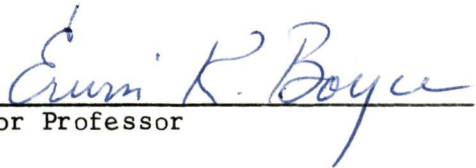


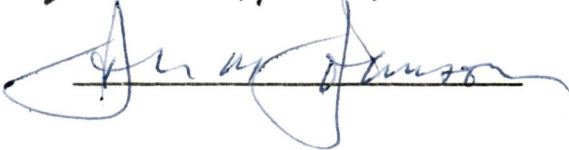
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To the Graduate Council:

I am submitting herewith a thesis written by Lemuel Gordon Beaver entitled "An Investigation of the Characteristics of an Agricultural Auger as a Means of Metering Shelled Corn." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Mechanized Agriculture.


Major Professor

We have read this thesis and
recommend its acceptance:

Accepted by the Council:


Vice President for
Graduate Studies and Research

AN INVESTIGATION OF THE CHARACTERISTICS OF AN
AGRICULTURAL AUGER AS A MEANS
OF METERING SHELLLED CORN

A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Lemuel Gordon Beaver

December 1967

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CHAPTER I

THE PROBLEM

I. INTRODUCTION

Man's basic knowledge of the physical world could perhaps be better understood by a review of his understanding and use of energy. The technological explosion of recent years has developed from this knowledge. Changes in the use of energy has progressed as manpower moved from animal power, and wind power to steam, electrical and internal combustion engines, and on to nuclear power. Each such progression has left its mark on agriculture (12).

In the last 100 years, energy sources have changed progressively. Around 1862 (12) energy sources were approximately 19 per cent machine, 65 per cent animal, and 16 per cent human labor. Today the energy source is about 99 per cent machine, less than 1 per cent animal, and less than 1 per cent human labor.

In 1900, 37.5 per cent of the people in the United States or 12.8 million persons were employed on farms (7). From 1918 to 1962, the farm population decreased over 6 million people. In 1962, the man-hours of labor used on the farm were 38 per cent of that used in 1918. The labor reduction was primarily due to off the farm migration to better jobs. Mechanization contributed to the increase in production per man-hour. In the area of crop production, the feed grains had the highest degree

of mechanization (7, 38). Seferovich (38) reported that between 1910 and 1958 production per man-hour increased 349 per cent for all feed grains. The increase in production per man-hour for all meat animals was only 25 per cent. Poultry made a progressive jump from a farm sideline to a highly mechanized multi-million dollar business. The dairy industry became the second most highly mechanized farm enterprise. From 1953 to 1962, Esminger (7) recorded the increase of farm production per man-hour. He reported that the increases from highest to lowest, were feed grains, poultry, milk cows, and meat animals.

Pinches (31) revealed that farm materials handling should be thought of as the mechanization of existing operations, so as to save labor, reduce extreme energetic demands, or to save time for other operations, but without absolute change in the size or type of enterprise.

Every phase of materials handling should be considered as an important link of the completely developed system of handling any one material. Inefficiency in any one phase, transportation or storage, could result in a "bottle-neck", thus reducing the efficiency of the entire system.

The development and improvement of materials handling techniques make it possible to harvest and store more crops in a shorter period of time with a large reduction in labor requirements.

Materials handling has always been a major chore for the farmer. It is necessary to handle many materials before a profit is made from a

farm enterprise. The same materials may be handled a considerable number of times before they reach their end use. Often a farmer's entire productive capacity is limited by what he can do in a limited period of time. This critical period is many times related to crop production, harvesting, feeding, and marketing (41).

Dobie and Curley found the development of an efficient farm material handling system to be based on several principles (5). They are:

1. To eliminate unnecessary handling of materials.
2. To eliminate unessential storage points by making the flow of materials continuous.
3. To handle maximum amounts of materials at a time.
4. To make use of condensed free-flowing forms of materials.

The increased use of materials handling has progressed because of the high cost and unavailability of labor, expanded livestock enterprise, and larger acreage with higher crop yields. About one-third of the farm work carried on is employed in and around the barns (21). As much as 80 per cent of the total work in dairy and poultry operations takes place in and around the farm buildings. Especially in poultry, most all this work consists of materials handling.

One ton of milk requires the handling of approximately three tons of feed, litter and manure. For a small dairy herd of twenty cows, the annual weight of materials handled would be approximately 500 tons. Much of this material would be handled five or more times increasing the annual volume to 2,000 tons (21, 30).

In his studies of farm labor, Kleis (21) concluded that there was a high correlation between the degree of materials-handling mechanization and over-all farm production efficiency.

Improved grain handling (27) has proved essential through the years because of larger crop yields, larger farm operations, more extensive acreages, faster shelled-grain harvesting, extended use of grain dryers, more on-the-farm storage, and shortages of labor. In the near future (4), most all the grains on and off the farm will be handled in bulk. Most recent census figures indicate the days of the bagger type combine to be limited. One reason for the trend to bulk handling is the portable grain auger, or screw conveyor, which simplifies procedures and reduces the handling costs of operation.

The screw conveyor principle (44) discovered by Archimedes (287-212 B. C.) made little improvement until Caldwell devoted himself to the project in 1874. After improvement of the sectional flight, he invented the helicod or continuous-flight type conveyor. Caldwell patented the helicoid in 1898 and it became a part of farm equipment. Today the screw conveyor is versatile; designed for uses of metering, elevating, digging, mixing, or spreading.

The use of the auger plays an important role in dairy operations, allowing an increase in herd size, a reduction in labor expense, and a decrease of chore time. In addition to being extensively used in conveying small grains and ground feeds, the auger is also employed in the handling of forages, fertilizers, and even liquid manure. Among some

of the other materials that are efficiently handled with augers are barley, soybeans, bran, shelled corn, corn meal, dry cottonseed, cottonseed hulls, ground limestone, oats, rice, rye, sawdust, and wheat (5).

Augers can be used to convey materials at any angle of elevation from horizontal to vertical. The standard pitch and the short pitch screw are the two primary screw types used for grain metering purposes. A standard pitch screw (5, 23, 37, 46) is used in most agricultural augers, the pitch being approximately equal to the diameter of the screw. For general purpose use, the standard pitch screw produces optimum performance under most conditions. Practically all farm screw conveyors manufactured are of the standard pitch type. Vertical and inclined augers sometimes employ a short pitch screw, one having the pitch equal to one-third or one-half the screw diameter. The short pitch screw is adapted to maintaining a large capacity while operating at high speeds and for inclinations of 70 degrees or above.

Although the auger has contributed greatly to advances in materials handling, mechanization still lags, somewhat, in the livestock enterprise. The time consuming job of crushing and mixing livestock feed could be improved to a great extent by more effective mechanization. Various tests have been conducted to determine the capabilities of the auger as a metering device. These tests included the use of varying screw speeds and auger inclinations while handling different types of materials. Power requirements and maximum capacity of the screw were also studied in conjunction with these tests.

II. STATEMENT OF THE PROBLEM

The auger has possibilities of use as a low volume continuous-flow metering device. The low volume auger, if employed as a continuous-flow metering device, would speed up the process of feed mixing and reduce the metering costs. The ingredients of a mixed feed could be metered directly into the feed mixer or hammermill; extra weighing operations and unnecessary materials handling could be reduced.

Small feed mixing systems would obtain optimum use of continuous-flow metering devices at low screw speeds below 150 revolutions per minute. More research conducted on the auger at screw speeds below 150 revolutions per minute would prove advantageous to its use as a continuous-flow metering device.

III. OBJECTIVES

The objectives of this investigation were:

1. To determine if a standard agricultural tube auger could be used to deliver and accurately meter shelled corn for use in feed mixing.
2. To determine the auger capacity per revolution of the screw at screw speeds of 20, 40, 60, 80, 100, and 150 revolutions per minute.
3. To determine the auger capacity of each angle at auger inclinations of 0 (horizontal), 15, 30, 45, 60, and 90 degrees (vertical).

