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ENVIRONMENTAL STUDIES WITH EARLY-WEANED PIGS

BY A. J. MUEHLING AND A. H. JENSEN

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Cover Photo: *overall view of environmental chamber.*

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Environmental Studies With Early-Weaned Pigs

By A. J. MUEHLING and A. H. JENSEN[1]

RAISING HOGS IN THE MIDWEST is rapidly becoming a specialized business. Multiple farrowing (farrowing from 6 to 12 times a year) and early weaning (weaning at 3 to 5 weeks of age) have become common practices.

When small pigs are weaned and taken away from the sow, a sizable source of heat is lost. Large investments are being made in an attempt to provide satisfactory conditions for these small pigs. In addition to the standard radiant-heat lamps, many other devices, including electric heating cable and hot-water pipes embedded in concrete floors, electrically heated pads, and gas-fired hovers, are being used to supply heat for baby pigs.

The use of these devices has given rise to questions such as how the small pigs will perform when heat is supplied only in the floor as compared with radiant heat supplied from heat lamps, and what type and quantities of heat are most desirable for early-weaned pigs. The need for information on the effect of environment, especially during low temperatures, has become obvious.

Heitman, Kelly, and Bond (1)* have reported on the effect of environment on finishing hogs, and Heitman, Hughes, and Kelly (2) have reported on the effect of environment on sows. Information on the effect of environment on the baby pig is limited. Newland, McMillen, and Reineke (3) reported that the American farmer loses over a million pigs annually from chilling. They also reported that the thermo-regulating mechanism of a newborn pig is not fully developed; as a result, the pig's body temperature in a cold environment drops quite rapidly for the first few hours after birth. Then the pig develops the ability to regulate its body temperature. They also found a significant correlation between the weight of a pig and its ability to adapt itself to its environment.

Howie *et al.* (4) reported that pigs did not appear to be fully able to regulate their temperature up to 3 weeks of age, and possibly not even up to 8 weeks. After examining existing data, Findlay (5) reported that the rectal temperature of baby pigs ranged from 98.3° to 104° F.

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* This number and similar numbers in parentheses refer to the literature citations on page 39.

Taylor *et al.* (6) reported that small, weak pigs appeared to chill when farrowed in a room at 40° F., but one litter of strong pigs appeared quite comfortable during their first 72 hours of life in a 33° F. room. According to Taylor *et al.*, auxiliary heat should be supplied in farrowing pens when room temperatures are below 45° F., but supplementary heat would seldom be required to prevent chilling of pigs that are over a week old.

In measuring the metabolic rates of small pigs fed *ad lib.* at air temperatures of 59°, 68°, 77°, and 86° F., Cairnie and Pullar (7) found that the critical temperature exceeded 86° F. for pigs weighing 13 pounds or less, and was about 68° F. for pigs weighing 22 pounds.

To determine the effect of environment on suckling pigs, Gill and Thomson (8) divided litters into equal groups and provided supplemental heat for half of each litter. They observed that ". . . the piglets getting no additional heating were able to withstand the cold. The average temperature was 44° F., and on many occasions, below the freezing point."

McLagan and Thomson (9) farrowed and raised pigs in four natural environments: (a) open pens in a large, drafty, concrete building with uninsulated floor; (b) same as (a), but with wooden sleeping platform; (c) wooden "arc hut" with an indoor run; and (d) wooden "arc hut" with an outdoor run.

Weanling pigs raised in environment (a) weighed, on the average, less than half as much as pigs farrowed and raised in environments (b) and (d), even though the air temperature differed by only two degrees (42.8° and 44.9° F.). They concluded that the kind of flooring provided for the pigs to lie on is of great importance, and that pigs can be reared in a house with an average air temperature of only 45° F. if the floor is well-insulated. They suggested that it is impossible to rear good pigs in an open pen in a large, cold, drafty building. Tests by Lucas and Thomson (10) also demonstrated the effect of the kind of floor and floor temperature upon small pigs.

FACILITIES AND EQUIPMENT USED

Environmental Chamber

In the winter of 1956, the Departments of Agricultural Engineering and Animal Science began a joint research project to study some of the aspects of furnishing heat to small pigs.

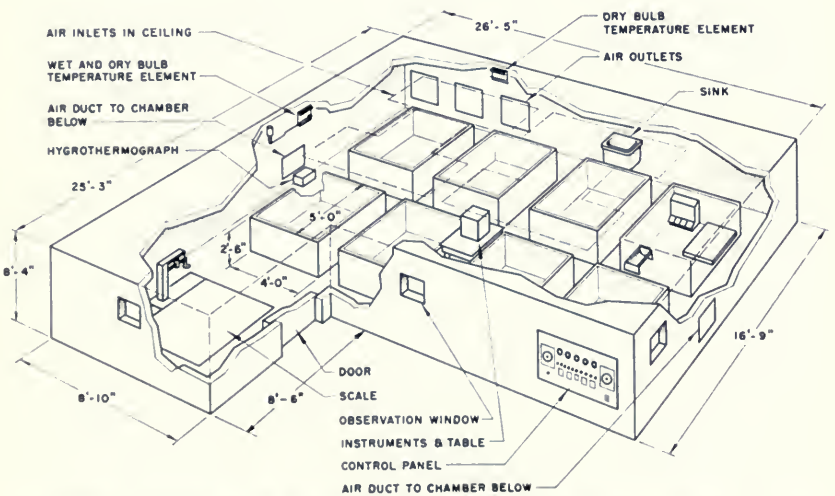
Experiments were conducted in a controlled climatic chamber located in the basement of the Animal Sciences Laboratory at the

University of Illinois. This chamber was constructed in 1950 for use in carrying on nutritional studies with controlled temperature and humidity. It is equipped with heavy steel partitions, allowing for the confinement and feeding of six large animals (steers, cows, etc.). These partitions can be removed to make the room suitable for any kind of experiment.

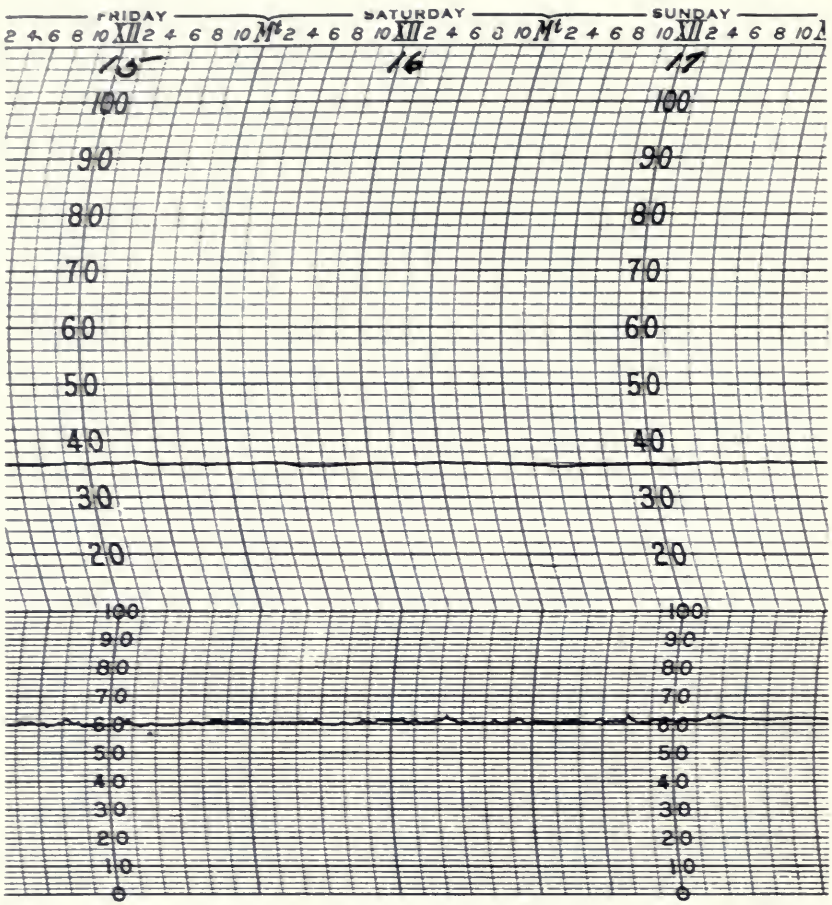
The chamber has a usable space of 26 feet, 5 inches by 16 feet, 9 inches. A platform scale is located off one end of the room in an area measuring 8 feet, 6 inches by 8 feet, 10 inches (see Fig. 1).

The chamber is entered through an airtight vestibule equipped with large refrigeration-type doors. These doors minimize the change of conditions within the chamber when anyone enters or leaves the chamber. The chamber is constructed to facilitate collecting the feces and urine from six large animals when they are in the stalls. Feces and urine ducts lead from the chamber to another small climatized room below the chamber where the collections are made. Air is circulated from the chamber above to maintain the identical conditions in the collection room.

The chamber is cooled with two Worthington compressors — one 20-hp. compressor (11.4 tons) and one 15-hp. compressor (4.7 tons). The air is conditioned in a Niagara "No-Frost" spray cooler with steam concentrator. The humidity of the air supply is regulated by cooling the air below the desired temperature to remove the correct



Environmental chamber in the Animal Sciences Laboratory, University of Illinois. (Fig. 1)



A section from a typical hygrothermograph trace for the environmental chamber. (Fig. 2)

amount of moisture, and then reheating the air before it is introduced into the room. The equipment will control the chamber temperature within ±0.5° F. from 120° to 20° F. (Fig. 2 shows a typical hygrothermograph trace for the chamber.) Humidity can be controlled fairly well when the chamber temperature is above 50° F. Humidity control is not reliable when the chamber temperature is below 50° F.

