ngiam-Rilling, and J.H. Smith. 1989. Relationships among mineral balance in the diet, early growth manipulation, and incidence of tibial dyschondroplasia in different strains of meat type chickens. Poultry Sci. 68:1263-1273.

Liu, S., D. E. Crawley, P.J. Barnes, and T.W. Evans. 1991. Endothelium-derived relaxing factor inhibits hypoxic pulmonary vasoconstriction in rats. Am. Rev. Respir. Dis. 143:32-37.

Louhelainen, K., J. Kangas, K. Husman, and E.O. Terho. 1987. Total concentrations of dust in the air during farm work. European J of Respiratory Diseases 71(Supp No. 152):73-79.

Maghirang, R.G., H.B. Manbeck, W.B. Roush and F. V. Muir. 1991. Air contaminant distributions in a commercial laying house. Trans-ASAE. 34:2171-2180.

Mahmoud, K.Z., M.M. Beck, S.E. Scheideler, M.F. Forman, K.P. Anderson and S.D. Kachman. 1996. Acute high environmental temperature and calcium-estrogen relationships in the hen. Poultry Sci. 75:1555-1562.

Maxwell, M., G. Robertson, and S. Spence. 1986. Studies on an ascitic syndrome in young broilers. 1. Haemotology and pathology. Avian Pathol. 15:511-524.

Montgomery, D.C. 1991. Design and Analysis of Experiments, 3rd Ed. New York, NY:Wiley & Sons.

Moore, P.A., Jr., T.C. Daniel, D.R. Edwards, and D.M. Miller. 1995. Effect of chemical amendments on ammonia volatilization from poultry litter. J. Env. Quality 24:293-300.

Muiruri, H.K. and P.C. Harrison. 1991a. Effect of peripheral foot cooling on metabolic rate and thermoregulation of fed and fasted chicken hens in a hot environment. Poultry Science, 70:74-79.

Muiruri, H.K. and P.C. Harrison. 1991b. Effect of roost temperature on performance of chickens in hot ambient environments. Poultry Science, 70:2253-2258.

Muiruri, H.K., Harrison, P.C. and H. W. Gonyou. 1991. The use of water-cooled roost by hens for thermoregulation. Applied Animal Behavior Science, 28:333-339.

Muiruri, H.K., Harrison, P.C. and H. W. Gonyou. 1990. Preferences of hens for shape and size of roosts. Applied Animal Behavior Science, 27:141-147.

Nairn, M.E., and A.R.A. Watson. 1972. Leg weakness of poultry-A clinical and pathological characterization. Aust. Vet. J. 48:645-656.

Nestor, K.E. 1984. Genetics of growth and reproduction in the turkey. 9. Long-term selection for increased 16-week body weight. Poultry Sci. 63:2114-2122.

Newberry, R.C. and R. Blair. 1993. Perches ease handling of broiler chickens. In: C.J. Savory (Editor), Proceedings of the 4th European Symposium on Poultry Welfare. Edinburgh, Scotland, September 18-21. Universities Federation for Animal Welfare, Potters Bar, Herts.

Newberry, R.C., Blair, R., Gill, S. and M. Knott. 1995. Health of broilers reared under two patterns of increasing light and with access to perches. Poultry Science, 74(Suppl.1):84.

Newberry, R.C., Hunt, J.R. & E.E. Gardiner. 1988. Influence of light intensity on behavior and performance of broiler chickens. Poultry Science, 67:1020-1025.

Novero, R.P., M.M. Beck, E.W. Gleaves, A.L. Johnson and J.A. DeShazer. 1991. Plasma progesterone and luteinizing hormone concentrations, and granulosa cell responsiveness, in heat-stressed hens. Poultry Sci. 70:2335-2339.

NRC, 1994. Nutrient Requirements of Poultry, 9th revised edition. National Research Council. National Academy Press. Washington D.C.

