GROWING EARTHWORMS IN ARTIFICIAL ENVIRONMENTS

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GROWING EARTHWORMS IN ARTIFICIAL ENVIRONMENTS

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By

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CHAPTER I

INTRODUCTION

The earthworms' geological history is as old as the soil in which they live. The first history of the earthworm has come down to us from the dawn of written history. The ancient Sumerians wondered at the habits of the earthworms in the soil of their arid country. The ancient Egyptians regarded them as direct representatives of the god of soil fertility. Aristotle studied and wrote a little about them. Thus, the importance of the earthworms among animals is obvious.

They are among the most common of our animals, and those about which little is known. Years and years of research failed to reveal some of the simplest facts about them. How, in the mysterious working of nature and the elements, did a worm that is so common in the Yucatan Peninsula of southern Mexico ever come to be called the African night crawler? The very first man that brought the first box full of them is still alive and actively fishing the waters off the Yucatan coast, yet the antecedents of the worm are completely shrouded in mystery; its date of origin or how and from where it migrated to the United States is still obscured in the dimness of antiquity.

Earthworms are found in many places. Some species are found in lakes and streams and some in the depths of the ocean water, while others are found in many different types of soils. They are known by a variety of names--earthworms, angleworm, fishworm, night crawler, dew-worm, and many others.

The economic importance of the earthworm is various. To many people, they are important as bait, being by far the most important fish bait used throughout the world by the young and old alike. Because of this demand, interested individuals throughout the country have developed industries with regard to collecting, raising and selling of earthworms. As soil conditioners, their value has been the subject of argument. Some claim that their activities in the soil are tremendous in improving the fertility of the soil, while others disagree with this idea and maintain that their presence only indicates that the soil is rich in organic matter. Whatever the case, this study is concerned particularly with their raising and not their agricultural importance.

There is little in the field of scientific literature on the raising and culture of earthworms. The amount of information available on the methods of culturing and the facts of their life histories is scattered through many books and pamphlets. As early as 1496, there was published in England in the Book of St. Albans an article entitled "Fysshynge wyth an Angle," by Julia Berners, a Benedictine nun. The article gave explicit instructions on the types of worms to use for bait and the methods of collecting them. This shows the importance of earthworms as fishbait. The method of looking for them in isolated places was, for many years, the rule. Around the 1920's, interested persons began to think about a quick way of procuring them for fish bait. The publication of Walton (20) did a lot to stir up people's interests. Accordingly, in 1942, Melvin (11) did his pioneering work. This was followed by many other workers.

Ball and Curry (1) have published much on the culture and agricultural importance of earthworms. They gave some interesting facts on the life history of some species of earthworms. Cooper's (3) information on the raising of earthworms, though scanty is also helpful to the beginner. One of the chief commercial worm culturists is Morgan (12), whose pamphlets are tremendously helpful to anyone interested in the problem of raising worms. He gave valuable information concerning culture media as well as raising and harvesting earthworms.

Other works referring to the culture and raising of earthworms include Swingle and Sturkie, Shields, and Kyle (17, 15, 6). It is to be noted that most of the works of these people are mere summaries of information on earthworms obtained from other books. They do not involve any laboratory experimentation. Only Morgan (12) did actual laboratory work on the culture of earthworms.

Some General Information on Earthworms

The earthworm belongs to the large group of organisms classified as annelida, of which there are approximately 7,000 known species. Their distribution is world-wide. They are constructed on a tube-within-tube plan. The body wall is soft, muscular, and covered with a very thin cuticle. The group includes such animals as the leeches, the sand worms and the earthworms, ranging in size from only a fraction of an inch to the giant worms of the tropics, and of Australia, measuring up to eleven feet in length. Most annelids are marine, some live in fresh water, some in the soil, while some live in moist places. They are all segmented.

Species of Earthworms and Distribution

The distribution of worms by species in Texas is not well known. Table I shows a list of common worms used as bait and sold by bait dealers (1).

TABLE I

SCIENTIFIC AND COMMON NAMES OF EARTHWORMS

Scientific Name	Common Name
Helodrilus caliginesus . . .	*Garden worm or dung worm
Helodrilus chloroticus . . .	*Garden worm or dung worm
Helodrilus foetidus	Red worm, manure worm, fish-worm, dung worm, fecal worm, English red worm, stripe worm, stink worm, branching or apple pomace worm
Lumbricus rubellus	*Leaf worm
Lumbricus terrestris	*Night crawler, dew worm, nightwalker, rainworm, angle-worm, orchard worm, or night lion
Octolasium lacteumf	*Garden worm or dung worm
Pheretima hawayana	*Swamp worm
Pheretima hilgendorfi . . .	*Swamp worm

*Most commonly used names

Of the worms listed in the table, the night crawler, *Lumbricus terrestris* is the most commonly cultivated and most commonly used as bait. It is the largest and most popular. The term "hybrid worm" is often used, especially in advertising literature, to designate a cross between two species of worms.

It is generally intended to give the impression that such a worm is larger, faster growing, or more active. There is little in the field of scientific literature to back this claim of the "hybrid worm" sellers. Ball *et al*. (1) actually put this to test by obtaining several samples of hybrid worms from the market for laboratory examination. He found out that the hybrid worms, so acclaimed to be larger and faster growing, are nothing more than the common red worm, *H. foetidus*.

Digestion and Feeding Habits of Earthworms

The majority of oligochaetes are omnivorous. That is to say, they are non-specific eaters. But they are selective, as it has been shown by Mangold (10) and Wittich (21) that particular types of leaves are eaten in preference to others. Earthworms (*L. terrestris*) come to the surface of the ground at night, searching mainly in the area surrounding the burrow entrance for food and drawing suitable leaves into the mouth of the burrow. It is obvious that during the passage of earthworms through the soil, much soil passes along the gut. This soil not only contains plant matter, but also the decomposing remains of animals, large and small, living protozoa, rotifers, and several other minute animal forms.

These will be ingested, adding their bulk to the food forage on the surface of the ground. A few oligochaetes are carnivorous, consuming rotifers, fish, frogs, flies and other worms (16). Because of the universal eating habits of most oligochaetes, they have a wide range of enzymes present in their gut (Fig. 1). Lesser and Taschenberg (9) made extracts of the gut of L. terrestris and incubated them with starch, glycogen, cellulose and insulin. All of these substances appear to be attacked and broken down. Other enzymes were later discovered and recorded.

