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Use of pneumatics in a precision snap bean planter

Sarjapuram Hanumappa Thimmappa

To the Graduate Council:

I am submitting herewith a thesis written by Sarjapuram Hanumappa Thimmappa entitled "Use of pneumatics in a precision snap bean planter." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

Houston D. Luttrell, Major Professor

We have read this thesis and recommend its acceptance:

John J. McDow, Lewis H. Dickson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

September 24, 1964

To the Graduate Council:

I am submitting herewith a thesis written by Sarjapuram Hanumappa Thimmappa entitled "Use of Pneumatics in a Precision Snap Bean Planter." 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 Agricultural Engineering.

Houston Luttrell
Major Professor

We have read this thesis and recommend its acceptance:

John J. McDow

Lewis H. Dickson

Accepted for the Council:

Hilton A. Smith
Dean of the Graduate School

USE OF PNEUMATICS IN A PRECISION SNAP BEAN PLANTER

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Sarjapuram Hanumappa Thimmappa

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CHAPTER I

INTRODUCTION

Sowing seed in the soil has been practiced ever since man learned to raise plants for his food. The simplest practice he adopted for raising crops on fields was just to throw seeds or broadcast them on the land where the plants were intended to be grown. With this simple start of the art of sowing, as man learned more and more about the behavior, growth and the art of crop husbandry, he searched for better ways of seeding or sowing seeds in order to accomplish better yields. The growth of plant science and the demand for better seeding practices besides the requirements of seed bed preparation, manuring, weed control, etc., lead him to the investigation and use of several devices or applicances or say equipment for planting seeds.

At present the plant science demands the planting of seeds in rows at specified width and at desired spaces between seeds in a row. Of course the distance between rows and spacing between seeds varies according to the nature of the crop. The plant science also demands that seeds to be placed either in groups (otherwise called hills) or single seeds. Placing of seeds in specified rows and at a given spacing is alone not sufficient. They have to be placed at desired depth and an environment of soil is to be created to obtain the desired stand of plants both in number and also in uniformity.

Seeds not only vary in shape and size with different crops but they also vary in size and shape within the same crop with different varieties and with the same variety crop in seeds. These variations in seeds and variations in the planting practices have lead to the development of various types of planting equipment that are now found in the market. The requirements of planting devices for most of the crops have been fairly accomplished as could be seen from the review of previous work briefly mentioned under Review of Literature.

Coming to the requirements of snap beans, they are required to be planted as single seeds in rows as close as cultural operations permit and at uniform spacings within a row in order to have a uniform stand of crop for obtaining maximum yields. The usual width between rows is three to five feet for pole beans and 28 to 38 inches for bush beans. The seed spacing within the row varies from 1-1/2 to 4 inches (17).[1] Tests conducted in Pulaski County, Kentucky, with the same fertilizer level and with varied overall spacing of five, seven, and nine plants per foot showed that

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[1]The number in parenthesis refer to the item number in Bibliography cited.

plants at seven per foot gave the maximum yield (18). Thus, the accuracy with which snap beans are to be planted for obtaining maximum yield is within a very small range. This demands the use of precision planting equipment which could meter beans in singles and plant them at correct spaces in the rows to get the desired stand of plants.

The standard horizontal corn planter found in the market with certain modifications of equipment and use of specially designed plates is being used by some farmers for planting snap beans. As these cylindrical shaped snap beans of the same variety vary both in diameter and in length of seeds, they are required many times to be graded to obtain accurate metering. Often ungraded seeds cost less than graded seeds, it is desirable to have a planter which could meter and plant seeds with precision irrespective of the size and shape of the seeds. The requirement of metering seeds of various sizes and shapes needs an approach quite different from the conventional plate metering devices. In the present investigations the possibility of separating single seeds from a group of seeds in a hopper through the use of pneumatic vacuum pressure was explored. It was thought that it would be possible to catch a single seed and separate it from the group by holding the seed with pneumatic vacuum pressure at the end of a suitably designed nozzle, positioned on the periphery of a rotating vertical disc or plate.

CHAPTER II

OBJECTIVE OF THE INVESTIGATION

The objectives of the present investigation were:

(1) To determine the possibility of using pneumatic vacuum pressure for separating seeds in singles from a group for adoption in planters.