Odom, T. W. 1993. Ascites syndrome: Overview and update. Poult. Dig. 52:14-22.

Palmer, R.M.J., D.S. Ashton, and S. Moncada. 1988. Vascular endothelium cells synthesize nitric oxide from L-arginine. Nature 333:664-666.

Palmer, R.M.J., A.G. Ferrige, and S. Moncada. 1987. Nitric oxide release accounts for the biological activity of endothelium-derived relaxing factor. Nature 327:524-526.

Panza, J.A., P.R. Casino, D.M. Badar, and A.A. Quyyumi. 1993. Effect of increased availability of endothelium-derived nitric oxide precursor on endothelium-dependent vascular relaxation in normal subjects and in patients with essential hypertension. Circulation 87 No 5:1475-1481.

Patel, V.C., R.W. McClendon, and J. W. Goodrum. 1996. Detection of cracks in eggs using color computer vision and artificial neural networks. AI Applications 10(3):19-28.

Payne, C.G. 1967. The influence of environmental temperature on egg production. In Environmental Control in Poultry Production, ed. J.C. Carter. London, England: Oliver & Boyd.

Peacock, A.J., C. Pickett, K. Morris, and J.T. Reeves. 1989. The relationship between rapid growth and pulmonary hemodynamics in the fast-growing broiler chicken. Am. Rev. Respir. Dis. 139:1524-1530.

Pierson, F.W., and P.Y. Hester. 1982. Factors influencing leg abnormalities in poultry. A review. World's Poultry Sci. J. 38:5-17.

Prayitno, D. S., C. J. C. Phillips and H. Omed. 1997. The effects of color of lighting on behavior and production of meat chickens. Poultry Sci. 76:452-457.

Pyrzak, R., N. Snapir, G. Goodman, E. Arnon and M. Perek. 1986. The influence of light quality on initiation of egg lying by hens. Poultry Sci. 64:1617-1622.

Pyrzak, R., N. Snapir, G. Goodman and M. Perek. 1987. The effect of light wavelength on the production and quality of egg of the domestic hen. Theriogenology 28:947-960.

Quarles, C.L. and H.F. Kling. 1974. Evaluation of ammonia and infectious bronchitis vaccination stress on broiler performance and carcass quality. Poultry Sci. 53:1592-1596

Rahn, A.P. 1978. A capital expenditure analysis teaching aid. Poultry Sci. 57:1503-1507.

Rahn, A.P. 1977. A strategic planning model for commercial laying flocks. Poultry Sci. 56:1579-1584.

Reece, F. N. and B. D. Lott 1982. Heat and moisture production of broiler chickens during brooding. Poultry Sci. 61:661-666.

Reece, F.N. and B.D. Lott. 1982. The effect of environmental temperature on sensible and latent heat production of broiler chickens. Poultry Science 61:1590-1593.

Reece. F. B and D.B. Lott. 1980. The effect of ammonia and carbon dioxide during brooding on the performance of broiler chickens. Poultry Sci. 59:1654.

Reece, F.N., Deaton, J.W. and L.F. Kubena. 1972. Effects of high temperature and humidity on heat prostration of broiler chickens. Poultry Science, 51:2021-2025.

Reece, F.N. and B.D. Lott. 1983. The effects of temperature and age on body weight and feed efficiency of broiler chickens. Poultry Science, 62:1906-1908.

Rees, D.D., R.M.J. Palmer, and S. Moncada. 1989. Role of endothelium-derived nitric oxide in the regulation of blood pressure. Proc. Natl. Acad. Sci. USA 86:3375-3378.

Reilly, W.M., Harrison, P.C. and H. W. Gonyou. 1992. Thermoregulatory perching behavior of commercial broilers of different ages. Journal of Animal Science, 70:(Suppl.1):171.

Reilly, W.M., Koelkebeck, K.W. and P.C. Harrison. 1991. Performance evaluation of heat stressed commercial broilers provided water-cooled floor perches. Poultry Science, 70:1699-1703.