4. To determine if the performance of the auger as a metering device would be consistent.

IV. DEFINITIONS OF TERMS USED

Angle of Repose. When a granular material is allowed to flow from a point, the pile is characteristic of the material. The angle which the side of the pile makes with the horizontal base, is called the angle of repose.

Auger. The auger is referred to as the screw and the screw housing combined.

Inclination. The number of degrees or deviation from the horizontal position is used to indicate inclination or angle of the auger.

Screw, Helix, and Helicoid. The screw, helix, and helicoid are referred to as the flighting mounted on the shaft or the screw itself.

Tube, Screw Housing. The tube or screw housing is the 4 inch housing in which the screw is mounted.

CHAPTER II

REVIEW OF LITERATURE

Automatic materials handling (36) implies that materials are available by mechanical means in a specific quantity, at a specific location, and at a desired time. Volumetric proportioning, limited to free-flowing materials, is the means by which most farm feed processing systems obtain automatic materials handling. Weight proportioning is used by many large commercial operations, but is usually controlled manually instead of automatically.

Auger capacity is related to speed, size and type of auger, and the characteristics of the materials to be handled. The degree of inclination, clearance between screw and tube, as well as length of exposed intake screw, and size of discharge opening also affects capacity (24, 45). Capacity is increased as the speed of the screw is increased up to a certain point, varying with the material and the size of auger (26). An increase in revolutions per minute of the screw resulted in a directly proportional increase in the capacity of grain metered until approximately 650 revolutions per minute were reached (24). When a screw speed of about 650 revolutions per minute was reached, an increase in revolutions per minute resulted in a less than proportional increase in capacity of grain metered.

In a study of some specific factors that affect the performance of inclined augers, Regan and Henderson (35) found that the maximum

capacity was reached at approximately 1,000 revolutions per minute. Miller (26) observed that, depending on the material handled, the maximum capacity for 4 inch augers was reached at a screw speed somewhat over 1,000 revolutions per minute. He also observed that a screw speed of 700 to 900 revolutions per minute was maximum capacity for 6 inch augers. Miller and Rehkugler (13) noted that the maximum capacity of 4 and 6 inch augers was reached at approximately 800 revolutions per minute when conveying wheat and oats. In these studies, maximum capacity occurred at the same revolutions per minute irrespective of the inclination. When auger capacity was at a maximum in relation to the speed of the screw, the further increase in revolutions per minute did not increase the capacity of grain metered. Failure to increase the capacity of grain metered by increasing the revolutions per minute was caused mainly by two factors. These factors were centrifugal force due to rotation of the grain mass at the intake of the auger, and maximum possible flow rate of grain through the auger intake (26, 35, 36).

Auger capacity decreases as the degree of inclination increases from horizontal to vertical (19, 24, 26, 35, 45). Up to 60 degrees inclination, the capacity decrease per degree of inclination was larger as compared to capacity from 60 to 90 degrees inclination (19). The capacity of the auger at 70 degrees of inclination is approximately 60 per cent of the auger as compared to horizontal position (24). In the vertical position, the auger metered 33 to 40 per cent of its capacity as compared with the horizontal position (26, 37). The lowest practical

inclination for auger operation should be used to obtain the maximum capacity.

Auger efficiency is also affected by the characteristics of the materials to be handled. Characteristics of the materials arbitrarily separates them into classifications of free-flowing and non-free-flowing materials (2, 39). A completely free-flowing material has no friction between its particles and therefore cannot be piled, having a 0 degree angle of repose. The material at rest would have a horizontal angle of repose. Low-moisture corn and wheat do pile or have an angle of repose, but are, nevertheless, considered as free-flowing materials. Semifluids are referred to by Singley (39) as materials being intermediate between solids and fluids. Under different conditions these materials would have characteristics resembling either solids or fluids. Dry sand and wheat, almost symmetrical in shape, show properties of flowing semifluids. These materials are held in place by friction of the particles on each other but without cohesion and are referred to as free-flowing materials.

Non-free flowing materials are a resultant of a cementing substance between the grains or a change in the characteristic of the material itself. Materials may become non-free-flowing when any of these cohesive forces are present (39). Dust, cracked grain, and foreign material may cause some materials to become relatively non-free-flowing (2). The degree of interlocking of irregular, granular or fibrous materials may also affect the flow characteristics (39).

Singly also referred to non-free-flowing materials as those that will not fill in after a portion has been removed. Some examples of non-free-flowing materials are silage, hay, manure, moist grain, and some ground feeds (39). The greatest problem with such materials in getting them from the area of storage onto a conveying mechanism. Materials can be moved to the discharge apparatus with sweep augers or other methods (32).

White, et al. (45) tested the power requirements of a 6 inch auger conveying high moisture shelled corn (25 per cent moisture) as compared to relatively dry shelled corn (14 per cent moisture). Three times as much power was required to handle high moisture shelled corn at the horizontal position as compared to low-moisture shelled corn (22, 27, 37, 45). Conveying high moisture corn vertically required little increase in horsepower as compared with conveying dry shelled corn vertically.

In general, handling materials with moisture contents above that required for safe storage will result in a reduction of capacity and a significant increase in power requirement (37).

White, et al., 1962, (45) conducted tests determining the effects of speed and length of exposed intake screw on capacity and power requirements of a 4 inch diameter auger. The material used was shelled corn. Three inclinations, 0, 45, and 90 degrees were tested at speeds of 200 to 1,180 revolutions per minute. The screw speed of 1,180 revolutions per minute gave the greatest increase in capacity to

increased length of exposed intake screw. This also took into account the three different inclinations of the auger. When length of exposed intake screw was increased from $4\frac{1}{2}$ to 30 inches, it was observed that the auger at the horizontal position and with a screw speed of 1,180 revolutions per minute almost doubled in capacity. With the same increase in length of exposed intake screw at inclinations of 45 and 90 degrees and a screw speed of 1,180 revolutions per minute, the capacity of augers at these angles more than doubled as compared with the horizontal position. The horsepower requirements also doubled with the capacity as the length of exposed intake screw was increased from $4\frac{1}{2}$ to 30 inches. After the maximum capacity was obtained for any given inclination, the increase in the revolutions per minute would also produce a corresponding increase in power requirements.

Tests were conducted at screw speeds of 200, 400, and 700 revolutions per minute at the horizontal position and auger inclinations of 45 and 90 degrees. Tests were also conducted at each of the screw speeds, increasing the length of exposed intake screw from 6, to 12, to 18, and to 24 inches. It was found that at the horizontal position and 45 degrees inclination, the auger capacity would reach a maximum about the same time or a little before 24 inches of intake screw was exposed. This occurred at each variable of screw speed. Maximum auger capacity at 90 degrees of auger inclinations was not obtained when a screw speed of 700 revolutions per minute and 24 inches of intake screw-exposure were used (45).

Other studies conducted (13, 22, 27, 37, 45) using various materials (soybeans, wheat, and oats) with a 6 inch auger revealed the same general relationship of capacity versus length of exposed intake screw. The most rapid increase in capacity occurred upon increasing the length of exposed intake screw from 0 inches to 6 inches. When comparing length of exposed intake screw with inclinations, the greatest percentage capacity was obtained at higher inclinations rather than at lower inclinations. This indicated the need of increased length of exposed intake screw at greater inclinations.

Power requirements of the screw are rated by the number of horsepower required per 10 foot length of auger for the given conditions. While not taking into account the different types of drives employed from motor to shaft, the horsepower requirement progresses linearly with screw speed from 300 to 1,000 revolutions per minute (26). Horsepower also varies with the type material handled. Maximum horsepower is required from 40 to 60 degrees of auger inclination (25). All of the tests reported have not been consistent within themselves in this area of research. Work completed by Lynn (24) at Clemson University, South Carolina, reported that the power requirement increased with inclination up to a maximum at 45 degrees, but decreased slightly at higher inclinations. Herum (17), having conducted experiments at the University of Illinois, revealed that at any given screw speed and delivery rate, power requirements increased with the increase of inclination until 60 degrees of auger inclination was obtained. At auger inclinations above 60 degrees

there appeared to be little increase in horsepower requirements. Horsepower demands increased directly as the length of auger increased, but overall length had no affect on capacity (43).