(2) To develop and test a system for using pneumatics for metering seed in a precision snap bean planter.

CHAPTER III

REVIEW OF LITERATURE

History of the Development of Sowing and Planting Equipment

Sowing or broadcasting by hand goes back even beyond the husbandman of ancient Egypt who scattered seed upon overflow land along the Nile after flood waters had gone down (14). This simplest method of delivering seed to the earth is still practiced in some parts of the world. The sower carries the receptacle for seed, a zinc "seed lip", seed sheet or basket, slug over his shoulders, and walking up and down the ridges in the field scatters handfuls of grain with semi-circular sweep of the arm across the body. To obtain the uniformity in sowing at the desired seed rate, braodcasting by hand demands considerable skill and experience (11). The seed was then pressed into the soil and covered by driving sheep or cattle over the fields. More conventionally the seeds were covered by dragging tree branches over the field.

Bert S. Gittins remarks:

> History does not record who invented the first seeding machine or drill, but the Chinese apparently had a wheelbarrow-type drill as early as 2800 B.C. with three spouts to carry seed into the soil. The Italians had a two-wheel seeder with metal tubes or funnels and crude furrow openers around 1600 A.D., but most of this early progress seems to have been lost through the wars and invasions which followed (14).

In England the early history of mechanical sowing is chiefly connected with the name of Jethro Tull, who about 1730 invented the corn drill to plant seeds in rows and had many imitators. In America the development of better plows, grain drills and harvesters was coincident with the westward expansion of the wheat belt (10). The first patent on a seeding machine was granted in 1799, but in 1840 and 1841 there were developments which distinguished American drills from those of English inventors. These included devices for delivering the seed and regulating its rate. The force feed (1851) has been described as "the most important invention of the drill industry in America." For all practical purposes, the era of "the sower" with his knapsack over his shoulder came to an end during the 1870's. After the war, there was considerable use of hand rotation seeders which the farmer strapped over his shoulders and operated by a hand crank. The end gate seeder appeared in the spring wheat areas during the early 1870's. Double-disk and single-disk furrow openers, introduced in the 1890's, cut through trash with less draft and encouraged use of larger units. In 1950, a grass seeding machine was introduced which permitted reseeding without destroying the existing sod, placed fertilizer and reduced the danger of erosion (14).

Unlike grain drills and seeders, the corn planter is stated to be strictly an American development, just as corn is a native American crop. Here again, the hoe was the starting point. The American Indians are described as using a hoe to open a hole three or four inches deep where four or five kernels could be dropped by hand and covered. From this planting, two or three stalks could grow and when they reached "hand's length" the hoe would be used to cut weeds and loosen the soil. Planting with a hoe was the prevalent method until about 1850. There may be doubt as to whether the 1799 seeding machine patent was for corn or a small grain machine. The first cotton planter patent was granted in 1825, and in 1828 came a wheelbarrow-type corn planter. It was hand pushed and was supposed to plant six to ten acres a day in four-foot rows as contrasted to planting one-half acre with a hoe. The two-row corn planter came into the picture in a limited way in 1839, and the first check row planter, a single-row walking planter, was invented in 1857. Neither planter made much impression.

One of the real milestones came in 1860 with the appearance of a two-row corn planter which was tripped by hand for cross-checking. The field was cross-marked first, and a man or boy pulled a trip lever each time the planter runners crossed a mark. This machine required two operators, one to drive and one to trip. First patents on this planter were issued in 1853, but the provision for a rider to operate the dropping mechanism was covered by a patent in 1860.

The extra man on the planter was an immediate challenge to inventors and in 1875 an automatic check row planter appeared which was accepted. It used knotted cord at first to trip the planting mechanism, but a planter wire with uniformly spaced buttons on it took over later. Thus, the corn planter became a one-man machine. Another improvement came in the early 1890's, the single-kernel accumulative drop corn planter. It planted any desired number of kernels in a hill. Meanwhile, cotton planters were making progress. Single row, one-mule planters were developed in the 1870's and 1880's.