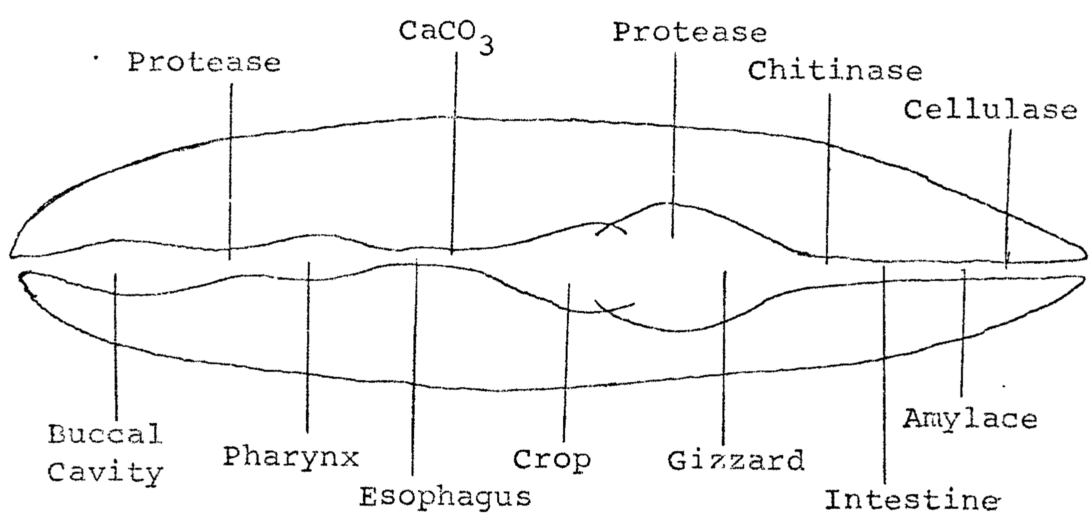

Fig. 1--The alimentary canal, structure and enzyme secretions.

The figure shows the various regions in which they are found in Lumbricus. (After Laverack [8] in Physiology of the Earthworm).

Earthworms feed on many diversified quantities of plant material, and the enzymes capable of utilizing the cellulose of these plants would be of considerable value. As shown in Fig. 1, and as has been confirmed by Tracey (19), cellulase is present. In view of the digestion of cellulose by symbiotic bacteria and protozoa in the alimentary canal of other animals such as cows, termites, and the shipworm, the production of cellulase by earthworms would be an interesting area for further investigation. It has also been established that the enzymes of the gut have distinctive pH optima; but the gut contents are stable with regard to pH, since it apparently varies only between about 6.3 - 7.3 along the gut length (14).

Calciferous Glands

These are glandular structures in the alimentary canal of the earthworms. They are of tremendous importance in the life of the earthworm. They occur as pouch-like diverticula somewhere along the length of the oesophagus, e.g., segments 11 and 12 in *L. terrestris* with an associated oesophageal pouch in segment ten (16). As the name implies, the cells that line these diverticula are glandular in nature, and they secrete calcium carbonate. They undergo cycles of activity, forming first, globules in the cytoplasm, which secondly gave rise to spicules of calcium carbonate; and these, thirdly, amalgamate to form irregular masses (2). These concentrations of calcium carbonates are released into the lumen of the glands and pass from there into the gut. Five major theories concerning the function of the calciferous glands are mentioned by Stephenson (16). These are (1) the absorption of oxygen, (2) the excretion of excess calcium (as carbonate) absorbed from the gut, (3) the absorption of nutritious material from the gut, (*4) the neutralization of the organic acids formed during digestion of vegetable matter contained in the gut, and, (5) the excretion of respiratory carbon dioxide.

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*Because of this function of the glands, if earthworms are put in slightly acid medium, it does not affect them adversely, for the medium will soon change to the neutral side. This function of the calciferous glands is of tremendous importance to the earthworm culturists. This will be discussed further in later chapters.

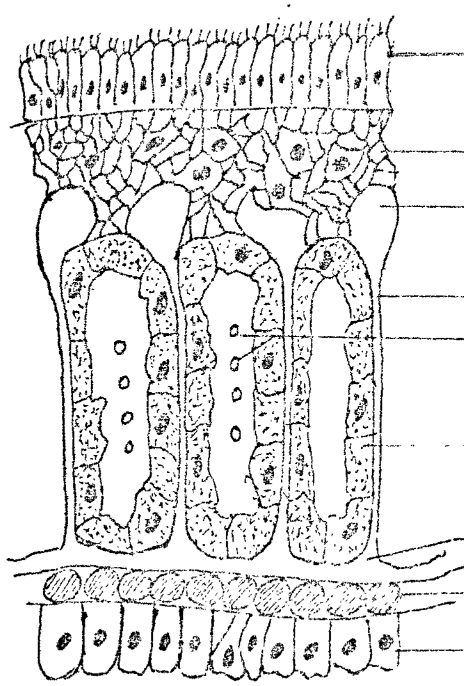

Fig. 2--Transverse section of calciferous glands of earthworm to show disposition of gut epithelium blood sinuses and chloragogen tissue (redrawn from Gabbay [4]).

Life Histories and Identification of Common Worm

In the northern region of the U. S., the red worm (Helodrilus foetidus) is the worm most successfully raised for sale, while in the south, it is the night crawler (Lumbricus terrestris). The egg-capsule of H. foetidus is lemon-shaped, about the size of the head of a kitchen match, and greenish-yellow in color. According to Ball and Curry (1), at 70^{o}F. an egg capsule containing two to four eggs is produced about every five days. The young hatch in about twenty-two days. When the temperature goes up to about 78^{o}F., egg-capsules are produced more often and hatch in a shorter length of time.

TABLE II

KEY FOR THE IDENTIFICATION OF COMMON EARTHWORMS AROUND DENTON*

Location of Clitellum	Species of Worm
Clitellum begins on segment 14	*Pheretima* sp.
Clitellum begins on segment 24; ventral side of	. . .
Clitellum has a pair of small protruding ridges on segment 28-30	*H. foetidus*
Clitellum begins on segment 27; ventral side of	. . .
Clitellum has a pair or protruding ridges from segments 31-33	*H. caliginosus*
Clitellum begins on segment 30	*O. lacteum*
Clitellum begins on segment 32	*L. terrestris*

*Modified from Ball and Curry

H. foetidus matures in 3.5 to 4 months. Olson (13) reported that this species may reach a length of 5.9 inches. Hutchens (5) suggested that this species should not be used to feed aquarium fish because of the strong-smelling body fluid which causes digestive disturbances in the fish. Many tropical fishes will refuse to eat it.

The egg-capsule of *Helodrilus caliginosus* is also lemon-shaped and greenish-yellow in color. Egg-capsules are produced on the average of every 8 days and have an average of two embryos per capsule. The incubation period is from 50 to 68 days, depending upon temperature. A length of 2 inches is reached at about five months after hatching. They are very slow in growth. Maturity is reached at 6 to 7 months.

Pheretima hawayana's egg-capsule, which is reddish-brown, contains one embryo. They measure 4-5 inches at maturity. This genus and many of its species are native to India and have been introduced into this country on plant imports. Their range and distribution are not well known. They have been found in several widely separated areas.

Lumbricus terrestris, the night crawler, is the largest of common worms. It produces a large, lemon-shaped, light-yellow capsule. These egg-capsules are produced on an average of 6-8 days and require an incubation period of about 10-15 days. A length of 3 inches is reached twenty days after hatching, and maturity after 70-80 days.

Habits of the African Night Crawler

The African night crawler is a variety of the night crawlers. It is called by various names, *viz*., giant tropical worm, Missouri giant, Morgan giant, ruby red, foot long worm, giant river worm, and the like. It is susceptible to cold and will not do well in very cold climates. Cold means nothing to them, probably, because they did not experience it in their native state. When the temperature suddenly drops, they do not try to avoid it by crawling to the deeper sub-soil; rather, they simply remain inactive and eventually freeze to death.