Because of the less efficient capacity of a vertical auger, White, et al. (45) conducted experiments on certain inlet screw or helix designs for a 6 inch auger. The six different designs tested consisted of a standard screw, a double screw, a standard screw with a one-half inch rim on its outer edge, a standard screw with winged attachments on its outer edge, a standard screw with a regular bearing attached, and a 7 inch diameter booster section for a 6 inch screw. All designs had 12 inches of exposed screw except the auger with regular bearing attachment which had a 6 inch exposed screw. The regular screw and the 7 inch diameter booster for a 6 inch screw were the only two designs with a bearing attachment. Screw capacities were tested at a speed range of 300 to 600 revolutions per minute.

The double screw conveyed 20 per cent more capacity than the 7 inch booster and standard screw with no bearing attachment which were the second most efficient. The standard helix with no bearing outperformed the standard helix with bearing attachment. All other helix designs did not prove of any assistance in increasing the capacity of the vertical auger. From this study, the double helix proved to be the simplest and most efficient method of increasing vertical auger capacity. The 7 or 8 inch booster section was the second best method for improving vertical auger capacity.

Accurate metering devices are imperative in today's feed processing and mixing systems. One volume metering device tested for this purpose was the proportioning orifice auger (28). The metering device was located inside the grain bin with the orifice plate being just inside the casing where material entered the auger. Meter discharge was controlled by adjusting the size of the orifice opening and adjusting speed of rotation. This device was tested under the pressure of 8 foot depth of material. The types of material used were oats, shelled corn, soybean oil meal, and ground feed. The amount of orifice opening was controlled by orifice settings ranging from one to twenty. The twenty graduations controlled orifice openings from 0 to 66 per cent open. Orifice graduations used in this experiment were from three to nineteen. Screw speeds tested were 100, 200, and 300 revolutions per minute.

The metering device could progressively operate from 0 flow to 18 tons per hour at 300 revolutions per minute. In many instances this large volume of material metered would be rather useless to many feed processing and mixing systems. The apparatus could not accurately meter high-moisture shelled corn. A uniform flow of grain was prohibited through the orifice because of the numerous grains that were crushed (28).

McGinty (25) ran an experimental analysis on an automatic feed processing control system, using automatic weight proportioning. His experimental apparatus consisted of three control parts: weight control, sequence control, and event control. Components of the system were 4 inch augers, grain bin A and grain bin B, one weigh tank, and one

dummy mixer tank. Whole grain milo was used to simplify the mixing process. The sequence of events was to weigh x pounds of ingredient A, weigh y pounds of ingredient B, fill mixer, mix and while mixing fill weigh tank with x and y pounds of ingredients, wait until mixing was complete, empty mixer. This system still needed further research to prove it reliable over a period of time (25).

Pucket and Peart (33) experimented with six types of volumetric meters. These meters were tested for accuracy at various rates of output and for different feed materials. They were also tested for accuracy when operated continuously and when operated intermittently.

The auger and the fluted-wheel meter were considered superior when cost and accuracy were taken into account. The vibrator meter was the most promising when considering costs and long life, trouble-free operation of the 6 metering devices. If feeds are to be metered that have a tendency to bridge in the feed bin, the metal-belt meter proved to give a more positive drive to the feed materials (33).

CHAPTER III

EXPERIMENTAL PROCEDURE

I. TEST EQUIPMENT AND MATERIAL

The experimental equipment consisted of 1,000 pounds of shelled corn (11.9 per cent moisture), a grain bin, an auger assembly, a power unit assembly, and collection buckets. The grain bin, in which the auger was placed, was constructed to hold approximately 23 bushels or 1,300 pounds of dry material.

A 4 inch diameter auger having only one bearing at the discharge end, was used for the experimental tests. The overall length of the screw was approximately 10 feet. The intake end of the auger was inserted about 13 inches in one side of the grain bin. The discharge end was maintained stationary above the collection bucket.

The power unit consisted of a voltage rheostat, an automatic timer, and a three-quarter inch electric drill (Figure 1). A counter was attached to the drill for accurate counting of the revolutions per minute of the screw.

Three plastic buckets were used to collect the metered shelled corn. The three buckets were weighed and numbered.

Grain bin. The grain bin was constructed from one-half inch thickness plywood. The bin, from which the auger was to be mounted, was

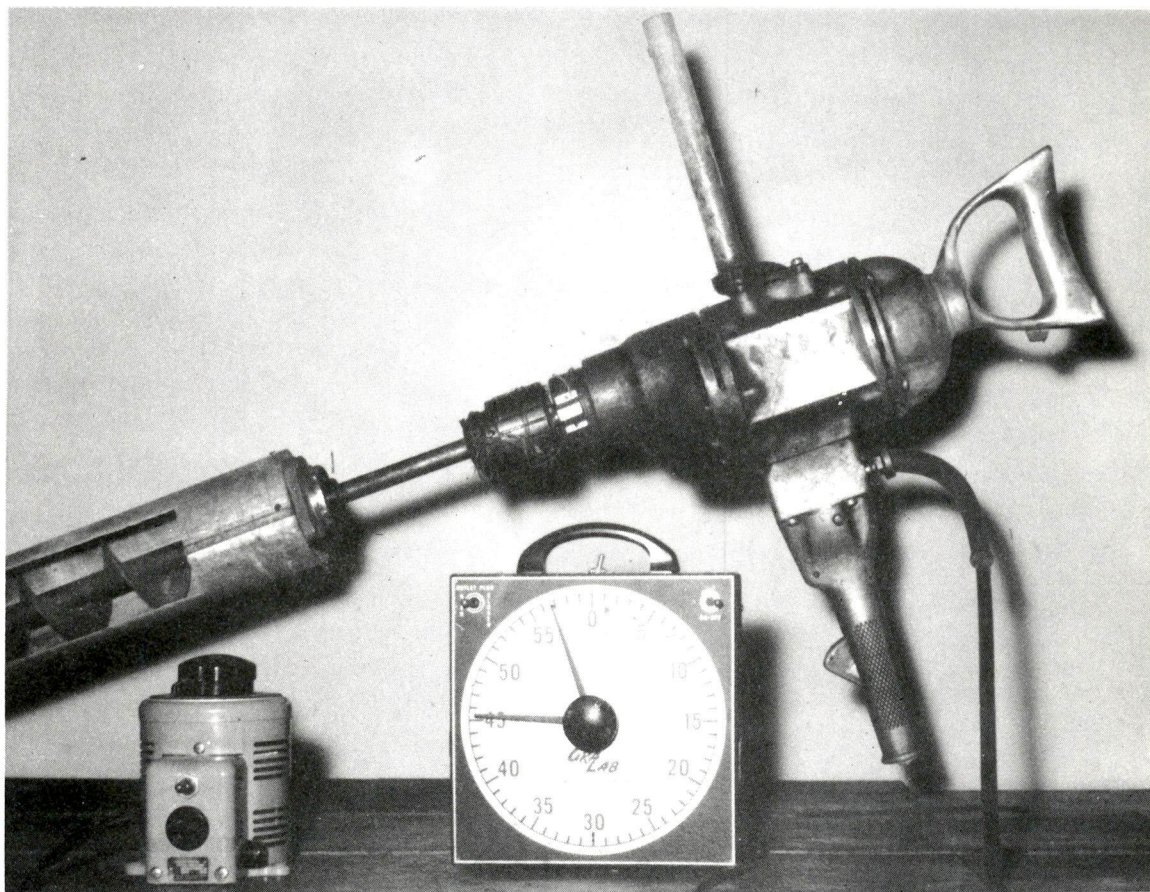


Figure 1. Power unit (three-quarter inch electric drill), voltage rheostat, and timer.