Fertilizer attachments were used on potato planters as early as 1880, and the 1900 census report mentions similar attachments for corn planters. Two-row potato planters were on record in 1917. Special tools for planting and cultivating vegetables and other narrow-row crops came along in 1868 with multiple-row units following a few years later. After World War I, planters which planted four, six or eight rows at a time were common in California and other vegetable growing areas.

After the coming of the tricycle-type tractor in 1924, tractor powered planters began to appear. First, there were horse-type planters pulled behind the tractor, but in a very short time, tractor-mounted equipment appeared, which is one of the truly significant trends of this modern age of power farming. One of the most interesting developments has been the planting of segmented seed in the production of sugar beets. The single-seed planters produced in 1939 were used for planting segmented seed with new seed plates in 1942, This manogerm seed planting led into the elimination of "labor" involved in thinning of sugar beets (14).

Precision Planting

Precision planting may be defined as the planting of single seeds accurately spaced in rows to obtain a uniform stand of plants. Morton (20) pointed out that a precision planter must have the ability to take single seeds from a body of seeds in a container and place them in a uniform pattern in a row. The complete path of the seed from the hopper to ground must be considered in the planter, not just the precision of a single mechanism, e.g. metering device. In re- examining some of the requirements of planting equipment, whether it be for sugar beets or some other crop, Barmington (4) stated that:

> First, the seed must be handled in such a way that it is not damaged to the extent that germination is affected. Second, the seed must be metered and conveyed to the bottom of the furrow in a uniformly distributed pattern. Third, the seed must be placed in the soil in such a way that all the factors affecting germination will be as favorable as possible.

The above requirements are designed to be accomplished in a conventional horizontal or vertical plate type planter as follows: the seeds held in a hopper over a revolving circular plate with a number of "cells" at its periphery exposed to and in contact with the seeds in hopper. As the plate moves through the mass of seeds, one to four seeds are caught in the cells and carried to a seed tube positioned behind a furrow opener. Excess seed in the cells are wiped out by a cut off device on the seed plate and the seeds are assisted to be positively emptied from the cells into the seed tube by an ejector fixed at the point of discharge of seed from the plate. The seed plate is rotated by a chain drive from a ground wheel of the planter. The depth of planting is regulated by depth control wheels. The seeds are pressed and covered by compacting wheels, drag chains or other covering devices.

The accuracy of planting to a uniform stand depends upon several factors. Some of the main factors involved are: (1) The physical characteristics of seeds such as the size and shape of seeds. (2) The peripheral speed of seed cells and the cell shape and size. (3) The type of cut off and ejector devices used. (4) The distance the seed travels from the point of ejection to the ground or the length of seed tube. (5) The size, shape and surface characteristics of the seed tube. (6) The type of furrow openers and covering devices. (7) The surface characteristics of seed bed. (8) The soil conditions of planting.

<u>Effect of physical characteristics of seeds on planting precision</u>. Accurate seeding requires that the seeds be of uniform size and shape and have such physical characteristics that they can be readily singled and handled by cell type metering devices. This involves accurate grading of seeds within acceptable limits to obtain the best results and different planter plates must be used for each grade. Wright (24) stated that "one way to reduce the number of grades in corn" (which poses numerous difficulties because of its odd shape and variation in size of kernels) is to "simply discard those sizes and shapes of seed that do not conform with the grades that comprise the bulk of the seed produced." This would considerably reduce the number grades and the planter plates that may have to be used. He further remarked that "this sounds interesting, but we do not expect it to be done because good crops are obtained from off-sized seeds and the price is relatively low."

The physical characteristics of some of the seeds like flax, sugar beet, cotton and vegetable crops are a challenge for the planter designer. In some cases the seeds are processed or treated with chemicals for improved planter performance. Processing of sugar beets for manogerm seeds, chemical delinting of cotton seeds, coating of lettuce seeds with inert material and sizing them to uniform spherical shapes are examples of seeds treated for better planting precision (7).