The conditioned air enters the chamber through a series of 10 intake grids in the ceiling and is exhausted through three 2-foot-square exhaust ducts at one corner of the room. Twenty-five percent of the

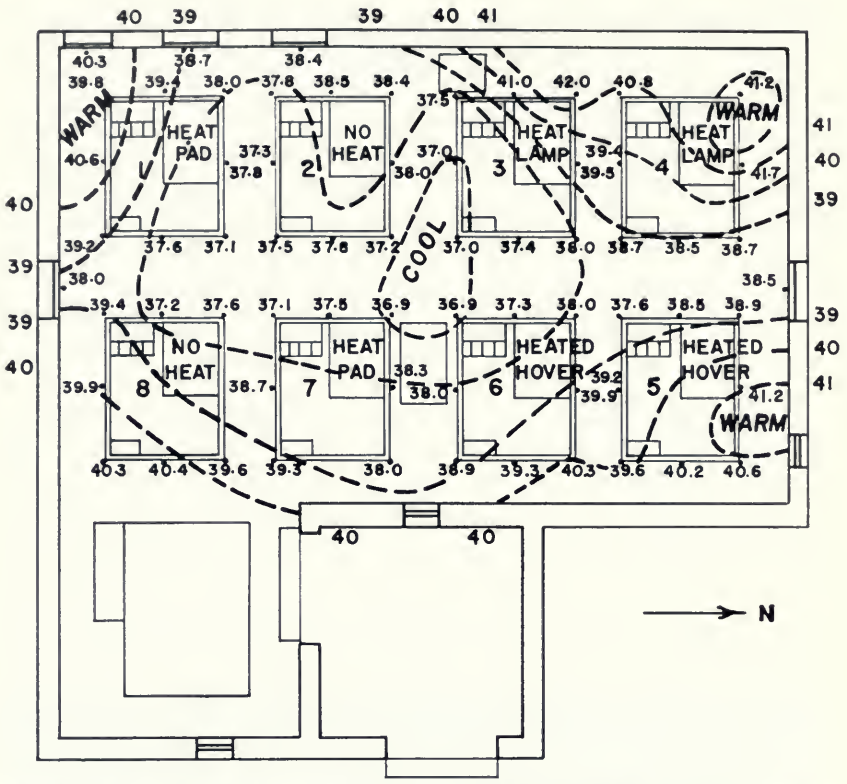
incoming air is fresh air, and 75 percent is recirculated air. The air in the chamber is changed every 8 minutes.

Air from the chamber is circulated through ducts at the ends of the room to the collection chamber below. Twenty-five percent of the total incoming air to the chamber is exhausted to the outside from the collection chamber. Air velocities within the chamber vary from 15 to 40 feet per minute, with higher velocities next to the exhaust ducts.

The chamber is controlled with Johnson Service Company equipment, and Taylor thermometers are used as the temperature-measuring elements. The instrument panel for the environmental chamber is located on the wall of the large animal laboratory outside the chamber (Fig. 3). A continuous trace of dry-bulb and wet-bulb temperature is recorded on the instrument panel.

Conditions within the chamber were checked several times during the experiments. Temperatures within the chamber were checked by taking thermocouple readings about 8 inches above the floor throughout the chamber. Fig. 4 shows the variation of temperature in the chamber at 3:00 p.m., June 24, 1958, during Test 6, when a room temperature of 38° F. was maintained. The temperature varied from 37° F. under the air-intake grilles to 42° F. under a heat lamp.

Instrument panel for the environmental chamber. **(Fig. 3)**



Temperature variation in the chamber, °F. (Test 6, 3:00 p.m., June 24, 1958). (Fig. 4)

Air velocities were measured in the chamber with an Anemotherm air meter. The velocities varied considerably, being highest at the exhaust air ducts. Fig. 5 shows the variation in air velocity within the chamber at 1:30 p.m., August 18, 1958, during Test 7, when the temperature in the chamber was 35° F. The maximum velocities were caused by the incoming air. High velocities were also shown near the three exhaust ducts, and near the ducts leading to the collection room below.

Equipment and Environmental Units

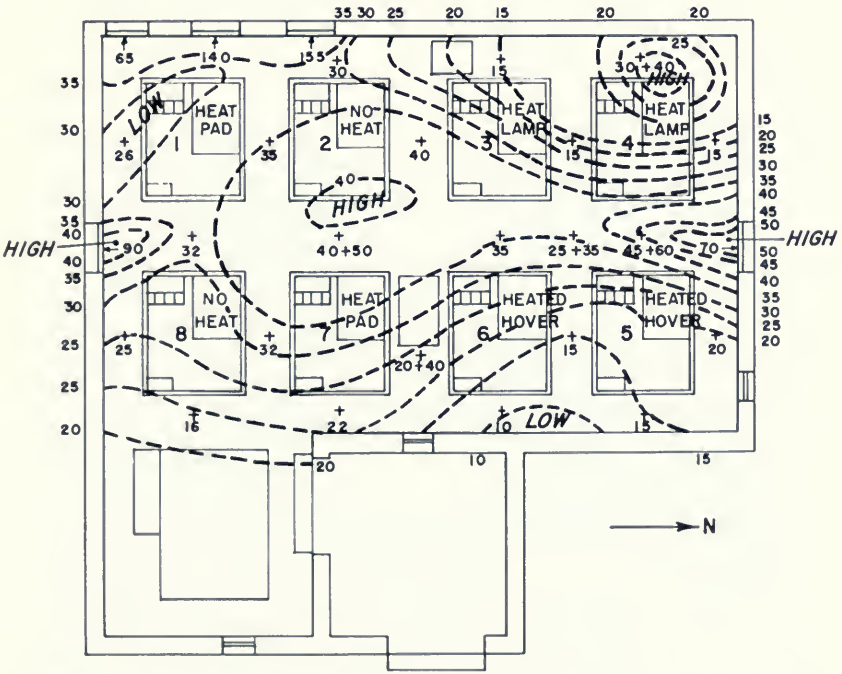
Eight 4- by 5-feet pens were used. These pens were 2 feet, 6 inches high, and were enclosed with ¼-inch hardware cloth. They were constructed in halves with hinges so that they could be easily dismantled and stored between tests. (For an overall view of the chamber, see

cover photo.) Each pen contained a self-feeder, a water trough, and some type of heat source or shelter. The types of heat sources and shelters studied are described below.

Wooden Overlay. Unheated 2-feet by 2-feet, 8-inch wooden overlays made of rough-cut 1-inch lumber were used in the first two experiments. The design provided an air space between the overlay and the concrete floor. Fig. 6 shows the pigs huddling in a corner on a wooden overlay when the chamber temperature was 60° F. Sometimes the pigs would avoid the overlay and lie on the floor in the corner of the pen.

Heat Lamp. Type R-40, 250-watt radiant heat lamps were used in most of the tests. These heat lamps were located approximately 18 inches above wooden overlays. The radiant heat lamp has been the conventional method of furnishing heat for small pigs on Illinois farms. A pen furnished with a heat lamp is shown in Fig. 7.

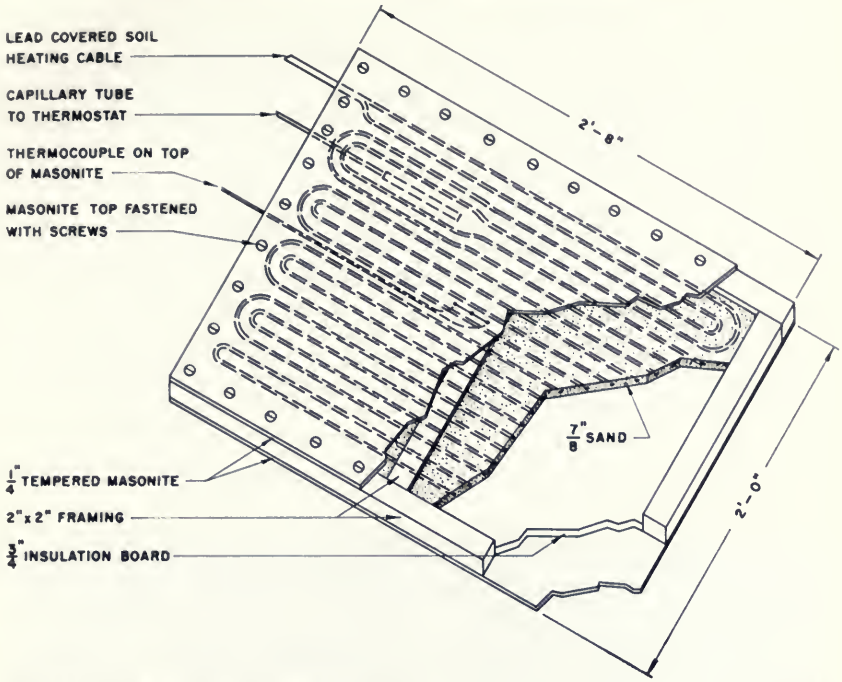
Heat Pad. Electrically heated pads were constructed to simulate the conditions of a radiant-heated floor. The 2-feet by 2-feet, 8-inch



Air-velocity variation in the chamber, ft./min. (Test 7, 1:30 p.m., Aug. 18, 1958). (Fig. 5)

Pigs huddling on a wooden overlay at a chamber temperature of 60° F. (Fig. 6)

Pen supplied with a 250-watt radiant heat lamp. Notice huddling of pigs at a chamber temperature of 40° F. (Fig. 7)



Construction details of 500-watt heat pad. **(Fig. 8)**

pads were built by embedding lead-covered heating cable in a 7/8-inch layer of sand and controlling the temperature of the pad with a thermostat.

Each of these heated pads drew 500 watts of electricity, giving a watt density of over 93 watts per square foot. This watt density is considerably higher than recommended for actual practice. The surface temperature of the pad was measured with a thermocouple junction glued in a groove on the surface of the pad. A detailed drawing of the heat pad is shown in Fig. 8. Pigs on these heat pads appeared to be comfortable (Fig. 9, upper left).

Unheated Hover. Three-sided, unheated plywood hovers built over wooden overlays were also used. The hovers were 2 feet by 2 feet, 8 inches, with a height of 1 foot, 3 inches. The floor of the unheated hovers was kept bedded either with sawdust or wood shavings.