4 feet in height, and 2 feet wide. Two opposite sides of the bin were inclined 58 degrees to increase the usable capacity of grain for test purposes (Figure 2). A 4 inch diameter hole was cut in the center of one side of the corn bin, $5\frac{1}{2}$ inches above the bin floor. From this access hole the auger was tested for the horizontal position and 15 degrees inclination. Another 4 inch diameter hole was centered and cut in the side of the bin for the 30, 45, and 60 degrees inclination tests. The bottom of the second hole measured 11 inches from the top of the first hole. This hole was made adjustable by a plywood collar fitting around the auger (Figure 3).

Auger. The selected size of agriculture screw was $3\frac{1}{2}$ inches in diameter with a standard pitch. The overall flighting length was 10 feet and 4 inches with a 11 inch bare shaft on the discharge end. The power unit was mounted on the 11 inch bare shaft.

The screw was mounted in an enclosed tube. The clearance between the tube was about one-quarter of an inch. Measurement of the overall length of the tube was 9 feet 8 inches. This tube length permitted the exposed intake length of screw to be 11 inches. A rectangular discharge opening, 8 inches in length by 3 inches in width, was cut 4 inches from the tube end (Figure 4).

A tight fitting 4 inch diameter wood block was inserted in the discharge end of the tube. A roller bearing was mounted on the wood block to support the screw drive shaft and power unit. Seven inches

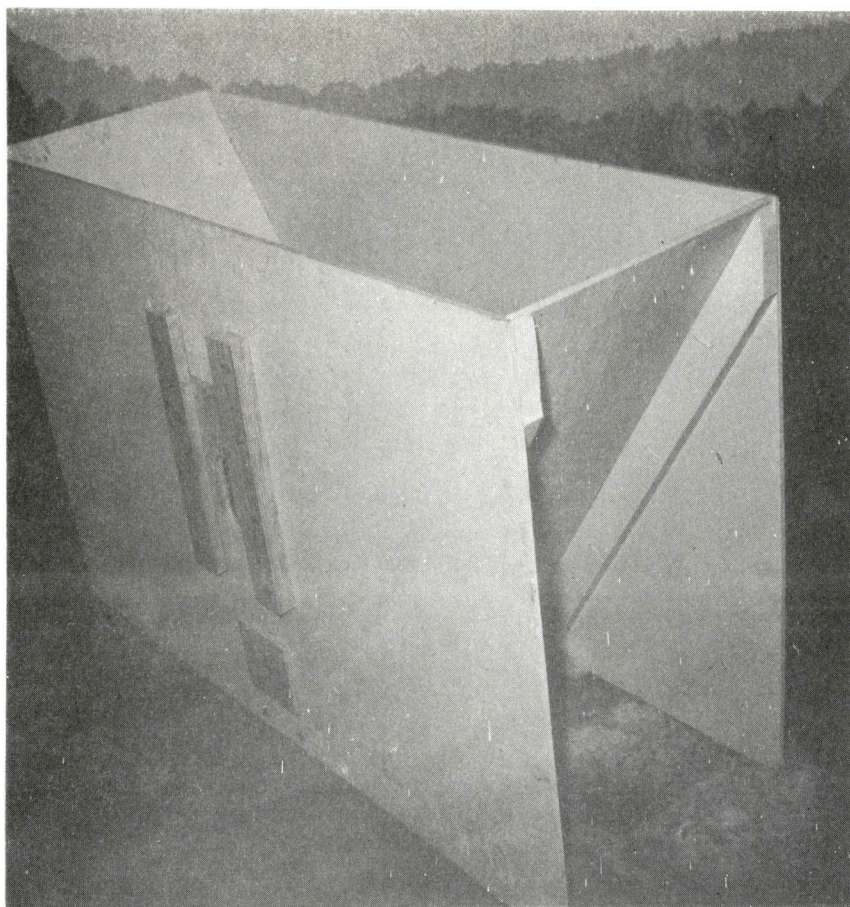


Figure 2. Grain bin.

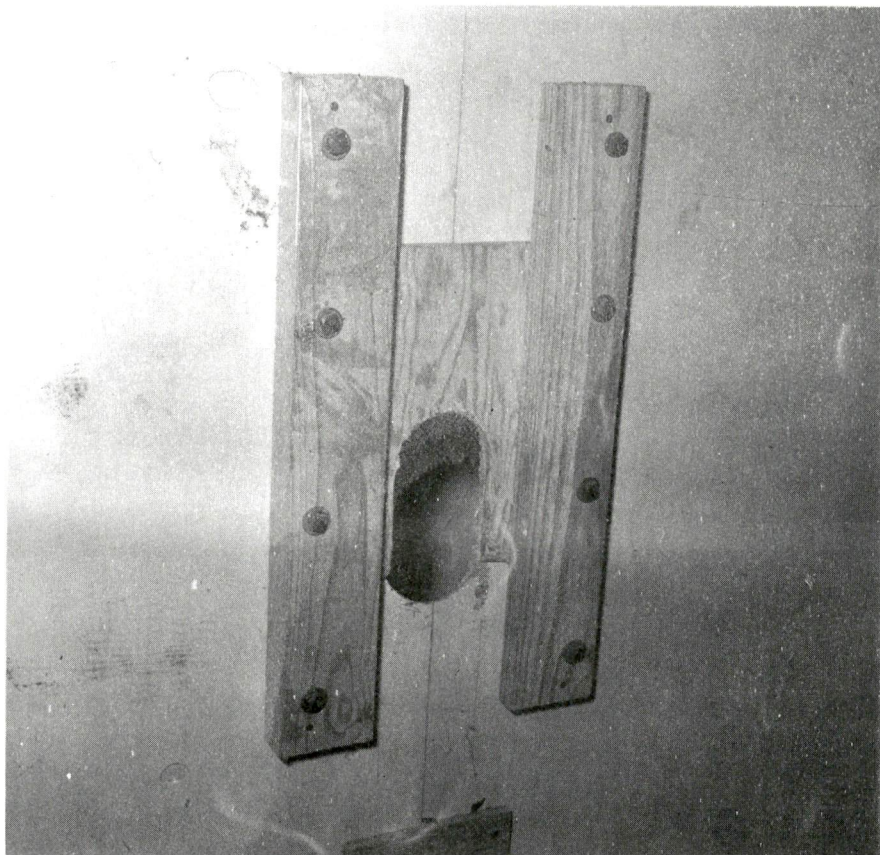


Figure 3. Adjustable auger hole.