<u>Effect of cell size, shape and speed on planting accuracy</u>. L. O. Roth and J. G. Porterfield (22) have indicated that relative size of a seed to the cell, relative shape of the seed and cell, relative speed of the seed and cell, distance a cell travels while exposed to seeds, and the time interval the cell is exposed to seeds, may exert a definite influence on the performance of a horizontal plate metering device. Roy Bainer (8) stated that

> . . . planters employing either vertical, horizontal, or inclined plates are capable of uniform metering of seed. It is essential that the cells in the plates fit the seed to be planted. The diameter of cell should be 1/64 inches larger than the maximum diameter of the seed to insure proper clearance. Movement of seed through the cell is further improved by tapering the cell wall from top to bottom. Tapering to an included angle of approximately 12 degrees is sufficient to insure free movement of seed through the cell. Proper plate thickness depends upon the type of seed. In the case of sugar beet seeds, plate thickness approaching the smaller dimension of the size of range of the seed are required to reduce the amount of multiple-cell fill.

A series of tests conducted by Barmington (2) with eight commercial sugar beet platners (both horizontal and vertical plate) revealed that most planters showed a tendency toward minimum seed damage at a speed which gave 100 per cent, or slightly less than 100 per cent, cell fill. When the plate speed was very slow and cell fill averaged 115 per cent or more, the seed damage was greater; and when plate speeds were increased so that cell fill fell off materially, the seed damage increased rather rapidly. On the basis of tests conducted he remarked that a small increase in plate cell size increases the percentage of cell fill very rapidly when the seed used contains a high percent of the small sizes. Graphs drawn from test data indicated that when the depth of seeds in the hopper was only one inch, the cell fill fell rapidly and reduced to less than 40 per cent when the plate speed was increased to over 50 feet per minute. It was further observed that two inches of seeds in the horizontal plate planters covered approximately half the plate in normal operation and gave equal and sometimes better cell fill than larger amounts of seed. Good cell fill can also be obtained with one inch of seed in the hopper if the seed is kept spread over at least half of the seed plate. He also stated that keeping the plate cell size as small as possible to accommodate the largest seed in the size range helped. He was of the opinion that by using the smallest plate cell possible and low planter speeds a fairly good job of planting can be done. Barmington concluded that the planter should be operated at a speed which would give very nearly 100 per cent cell fill and lower speeds with corresponding increases in cell fill would not be too harmful.

Seed damage. Most of the seed damage in conventional plate type planters were found to occur at the points of cut-off and ejection. For best results of planting, besides accurate spacing of seeds, seed damage must be a minimum. In most cases spring loaded cut-offs and false plates for backing up the seed plate except at the point of discharge are employed. Extra seeds well anchored in the cell usually force the out-off to lift permitting them to pass underneath instead of being sheared. Barmington (3) had pointed out two possibilities of overcoming seed damage: (1) Make the seed plate fill with seed and pass out of the seed body in the hopper in such a way that no cut-off is necessary, or (2) make the cut-off so flexible and gentle that seed will not be broken. He found that some commercial planters adopting such devices showed practically no seed damage, but the distribution was poor. An English made "Stanhay" planter using a very flexible rubber belt with seed cells perforated in the belt showed interesting results. A rubber-faced cut-off wheel, which rotated opposite to the direction of belt travel, wiped off excess seed from the seed belt. This planter handled seed very gently, caused no seed damage and produced good distribution (3). A similar belt metering device developed by J. G. Futral and R. L. Allen (12) at Georgia Agricultural Experiment Station for peanuts showed that the seed damage was less than one per cent, although the peanuts used had been shelled six months previously and dried to obtain material which would be easily damaged. Upon analyzing some commercial beet planters, C. T. Morton and W. F. Buchele (20) observed that a rotating wire brush used as a seed cut-off device eliminated seed damage caused by shearing and grinding, regulated cell fill, and prevented bridging of the seeds in the hopper.

Roy G. Brandit and Zdenek Fabian (9) stated that the knocker roller location or timing of the discharge opening determined first-stage accuracy in the drill spacing and hill drop grouping. Positive discharge of the seeds from the seed cells is necessary to maintain uniformity in metering. The star wheel knockout devices used in some planters was found to insure positive and uniform dropout of seeds from plate cell while the kick-out tongue did not discharge seeds from all the cells (20). Barmington (4) in an attempt to improve seed distribution in a conventional plate type planter, modified a commercial planter by replacing the seed knocker with an air ejection device and a one-fourth inch copper seed tube was used to give the system an "air rifle" effect. Air pressure from 5 to 30 pounds per square inch were used. The air ejection in the planter tested showed poorer distribution of seed than when the standard star wheel knocker and seed tube were used.