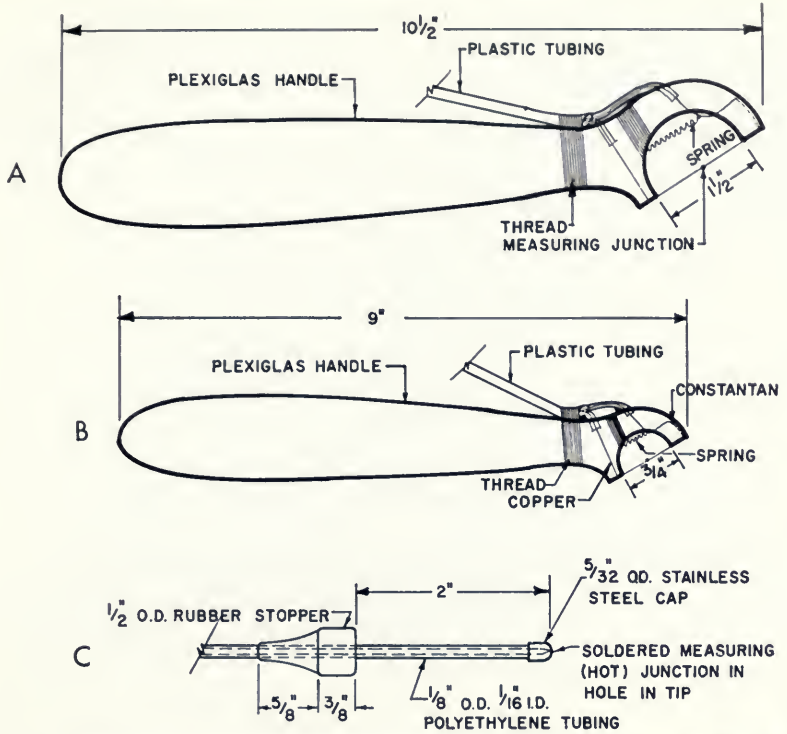
Heated Hover. Three-sided plywood hovers built over the 500-watt thermostatically controlled heat pads were also used (Fig. 9). The floors of the heated hovers were kept clean, and no bedding was used.

Measuring Instruments

The thermocouple was found very useful for measuring the pigs' body and skin temperatures. Thermocouples indicate temperature rapidly, and can be read to a high degree of accuracy. All thermocouples used in these tests were constructed with Revere Corporation of America thermocouple wire #WW2755. This wire is composed of seven strands of No. 36 gage (0.0005-inch) copper wire and seven strands of No. 37 constantan wire. Each kind of wire was encased with a nylon covering, and a separate nylon covering encased the two wires.

Two skin-temperature measuring instruments were fabricated, following the description of Elder (11). (See Fig. 10.) The thermocouple junction of the smaller instrument joins one strand of copper wire to one strand of constantan wire, and the thermocouple junction of the larger instrument joins seven strands of each kind of wire. The small instrument gave a reading within 2 to 4 seconds, but was

Left, pigs lying on the warm surface of a heat pad at a chamber temperature of 50° F. Right, pigs huddling in the corner of an unheated hover at a chamber temperature of 38° F. Below, pigs lying in heated hover at a chamber temperature of 38° F. (Fig. 9)



Thermocouple measuring instruments: (A) large plexiglass skin-temperature measuring instrument joining all seven strands of thermocouple wire; (B) small plexiglass skin-temperature measuring instrument joining only one strand of thermocouple wire; (C) rectal probe for measuring body temperature. (Fig. 10)

quite fragile. Although the large instrument required 10 to 15 seconds for a reading, it was used for most of the skin-temperature measurements because of its sturdiness. All of the skin-temperature measurements during the tests were taken across the middle of the pig's back.

During Tests 1 and 2, skin-temperature measurements were made while the pigs were lying down, but in the remainder of the tests the pigs were held (Fig. 11).

A 2-inch rectal probe was constructed according to Fahnestock (12), using polyethylene tubing with a stainless steel cap (Fig. 10). A small rubber cork was used to limit the depth of insertion. The thermocouple wire was run through the polyethylene tube, and the copper-constantan junction was soldered into the end of the steel cap.

A true body temperature could not be recorded until the measuring junction of the probe reached equilibrium (usually about 60 seconds after insertion). Most body temperatures were taken when the pigs were held.

All of the thermocouples were read with a Leeds and Northrup "Speedomax" self-balancing potentiometer. This equipment could be read to the nearest 0.001 millivolt, which gave the temperature to the nearest tenth of a degree. A Leeds and Northrup 10-point switch was used with the potentiometer so that 10 thermocouples could be read by merely turning the switch. The potentiometer would come to balance and indicate the temperature of a measuring junction within a few seconds after turning the switch. An ice bath at 32° F. was used for the reference junction on all thermocouple measurements.

CHARACTERISTICS OF HEATING UNITS

Heat-Pad Temperature

Many farrowing houses are being built today with some form of heat provided in the floor. One question that has arisen is "How warm should the floor be for small pigs?"

Thermocouples were glued to the surface of the masonite tops of the heat pads to measure the surface temperature of the pads. The copper and constantan leads were placed on the underside of the masonite top and run through separate holes drilled 3 inches apart in the center of the pad. A groove was made between the two holes on the top surface of the pad, and the thermocouple junction was glued into this groove.

The temperatures of the pads were controlled by thermostats, with displaced bulb elements buried in the sand next to the masonite

Measuring pig's skin temperature with touch thermocouple instrument. (Fig. 11)

top. Two thermostats were used. One was a United Electric thermostat with a differential of approximately 2 degrees and a range from 70° to 170° F.; the other was a Minneapolis-Honeywell thermostat with a differential of 5 degrees and a range from 40° to 180° F.

The thermostats were set to maintain a heat-pad temperature that appeared to be comfortable for the small pigs. The surface temperature of the heat pads was checked periodically during the tests. These temperature measurements varied from 105° F. to 125° F., but 110° F. was about the average temperature at which the pigs appeared most comfortable.

Several tests were made during a 40° F. experiment to try to determine the "comfort zone" of the pads. The pads were turned on continuously while the pigs were lying on them, and temperatures were recorded until the pads became too warm for the pigs. In all measurements taken, the pigs started becoming restless when the pads reached approximately 130° F., and would not stay on the pads when the temperature was over 140° F.

Power Required to Maintain Heating Units

A 250-watt heat lamp requires 6 kilowatt hours per day. This power requirement remains constant regardless of the variation in outside temperature.

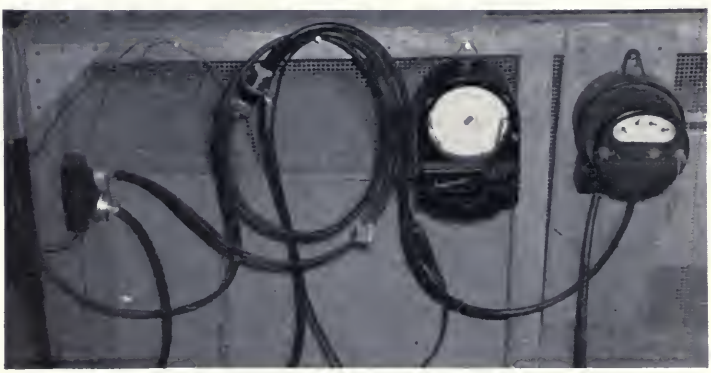
Watt-hour meters were connected to each of the pairs of heating units, and daily records were kept. Since two units were controlled with one thermostat, only one watt-hour meter was needed with each pair of heating units. The average power requirements for the heating units are shown below.

	Chamber temperature (degrees F.)	*Heat lamp* (kilowatt hours per day per lamp)	*Heat pad* (kilowatt hours per day per pad)	*Heated hover* (kilowatt hours per day per pad)
Experiment 1	60	6	....	....
Experiment 2	60	6	1.78 and 2.43[a]	....
Experiment 3	50	6	2.90	3.14
Experiment 4	40	6	4.03	4.15
Experiment 5	40	6	3.92	4.00
Experiment 6	38	6	4.29	3.91
Experiment 7	37	..	....	3.97 and 3.53[b]

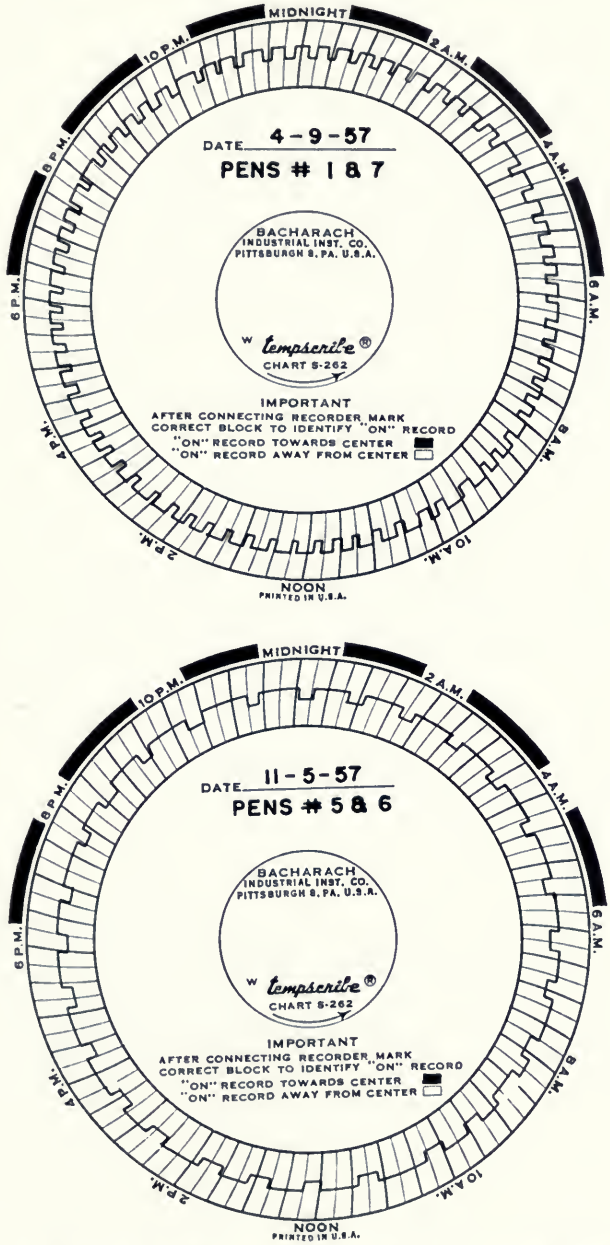
[a] Heat pads were controlled with separate thermostats.
[b] A slot was cut in the end of the hover and the trough of the feeder was placed inside the hover.