Of the several types of worms that are used for bait, the African night crawler is the best choice for the fishermen because of its availability from the breeders. All that it requires is protection from cold. It is more adaptable to inside propagation than any other worm. Apart from its susceptibility to cold if exposed, it is easier to raise than the wigglers or manure worms.

The African night crawler deposits capsules much more often than other types of worms. These capsules hatch and develop a little quicker than other worms. Methods of copulation are the same as in other worms, and it takes less time. The subsequent formation and shedding of the capsule normally takes but a few minutes. It is to be noted, however, that not all of the capsules are fertilized.

Crawling is the most serious hazard to be faced by the breeder of the African night crawlers. They travel fast, are nocturnal, and have been known to travel about 100 feet in one night.

Although past information about the African night crawler is very fascinating and interesting, there is nothing in the literature concerning the most effective propagation of these worms in artificial environments. This study was initiated with the idea that it might prove helpful to fishbait dealers and others. It could also serve as a pioneering work on the propagation of the African night crawlers in artificial environments.

Statement of Problem

This study is intended to investigate the artificial environmental conditions that would favor the most effective propagation of the African night crawler. "Artificial environmental conditions" as used here refers to bedding materials, food, water, content of bedding, hydrogen ion concentration, and concentration of subjects per unit of bedding materials. "Propagated most effectively" as used here refers to the growth of the worms, their vigor as evidenced by inspection, and their minimum death loss.

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CHAPTER II

MATERIALS AND METHODS

Organisms

The organisms used in this study were the African night crawlers, because of the claim that they are very hard to raise under controlled environments. The others were used so as to establish a basis for comparison between the African night crawler and other common native worms (see chapter 1).

Bedding Containers

The containers for propagating earthworms may be of various sizes depending on certain factors, viz., type of containers, location of the containers and season of the year the operation will be started. Indoor cultures require more care than outdoor culture. For the indoor culture, moisture, temperature, food and light must be controlled for successful worm storage.

Size of Containers

Sizes vary, from plastic cylinders, 3 inches by 2 inches by 6 inches, to a barrel 30 gallons in capacity.

They may be rectangular, square, or any shape as long as they are hollow inside.

Plastic Beds

Plastic open boxes were the materials actually used in this study. They were of three sizes. At the beginning of the experiment large plastic rectangular open boxes were used (23 inches x 13 inches x 7 inches). For the different tests moderate sized plastic open boxes were used. Each of these boxes was 13 inches by 11 inches by 6 inches. The bottoms were made coarse by lean and porous concrete mixture to provide for drainage. Plastic open boxes of all sizes can be used and they are the easiest to use in any type and size of operation. They are inexpensive, easy to install, and durable. Holes should not be provided in the plastic boxes if the room is supplied with an evaporative cooler, as was the case in this study. Extreme care must be taken to see that the beddings are not watered excessively, as they become water-logged and create an extremely hazardous situation for the worms.

A rack (Fig. 3) was made on which the plastic boxes were set for easy access, and proved most helpful in the effective propagation of the worms.

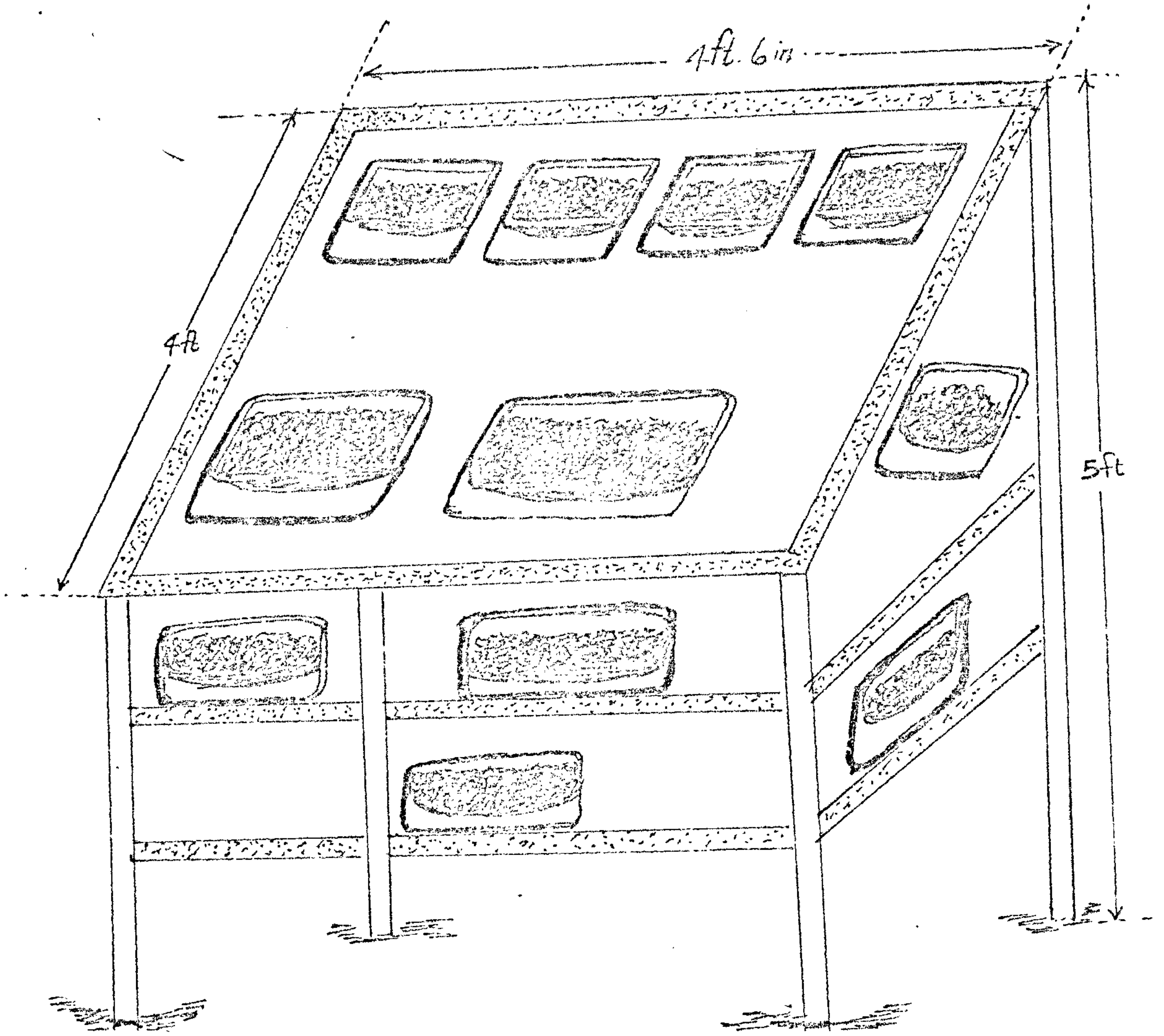

Fig. 3-- A rack on which worm boxes are placed for easy access. This rack is able to hold 36 boxes of worms.