Influence of seed path and travel. When the seeds were discharged from the plate cells, the manner in which the seeds leave the cells, the nature of seed tube, and the distance the seed travels after it left the cell before reaching the ground appear to have some influence on the dispersion of seeds. J. W. Autry and E. W. Schroeder (1) pointed out that as the seeds are ejected from the cell, they have motion relative to the ground in three planes. These are caused by the force of gravity, by the peripheral speed of the plate and by the ground speed of planter acting in three different planes. They further stated that assuming that the seed which fall without ejection will have zero initial vertical velocity, then the seed takes the path of a general form of a parabola. Therefore, they suggested that the seed tube must be designed to convey the seeds through an approximately parabolic path if the seeds were to fall without interference from the tube itself. They also stated that "the path of the seeds is varied by changes in plate speed, consequently, the tube must also conform in some degree to variations of the parabola resulting from increased speed or from an initial veocity imparted to the seed by the knock-out." A properly designed trajectory-type tube conforming to the path of seed as affected by plate speeds and knock-outs showed marked improvement in seed dispersion.

Roy Bainer (8) stated that "seeds upon leaving the cell have a component of velocity equal to the speed of the cell. The trajectory followed by each is quite variable." He observed that the substitution of small smooth tubes for the large spiral ribbon tubes found on many planters confined the path of the trajectories to a space equal to the tube. The smooth tube also offered less restriction to the seed as it fell to the furrow. This was verified by a series of investigations made with beet planters. Morton and Buchele (20) tested some commercial beet planters and concluded that seeds falling inside a long length of seed tube had irregular curved paths. These paths were affected by the angle which the seed enters the tube, the weight of the seed, shape of the seed and the vibration in the unit during operation. After the seed left the lower edge of the seed tube, the velocity and direction of its fall are different. This caused lateral and longitudinal displacement of seed.

Furrow openers and covering devices. It is not sufficient for the seeds to be laid in the soil at the required specings and depth. An environment for emergence of all the seeds planted must also be created. McBirney (19) stated that

> The percent of emergence seems to be directly correlated with the amount of moisture which the soil contains, holds and transfers to the seed. Anything which can be done to the soil to increase its moisture holding capacity and its intimate contact with the seed, to more readily transfer moisture to the seed increases the percent of seedling emergence. This applies both to seed bed preparation and to planter characteristics such as improved openers or press wheels.

Further he continued

> . . . our studies to improve seedling emergence during the past few years have shown in general that a well-settled bed which is fairly fine, but is not so firm or solid that the press wheels will not close the seed furrow, produces the best seedling emergence.

Some investigations made by him showed that a conventional, double-disk opener with regular flat rim press wheels were significantly as good as other devices (concave rim, beveled rim) in seedling emergence. His studies revealed that in general, the press wheels should have as much pressure on them as possible without carrying so much of the planter weight that the planter wheels would slip excessively. Futral and Allen (12) found in their trials of soybean planting that disk openers were superior to sword openers under the very dry soil conditions. The disks produced less soil disturbance and better compaction than the sword openers that were used for comparison.

Influence of surface characteristics of seed bed and soil conditions. The surface condition of the seed bed and the soil condition at the time of planting appears to have some influence on the accuracy of planting and seedling emergence. Autry and Schroeder (1) were of the opinion that the scattering of seeds as they strike the soil was difficult to evaluate because of wide variations in soil conditions and in the design of opening and covering devices. In general they commented that the extent of scattering in the furrow is related to the kinetic energy ($1/2\ MV^2$) of each falling seed. The ground scattering should be approximately proportional to the height of hopper, if the seeds were free to disperse as they struck the soil. On a series of tests conducted by Autry and Schroeder showed that ground scattering is decidedly affected by the height of fall, but it could be reduced by partial restriction of the furrow and by the use of a hopper height of 18 inches or less. Some studies made in Michigan by McBirney (19) on the development of sugar beet planters indicated that "seedling emergence was better on the check planting than where the seed bed was milled up finer by rotary tillage."