The power requirements for the heat pads and heated hovers were approximately 2 kilowatt hours per day at 60° F., 3 kilowatt hours per day at 50° F., and 4 kilowatt hours per day at 40° F.

The amount of time the heating units were on was also checked with Tempscribe on-off recorders. A watt-hour meter and an on-off recorder are shown in Fig. 12. The on-off recorder has a circular chart



Tempscribe on-off recorder and watt-hour meter used in all tests. (Fig. 12)



Typical 24-hour traces from on-off recorders showing the different characteristics of the two thermostats used in all tests. (Fig. 13)

that is driven with a clock and rotates every 24 hours. A pen makes a continuous trace on the chart. When no current is going through the recorder, the pen makes a circular trace. When the current is on, however, an electro-magnet moves the pen, and the pen continues to make a smaller circular trace as long as current is passing through the instrument. Two 24-hour traces from the heating units controlled by the two thermostats are shown in Fig. 13. These traces show how often and how long the current was on. The watt-hour meters were more accurate in determining the actual amount of power consumed, but the on-off traces were useful in showing the characteristics of the individual thermostats.

FEEDING AND MANAGEMENT EXPERIMENTS

For all tests, pigs approximately 2 to 2½ weeks of age were weaned to dry, complete diets. Outcome groups of 4 or 8 pigs each were formed on the basis of litter, weight, and condition. Each treatment group of 4 pigs was confined to a pen. Diet was provided in a 4-hole self-feeder, and water was supplied in ¾-gallon open troughs.

In certain experiments, ration comparisons were superimposed upon the environmental considerations.

The first 8 experiments were carried out in the environmental chamber in the Animal Sciences Laboratory. Experiment 9 was conducted in a shed on the University Swine Farm. Weight gain, feed efficiency, and other appropriate measurements were recorded at prescribed intervals. The rations used are listed in Table 1. (The statistical analyses tables of gain and feed data appear in Appendix II.)

Experiment 1

In the first experiment, 16 Duroc and Yorkshire pigs were weaned when they were about 11 days old and placed in the chamber when 14 days old. The room temperature was 60° F., and the relative humidity was 60 percent. In this preliminary test, 4 pigs were placed in each of the four pens. Two of the pens had supplemental heat from 250-watt bulbs; the other two pens did not have supplemental heat. One pen of pigs in each environment received 4-percent corn oil in the ration, and the other received 4-percent wheat-germ oil.

The results in Table 2 show that pigs provided supplemental heat gained 0.35 pound per day, while pigs without heat gained only 0.23 pound per day. This difference in gain is reflected in the greater feed intake by the pigs given supplemental heat. Feed required per pound

of gain was 2.05 pounds in the heat-supplemented pen and 2.45 pounds in the pens without heat.

Daily gains were about the same for the two rations. Feed required per pound of gain was 2.44 pounds for the 4-percent corn oil diet (Ration 1), and 2.06 pounds for the 4-percent wheat-germ oil diet (Ration 2).

It was observed that pigs without supplemental heat huddled together most of the time. Although wooden overlays were provided, the pigs huddled in a corner on the concrete floor, apparently in an attempt to get some shelter from the corner frame pieces. The pigs shivered continuously within a couple of hours after they were placed in the chamber. Some pigs shivered occasionally even after two weeks.

Body (rectal) and skin temperatures were recorded daily for the first week and twice weekly during the last two weeks. With no supplemental heat, body temperatures varied from 99.8° F. to 103.3 F., with an average of 101.4° F. With supplemental heat, the range was 99.8° F. to 103.9° F., with an average of 101.9° F.

Skin-temperature readings gave a wider range. Pigs without heat ranged from 82.0° F. to 93.7° F., with an average of 89.1° F., and pigs with supplemental heat ranged from 81.0° F. to 108.6° F., with an average of 96.1° F. This temperature difference was statistically significant ($P<0.001$). Since the pigs were usually lying under the heat

Table 1. — Composition of Control Rations

Ingredients	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Exp. 7 & 8	Exp. 9
				(percent)				
Ground yellow corn	26.0	25.5	30.7	25.0	30.0	20.1	50.0	34.3
Solvent soybean meal	....	....	....	....	....	....	8.0	8.0
Rolled oats	....	....	....	....	28.0	18.0	....	....
Crude casein	18.8	15.8	14.3	16.0	....	....	....	....
Dried skimmilk	....	....	....	....	25.0	30.0	20.0	25.0
Dried whey	2.5	25.5	10.0	10.0	5.0	10.0	10.0	10.0
Fishmeal	....	....	....	....	5.0	5.0	5.0	10.0
Condensed fish solubles	2.5	2.5	2.5	2.5	....	....	3.0	3.0
Brewers' dried yeast	2.0	2.0	2.0	2.0	2.0	2.0	....	....
Dicalcium phosphate	3.5	3.5	2.5	2.5	1.3	1.2	1.3	1.3
Ground limestone	....	....	0.5	0.5	0.2	0.2	0.2	....
Mineral mix No. 1[a]	0.2	0.2	0.2	0.2	....	....	....	....
Iodized salt	0.5	0.5	0.5	0.5	....	....	....	....
Trace-mineralized salt[a]	....	....	....	....	0.5	0.5	0.5	0.5
Vitamin-antibiotic mix[a]	++	++	++	++	++	++	++	++
Corn oil	4.0	4.0	3.0	7.0	3.0	3.0	1.0	....
Cerelose	40.0	20.5	33.8	16.8	....	....	....	....
Lactose	....	....	....	16.0	....	10.0	1.0	8.0
Cellulose	....	....	....	1.0	....	....	....	....

[a] See Appendix I.

Table 2. — Experiment 1. Chamber Conditions: 60° F. and 60 percent relative humidity

(May 1 to May 22, 1956 — 21 days)

Environment and ration[a]	Average initial weight (pounds)	Average daily gain (pounds)	Average daily feed (pounds)	Feed per pound of gain (pounds)	Temperature °F.		Heart beat per minute	Respiration per minute
					Body	Skin		
Wooden overlay, Ration 1..	7.9	.21	.57	2.76	101.3	89.0	148	28
Wooden overlay, Ration 2..	7.6	.26	.56	2.14	101.5	89.2	152	40
Heat lamp, Ration 1.....	7.6	.37	.79	2.13	102.0	96.7	142	50
Heat lamp, Ration 2.....	7.4	.33	.66	1.99	101.8	95.5	140	52
Average for								
Wooden overlay.....	7.8	.23	.56	2.45	101.4	89.1	150	34
Heat lamp.....	7.5	.35	.72	2.05	101.9	96.1	140	51
Ration 1.....	7.8	.29	.68	2.44	101.6	92.8	144	40
Ration 2.....	7.5	.30	.61	2.06	101.6	92.4	146	46
All tests.....	7.6	.29	.65	2.25	101.6	92.6	145	43

[a] Ration 1 contained 4-percent corn oil and Ration 2 contained 4-percent wheat-germ oil.

lamp while the temperatures were recorded, it is not surprising that these differences occurred.

Limited measurements of heart rates and respiration rates were collected. The heart rate was higher and the respiration rate lower when there was no heat, the reverse occurring when supplemental heat was provided.

Experiment 2

In Experiment 2, eight pens of 4 pigs each were used. The room temperature was 60° F., with a relative humidity of 60 percent. Environment variations in individual pens were the use of a wooden overlay, wooden overlay with hover, heat pad, and a heat lamp suspended above the wooden overlay. The pigs in replicate 2 received 0.25 percent of a proteolytic enzyme[1] preparation in addition to the control ration.

Body and skin temperatures were recorded for the first three days, then twice a week. The experiment was terminated on the fourteenth day because of failure of the refrigeration equipment.

The results shown in Table 3 indicate responses quite different from those in Experiment 1. Average daily gains were highest for the pigs having wooden overlays and lowest for the pigs under the heat lamps. The pigs on wooden overlays consumed the most feed, and the pigs on heat pads utilized the diets most efficiently.

Adding an enzyme preparation (Pep-Swin) at a level of 0.25 percent of the ration did not prove nutritionally beneficial.

[1] Pep-Swin, supplied by the Cudahy Laboratories, Omaha, Nebraska.

Table 3. — Experiment 2. Chamber Conditions: 60° F. and 60 percent relative humidity

(July 18 to August 1, 1956 — 14 days)

Environment and ration[a]	Average initial weight (pounds)	Average daily gain (pounds)	Average daily feed (pounds)	Feed per pound of gain (pounds)	Temperature °F.	
					Body	Skin
Heat pad, Ration 1	7.2	.46	.61	1.33	101.6	85.1
Ration 2	6.3	.41	.62	1.51	101.1	85.1
Heat lamp, Ration 1	7.2	.44	.65	1.48	101.8	90.5
Ration 2	6.8	.29	.60	2.07	102.0	96.0
Unheated hover, Ration 1	6.3	.36	.59	1.64	101.5	84.6
Ration 2	7.2	.42	.64	1.52	101.4	83.4
Wooden overlay, Ration 1	7.3	.42	.67	1.59	101.8	85.2
Ration 2	7.1	.46	.75	1.63	101.6	86.5
Average for						
Heat pad	6.8	.43	.61	1.42	101.3	85.1
Heat lamp	7.0	.37	.62	1.65	101.9	93.2
Unheated hover	6.7	.39	.61	1.56	101.4	84.0
Wooden overlay	7.2	.44	.71	1.61	101.7	85.9
Ration 1	7.0	.42	.63	1.50	101.6	86.3
Ration 2	6.8	.39	.65	1.67	101.5	87.8
All tests	6.9	.40	.64	1.58	101.5	87.0

[a] Ration 1 contained 20-percent sugar and Ration 2 contained 0.25-percent Pep-Swin.