Corrugated Paper Boxes

These were collected from shopping centers and grocery stores. They were cut into pieces and ground in a machine twice. The ground papers were then put in large containers with water and left to undergo a sort of fermentation for about five days. After this, the ground materials were squeezed dry and put in the sun to dry completely. They were ground a second time with the machine. The finely ground products were put into large storage containers and kept damp for another two days, after which they were put into the plastic open boxes. The quantity of bedding materials placed into each box was dependent upon the size of the box and the aim of the particular experiment. For this study, some of the boxes were filled nearly to the brim, some were half filled, while some were three-quarters full.

Plain Paper Boxes

Plain paper boxes and cardboard of all sizes were collected and treated in the same way as corrugated paper boxes.

Peat Moss

This consisted of partially carbonized vegetable matter formed by the partial decomposition in water of various plants (as mosses of the genus *Sphagnum*). Large quantities of peat moss were put into large containers and moistened excessively for about five days. After the materials were soaked, they were squeezed dry and left ready to be inoculated with earthworms.

Cow Manure

The cow manure consisted of cow dungs collected from a ranch. It was dried and ground with a machine. The fine products were put in water in large storage containers and left to ferment for three or four days. After this, the material was squeezed a little to get rid of the excess water. It was then put in the plastic open boxes ready to receive worms.

Combinations of Bedding Materials

Various combinations were made of the original media in different proportions to give new bedding materials. This is better illustrated in the section to follow.

Setting of Bedding for Different Tests

Environments

The test for the best environment required many boxes because of the different combinations. These were tried with or without food to see which of them could be considered both food and bedding. The following are the combinations of the different environments subjected to tests for a period of 90 days:

1. a. Soil with food

   b. Soil without food

2. a. Ground corrugated paper with food

   b. Ground corrugated paper without food

3. a. Peat moss with food

   b. Peat moss without food

4. a. Ground plain paper with food

   b. Ground plain paper without food

5. a. Cow manure with food

   b. Cow manure without food

6. a. Soil and ground corrugated paper with food

   b. Soil and ground corrugated paper without food

7. a. Peat moss and corrugated paper with food

   b. Peat moss and corrugated paper without food

8. a. Peat moss and plain paper with food

   b. Peat moss and plain paper without food

9. a. Peat moss and cow manure with food

   b. Peat moss and cow manure without food

10. a. Cow manure and papers with food

    b. Cow manure and papers without food

11. a. Soil and peat moss and papers with food

    b. Soil and peat moss and papers without food

12. a. Cow manure and peat moss and papers with food

    b. Cow manure and peat moss and papers without food

Food

The test to determine the best type of food took four boxes for a period of 90 days. The combination of bedding materials used in this test was the peat moss, papers (plain and corrugated) and cow manure in equal proportions. The first box was fed with oatmeal, the second with grass clippings, the third with corn meal, and the fourth with wheat germ. The feeds were put on top of the bedding in dabs. The subjects were periodically inspected. They were kept under these conditions for a period of 90 days.

Water Content

Three ways of determining the water content of bedding were used in this study. The easiest of the methods consisted of setting three boxes aside with media to each of which was added 25 weighed worms. One of the boxes was left merely damp, that is, no drops of water from a squeezed handful. This is the arid condition. A second box was left wet enough so that a few drops of water could be squeezed from a handful. A third box was left saturated so that much water would come from a squeezed handful. All boxes were set aside under these conditions for about three months. The arid box was supplied with 8 ounces of water every 26 days;

and the saturated box with enough water to, more or less, flood the bedding materials. The boxes were checked every 40 days.

Another method of determining water content was the so-called field or capillary capacity. This is calculated on the basis of oven dry weight (105°C for 24 hours), which is taken as 100 percent. For instance, if a sample weighs 60 grams when moist and 40 grams when oven-dried, the moisture content is 50 percent (60-40=20; then $\frac{20}{40} \times \frac{100}{1} = 50$ percent). This method could only be used at the beginning of the experiment. Sample boxes could be maintained throughout the period of the experiment; and these could be used to compare actual culture boxes.

A third method tried consisted of measuring with a soil water content meter, Model BN-2B (Greiner Scientific Corporation, N.Y.). The blocks of the meter were put in each box, and with connecting wires the moistures were read on the meter. The superiority of this method over all others was the fact that the moisture content of the bedding could be read at any time. It also prevented over-watering of the beddings throughout the period. With this instrument, the normal condition is 55-65 percent moisture; the arid is less than 20 percent moisture, and the water-logged is taken to be above 90 percent moisture.

Temperature

Three boxes were also provided for this. One of them was put in a controlled environment of 90°F. and above. Another box was left in the room at a normal temperature range of 75° to 85°F. A third box was left in the bottom portion of an old refrigerator which varied from 30° to 40°F. All of the temperatures were adjusted periodically. Fortunately, the experiment was done during the winter season, which favored the determination of the cold limits. Accordingly three boxes were put on the window sills. The temperature readings here ranged from 26° to 40°F. for two weeks.

Hydrogen Ion Concentration

The measurement of pH took three boxes. One box had a pH of 5-5.7 as determined by Hydrion pH Paper. Another box was prepared with ordinary peat moss without any additives. This box had a pH of nearly 7, which is neutral. A third box was made basic by adding ground papers and a small amount of a dilute solution of sodium hydroxide. It is to be noted that any basic solution could be added to the bedding materials to produce the desired pH. The same is true of acid solutions. The boxes were set aside for about ten days before worms were put in them.

Concentration

Various concentrations were tried. The bedding materials used in this experiment consisted of a combination of three media. These included ground corrugated paper box, peat moss, and cow manure proportional to 1/3:1/3:1/3 or 1:1:1. Five boxes were prepared with this media, as follows: the first box, 8 inches in diameter and 3 inches deep with 30 worms -- 5 cubic inches per worm; the second box, 8 inches diameter and 3 inches deep with 50 worms -- 3 cubic inches per worm; the third box, 8 inches diameter and 4 inches deep with 100 worms -- 2 cubic inches per worm; the fourth box, 8 inches diameter and 5 inches deep with 250 worms -- 1 cubic inch per worm; and the fifth box, 8 inches diameter and 6 inches deep with 500 worms -- 3/5 cubic inches per worm. The worms were weighed collectively group by group before they were put in the boxes. At the end of the test period the worms in each box were counted and recorded (Table IX).

Care of Cultures

After the bedding materials had been prepared, earthworms were spread out on top of the bedding materials in each box and were allowed to work their way into the beddings. Those that failed within a few minutes were taken off and discarded.

Feed and Feeding

Care in the preparation of the bedding makes the difference between success and failure in any worm culturing operation, especially when dealing with African night crawlers. Worms must neither be over-fed nor under-fed. In order to provide a happy medium between the two extremes, the worms were started with being underfed (about four ounces of corn meal per box for three weeks). The feeds were spread on top of the bedding each time. Another method of putting the food in a straight line across the bedding was also tried. The feeds included cornmeal, wheat, barley, oatmeal, and grass clippings. Of all of these, the cornmeal was chosen to be fed to the worms because it was easier to feed in worm pits.