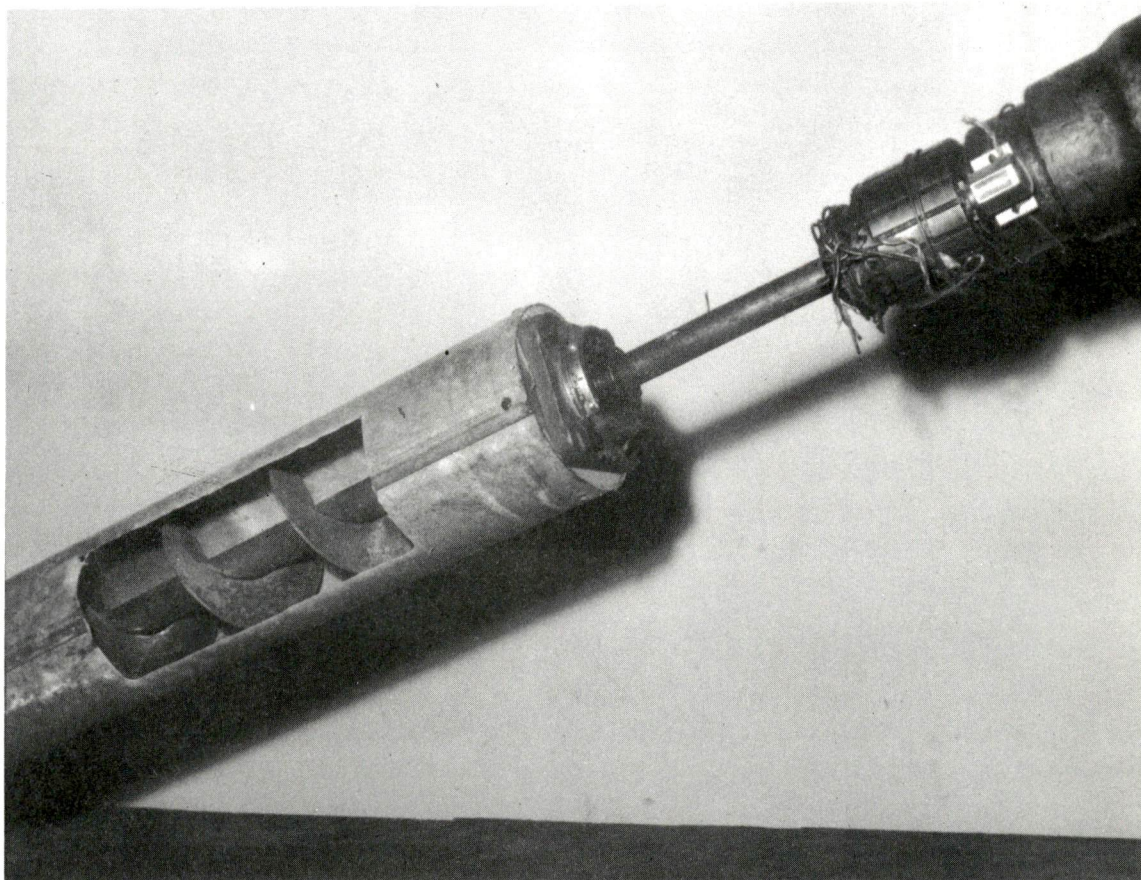


Figure 4. Auger discharge opening, venter-root counter, and electric drill.

bare shaft protruded from the bearing onto which the power unit was attached.

Power unit. A three-quarter inch heavy duty electric drill was the power source for the screw. The drill was rated at 375 revolutions per minute at 110 volts with a current of $7\frac{1}{2}$ amperes.

The drill was mounted on the end of the 7 inch bare screw shaft by using the standard Jacobs Chuck. Rotation of the drill was limited by an extended pipe handle.

II. INSTRUMENTATION

Revolution per minute counter, time control, and rheostat. The number of revolutions per minute were determined by a Veeder-Root indexing counter which was attached to the drill housing. A wire trigger attached to the rotating part of the drill recorded each revolution on the counter.

Accurate time periods were maintained by using a timer in the circuit with the rheostat and power drive unit. The timer stopped the screw automatically after it was started.

Speed of the screw was varied by regulating the voltage to the drill with a rheostat. Screw speed ranged from 20 to 150 revolutions per minute.

Sample measurement. All samples were weighed on a 75 pound capacity Toledo Scale. The dial reading on these scales was graduated into ounces.

III. PROCEDURE

In order to evaluate the 4 inch auger as a metering device, various auger inclinations and screw speeds were tested. It was thought the most common inclinations in everyday use would be represented by the following inclinations: 0 (horizontal), 15, 30, 45, 60, and 90 degrees (vertical). At each of these inclinations, screw speeds of 20, 40, 60, 80, 100, and 150 revolutions per minute were tested. The lower screw speeds would indicate that the auger could be a practical device for metering materials in small operations.

In order to determine the consistent metering capacity, a series of replicated tests were conducted. Each test was an individual auger inclination. The auger inclinations tested were 0 (horizontal), 15, 30, 45, 60, and 90 degrees (vertical). Tests I, II, III, IV, V, and VI were, respectively, 0 (horizontal), 15, 30, 45, 60, and 90 degrees (vertical) auger inclination.

For any specific test the auger was set at the desired inclination and six one-minute test runs were made at screw speeds of 20, 40, 60, 80, 100, and 150 revolutions per minute. Data on true speed and capacity were noted. Subsequent two-minute runs on Test I and II under similar conditions revealed no change in metering characteristics of the auger. On this basis, no further tests were conducted on the two-minute time periods.

A general procedure was followed within each of the six tests conducted. The rheostat was set for the approximate output voltage that would control the screw speed with the required range. Three trial periods were used to calibrate the desired revolutions per minute of the screw. The timer was set for one minute. In all tests, the timer started the screw for the time period and stopped automatically. At the end of each time period the count of revolutions for the one-minute test were recorded from the counter dial. The last part of a revolution at the end of a time period was arbitrarily counted to the nearest one-quarter of a revolution. The collection bucket of grain was weighed to the nearest ounce. Allowance was made for the bucket weights. The number of ounces was converted to one-hundredths of a pound.

Test I and II, 0 and 15 degrees auger inclination, were performed with the auger extending from the bottom hole in the corn bin. A support was used to maintain the discharge end of the auger at all inclinations, except vertical. In all tests, a minimum of about 6 inches was maintaining between the flighting of the exposed intake screw and the sides and bottom of the bin.

Test III, IV, and V, 30, 45, and 60 degrees auger inclinations, were conducted with the auger protruding from the adjustable opening in the side of the bin (Figure 5). When at higher auger elevations this adjustable hole was essential in preventing the exposed intake screw from contacting the bin floor.

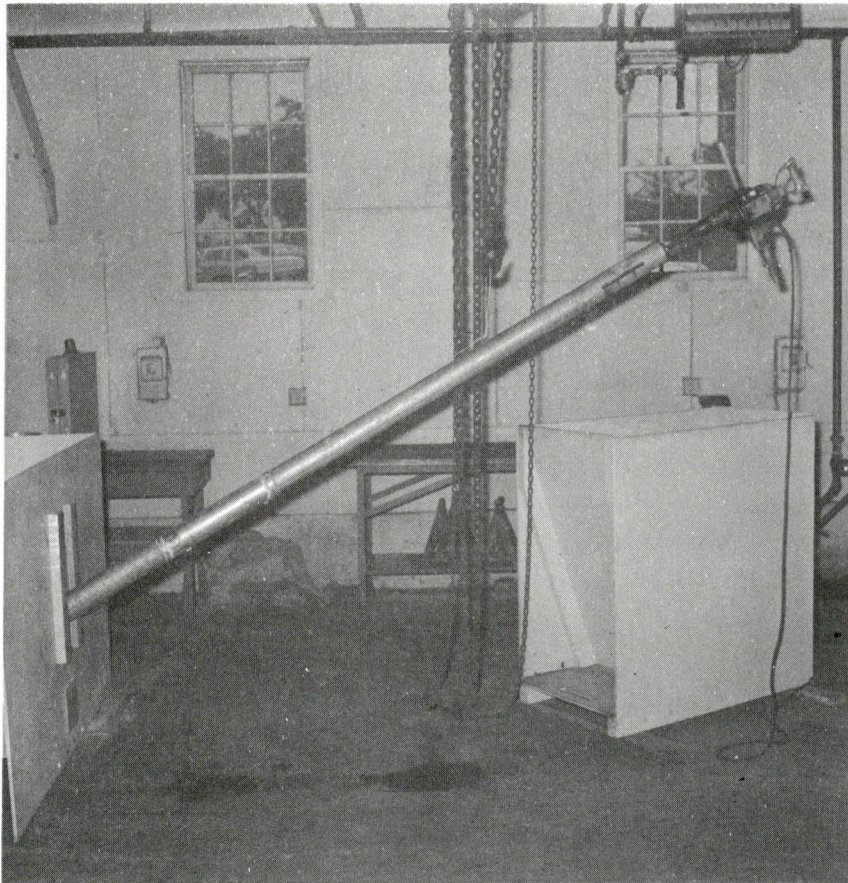


Figure 5. Auger in adjustable hole at 30 degrees inclination.

Test VI, 90 degrees auger inclination (vertical), was performed by bolting a collar around the auger to maintain it at vertical position. This collar mounted across the top of the bin steadied the auger in the center of the bin, preventing the screw from contacting the bin floor. The auger is shown in vertical position in Figure 6.



Figure 6. Auger at vertical position.

CHAPTER IV

DISCUSSION OF THE RESULTS

In order to evaluate the use of a standard agricultural auger for metering shelled corn, tests were conducted at different auger inclinations in conjunction with varying screw speeds.