There were no significant differences in body temperature, but treatment did significantly affect skin temperatures ($P<0.01$). The pigs in the pens with heat lamps had the highest average skin temperature, 93.2° F.

Experiment 3

A temperature of 50° F. and a relative humidity of approximately 60 percent were maintained in the chamber during the third experiment. Thirty-two Hampshire pigs, averaging approximately 17 days of age, were allotted to treatment. Environmental treatments in individual pens were unheated hover, heat pad, heated hover, and heat lamp. Ration comparison was 3-percent corn oil or 3-percent wheatgerm oil. (The results of Experiment 3 are shown in Table 4.)

Average daily gain was highest for the pigs provided with heat pads. The pigs in the unheated hovers showed the lowest gains and required the greatest amount of feed per pound of gain. There were no statistically significant differences due to ration treatment.

As in the previous tests, there was little variation in body temperatures, and skin temperatures were highest in the pens with heat lamps.

Experiment 4

In the fourth experiment, the chamber temperature was 60° F. when the pigs were placed in the pens, and was gradually lowered to 40° F. during the first 20 hours. A temperature of 40° F. and 60 per-

Table 4. — Experiment 3. Chamber Conditions: 50° F. and 60 percent relative humidity

(December 14, 1956 to January 4, 1957 — 21 days)

Environment and ration[a]	Average initial weight (pounds)	Average daily gain (pounds)	Average daily feed (pounds)	Feed per pound of gain (pounds)	Temperature °F.	
					Body	Skin
Heat pad, Ration 1	6.5	.45	.80	1.77	100.8	86.7
Ration 2	6.2	.54	.89	1.65	101.3	86.1
Heat lamp, Ration 1	6.6	.55	1.01	1.84	102.2	94.5
Ration 2	6.3	.37	.69	1.88	101.6	96.7
Heated hover, Ration 1	6.2	.36	.70	1.94	101.2	87.3
Ration 2	6.4	.47	.87	1.86	101.2	87.7
Unheated hover, Ration 1	7.2	.47	.94	1.96	100.9	85.7
Ration 2	6.7	.30	.72	2.41	101.2	88.4
Average for						
Heat pad	6.4	.50	.84	1.71	101.1	86.4
Heat lamp	6.5	.46	.85	1.86	101.8	95.8
Heated hover	6.3	.42	.80	1.90	101.2	87.5
Unheated hover	6.9	.39	.85	2.18	101.0	87.2
Ration 1	6.6	.42	.79	1.88	101.2	88.3
Ration 2	6.4	.46	.90	1.95	101.3	89.7
All tests	6.5	.44	.84	1.92	101.3	89.1

[a] Ration 1 contained 3-percent corn oil and Ration 2 contained 3-percent wheat-germ oil.

cent relative humidity were maintained throughout the remainder of the experiment.

Auxiliary heat treatments were identical with those of Experiment 3. Ration comparison was 7-percent corn oil or 7-percent egg fat as energy additions.

During the first week, the pigs in the heated hovers appeared to be more comfortable than those in the other pens. The pigs with the heat lamps and those on the heated pads shivered noticeably the first week to 10 days; then they appeared to be well adjusted to the environment. The pigs in the unheated hovers huddled together in the corner of the hovers in an attempt to keep warm. Pronounced shivering gradually diminished during the first 14 days, however, and little was noticed after that time.

There was considerable variation in performance (Table 5). Pigs with heat lamps and heat pads gained only 0.23 pound and 0.24 pound per day, respectively, while pigs in the heated and unheated hovers gained 0.35 pound and 0.34 pound per day, respectively.

Average feed required per pound of gain was lowest in the pens with heated hovers.

Body temperatures were quite similar, and average skin temperature was highest for the pigs having heat-lamp protection.

The pigs receiving the ration containing corn oil gained more rapidly and required less feed per pound of gain than the pigs receiving the ration containing egg fat.

Table 5. — Experiment 4. Chamber Conditions: 40° F. and 60 percent relative humidity
(April 8 to April 29, 1957 — 21 days)

Environment and ration[a]	Average initial weight (pounds)	Average daily gain (pounds)	Average daily feed (pounds)	Feed per pound of gain (pounds)	Temperature °F.	
					Body	Skin
Heat pad, Ration 1	8.4	.22	.65	2.96	103.0	88.1
Ration 2	8.4	.26	.71	2.75	103.7	87.2
Heat lamp, Ration 1	8.2	.26	.56	2.14	103.8	95.1
Ration 2	8.0	.20	.55	2.74	103.4	97.7
Heated hover, Ration 1	8.2	.45	.77	1.71	103.4	89.5
Ration 2	7.8	.26	.63	2.42	103.0	89.7
Unheated hover, Ration 1	8.5	.30	.78	2.60	103.0	90.1
Ration 2	8.4	.38	.72	1.90	104.0	90.4
Average for						
Heat pad	8.4	.24	.68	2.85	103.4	87.6
Heat lamp	8.1	.23	.56	2.44	103.6	96.4
Heated hover	8.0	.35	.71	1.97	103.2	89.6
Unheated hover	8.4	.34	.74	2.18	103.5	90.2
Ration 1	8.3	.31	.69	2.22	103.3	90.7
Ration 2	8.1	.28	.67	2.40	103.5	91.2
All tests	8.2	.29	.68	2.31	103.4	90.9

[a] Ration 1 contained 7-percent corn oil and Ration 2 contained 7-percent egg fat.

Experiment 5

Experiment 5 was essentially the same as Experiment 4, except that the ration treatment was 0.05 percent saccharin or 20 percent cane sugar.

The 32 pigs used in this experiment averaged 2.5 days older and 2.3 pounds heavier than the pigs in Experiment 4, and general performance was much superior (Table 6).

Table 6. — Experiment 5. Chamber Conditions: 40° F. and 60 percent relative humidity
(October 29 to November 19, 1957 — 21 days)

Environment and ration[a]	Average initial weight (pounds)	Average daily gain (pounds)	Average daily feed (pounds)	Feed per pound of gain (pounds)	Temperature °F.	
					Body	Skin
Heat pad, Ration 1	10.7	.63	1.01	1.60	101.7	85.5
Ration 2	9.9	.51	.83	1.62	101.3	85.0
Heat lamp, Ration 1	10.6	.50	.86	1.73	101.2	93.4
Ration 2	10.0	.55	.96	1.74	101.4	94.3
Heated hover, Ration 1	10.9	.66	.94	1.43	102.3	85.8
Ration 2	10.1	.37	.76	2.05	101.2	85.8
Unheated hover, Ration 1	11.1	.72	1.14	1.58	101.7	86.2
Ration 2	10.3	.53	.93	1.75	101.9	85.5
Average for						
Heat pad	10.3	.57	.92	1.61	101.5	85.2
Heat lamp	10.3	.53	.92	1.74	101.4	94.0
Heated hover	10.5	.52	.90	1.74	101.8	85.8
Unheated hover	10.7	.63	1.04	1.66	101.8	85.8
Ration 1	10.8	.63	.99	1.58	101.8	86.9
Ration 2	10.1	.49	.88	1.79	101.4	87.6
All tests	10.5	.56	.94	1.68	101.6	87.3

[a] Ration 1 contained 20-percent sugar (replacing corn), and Ration 2 contained 0.05-percent saccharin.

The pigs with unheated hovers had the highest average daily gain, 0.63 pound. This gain reflects total feed intake, since adjusting gain for feed intake showed all gains to be similar. Average feed efficiencies were very good in all treatments, ranging from 1.61 to 1.74 pounds of feed per pound of gain.

Average gain for the pigs on the ration containing cane sugar was 0.63 pound per day, as compared with 0.49 pound per day when the ration contained saccharin. This difference was significant ($P<0.01$).

Body and skin temperatures were recorded on the first and last days of the experiment. Body temperatures were all about the same, but skin temperatures varied considerably, with the pigs having 250-watt lamps for auxiliary heat again showing the highest readings.

Experiment 6

Experiment 6 was designed to attempt evaluation of initial size of pig and the pig's subsequent performance when subjected to an environment of 38° F. and 60 percent relative humidity.

It was originally planned to divide each litter into light and heavy outcome groups and distribute the pigs equally among treatments. When the chamber was accessible, however, the only available pigs were from litters of different ages and uneven numbers. As a result, littermates were not randomly distributed among treatments. For example, distribution on a weight basis determined that two pigs in pen 3 and all pigs in pens 4 and 5 were from the same litter. The daily gains were 0.65 pound for the two pigs in pen 3, and 0.70 and 0.75 pound for the pigs in pens 4 and 5, respectively. The number of pigs and average daily gains for the three additional litters used in the test were 5 pigs, 0.147 pound; 9 pigs, 0.082 pound; and 6 pigs, 0.125 pound.

Feed required per pound of gain was 1.50 pounds in pen 4 and 1.43 pounds in pen 5.

Obviously, then, the results in Table 7 do not constitute a valid measure of the effects of treatment. They do, however, emphasize the importance of littermate outcome groups, method of distribution to treatment, and interpretation of data.

Experiment 7

Experiment 7 was designed to study the effect of environment and feeder location upon pig performance.

In the preceding experiments, the pigs in heated hovers or under heat lamps seemed reluctant, especially during the first 7 to 10 days, to leave the warmth of the sleeping area to eat at the feeder. The

unprotected pigs showed signs of definite discomfort — shivering, huddling, rough hair coats, and humped backs.

Therefore, an attempt was made to find a more definite measure of physiological stress. In addition to recording body and skin temperatures, blood analyses were made. The samples were taken from the jugular vein of each pig in the second replicate on the first, fourteenth, and twenty-first days of the experiment. Hemoglobin, hematocrit, and red and white blood-cell counts were determined.