Watering was carefully done along with the feeding. Care was taken to prevent over-watering. It was always done with a sprinkler and was done lightly and often. During winter, water used was near room temperature to prevent the worms from freezing.

Control of Pests

Earthworm cultures afford an ideal habitat for many undesirable pests. Mites, ants, sowbugs and springtails are always present. The use of sulfur dust, pyrethrum dust, or insecticides containing rotenone will keep many of them away. Care must be exercised in using insecticides or the whole population of worms may accidentally be destroyed.

Harvesting Procedure

The boxes were harvested one by one. The contents of the box were emptied on cellophane spread on the floow or on a large table, and the worms were sorted out of the materials.

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CHAPTER III

RESULTS

Observations on Various Media

Tables III and IV summarize the data obtained from the various media and their combinations.

Soil

In this study the soil did not do well in that it did not promote growth and reproduction. Soil without food did not support the lives of the worms, for by the end of the 45th day all of the original test population were dead. The combinations involving soil were also not as good as other soilless media.

Corrugated Paper Box

This was observed to be an excellent food and bedding for the earthworms for about four weeks. At the end of this period, the worms in ground paper required some feeding.

Plain Paper Box

This was a good bedding material if food was adequately supplied. Without the food it proved an unfavorable environment for the worms.

LEGEND FOR TABLES III AND IV

1. a. Soil with food
   b. Soil without food

2. a. Ground corrugated paper with food
   b. Ground corrugated paper without food

3. a. Peat moss with food
   b. Peat moss without food

4. a. Ground plain paper with food
   b. Ground plain paper without food

5. a. Cow manure with food
   b. Cow manure without food

6. a. Soil and ground corrugated paper with food
   b. Soil and ground corrugated paper without food

7. a. Peat moss and corrugated paper with food
   b. Peat moss and corrugated paper without food

8. a. Peat moss and plain paper with food
   b. Peat moss and plain paper without food

9. a. Peat moss and cow manure with food
   b. Peat moss and cow manure without food

10. a. Cow manure and papers with food
    b. Cow manure and papers without food

11. a. Soil and peat moss and papers with food
    b. Soil and peat moss and papers without food

12. a. Cow manure and peat moss and papers with food
    b. Cow manure and peat moss and papers without food

TABLE III

OBSERVATIONS ON HEALTH OF SUBJECTS AS DETERMINED BY DEATH OR REPRODUCTION IN DIFFERENT MEDIA FOR A PERIOD OF 90 DAYS

Period Ending	1 Day	15 Days	30 Days	45 Days	60 Days	75 Days	90 Days
1. a.	25	14	9	6	3	15	15
b.	25	16	5	0	0	0	0
2. a.	25	24	24	20	20	40	40
b.	25	25	24	18	16	10	5
3. a.	25	20	20	20	25	50	50
b.	25	20	20	10	10	2	2
4. a.	25	22	22	20	23	36	40
b.	25	24	20	16	10	2	2
5. a.	25	25	25	24	30	45	50
b.	25	25	25	25	25	36	40
6. a.	25	23	20	20	20	30	30
b.	25	20	20	16	10	10	5
7. a.	25	24	24	22	22	40	45
b.	25	25	20	20	16	10	10
8. a.	25	20	20	20	30	40	40
b.	25	20	16	16	16	10	6
9. a.	25	24	24	24	40	50	56
b.	25	25	25	25	25	30	35
10. a.	25	25	25	25	36	45	52
b.	25	25	24	24	29	34	34
11. a.	25	24	24	23	20	30	36
b.	25	20	20	20	15	10	5
12. a.	25	25	24	24	30	40	50
b.	25	25	25	25	25	30	30

TABLE IV

OBSERVATION ON WEIGHT CHANGES IN GRAMS OF SUBJECTS IN DIFFERENT MEDIA FOR A PERIOD OF 90 DAYS

Period Ending	1 Day	15 Days	30 Days	45 Days	60 Days	75 Days	90 Days
1. a.	20	10	5	4	2	6	8
b.	20	9	2	0	0	0	0
2. a.	19	19	19.4	16.6	17	23	25
b.	20	15	12	10	10	6	2
3. a.	20.1	16	16.2	16.3	20.6	25	25
b.	20	15	12	6	5	1	1
4. a.	20.3	16	16.2	16.1	18.6	20.7	23
b.	18.6	14	10	10	4	.3	.3
5. a.	18	20	20.2	20	20.6	26.7	28.2
b.	18	16	16.6	18	16.3	20.5	20.5
6. a.	19.2	20	16	16	14	14	16
b.	18.2	14	12	8	6	4	.5
7. a.	20.2	20	20.6	19	19	21	21.6
b.	21	18	18	14	10	5	3.5
8. a.	21.5	18	18.6	18.8	20.6	22	23
b.	18.2	16	10	8.8	6	4	1
9. a.	19.1	19	19.6	19.6	23	25	30
b.	19	19	19	19	18	19	20
10. a.	19	20.6	20.8	21	23	25	26
b.	19	19	18	18	19	19	18
11. a.	20	19	19.6	19	18	20	20.6
b.	20	15	15	12	8	4	1
12. a.	19.2	19.7	19	19.5	21	21.6	22
b.	18.2	18	18	17.5	16	17.7	18

Cow Manure

The cow manure is an example of bedding material and food at the same time (Table IV). It supported growth and encouraged reproduction. The reproduction rate was faster in it than in most of the other materials. Its combination with other beddings showed a decided superiority. All combinations with cow manure produced lively and healthy worms, and they favored reproduction.

Peat Moss

This proved to be an excellent bedding material, but unsatisfactory food for the earthworms. They did very well in it with food and water. Without food they did not do well. Peat moss encouraged reproduction in this study, just as did the cow manure.

TABLE V

OBSERVATIONS ON THE CONDITION OF SUBJECTS AS DETERMINED BY DEATH OR REPRODUCTION IN DIFFERENT FOODS FOR A PERIOD OF 90 DAYS

Period Ending	1 Day	15 Days	30 Days	45 Days	60 Days	75 Days	90 Days
Box 1. Cow manure & peat moss with oatmeal	50	45	40	40	30	40	40
Box 2. Cow manure & peat moss with grass clippings	50	35	30	20	20	20	15
Box 3. Cow manure & peat moss with cornmeal	50	50	45	45	65	90	90
Box 4. Cow manure & peat moss with wheat germ	50	50	30	25	20	15	10

Food

Tables V and VI summarize the data obtained from the experiment on food. The results proved that cornmeal was the best food for the African night crawler. The worms were more lively and healthier there than in other boxes with other foods. They also reproduced faster in it.

TABLE VI

OBSERVATION ON STATE OF SUBJECTS AS DETERMINED BY WEIGHT CHANGES (GRAMS) IN DIFFERENT FOOD FOR A PERIOD OF 90 DAYS

Period Ending	1 Day	15 Days	30 Days	45 Days	60 Days	75 Days	90 Days
Box 1. Cow manure & peat moss with oatmeal	20	18.1	18.6	15	13.6	18	18.6
Box 2. Cow manure & peat moss with grass clippings	23	14.01	10.6	8.2	5	5	3
Box 3. Cow manure & peat moss with cornmeal	20	23	22	23	30	40	42
*Box 4. Cow manure & peat moss with wheat germ	21	23	13.6	8.3	6.7	4	2

*This shows the effect of acid formation. The pH of bedding at the end of the experiment (4) was 5.8.