Total screw capacity was taken at the end of one-minute time periods. At each screw speed of 20, 40, 60, 80, 100, and 150 revolutions per minute, six replications were recorded of the total screw capacity. Each of these screw speeds were repeated at auger inclinations of 0 (horizontal), 15, 30, 45, 60, and 90 degrees (vertical). The data collected of these total capacities of shelled corn metered per minute are shown in Table VI-XI of the Appendix. The same data collected of total capacities of shelled corn metered per minute were adjusted to pounds of shelled corn metered per revolution of the screw. This data is also part of Table VI-XI of the Appendix. Since the revolutions per minute could not be maintained at the exact speed in each one minute test, it was necessary to adjust the data to pounds per revolution of the screw. This eliminated a possible error when the data analysis was computed. The average pounds of shelled corn metered per revolution of the screw is shown in Table I.

At the horizontal position and for all speeds the auger handled the maximum capacity as compared to other inclinations. At any one auger

TABLE I
AVERAGE POUNDS OF SHELLED CORN METERED PER REVOLUTION
OF A 4 INCH AUGER

Auger Speed	Inclination of Auger					
	0	15	30	45	60	90
20	0.685	0.648	0.620	0.564	0.488	0.187
40	0.684	0.649	0.610	0.563	0.500	0.195
60	0.683	0.646	0.607	0.560	0.490	0.212
80	0.680	0.646	0.609	0.557	0.493	0.226
100	0.685	0.644	0.609	0.556	0.494	0.239
150	0.692	0.646	0.607	0.552	0.487	0.264

inclination, an increase of 20 revolutions per minute in screw speed, resulted in a corresponding increase in total poundage of shelled corn metered (Figure 7). This is consistent with other studies on auger capacities.

The auger capacity at all inclinations decreased in per cent when compared to the auger capacity at 0 degrees inclination (horizontal). Data representing the per cent of horizontal capacity delivered at all other inclinations are shown in Table II. At any given screw speed, it was noted that the average per cent auger capacity decreased with an increase of inclination. As the auger inclination was increased from 0 degrees (horizontal) to 90 degrees (vertical), there was an inverse relationship in total capacity of shelled corn metered. The amount (pounds) of shelled corn metered per revolution of the auger also decreased with respect to the increase of auger inclination (Figure 8). All the curves, consisting of different screw speeds, closely followed the same pattern.

At any given auger inclination the average pounds of shelled corn metered per revolution of the screw remained somewhat consistent as the screw speed was increased from 20 to 150 revolutions per minute (Figure 8). Test VI, 90 degrees auger inclination (vertical), had an average increase of 0.0765 pounds per revolution between 20 and 150 revolutions per minute screw speeds.

An analysis of variance was made on the pounds of shelled corn metered per revolution of the screw. Each set of the six replications

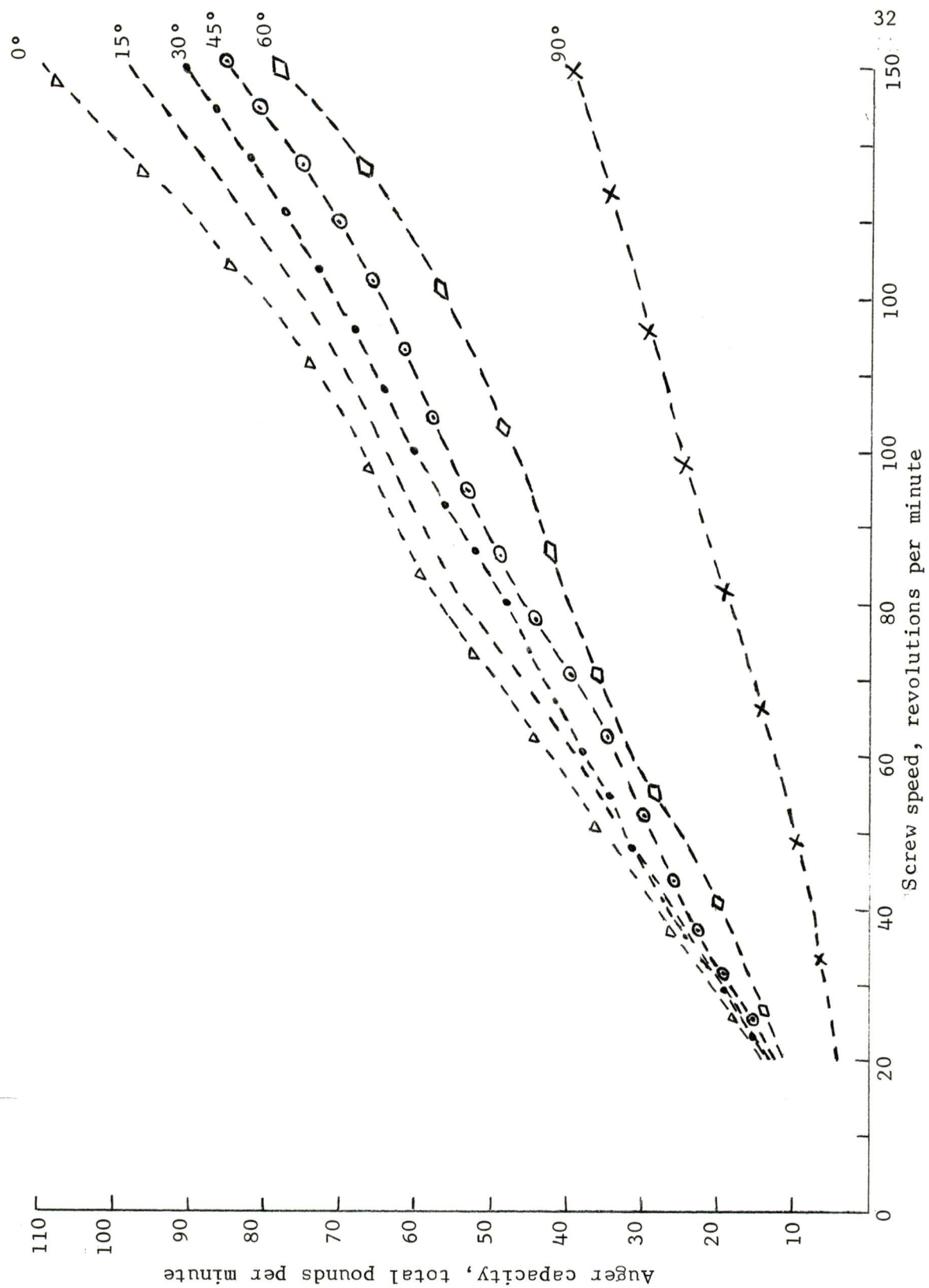


Figure 7. Total auger capacity related to inclination and screw speed.

TABLE II
PER CENT OF SHELLLED CORN METERED PER REVOLUTION OF A
4 INCH AUGER AT VARYING INCLINATIONS

Auger Speed	Inclination of Auger					
	0	15	30	45	60	90
20	100.00	94.57	90.55	82.38	71.29	27.40
40	100.00	94.77	89.09	82.22	73.05	28.47
60	100.00	94.62	88.87	82.07	71.81	31.15
80	100.00	94.95	89.60	81.94	72.58	33.23
100	100.00	94.10	88.94	81.21	72.18	34.93
150	100.00	93.39	87.69	79.82	70.35	38.17