Half of the pens had unheated hovers, and the other half had hovers with electrically heated pads for floors. (See Fig. 9, page 12.) Within these two treatments, pigs either had access to feed within the hover, or they had to leave the hover to get to the feeder. To provide feed within the hover, a slot was cut out of the end. The trough of the feeder was put in the slot, allowing access to feed from within the hover (Fig. 14).

Table 7. — Experiment 6. Chamber Conditions: 38° F. and 60 percent relative humidity

(June 19 to July 10, 1958 — 21 days)

Environment and weight grouping	Average initial weight (pounds)	Average daily gain (pounds)	Average daily feed (pounds)	Feed per pound of gain (pounds)	Temperature °F.	
					Body	Skin
Heat pad, light	9.4	.21	.45	2.16	101.7	86.4
heavy	11.3	.04	.30	7.50	103.2	86.4
Heat lamp, light	8.0	.39	.65	1.68	101.4	95.9
heavy	10.6	.70	1.05	1.50	102.4	96.3
Heated hover, light	8.2	.24	.48	1.99	102.8	88.9
heavy	10.8	.75	1.07	1.43	102.4	88.8
Unheated hover, light	9.5	.17	.43	2.52	102.6	89.6
heavy	11.5	.04	.45	11.15	101.7	87.2
Average for						
Heat pad	10.4	.13	.37	4.83	101.5	86.4
Heat lamp	9.3	.54	.85	1.59	102.6	96.1
Heated hover	9.5	.49	.77	1.71	102.9	88.8
Unheated hover	10.5	.10	.44	6.83	102.0	88.4
Light weights	8.8	.25	.50	2.09	102.3	90.2
Heavy weights	11.1	.38	.72	5.39	102.3	89.8
All tests	9.9	.31	.61	3.74	102.3	90.0

The data in Table 8 show that pigs in the heated hovers gained approximately 11 percent faster on 8 percent less feed than the pigs in the unheated hovers — 0.49 pound and 1.74 pounds and 0.44 pound and 1.90 pounds, respectively. Location of feeder had no apparent effect upon total feed consumption and general performance. Neither body nor skin temperatures were affected by treatment.

Table 8a shows the blood-analysis data determined from the blood samples. The limited number of samples and wide variations within treatments preclude definite conclusions.

Table 8. — Experiment 7. Chamber Conditions: 37° F. and 60 percent relative humidity

(July 30 to August 21, 1958 — 21 days)

Environment and feeder location	Average initial weight (pounds)	Average daily gain (pounds)	Average daily feed (pounds)	Feed per pound of gain (pounds)	Temperature °F.	
					Body	Skin
Heated hover, inside	7.1	.49	.81	1.65	103.1	89.0
	7.7	.50	.91	1.82	102.8	88.2
outside	7.5	.44	.77	1.76	102.7	87.8
	7.7	.55	.95	1.73	102.8	88.5
Unheated hover, inside	7.7	.41	.88	2.14	102.7	88.6
	7.5	.49	.88	1.79	102.3	89.6
outside	7.5	.50	.89	1.78	102.6	90.6
	7.4	.37	.70	1.89	102.8	88.8
Average for						
Heated hover, inside	7.6	.49	.85	1.74	103.0	88.6
outside	7.6	.49	.85	1.74	102.7	88.1
Total	7.6	.49	.85	1.74	102.8	88.4
Unheated hover, inside	7.7	.45	.88	1.96	102.4	89.7
outside	7.4	.44	.81	1.84	102.7	88.4
Total	7.5	.44	.84	1.90	102.6	88.9
Inside hover	7.6	.47	.86	1.85	102.7	89.1
Outside hover	7.5	.46	.83	1.79	102.7	88.3

Table 8a. — Summary of Analyses of Blood Samples Taken on 7th, 14th, and 21st Days, Experiment 7

Environment	7th Day	14th Day	21st Day
Hemoglobin (grams per 100 cc.)			
Unheated hover	9.83 (7)[a]	9.88 (8)	8.11 (7)
Heated hover	10.09 (7)	11.10 (8)	7.96 (8)
Hematocrit (percent)			
Unheated hover	52.53 (3)	47.77 (6)	49.53 (3)
Heated hover	47.67 (3)	43.30 (5)	36.11 (2)
Red Blood Cells (10^6/mm.^{3} of blood)			
Unheated hover	7.20 (4)	6.16 (4)	5.22 (3)
Heated hover	6.40 (4)	6.48 (4)	5.10 (4)
White Blood Cells (10^3/mm.^{3} of blood)			
Unheated hover	.....	28.20 (4)	23.94 (3)
Heated hover	.....	35.00 (4)	29.75 (4)

[a] Figures in parentheses indicate number of pigs represented in each value.

Experiment 8

Under the environmental conditions imposed during the first seven experiments, temperature was maintained within a range of 2 or 3 degrees Fahrenheit, and relative humidity was held within 3 or 4 percent of the prescribed percent. Determinations of air movements proved the chamber to be relatively free from drafts. In general, the pigs readily adapted themselves to the constant though cool environment. Experiment 8 was designed to study the effect of varying tem-

Hover with slot cut out of one end to allow access to feed from within hover. (Fig. 14)

peratures upon pig performance, using the same hover and feeder arrangements as those used in Experiment 7.

For the first 24 hours of the test, 60° F. and 60 percent relative humidity were maintained. After the first 24 hours, cycling of 60° F. during the day and 38° F. during the night was followed.

Because of mechanical difficulty with the refrigeration unit, the test was terminated on the fourteenth day.

Blood samples were taken from all pigs in replicate 2 on the first, seventh, and fourteenth days.

The data in Table 9 show considerable variation in performance between pens. Average daily gain and feed required per pound of gain were 0.24 pound and 1.98 pounds for the heated hovers, and 0.21 pound and 2.24 pounds for the unheated hovers.

The effects of feeder location are similar to those in Experiment 7 — the pigs provided feed inside the hover gained slightly more rapidly but needed more feed per unit of gain.

Analyses data of blood samples taken on the first, seventh, and fourteenth days of the experiment are shown in Table 9a. The environment had no apparent effect on these blood fractions.

Experiment 9

Since essentially draft-free conditions existed in the controlled environment chamber, temperature difference was the only measurable variable in the environment. Perhaps the apparent adaptability of even the 2-week-old pig to an air temperature of 40° F. was due in part to the constancy of the environment. Under farm conditions, it has fre-

Table 9. — Experiment 8. Chamber Conditions: 60° F. during the day, 38° F. at night; 60 percent relative humidity

(October 7 to October 20, 1958 — 14 days)

Environment and feeder location	Average initial weight (pounds)	Average daily gain (pounds)	Average daily feed (pounds)	Feed per pound of gain (pounds)
Heated hover, inside	10.6	.15	.40	2.65
outside	10.9	.19	.38	2.02
inside	10.2	.43	.60	1.40
outside	10.6	.21	.39	1.87
Unheated hover, inside	10.7	.18	.47	2.60
outside	10.3	.32	.56	1.75
inside	10.6	.23	.46	1.99
outside	10.3	.12	.32	2.65
Average for				
Heated hover, inside	10.4	.29	.58	2.02
outside	10.7	.20	.39	1.94
Total	10.5	.24	.48	1.98
Unheated hover, inside	10.6	.20	.46	2.29
outside	10.3	.22	.48	2.20
Total	10.4	.21	.47	2.24
Inside hover	10.5	.24	.52	2.15
Outside hover	10.5	.21	.43	2.07

Table 9a. — Summary of Analyses of Blood Samples Taken on 1st, 7th, and 14th Days, Experiment 8

Environment and number of pigs	1st Day	7th Day	14th Day
Hemoglobin (grams per 100 cc.)			
Unheated hover (8 pigs)	6.17	6.36	6.84
Heated hover (8 pigs)	6.48	6.94	6.68
Hematocrit (percent)			
Unheated hover (8 pigs)	25.14	27.10	29.22
Heated hover (8 pigs)	25.76	29.02	29.58
Red Blood Cells (10^6/mm.^{3} of blood)			
Unheated hover (4 pigs)	7.04	5.92	5.90
Heated hover (4 pigs)	4.96	5.07	4.92
White Blood Cells (10^3/mm.^{3} of blood)			
Unheated hover (4 pigs)	10.24	11.20	16.96
Heated hover (4 pigs)	10.40	8.16	16.16

quently been observed that young pigs provided inadequate shelter from drafts and moisture performed poorly.

Experiment 9 was conducted at the University Swine Farm. The 32 pigs were confined to a room in an unheated building. Four hardware-cloth pens were located on each side of a temporary partition. The pens on one side of the partition had heated hovers; the other four pens had only a wooden overlay for a sleeping area. For two hours a day (from 5 a.m. to 6 a.m., and from 4 p.m. to 5 p.m.) the unprotected pigs were subjected to the direct breeze from a 10-inch oscillating fan operated at slow speed.

Half of the pigs under each environment received a ration containing 8 percent lactose or corn oil.

Blood samples were taken from two pigs in each pen (representing two littermate outcome groups) on the first, seventh, fourteenth, and twenty-first days. Hematocrit, hemoglobin, and white-blood-cell counts were determined.

The results in Table 10 show that, on the average, the pigs protected by heated hovers gained 6 percent faster on about 25 percent less feed than the pigs without hover protection.

Table 10. — Experiment 9. Variable Environment in Swine Farm Building

(November 25 to December 16, 1958 — 21 days)

Environment and ration[a]	Average initial weight (pounds)	Average daily gain (pounds)	Average daily feed (pounds)	Feed per pound of gain (pounds)
No heat, Ration 1	11.4	.29	.61	2.12
	11.6	.11	.42	3.78
Ration 2	11.3	.51	.82	1.60
	11.9	.34	.60	1.76
Heated hover, Ration 1	11.5	.44	.60	1.37
	11.8	.47	.61	1.30
Ration 2	11.7	.24	.49	2.05
	11.4	.21	.47	2.23
Average for				
No heat, Ration 1	11.5	.20	.51	2.95
Ration 2	11.6	.42	.71	1.68
Total	11.5	.31	.61	2.31
Heated hover, Ration 1	11.6	.45	.60	1.33
Ration 2	11.5	.22	.48	2.14
Total	11.5	.33	.54	1.73
Ration 1	11.5	.32	.55	2.14
Ration 2	11.5	.32	.59	1.91

[a] Ration 1 contained 8-percent lactose and Ration 2 contained 8-percent corn oil.