Note: See Table V for a discussion of this Table.

TABLE VII

OBSERVATIONS ON THE TEMPERATURE AND STATE OF SUBJECTS FOR A PERIOD OF 48 DAYS

	Period Ending	1 Day	8 Days	16 Days	24 Days	32 Days	40 Days	48 Days
Box 1 Controlled	No. of worms	25	16	16	10	6	3	3
Environment 100-110 F.	Wt. in grams	20	8	6	2	2	1.0	1
Box 2 Normal	No. of worms	25	25	25	25	25	25	25
Environment 75-85 F.	Wt. in grams	18	19	19.2	20	20	20.3	21.6
Box 3 Cold	No. of worms	25	10	5	0	0	0	0
Environment 30-50 F.	Wt. in grams	19.6	3	1	0	0	0	0

Temperature

As can be seen from Table VII, the African night crawler preferred heat to cold. On the 24th day none of them remained in the cold environment, whereas, 10 were still alive in the controlled environment. The normal temperature for the African night crawler was found to be 75-85°F.

TABLE VIII

OBSERVATIONS ON MOISTURE CONTENT AND STATE OF SUBJECTS FOR A PERIOD OF 90 DAYS

	Period Ending	1 Day	15 Days	30 Days	45 Days	60 Days	75 Days	90 Days
Box 1 Arid environ.: Less than 20% moisture content	No. of worms	25	25	20	12	5	3	0
	Wt. in grams	20	15	8	5	1	0.25	0
Box 2 Normal environ.: 55-65% moisture content	No. of worms	25	25	24	24	24	30	30
	Wt. in grams	19	19.5	18	18.6	18.9	23	24
Box 3 Water-logged environ.: 90% and above moisture con.	No. of worms	25	20	10	5	1	0	0
	Wt. in grams	19.2	15	3	1.2	0.01	0	0

Moisture

Table VIII summarizes the data obtained from the experiment on moisture. As seen from the table, both the arid and the water-logged were not suitable, for they did not support growth.

TABLE IX

OBSERVATIONS ON THE CONCENTRATION AND THE STATE OF SUBJECTS FOR 180 DAYS

	Bedding Capacity (cu.in.)	No. of worms at beginning		No. of worms at end		Space per subject at the beginning
		Subj.	Wt(g)	Subj.	Wt (g)	
Cow manure w/o food	151	50	28	20	10	3 cu.in. per subject
Cow manure w/o food	201	100	75	50	20	2 cu.in. per subject
Cow manure w/o food	251	150	95	20	10	1 3/5cu. in. per subject
Cow manure with food	251	200	120	650	458	1 ¼ cu. in. per subject
Cow manure with peat & papers with food	151	30	15	660	468	5 cu.in. per subject
Cow manure with peat & papers with food	151	50	30	106	30	3 cu.in. per subject
Cow manure with peat & papers with food	201	100	72	330	100	2 cu.in. per subject
Cow manure with peat & papers with food	251	250	150	1000	600	1 cu.in. per subject
*Cow manure with peat & papers with food	301	500	265	650	150	3/5 cu. in. per subject

*Effect of overcrowding at the beginning of experiment is obvious. The final population is very weak and unhealthy as shown by the weight.

<u>Concentration of Subjects</u>

In Table IX is the summary of data obtained from the experiment on concentration. The results indicated that the lowest limit of concentration is between 3/5 cubic inch and 1 cubic inch per subject. This will be discussed further.

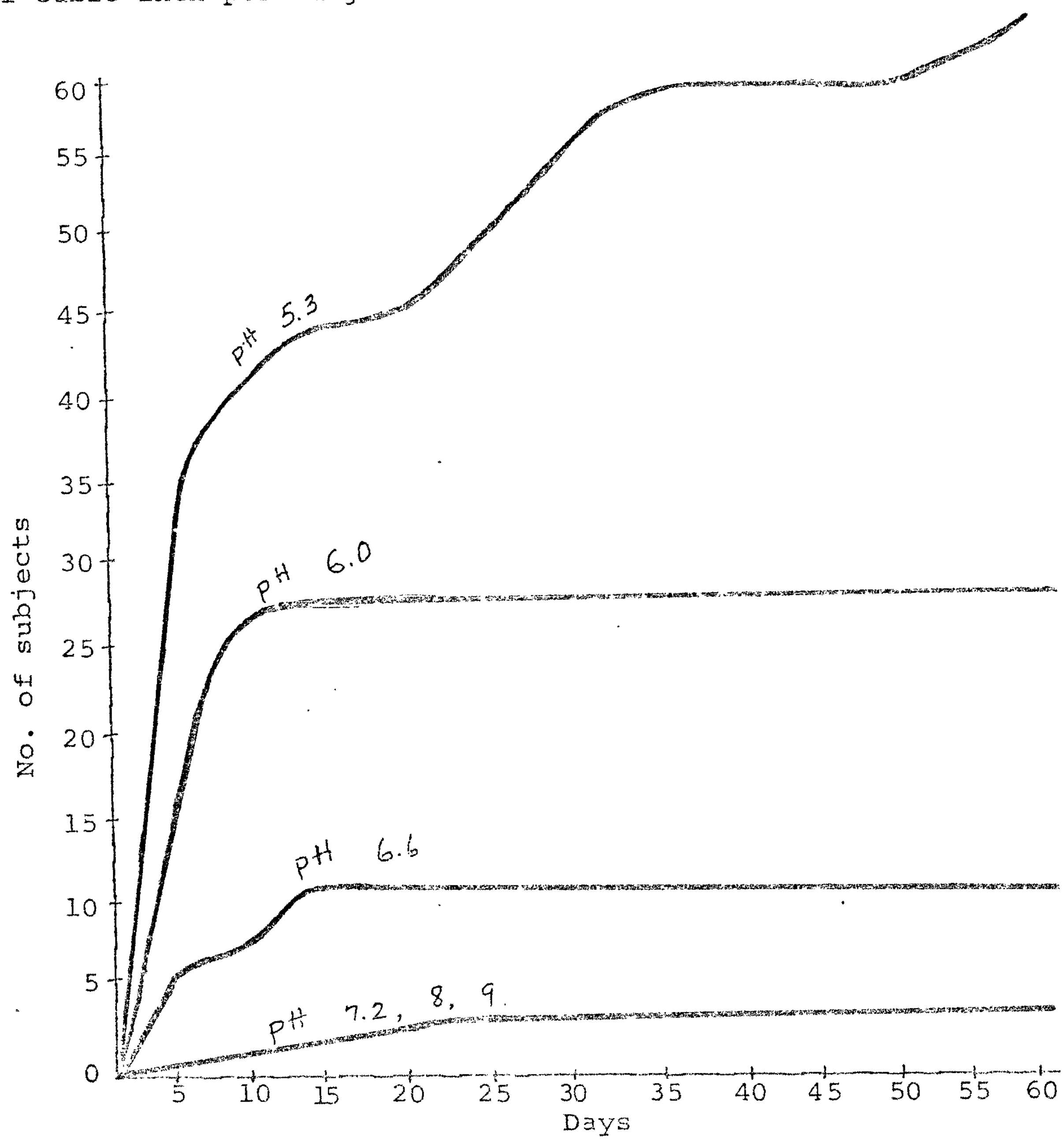

Fig. 4--Conditions of subjects at pH 5.3, 6.0, 6.6, 7.2, 8 and 9.