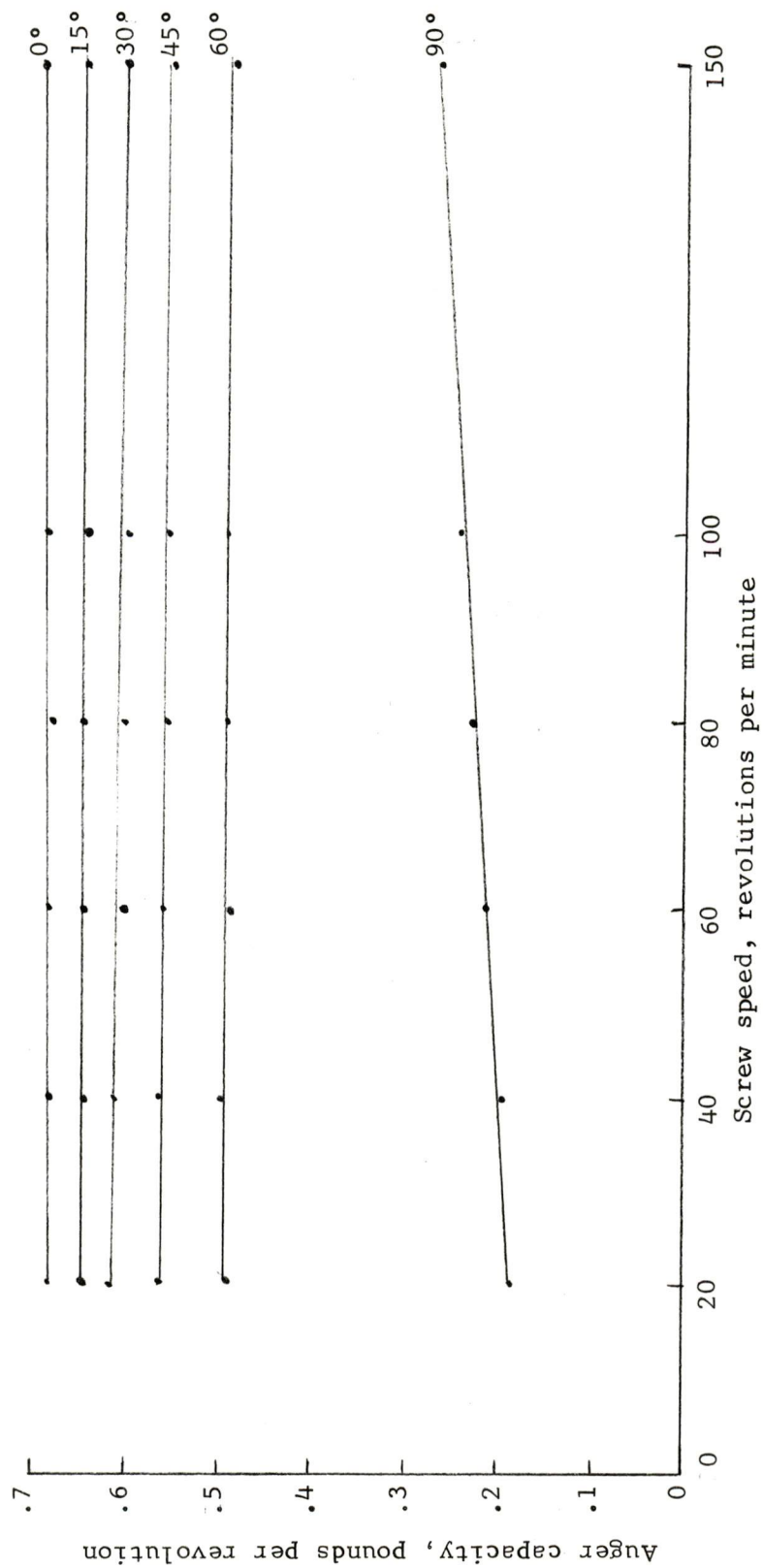


Figure 8. Pounds per revolution auger capacity at varying screw speeds and inclinations.

represented a treatment. Each treatment involved a change in screw speed and auger inclination. The analysis indicated that there was no significant difference among replications. The F-test at the 0.01 level of probability indicated that difference among treatments existed (Table III). The Duncan's Multiple Range Test was conducted to identify the treatments which were different at the 0.01 probability level. The treatments in Table IV that are connected by a vertical line were not different. This revealed that ninety-nine out of 100 times the treatments connected with a vertical line were not different.

The variation from the minimum to the maximum of each treatment is shown in Table V.

TABLE III
CAPACITY PER REVOLUTION OF THE 4 INCH AUGER AT DIFFERENT
SCREW SPEEDS AND INCLINATIONS

Source	Analysis of Variance			
	Degrees of Freedom	Sum of Squares	Variance	F Value
Total	215	5.13232144		
Treatment	35	5.12608394	0.14645954	4,310.16892289**
Replication	5	0.00028996	0.00005799	1.70659211 ns ¹
Error	175	0.00594754	0.00003398	

**Double asterisk refers to significances at 1 per cent level.

¹ns refers to no significance.

TABLE IV

CAPACITY PER REVOLUTION OF THE 4 INCH AUGER AT DIFFERENT
SCREW SPEEDS AND INCLINATIONS

Duncans Multiple Range			
Treatment		Treatment Means	
Degrees Auger Inclination	Screw Speed RPM	Pounds Per Revolution	Statistical Significance
90	20	0.1878	
90	40	0.1950	
90	60	0.2128	
90	80	0.2161	
90	100	0.2393	
90	150	0.2643	
60	150	0.4871	
60	20	0.4886	
60	60	0.4905	
60	80	0.4938	
60	100	0.4945	
60	40	0.5003	
45	150	0.5526	
45	100	0.5563	
45	80	0.5575	
45	60	0.5606	
45	40	0.5631	
45	20	0.5646	
30	60	0.6070	
30	150	0.6071	
30	100	0.6093	
30	80	0.6096	
30	40	0.6101	
30	20	0.6206	
15	100	0.6446	
15	80	0.6460	
15	60	0.6463	
15	150	0.6466	
15	20	0.6481	
15	40	0.6490	
0	80	0.6803	
0	60	0.6830	
0	40	0.6848	
0	100	0.6850	
0	20	0.6853	
0	150	0.6923	

TABLE V
POUNDS PER REVOLUTION VARIATION WITHIN EACH
TREATMENT (MAXIMUM TO MINIMUM)

Auger Speed	Inclination of Auger					
	0	15	30	45	60	90
20	0.082	0.034	0.009	0.008	0.013	0.011
40	0.013	0.008	0.004	0.003	0.009	0.014
60	0.010	0.007	0.002	0.004	0.007	0.004
80	0.013	0.005	0.006	0.003	0.003	0.006
100	0.010	0.005	0.004	0.003	0.002	0.005
150	0.010	0.007	0.002	0.002	0.005	0.013

CHAPTER V

SUMMARY AND CONCLUSIONS

An investigation was conducted to determine if a standard agricultural auger could be used as a means of metering shelled corn. To accomplish these objectives a test was conducted to obtain the amount (pounds) of shelled corn the auger would meter. Two variables were employed in the experiment, inclination of the auger and speeds of the screw. Total pounds of shelled corn were collected during one-minute time periods. The data collected was converted in pounds of shelled corn delivered per revolution of the screw.

The capacity per revolution decreased with the increase in inclination. Throughout the experiment, total capacity delivered per minute by the auger increased linearly with the increase in revolutions per minute. The total capacity of the auger at 90 degrees inclination (vertical) was approximately 27 to 38 per cent of the total capacity at 0 degrees inclination (horizontal).

Based on the analysis of variance, there was no significant difference among replications. A highly significant difference was found among treatments. This analysis indicated ($P < 0.01$) that with regard to the 4 inch auger one determination of pounds of shelled corn metered would be as valid as six determinations.

Based upon the results of the tests, the following conclusion was made: The 4 inch diameter, standard pitch screw auger can be used

as a means of metering shelled corn within the limits of the tests studied.

The following areas are suggested for additional study and analysis:

1. The use of better facilities to be able to conduct similar tests during longer time periods.
2. Conduct similar metering tests using various ground feeds.
3. The effect of clearance between screw and screw housing on auger efficiency.
4. Tests designed to study the relationship of screw pitch on consistency of metering.
5. The relationship of auger diameter on the accuracy of metering materials.