Renden, J.A., S.F. Bilgili, R.J. Lein, and S.A. Kincaid. 1991. Live performance and yields of broilers provided various lighting schedules. Poultry Sci. 70:2055-2062.

Riddell, C. 1981. Skeletal deformities in poultry. Adv. Vet. Sci. Comp. Med. 25:277-310.

Rizk, S.W., P.E. Stake, and R.W. Simons, III. 1980. Curled toes and perosis-like leg abnormalities in caged reared broilers. Poultry Sci. 59:308-315.

Roush, W.B. and T. L. Cravener. 1997. Artificial neural network prediction of amino acid levels in feed ingredients. Poultry Science. 76:721-727.

Roush, W.B., Y. Kochera, Kirby, T.L. Cravener, and R.F. Wideman, Jr. 1996. Artificial neural network prediction of ascites in broilers. Poultry Science 75:1479-1487.

Roush, W.B., T.L. Cavener, Y. Kochera Kirby, and R.F. Wideman, Jr. 1997. Probabilistic neural network prediction of ascites in broilers based on minimally invasive physiological factors. Poultry Science 76:1513-1516.

Rowland, G.N. 1989. Broiler leg problems: Some causes and effects. Poultry Digest, 48:52,54-56.

SAS Institute. 1985. SAS® User's Guide: Statistics Version, 5th Ed. Cary, NC:SAS Institute, Inc.

Scheideler, S. E. 1990. Research Note: Effect of various light sources on broiler performance and efficiency of production under commercial conditions. Poultry Sci. 69:1030-1033.

Scott, N.R., J.A. DeShazer and W.L. Roller. 1983. Effects of the thermal and gaseous environment on livestock. Chapter 7. In: Ventilation of Agricultural Buildings, M.A.Hellickson and J.N. Walker (eds.). ASAE Monograph No. 6. St. Joseph, MI.

Simensen, E. and L.D. Olson. 1980. Aerosol transmission of Pasteurella multocida in turkeys. Avian Diseases 24(4):1007-1010.

Simpson, G.D. and H. S. Nakaue. 1987. Performance and carcass quality of broilers reared on wire flooring, plastic inserts, wood slats, or plastic-coated expanded metal flooring each with or without padded roosts. Poultry Science, 66:1624-1628.

Staten, F.E., E. M. Kreider and P.C. Harrison. 1986. The influence of roost temperature on shank surface temperature in the heat stressed fowl. Poultry Sci. 65:(Suppl. 1):131.

Suk, Y., and K. W. Washburn. 1995. Effects of environment on growth, efficiency of feed utilization, carcass fatness, and their association. Poultry Sci. 74:285-296.

Tamir, H., and S. Ratner. 1963a. Enzymes of arginine metabolism in chicks. Arch. Biochem. Biophys. 102:249-258.

Tamir, H., and S. Ratner. 1963b. A study of ornithine, citrulline and arginine synthesis in growing chick. Arch. Biochem. Biophys. 102:259-269.

Taube-Netto, M.. 1996. Integrated planning for poultry production at Sadia. Interfaces 26:38-53.

Taylor, J., R.L., R.E. Austic, and R.R. Dietert. 1992. Dietary arginine influence Rouse Sarcoma growth in a major histocompatibility B complex progressor genotype. P.S.E.B.M. 199:38-41.

Timmons, M.B., R.S. Gates, R.W. Bottcher, C.T.A. Carter, J. Brake, and M.J. Wineland. 1995. Simulation analysis of a new temperature control method for poultry housing. J. Agricultural Engineering Research 62 (4):237-245.

Wideman, R.F., Y. Kochera-Kirby, M. Ismail, W. Bottje, R.W. Moore, and R.C. Vardeman. 1995. Supplemental L-arginine attenuates pulmonary hypertension syndrome (ascites) in broilers. Poultry Sci. 74:323-330.