Hydrogen Ion Concentration

Figure 4 shows the limitation of African night crawler in acid. Acid is its most serious hazard. The lowest limit of pH that it can withstand is in the 5 range according to the results of this experiment. Alkalinity is not a problem for the African night crawler.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

Discussion

The need for artificial environmental conditions for an effective propagation of the African night crawler is great, especially for the fish bait breeders, and for individual scientists who want to know something about this type of worm and its cultivation. This study, according to the results obtained, has established a number of things relative to the effective propagation of the African night crawler. The best environments, the best food, the ideal or normal temperature, and the normal moisture content have all been established.

Comments on Various Media

Soil.--This natural home of the earthworms was used in this study as a control. It was used alone and in combination with other soilless materials. In all cases, the soilless materials were better than the soil. Compared with other materials (Table III), at the end of the 60 days only 3 of the original test populations were alive and they were very unhealthy. During this same period, the worms in some soilless media, viz., peat moss, cow manure and other combinations involving cow manure, started to reproduce and increase rapidly. Soil without food was unfavorable, as seen from the table.

Ground paper boxes.--According to this study, the ground paper boxes proved to be good soilless, odorless bedding materials for the earthworms (Tables III and IV). The results proved that the ground corrugated paper boxes were better than the ground plain ones. The worms in corrugated boxes required samller amounts of food than those in the plain ones, because the corrugated box is made of wood fibers treated with glue, whereas the plain ones do not have glue in them. These glues are made from animal products reduced to a protein base, gelatin, or of vegetable proteins. Thus, they are high in protein content. The worms then feed on protein and cellulose from the paper. This ability of the earthworm to digest cellulose is of considerable importance, since other animals, viz., termites and grass eating mammals, have to depend on symbiotic bacteria and protozoans. A combination of these papers is an excellent bedding material for the beginner's experiments. The corrugated paper box supported the growth of tht night crawlers. They were lively and possessed a lighter color than the worms in different bedding materials. It also encouraged reproduction, but not as much as the peat moss or the cow manure. At the end of 60 days (Table III) only five of the original test population died; and, at the end of the period, 40 worms were harvested, indicating twenty new ones or an increase of fifteen from the original test population.

Peat moss.--Based on the results obtained from this study, the peat moss proved to be very useful. It is an essential material in storing and packaging earthworms. It has the characteristic of being slightly acid at the beginning, but if it is soaked sufficiently long enough with water, the acidity will disappear. The peat moss is good only with food. Without food it is useless (Table III). At the end of 60 days, the results showed that only ten of the original populations remained; and they were starved, as shown by their weights (Table IV). At the end of the period only two worms were harvested, which indicated that peat moss without food is not a good material. With food, they started to increase from the 60th day; and at the end of the period, the population doubled the original. Here again it must be noted that we had 30 new worms. Thus, the peat moss is a good earthworm bedding that encourages rapid reproduction. It is surpassed only by cow manure in combination with either peat moss or the papers.

One major drawback of the peat moss, as experienced in this study was that some brown mites occasionally grew in it in profuse numbers. They did not appear to harm the healthy ones; but they ate the weak, the injured, and the dead. They were dangerous, and should be carefully controlled early. Hyche (1) reported that 80-90 percent control of such mites in worm beds was obtained by using a spray made up of one pint of 25 percent emulsifiable parathion concentrate to 100 gallons of water.

Cow manure.--This is an excellent bedding and food just like the corrugated paper box but only slightly superior to it (Table III). Without food the cow manure is very good. It has the advantage of being almost pure vegetable matter which has been reduced by the action of the enzymes and other secretions in the alimentary canal of the cow. According to the results obtained, the population started to increase at the 60th day. Almost none of them died up to this date. It started as a congenial environment from the beginning. By inspection, the worms were found to be healthy, dark brown, robust, and more lively than those in most of the other bedding materials. It is only surpassed by a combination of cow manure and peat moss in equal proportions. This combination had more than double the original population; and the weight data indicates the health of the worms (Table IV).

One serious disadvantage of the cow manure as experienced from this study, was that it gave some offensive odor when wet. About the only thing that can be done to correct this is to regulate the amount of water added. Any chemical used to destroy odors could be hazardous to the life of the worm.

A combination of cow manure, peat moss and papers provided an excellent environment for the worms. As seen from Table III, only one of the original worms died before reproduction set in; and at the end of the period, 50 worms were harvested, which doubled the original population. On inspection, the worms were lively and healthy throughout the period. The combination also encouraged reproduction. It has the same efficacy as the cow manure by itself, or the combination of cow manure with the papers (corrugated boxes and the plain boxes). This cow manure with the papers was also good in relation to reproduction. One major merit of the combination is that none of the worms put in it died before they continued to reproduce. The others did not react similarly. The combination of cow manure and papers with food is probably one of the best bedding materials in relation to packaging, and storing; and as a reproductive stimulator, it is unsurpassed.

The combination of peat moss and papers, alluded to previously, was a very good environment for the worms; then soil was added and the quality of the materials changed adversely (Tables III and IV). It supported growth quite well since only 5 of the original test population died. Yet reproduction did not start until the 75th day, which meant that it did not encourage the rapid production of egg-capsules. The reason for this may be partly in the fact that the combination did not retain moisture as did the others without soil, and partly in the fact that the mixture became heavier, thereby limiting the circulation of free oxygen in the bedding.

Thus, in the test for the best environments, it has been established through experiments that cow manure, and all combinations involving cow manure, viz., cow manure with peat moss, cow manure with papers, and cow manure with peat moss and papers are the best artificial environments. However, the peat moss alone or the corrugated box alone must not be underestimated. These, too, are good either separately or in combination. The two can be grouped as being in the second place; but in the complete absence of cow manure, they may be considered as having nearly the same efficacy as the cow manure especially if the papers are finely ground.

Comments on Different Tests

Food.--The results of the experiment on food showed that oatmeal, though good, did not encourage reproduction (Tables V and VI). By inspection, the worms fed with oatmeal were not as active as they ought to be. Some two-fifths of the test population died after 60 days (Table V). Their weights showed that they did not utilize the food very much, for the initial weight was 50 grams and the weight at the end of the period was 18.6 grams. Though there were some new young at the end, the final total was not as great as the original number of worms.

The grass clippings did poorly as a food on artificial media. As many as three-fifths of the original number died before 60 days (Table V). The health and vigor of the subjects were jeopardized by this food. By inspection, the worms looked weak and inactive and did not reproduce at all; instead, they died rapidly, so that by the end of the period, only 15 of the original number remained and these were very weak and unhealthy.