Effect of planting speed. The tests conducted on Hill-Drop planters by Autry and Schroeder (1) for determinining the effect of ground speed on dispersion indicated that the seed dispersion was lowest in the vicinity of three miles per hour. G. Brandit and Zdenek Fabian (9) stated in relation to developing a high speed precision planter that the rotative valve type, hilldrop mechanism offering zero velocity relationship between seeds and the ground gave the best results. With the belt-type metering planter developed at Georgia Experiment Station, the highest possible speeds were used in trials ranging from ten miles per hour on straight rows to 3.5 miles per hour on curving hills. Soybeans planted "at speeds above four miles per hour enough scatter in the row was produced to provide a surprisingly uniform spacing averaging one inch. Admittedly dangerous speeds of 15 miles per hour were reached in this test without affecting stands." (12) Speeds of four to six miles per hour seem to be a practical maximum from the drivers viewpoint according to some authors.

Technique of Evaluating Planting Accuracy

To evaluate the accuracy of a precision planter and to compare performance of different planters, some way of measuring the accuracy of planting is required. The measures that need to be assessed are (1) the seed damage, (2) the per cent of cell fill and seed rate, (3) accuracy of spacing between seeds and accuracy of depth of planting and (4) the final seedling emergence.

To determine the seed damage under a particular set of conditions of a planter, the planter is run by an external source of power and the seeds discharged over a specified time interval are collected. The per cent of seed damage is estimated by the weight of broken seed separated by screening to the total seed (2).

The per cent of cell fill at different cell speeds is determined by calculating the number of cells passing through the seeds in the hopper during a known interval of time and collecting the seeds during that interval from the seed tube. Multiplying the mean number of seeds per unit weight by the weight of seeds collected and dividing the product by the number of cells passed through the hopper, the cell fill in seeds per cell is obtained.

The accuracy of measuring the variations in spacing and depth of seeds planted is termed in different ways like "dispersion coefficient", "coefficient of variation" or "coefficient of inaccuracy". A method of scoring the accuracy of seed spacings planted was adopted by Barmington (3). His method included a system of evaluation based on 100 seed intervals. A theoretical spacing was assumed and the interval between the consecutive seeds was measured. If the interval was equal to from a half to one theoretical spacing a score of plus one was given. If the interval was less than half the theoretical spacing, a negative score of minus one was given. The skip of seeds was also taken into account by assigning a score of minus one for every one and a half spaces skipped. Thus the total score over a 100 seed intervals was determined. The difference between the positive and the negative totals was the score for the planter. It would have a maximum value of 100. A planter with the seeds planting in the true theoretical intervals would have an added score of zero. A negative result indicated poor performance (3).

An effective way of determining the seed intervals on the field is to plant seeds and uncover them with a putty knife and a paint brush carefully without disturbing the seeds in the soil. The distance from one end to the same respective end of the consecutive seeds is measured and the difference between consecutive readings gives the seed interval. The variation in depth is measured by the vertical distance of seed tops to a reference horizontal plane established by a straight bar kept at the top of uncovered seeds. The tops of seeds located by using flat head nails into the soil near the seeds (5).

Compared to the cumbersome method of uncovering seeds, a laboratory method of estimating the seed dispersion was evolved. In this case the seeds coming out of the seed tube are caught on greased boards or a belt moving at the same velocity as the ground speed of planter. When the seed metering device is run by an electric motor, the seeds are held in position on the greased board or belt. The seed intervals are measured. The deviation from the mean spacing of seeds by the actual intervals of seeds is determined. The deviations are statistically analysed by a measure of standard deviation which is a measure of "dispersion of seeds" and is termed as "dispersion coefficient". The dispersion coefficient is given by:

$$\text{Dispersion coefficient} = \sqrt{\frac{\Sigma Si^2 - \frac{(\Sigma Si)^2}{n}}{n - 1}}$$

where Si is the distance between the consecutive seeds and n is the number of seed intervals measured.

When this coefficient is divided by the mean seed spacing it results in a non-dimensional coefficient termed as "coefficient of variation". When this approaches zero, the planter is approaching perfection. This coefficient of variation could be used to compare the performance of different planters (8).

Bruhn (5) described a photographic method of measuring the time intervals between the seeds as they passed out of the seed tube by the use of a movie camera. The treatment of the time intervals and statistical analysis of these intervals found to give the same results of coefficient of variation, which the author called "coefficient of inaccuracy".