Widowski, T. M., L. J. Keeling, and I. J. H. Duncan. 1992. The preferences of hens for compact fluorescent over incandescent lighting. Can. J. Anim. Sci. 72:203-211.

Xin, H. and J.D. Harmon. 1996. Responses of group-housed neonatal chicks to post-hatch holding environment. Trans. of the ASAE 39(6): 2249-2254.

Xin, H., J.A. DeShazer and M.M. Beck. 1992. Responses of prefasted growing turkeys to acute heat exposure. Transactions of the ASAE 35(1):315-318.

Xin, H., J.A. DeShazer and M.M. Beck. 1987. Post-effect of ammonia on energetics of laying hens at high temperatures. Trans. ASAE. 30(4):1121-1125.

Xin, H., I.L. Berry, and G.T. Tabler. 1996. Minimum ventilation requirement and associated energy cost for aerial ammonia control in broiler houses. Transactions of the ASAE 39(2): 645-648.

Xin, H., J.L. Sell, and D.U. Ahn. 1996. Effect of light and darkness on heat and moisture production of broilers. Trans. of the ASAE 39(6): 2255-2258.

Yanagisawa, M., H. Kurihara, S. Kimura, Y. Tomobe, M. Kobayashi, Y. Mitsui, Y. Yazaki, K. Goto, and T. Masaki. 1988. A novel potent vasoconstrictor peptide produced by vascular endothelial cells. Nature 332:411-415.

Zhang, Y., A. Tanaka, E. M. Barber and J. J. R. Feddes. 1996. Effect of frequency and quantity of sprinkling canola oil on dust reduction in swine buildings. Trans. of the ASAE 39(3):1077-1081.

Zimmerman, N. G. 1986. Effect of light source on broiler growth performance. Poultry Sci. 65(supplement):151 (Abstr)

Zulovich, J.M. and J.A. DeShazer. 1990. Estimating egg production declines at high environmental temperatures and humidities. ASAE Paper No. 90-4021. St. Joseph, MI:ASAE.

ATTACHMENT A
PROJECT LEADERS

Institution	Leader	Area of Specialization
Agricultural Experiment Stations		
Connecticut-Storrs	M. J. Darre [1]	Physiology, Poultry Management
Illinois	P. C. Harrison G. L. Riskowski K. W. Koelkebeck [1]	Physiology Engineering Poultry Management
Iowa	H. Xin	Biosystems Engineering, Environmental Physiology
Maryland	L. E. Carr [1] I. Estevez	Engineering Poultry Behavior
Michigan	A. Rahn [1]	Poultry Economics
Minnesota	K. A. Janni S. L. Noll [1]	Engineering Poultry Management, Nutrition
Nebraska	M. M. Beck [1]	Physiology
Pennsylvania	W. B. Roush [1] P. Patterson E. Wheeler	Operations Research, Modeling Layer Management, Nutrition Engineering, Environmental Control
Texas	T. Odom [1]	Physiology, Environment
Industry Cooperators		
Poultry Management Systems, Inc., East Lansing, Michigan	D. Powell	Systems Engineering
Hy-Vac, Inc., Adel, Iowa	A. Yersin	Poultry Management, Nutrition
Perdue Farms, Salisbury, Maryland	H. Engster	Nutrition

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[1] Voting Member

ATTACHMENT B

RESOURCES

Station	SY	PY	TY
Connecticut-Storrs	0.15	0.00	0.00
Illinois	0.25	0.00	0.00
Iowa	0.20	0.50	0.00
Maryland	0.60	0.50	0.50
Michigan	0.10	0.00	0.00
Minnesota	0.40	0.50	0.50
Nebraska	0.40	0.30	0.30
Pennsylvania	0.70	0.10	0.20
Texas	0.25	0.00	0.20
TOTALS	**3.05**	**1.90**	**1.70**