Daily gains on the two rations were the same, but 2.14 pounds of lactose ration were required per pound of gain, and only 1.91 pounds of corn-oil ration were required per pound of gain. However, this apparent advantage for the corn-oil rations reflects the extremely poor performance in one of the unheated pens, where the pigs on the lactose ration gained only 0.11 pound per day and required 3.78 pounds of feed per pound of gain.

Statistical analysis of the gain data revealed a highly significant interaction between diet and pen environment. This interaction cannot be satisfactorily explained, since performance within treatments varied considerably.

Hygrothermograph recordings during the test period showed a temperature range from a low of 25° F. to a high of 66° F. The average daily low temperature was approximately 41° F., and the average daily high temperature was 48.5° F.

The blood-analyses data are shown in Table 10a. Considerable variation was again encountered. It is interesting, however, that the average hematocrit values for each treatment were highest on the seventh day, although there was no apparent change in hemoglobin values.

On the average, white-blood-cell (WBC) counts increased with time on test and, with the exception of no-hover corn-oil treatment on the twenty-first day, increased more under no-hover than under hover treatment. Comparing only the values for the first and fourteenth days, WBC's increased 70.37 percent under no-hover and only 22.65 percent under heated-hover treatment.

Discussion

In recent years, environmental temperatures of 75° F. to 80° F. have been recommended as minimum for pigs from birth up to 3 weeks of age. To provide this environment, supplemental sources of heat have been necessary. The heat lamp has commonly been used in various kinds of brooder-type arrangements.

It was observed that the newborn pig farrowed into a cool area found its way to the brooder and took advantage of the warmth from the bulb. As the pig increased in age and size, he moved outward from directly under the lamp for his sleeping area. This fact suggested that less supplemental heat was necessary for comfort as he increased in age and, particularly, body size.

A heat lamp or other supplemental heat device not only provided warmth for the pigs but also attracted them away from the sow,

Table 10a. — Summary of Analyses of Blood Samples Taken on 1st, 7th, 14th, and 21st Days, Experiment 9

Environment and number of pigs	1st Day	7th Day	14th Day	21st Day
Hemoglobin (grams per 100 cc.)				
No hover				
Lactose (5 pigs)	7.01	6.92	6.70	6.97
Corn oil (5 pigs)	7.78	7.79	7.13	7.78
Average	7.39	7.35	6.91	7.37
Heated hover				
Lactose (4 pigs)	6.51	7.44	7.21	6.61
Corn oil (6 pigs)	6.87	6.32	7.52	6.70
Average	6.69	6.88	7.36	6.65
Total average	7.04	7.11	7.13	7.01
Hematocrit (percent)				
No hover				
Lactose (8 pigs)	24.14	29.56	25.62	24.89
Corn oil (8 pigs)	28.84	32.60	27.50	27.71
Average	26.49	31.08	26.56	26.30
Heated hover				
Lactose (8 pigs)	23.37	29.98	26.10	27.17
Corn oil (8 pigs)	26.87	29.95	29.15	25.86
Average	25.12	29.96	27.62	26.51
Total average	25.80	30.52	27.09	26.40
White Blood Cells (10^3/mm.^{3} of blood)				
No hover				
Lactose (8 pigs)	7.60	9.56	11.80	15.52
Corn oil (8 pigs)	7.52	11.48	13.96	10.92
Average	7.56	10.52	12.88	13.22
Heated hover				
Lactose (8 pigs)	7.80	9.20	9.70	14.75
Corn oil (8 pigs)	7.96	9.13	9.63	13.16
Average	7.88	9.16	9.66	13.95
Total average	7.72	9.84	11.27	13.58

reducing crippling and mashing by the dam. The sow's body, however, is an excellent source of warmth for the newborn pig (Bond *et al.* 13).

The average results of all experiments except Experiment 6 are shown in Summary Tables 11, 12, and 13. Since these results varied considerably, it is difficult to make a conclusive interpretation of the individual test data. Hays *et al.* (14) have pointed out that an examination of summaries of 51 baby pig experiments showed average coefficients of variation of 13.7 percent for gains and 8.8 percent for feed required per pound of gain. These authors also emphasize the importance of genetic background in allotment to treatment.

In Experiment 6, litter averages ranged from 0.70 to 0.08 pound gain per day. Since litters were unevenly distributed across treatments, the effect of the treatments could not be measured. For this

reason, the data from Experiment 6 are not included in the summary tables.

The summary of average daily gains in eight experiments (Table 11) shows no definite effects of the varied environmental conditions studied. In Experiments 3, 4, 5, 7, and 8, the average daily gain was 0.41 pound in the heated hovers and 0.40 pound in the unheated hovers.

In Experiments 2, 3, 4, and 5, the average daily gain was 0.44 pound for the heated hover, 0.40 pound for the heat lamp, and 0.44 pound for the heat pad. Three comparisons of all treatments except wooden overlay show average daily gains ranged from 0.45 to 0.41 pound.

Feed per pound of gain comparisons are shown in Table 12. The average of five comparisons shows that pigs in unheated hovers required 8.5 percent more feed per pound of gain than pigs in heated hovers. Four comparisons showed little difference between unheated hover, heat lamp, and heat pad, while three comparisons showed values of 1.87 for heated hover, 2.01 for unheated hover, 2.02 for heat lamp, and 2.06 for heat pad. The greatest difference in feed efficiency oc-

Table 11. — Summary of Average Daily Gains in 8 Experiments[a]

	Average initial weight (pounds)	Temperature, F.	Environments				
			Heated hover	Unheated hover	Heat lamp	Heat pad	Wooden overlay
			(pounds)				
Experiment 1.....	7.6	60°	...	...	.35	...	.23
Experiment 2[b]....	6.9	60°	...	.39	.37	.43	.44
Experiment 3.....	6.5	50°	.42	.39	.46	.50	...
Experiment 4.....	8.2	40°	.35	.34	.23	.24	...
Experiment 5.....	10.5	40°	.52	.63	.53	.57	...
Experiment 7.....	7.5	37°	.49	.44	...	...	...
Experiment 8[b]....	10.5	60° day, 38° night	.24	.21	...	...	...
Experiment 9[c]....	11.5	variable	.33	...	...	...	.31
Averages							
Heated hover and unheated hover (5 comparisons).....			.41	.40	...	...	...
Unheated hover, heat lamp, and heat pad (4 comparisons).....			...	.44	.40	.44	...
Heated hover, unheated hover, heat lamp, and heat pad (3 comparisons).....			.43	.45	.41	.44	...

[a] Data from Experiment 6 are omitted.
[b] Experiments 2 and 8 each lasted 14 days. Each of the other experiments lasted 21 days.
[c] Experiment 9 was carried out at the University Swine Farm. Temperatures ranged from 25° to 66° F.

Table 12. — Summary of Feed per Pound of Gain in 8 Experiments[a]

	Average initial weight (pounds)	Temperature, F.	Environments				
			Heated hover	Unheated hover	Heat lamp	Heat pad	Wooden overlay
					(pounds)		
Experiment 1.....	7.6	60°	....	....	2.05	....	2.45
Experiment 2[b]....	6.9	60°	....	1.56	1.65	1.42	1.61
Experiment 3.....	6.5	50°	1.90	2.18	1.86	1.71	....
Experiment 4.....	8.2	40°	1.97	2.18	2.44	2.85	....
Experiment 5.....	10.5	40°	1.74	1.66	1.74	1.61	....
Experiment 7.....	7.5	37°	1.74	1.90	....	....	....
Experiment 8[b]....	10.5	60° day, 38° night	1.98	2.24	....	....	....
Experiment 9[c]....	11.5	variable	1.73	....	....	....	2.31
Averages							
Heated hover and unheated hover (5 comparisons).....			1.87	2.03	....	....	....
Unheated hover, heat lamp, and heat pad (4 comparisons).....			....	1.89	1.92	1.90	....
Heated hover, unheated hover, heat lamp, and heat pad (3 comparisons).....			1.87	2.01	2.02	2.06	....

[a] Data from Experiment 6 are omitted.
[b] Experiments 2 and 8 each lasted 14 days. Each of the other experiments lasted 21 days.
[c] Experiment 9 was carried out at the University Swine Farm. Temperatures ranged from 25° to 66° F.

curred in Experiment 9. This test was conducted in an unheated building where pigs were subjected to variable temperatures and artificial drafts. Thirty-three and one-half percent more feed was required per pound of gain when the pigs had no supplemental warmth under these conditions.

It is surprising that the environments imposed did not, on the average, materially affect the growth rate of pigs weaned at 2 to 2½ weeks of age. These results suggest that the thermo-regulatory system of the 2-week-old pig is sufficiently developed to allow adaptation to environmental temperatures as low as 38° F. It must be emphasized, however, that the pigs were provided ample bedding and kept free of dampness and drafts. Therefore, except in Experiment 9, the adaptation was essentially to temperature alone.

Within a few minutes after subjection to the cool environment, pigs without supplemental heat shivered markedly. In an attempt to conserve body heat, the pigs huddled together, usually against the feeder or in the most protected corner available (Figs. 7 and 9). Pigs with the heat lamp, heat pad, or heated hover quickly located the

heated area. During the first two or three days of a trial, pigs having heat lamps or heat pads would huddle together, but very little huddling and shivering were observed in the heated hovers.

In addition to shivering, pigs without supplemental heat became humpbacked in appearance, and their hair coats became rough-looking. "Raising" of the hair occurred within a few hours. The pigs with heated hovers were not observed to shiver, and they maintained a sleek, smooth appearance throughout the trial. This contrast was particularly evident in Experiment 9, which was conducted under cold, drafty conditions. Toward the end of the test period, pigs without supplemental heat improved in appearance. The small, poor-performing pigs recovered least. Newland *et al.* (3) reported that the insulative "hair raising" reaction to cold was exhibited by pigs one hour old. Thus the shivering and pilomotor mechanisms were quickly used by the pig as defensive measures against the lowering of body temperature.