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APPENDIX

TABLE VI

PERFORMANCE DATA FOR A 4 INCH AUGER HANDLING SHELLLED CORN
AT 0 DEGREES INCLINATION (HORIZONTAL)

Rated Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
20	19.50	13.31	0.680
	22.00	14.50	0.659
	21.75	15.13	0.741
	21.50	14.63	0.680
	21.50	14.63	0.680
	21.75	14.63	0.672
40	39.75	27.56	0.693
	41.50	28.25	0.680
	41.50	28.31	0.682
	42.00	28.87	0.687
	43.00	29.36	0.682
	41.75	28.62	0.685
60	60.50	41.25	0.681
	61.50	41.87	0.680
	61.50	41.93	0.681
	62.00	42.56	0.686
	62.75	43.31	0.690
	63.75	43.37	0.680
80	86.25	59.00	0.684
	82.75	56.31	0.680
	82.75	56.49	0.682
	83.50	56.99	0.682
	85.50	57.38	0.671
	86.00	58.82	0.683
100	95.75	65.00	0.678
	95.25	65.44	0.687
	97.75	67.31	0.688
	99.25	67.93	0.684
	99.75	68.63	0.688
	100.00	68.57	0.685

TABLE VI (CONTINUED)

Rated Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
150	160.50	110.19	0.686
	158.50	109.94	0.693
	159.50	110.44	0.692
	158.25	109.75	0.693
	158.75	110.19	0.694
	159.00	110.81	0.696

TABLE VII

PERFORMANCE DATA FOR A 4 INCH AUGER HANDLING SHELLLED CORN
AT 15 DEGREES INCLINATION FROM HORIZONTAL

Rated Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
20	18.75	11.69	0.623
	22.75	14.81	0.650
	22.75	14.87	0.653
	22.50	14.69	0.652
	20.25	13.31	0.657
	20.25	13.25	0.654
40	37.75	24.69	0.654
	37.75	24.41	0.646
	41.00	26.62	0.649
	41.75	27.00	0.646
	40.75	26.50	0.650
	41.00	26.62	0.649
60	58.75	38.19	0.650
	59.75	38.69	0.647
	60.25	38.88	0.643
	60.50	39.12	0.646
	60.25	38.94	0.646
	60.24	38.93	0.646
80	84.75	54.87	0.647
	83.25	53.62	0.644
	82.75	53.63	0.648
	84.75	54.56	0.643
	84.75	54.93	0.648
	85.25	55.13	0.646
100	98.25	63.25	0.643
	99.50	63.88	0.642
	100.00	64.63	0.646
	100.00	64.56	0.645
	100.75	65.19	0.647
	101.50	65.56	0.645

TABLE VII (CONTINUED)

Rated Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
150	149.50	96.18	0.643
	151.75	97.68	0.643
	152.00	98.57	0.648
	151.75	98.69	0.650
	153.25	99.25	0.647
	153.50	99.75	0.649

TABLE VIII

PERFORMANCE DATA FOR A 4 INCH AUGER HANDLING SHELLLED CORN
AT 30 DEGREES INCLINATION FROM HORIZONTAL

Rated Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
20	21.00	12.93	0.615
	21.50	13.25	0.616
	21.50	13.12	0.610
	21.75	13.37	0.614
	21.25	13.06	0.614
	21.00	13.00	0.619
40	43.75	26.81	0.612
	44.50	27.25	0.612
	44.50	27.06	0.608
	45.00	27.50	0.611
	45.75	27.87	0.609
	45.75	27.87	0.609
60	61.50	37.31	0.606
	62.50	38.06	0.608
	62.75	38.12	0.607
	62.50	37.93	0.606
	62.50	38.06	0.608
	63.25	38.44	0.607
80	76.50	46.44	0.607
	79.00	48.50	0.613
	80.00	48.81	0.610
	79.50	48.56	0.610
	79.25	48.19	0.608
100	100.25	61.06	0.609
	100.50	61.44	0.611
	101.50	61.87	0.609
	101.50	61.62	0.607
	100.50	61.37	0.610
	101.00	61.69	0.610

TABLE VIII (CONTINUED)

Rated Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
150	149.50	90.62	0.606
	150.75	91.56	0.607
	150.50	91.37	0.607
	151.75	92.25	0.607
	151.75	92.31	0.608
	151.50	92.19	0.608

TABLE IX

PERFORMANCE DATA FOR A 4 INCH AUGER HANDLING SHELLLED CORN
AT 45 DEGREES INCLINATION FROM HORIZONTAL

Rated Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
20	22.75	12.75	0.560
	23.50	13.37	0.568
	21.75	12.37	0.568
	23.25	13.19	0.567
	22.50	12.62	0.560
	21.00	11.87	0.565
40	43.00	24.25	0.563
	43.75	24.56	0.561
	42.75	24.12	0.564
	43.50	24.50	0.563
	44.75	25.25	0.564
	44.50	25.12	0.564
60	59.50	33.37	0.560
	59.50	33.31	0.559
	59.50	33.50	0.563
	59.50	33.37	0.560
	59.75	33.62	0.562
	59.00	33.06	0.560
80	82.50	46.06	0.558
	83.25	46.50	0.558
	83.75	46.69	0.557
	83.25	46.56	0.559
	81.25	45.31	0.557
	81.50	45.37	0.556
100	100.25	55.75	0.556
	100.75	56.06	0.556
	101.25	56.31	0.556
	101.50	56.37	0.557
	101.75	56.75	0.555
	101.50	56.69	0.558

TABLE IX (CONTINUED)

Rated Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
150	153.75	84.93	0.552
	154.00	85.12	0.552
	153.75	84.94	0.552
	154.00	85.38	0.554
	155.00	85.75	0.553
	154.75	85.62	0.553

TABLE X

PERFORMANCE DATA FOR A 4 INCH AUGER HANDLING SHELLLED CORN
AT 60 DEGREES INCLINATION FROM HORIZONTAL

Rated Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
20	22.00	10.93	0.496
	22.75	11.00	0.483
	23.50	11.44	0.486
	24.25	11.81	0.487
	25.00	12.31	0.492
	22.50	11.00	0.488
40	43.00	21.31	0.495
	37.50	18.69	0.498
	38.75	19.44	0.501
	37.75	18.93	0.501
	38.25	19.25	0.503
	38.25	19.31	0.504
60	62.50	30.44	0.487
	64.75	31.69	0.489
	66.50	32.75	0.492
	66.75	32.75	0.490
	67.76	33.31	0.491
	66.75	33.00	0.494
80	81.50	40.25	0.493
	81.75	40.50	0.495
	81.75	40.50	0.495
	82.50	40.81	0.494
	82.50	40.81	0.494
	83.25	41.00	0.492
100	94.00	46.44	0.494
	94.00	46.50	0.494
	94.50	46.93	0.496
	96.50	47.81	0.495
	96.75	47.93	0.494
	97.00	47.93	0.494

TABLE X (CONTINUED)

Rated Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
150	149.00	72.31	0.485
	149.25	72.94	0.488
	149.00	72.87	0.489
	149.25	72.87	0.488
	150.25	73.56	0.489
	151.25	73.31	0.484

TABLE XI

PERFORMANCE DATA FOR A 4 INCH AUGER HANDLING SHELLED CORN
AT 90 DEGREES INCLINATION (VERTICAL)

Related Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
20	21.75	4.12	0.189
	21.50	4.19	0.194
	21.25	4.00	0.183
	21.50	4.00	0.186
	22.50	4.25	0.188
	22.00	4.12	0.187
40	39.00	7.31	0.187
	39.25	7.56	0.192
	38.75	7.56	0.195
	39.25	7.69	0.195
	38.50	7.75	0.201
	38.50	7.75	0.200
60	62.25	13.19	0.211
	62.25	13.25	0.212
	61.25	13.12	0.214
	62.25	13.19	0.211
	63.25	13.56	0.214
	61.00	13.12	0.215
80	82.00	18.69	0.227
	84.25	18.81	0.223
	84.50	18.93	0.224
	84.50	19.25	0.227
	84.75	19.44	0.229
	85.00	19.31	0.227
100	102.75	24.44	0.237
	104.25	24.75	0.237
	105.00	25.19	0.239
	105.25	25.31	0.240
	105.50	25.50	0.241
	105.50	25.56	0.242

TABLE XI (CONTINUED)

Related Screw RPM	True RPM	Pounds Delivered Per Min.	Pounds Delivered Per Rev.
150	153.25	39.62	0.258
	150.50	39.56	0.262
	150.00	39.93	0.266
	152.75	40.00	0.261
	150.50	40.44	0.268
	150.50	40.87	0.271