The wheat germ did the poorest as a food for the African night crawler. At the beginning it was good, but after 30 days, two-fifths of the population were dead because of acid formation in the bedding, caused by the food. As the worms are very susceptible to acid, the effect lasted until the end of the period, and it nearly destroyed the whole population. There was no reproduction in this type of food either.

The best food, according to this study, was found to be the cornmeal. It encouraged reproduction tremendously, as they nearly doubled the original population at the end of 90 days. Besides, the bedding was full of eggs at the end of the period. By inspection, the worms were found to be very healthy and active throughout the period. The weight data showed that they gained 22 grams at the end of the period. The cornmeal is decidedly the best food for the African night crawlers. The de-germinated type of cornmeal is the best choice. The self-rising cornmeal is not as good, probably because of its many additives.

Temperature.--The African night crawler is sensitive to cold, as seen from Table VII. The normal temperature is 75-85^{o}F. This is the ideal temperature for fast growth and effective propagation of the worms. It is evident from Table VII, box 2, that this normal temperature supported the growth of the test population. There was no increase by means of reproduction because of the short period of the test. At the end of the period, the bedding was full of many egg-capsules. There was an increase in weight, showing that the temperature was conducive to the health and activity of the worms. Box 3 showed that at the end of 16 days, as many as four fifth of the population had died, and on the 24th day, no worms were left. This indicated that they are very susceptible to cold. This experiment also showed that the African night crawler could survive temperatures above 100^{o}F for some days if there is an evaporative cooler in the room, and if the bedding is supplied with water regularly.

In testing for the cold limit, the temperature of the old refrigerator was set at warm, and the temperature at the bottom of the refrigerator was 45^{o}F. The night crawlers became very inactive and they all died the third day. Then, those at the window sills were checked and most of them were also found dead. Those that were living were half dead. Thus, the conclusion is that for the night crawlers to survive and be healthy, the temperature should be from 55° F up to the normal upper limit, which is about 100° F. Any temperature above or below these limits will only kill the night crawler.

Moisture.--The results of moisture tests showed that the night crawler does not adapt itself in the arid as well as in the water-logged conditions. After 30 days of experimentation, as high as three-fifths of the test populations were dead (drowned). At the same time, the arid environment had just lost 1/5 of the test population. From the 45th day, it rapidly decreased to less than half of the test populations. The normal environment (55%-65% moisture content) is best for the night crawlers. By inspection, the worms were lively and healthy and reproduced moderately well.

Hydrogen ion concentration.--This is the condition of bedding with regard to acidity or alkalinity. Figure 4 showed the state of worms from the acid range through the neutral to the basic side. The results proved that the night crawlers are susceptible to acid. In 5 days, as many as 35 out of 75 worms died in a pH of 5.3. At a pH of 6, the worms gradually adjusted after an initial loss. The pH in the 7 range is quite normal for the night crawler, for very few of them died. The pH in the 8 and 9 range appeared not to be different from the neutral range.

Concentration of subjects.--The cow manure was tried for about six months without food. From this test, a discovery was made that the cow manure as a food and bedding at the same time has limitations. For a shorter period and with fewer subjects in a large quantity of bedding of cow manure, it will serve as food and bedding (Table IV). In this test, none of the boxes of cow manure without food did well. The reason is obvious. None of the boxes allowed up to 5 cubic inches per subject (Table IX). Since there was no feeding, overcrowding and competition for food set in from the beginning, and within a month, most of the worms died. The egg-capsules that were produced by the worms before they died hatched out and continued with the same problems that killed their parents. The cow manure with food did well. At the end of six months, they tripled the original population. This was not too good; but it was better than the others without food.

The box with 30 worms at the beginning did very well. A close look showed that it allowed up to 5 cubic inches per subject in a bedding of different materials: cow manure, peat moss and papers. This combination was supplied with food and water regularly. At the end of the period, a population above 600 was counted. The second box, with fifty worms, did very poorly at the end, as did the one with 100 worms. No explanation can be given for this. But the box with an initial 250 worms did very well, with 1000 worms at the end of the test. The last box, with 500 worms at the beginning, did very poorly, probably because of overcrowding. The results of this test, though inconsistent, showed that there is a point in the population increase of the earthworm where overcrowding obviously sets in and the health and vigor of the animals is jeopardized. This point lies somewhere between 0.6 cubic inches and 1 cubic inch per subject insofar as it can be determined. Further investigation will be needed to confirm this.

On the whole, it is well to remember that no elaborate equipment is necessary for the "operation" described in this study. A cool cellar or a small room cooled by water circulating through pipes or hoses, or by an inexpensive evaporative cooler, would be a good place to keep the worms. Surely, if the conclusions obtained as a result of this study are followed carefully, the African night crawlers can be effectively propagated in the most inexpensive artificial media.

Conclusion

This study, through experimental methods has been able to determine the best artificial environmental conditions which favor the most effective propagation of the African night crawlers.

Backed up by the results of the experiments in this study, the best food was discovered. This is the cornmeal. The best artificial environments were found; these are cow manure separately, or cow manure with peat moss alone or with ground papers. These artificial environments are found to be good because they support the growth of the subjects, increasing their health and vigor and reproduction (Table III and IV).

The normal or ideal temperature was found to be from 75° F to 85° F, and also the normal moisture content, which is from 55 to 65 percent. A slight increase or decrease of 5-10 percent is also considered normal if it only lasts for

5 range, only confirming the general belief. The neutral pH was found to be the optimum.

As regards concentration, the results obtained in this study, though inconsistent, showed that the point at which overcrowding obviously set in was between 0.6 to 1 cubic inch per subject. This particular area will need further investigation before any absolute conclusion can be drawn.

Thus far, the answers to questions as to the best food, the best artificial environment, the ideal or normal temperature, the normal moisture content and the subject concentration have been given wholly or partially in this study. For a future researcher, the area of concentration of subjects needs more investigation. It may also be worth while to compare the African night crawlers with other common worms, considering the same questions.

Lastly, in addition to the foregoing conditions, of greatest importance to the raising of the African night crawler is the place or condition of the bedding and the temperature of the cool surrounding atmosphere.

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CHAPTER V

SUMMARY

It has been shown experimentally in this study that the African night crawler can be effectively propagated under the following conditions:

1. Food. The best food was found to be corn meal; and it was chiefly used throughout the study.

2. Environment. The best environment (bedding materials) was found to be the cow manure, followed by all soilless combinations involving cow manure. The peat moss and corrugated paper boxes were good in the absence of cow manure and could be utilized with confidence.

3. Temperature. The ideal temperature was established to be between 75° to 85° F, and was found to be a major factor in the reproduction of the African night crawler.

4. Moisture. The normal moisture content was established. This lay between 55 to 65 percent. Below 20 percent or above 90 percent was found to be detrimental to the life of the African night crawler.

5. Hydrogen ion concentration. The ideal pH was established as being somewhere between 7 and 7.4.

6. Concentration. It was established that the African night crawlers reproduced faster when they are closely concentrated in a bedding. This optimum concentration allowing for greater reproductive potential appears to fall somewhere between 0.6 cubic inches and 1.0 cubic inches per earthworm. This particular question however, will require further investigation.

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