The pigs in the unheated hover were observed to spend more time eating and, with the different possible comparisons, consumed on the average more feed per day (Table 13). Considering the extra feed required per pound of gain (Table 12), this fact suggests that basal

Table 13. — Summary of Average Daily Feed Consumption in 8 Experiments[a]

	Average initial weight (pounds)	Temperature, F.	Environments				
			Heated hover	Unheated hover	Heat lamp	Heat pad	Wooden overlay
			(pounds)				
Experiment 1.....	7.6	60°	...	...	.72	...	.56
Experiment 2[b]....	6.9	60°	...	.61	.62	.61	.71
Experiment 3.....	6.5	50°	.80	.85	.85	.84	...
Experiment 4.....	8.2	40°	.71	.74	.56	.68	...
Experiment 5.....	10.5	40°	.90	1.04	.92	.92	...
Experiment 7.....	7.5	37°	.85	.84	...	...	...
Experiment 8[b]....	10.5	60° day, 38° night	.48	.47	...	...	...
Experiment 9[c]....	11.5	variable	.54	...	...	...	.61
Averages							
Heated hover and unheated hover (5 comparisons).....			.72	.78	...	...	...
Unheated hover, heat lamp, and heat pad (4 comparisons).....			...	.81	.74	.76	...
Heated hover, unheated hover, heat lamp, and heat pad (3 comparisons).....			.80	.88	.78	.81	...

[a] Data from Experiment 6 are omitted.
[b] Experiments 2 and 8 each lasted 14 days. Each of the other experiments lasted 21 days.
[c] Experiment 9 was carried out at the University Swine Farm. Temperatures ranged from 25° to 66° F.

metabolic rate increased as a means of greater body-heat production. This reaction is typical of the behavior of other species (Hart, 15).

Body and skin temperatures were recorded at pre-scheduled times during the first seven experiments. In no instance did treatment significantly affect body temperature. Thus the thermoregulatory system of the 2- to 3-week-old pig is capable of maintaining normal body temperature under the conditions of stress imposed in these trials.

Skin temperatures were significantly affected by supplementary heat source. In each comparison of heat lamp with other types of supplementary heat, pigs with the heat lamps always had the highest skin temperatures. This result would be expected, since point of temperature measurement was the middle of the back, and the pigs were usually removed from direct exposure to the heat bulb for the temperature measurement.

The blood analyses in Experiments 7, 8, and 9 produced no definite indication of physiological stress in response to environments. Hemoglobin, hematocrit, and white-blood-cell counts were determined in all three experiments, and red-blood-cell count was also determined in Experiments 7 and 8. Because of the large variations within treatments and the limited number of samples, definite conclusions cannot be made. Newland *et al.* (3) showed a significant drop in hematocrit in 2- to 4-day-old pigs chilled 3 hours in a 34° F. environment, while pigs 10 days old and older exhibited no significant drop in hematocrit after exposure for four hours at 34° F., or overnight at an average of 25° F.

Nutritional considerations were secondary in the experimental designs, and concise measurements could not be determined. The one instance of significant ($P<0.01$) ration effect on growth rate occurred in Experiment 5, when 20-percent cane sugar proved superior to 0.05-percent saccharin.

SUMMARY

1. Nine experiments were conducted to study the effect of environment upon performance. These experiments involved 272 pigs weaned at 2 to 2½ weeks of age.

Eight of the tests were conducted in a controlled environment; one test was conducted under "farm" conditions.

2. An average of all tests showed that none of the supplementary units (heat lamp, heat pad, heated and unheated hovers) significantly affected growth rate of pigs confined for 2 or 3 weeks in a chamber having constant temperatures as low as 38° F.

3. Pigs without supplementary heat required more feed per pound of gain than pigs with supplementary heat. This fact reflects the metabolizable energy used in shivering and other physiological reactions to maintain body temperature.

4. In one "farm" test in which temperatures varied from 25° F. to 66° F. and forced drafts were employed, pigs having access to heated hovers grew 6 percent faster on 25 percent less feed than unprotected pigs.

5. Under the conditions imposed, body temperature was not significantly affected by environment. However, skin temperatures were significantly different when heat lamps provided supplementary heat.

6. Blood analyses, red-blood-cell and white-blood-cell counts, hematocrit, and hemoglobin, did not prove sufficiently sensitive to indicate physiological stress as a result of the imposed environments.

7. Pigs weaned at 2 to 2½ weeks of age adapted to constant temperatures as low as 38° F. when kept free of drafts and dampness.

8. Locating the feed inside the heated and unheated hovers did not improve feed efficiency but slightly increased the rate of gain.

9. The optimum surface temperature of the heat pads, as determined by apparent comfort of the pigs, was about 110° F.

10. Thermostatically controlled 500-watt heat pads required approximately 2, 3, and 4 kilowatt hours of power per day when chamber temperatures were 60° F., 50° F., and 40° F., respectively. A 250-watt heat lamp in continuous use required 6 kilowatt hours per day.

APPENDIX I: Composition of Mineral and Vitamin Premixes

Mineral Mixture No. 1

This mixture is designed to supply all mineral elements except calcium, phosphorus, sodium, chlorine, and potassium. It is added as 0.2 percent of the ration.

Ingredients	*Grams for 100-pound mixture*
Magnesium carbonate ($MgCO_3$)	31,144.4
Ferrous sulfate ($FeSO_4$)	9,080.0
Manganese sulfate ($MnSO_4 \cdot H_1O$)	2,724.0
Cobalt chloride ($CoCl_2 \cdot 6H_2O$)	908.0
Cupric sulfate ($CuSO_4$)	908.0
Sodium fluoride (NaF)	181.6
Zinc carbonate ($ZnCO_3$)	363.2
Potassium iodide (KI)	90.8

Hardy's Super Trace-Mineral Salt

In this report, trace-mineralized salt (TM salt) refers to Hardy's Super Trace-Mineral Salt with the following guaranteed composition.

Element	*Percent (not less than)*
Salt	97.000
Zinc	0.500
Manganese	0.400
Iron	0.330
Copper	0.048
Iodine	0.011
Cobalt	0.022

Vitamin and Antibiotic Mixture

Ingredients	*Addition per pound of ration*
Thiamine HCl	2.2 mg.
Riboflavin	4.5 mg.
Calcium panthothenate	25 mg.
Nicotinic acid	14 mg.
Folic acid	0.18 mg.
Pyridoxine HCl	2.2 mg.
Vitamin B_{12}	0.013 mg.
Biotin	0.03 mg.
Para-amino benzoic acid	8.8 mg.
Inositol	85 mg.
2-methyl-1, 4-naphthoquinone	0.85 mg.
Ascorbic acid	13.6 mg.
Choline chloride	682 mg.
Chlortetracycline HCl	23 mg.
Streptomycin	37.7 mg.
Procaine penicillin	23 mg.
Vitamin A	4,320 I.U.
Vitamin D	540 I.U.

APPENDIX II: Statistical Analyses of Gain and Feed Data

Source	d.f.	Mean square of gain[a]	d.f.	Mean square of daily feed	Mean square of feed per pound of gain
Experiment 1					
Heat treatment (H)	1	1892	1	.0240	.1521
Ration (R)	1	9	1	.0056	.1444
H × R	1	484	1	.0031	.0576
Litters	2	1519			
Error	9	543			
Experiment 2					
Heat treatment (H)	3	1.9433	3	.0042	.0619
Ration (R)	1	.0603	1	.0010	.0674
H × R	3	2.5705	3	.0016	.0240
Pens	7	1.9431			
Error	24	2.6079			
Experiment 3[b]					
Heat treatment (H)	3	276.6	3	.0018	.0788
Ration (R)	1	1020.1	1	.0098	.0105
H × R	3	651.2	3	.0280	.0340
Outcome groups	3	364.1			
R × H × RH	7	429.0			
Error	18	237.2			
Experiment 4					
Heat treatment (H)	3	14.8279	3	.0137	.2289
Ration (R)	1	4.5052	1	.0038	.0200
H × R	3	13.2961	3	.0032	.2264
Outcome groups	3	16.2095*			
Error	21	5.2620			
Experiment 5					
Heat treatment (H)	3	7.5921*	3	.0119	.0077
Ration (R)	1	40.9131**	1	.0276	.0841
H × R	3	16.2113**	3	.0106	.0409
Outcome groups	3	17.0686**			
Error	21				
Experiment 7[c]					
Shelter (S)	1	.0210	1	.0010	.0512
Feeder location (F)	1	.0004	1	.0036	.0072
S × F	1	.0005	1	.0036	.0098
Replicate	1	.0085	1	.0001	.0012
Outcome group (O)	3	.0367			
R × O	3	.0100			
Remainder	20	.0143	3	.0131	.0270
Experiment 8[c]					
Shelter (S)	1	.1804	1	.0002	.1378
Feeder location (F)	1	3.1005	1	.0098	.0153
S × F	1	9.1032	1	.0041	.0001
Pens (within S × P)	4	12.4458			
Outcome groups	3	9.9052			
Error	20	9.9891			
Replicate	..		1	.0002	.1540
Remainder	..		3	.0162	.4099
Experiment 9					
Diet (D)	1	.5151	1	.0025	.1081
Shelter (S)	1	.0250	1	.0098	.6670
Outcome groups (G)	3	70.4360*			
Pens in treatment (P)	4	7.6141			
D × S	1	139.7466**	1	.0512	2.1528
D × G	3	31.0366			
S × G	3	3.9111			
D × S × G	3	31.5170			
T × G	10	11.7114			
Replicate	..	.....	1	.0221	.4656
Remainder	..	.....	3	.0068	.2359

[a] Co-variance analysis with adjustment to equal initial weights.
[b] Estimated daily gain used for two pigs that died.
[c] Analysis included one estimated gain value for a pig removed during the first week of the experiment.
* $P < 0.05$
** $P < 0.01$

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