Ing. K. Weller (25) continuing the work of late Dr. Hage reported to have done some experimental work on the use of pneumatics in the design of a planter.

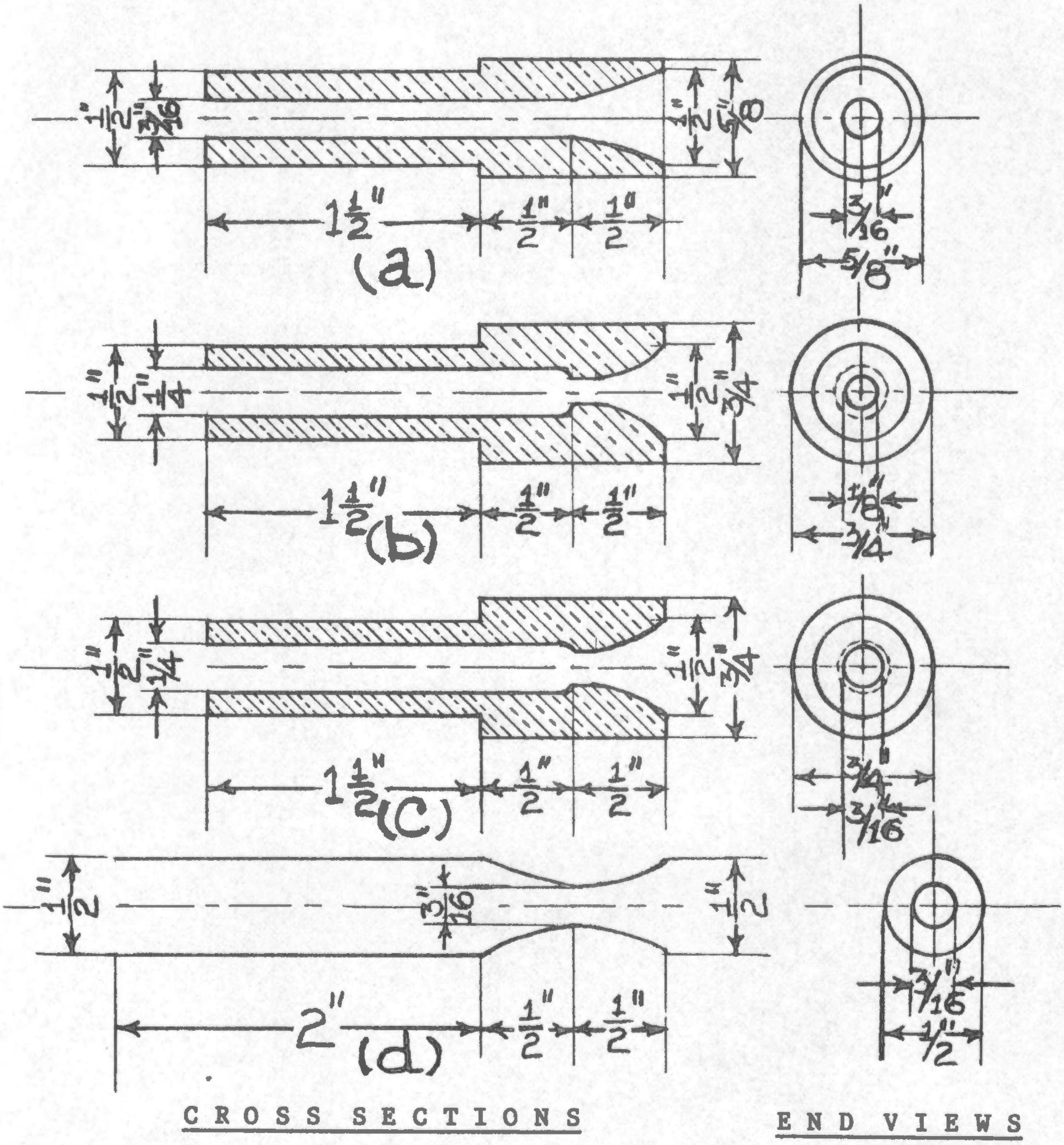
CHAPTER IV

EQUIPMENT

Preliminary Testing

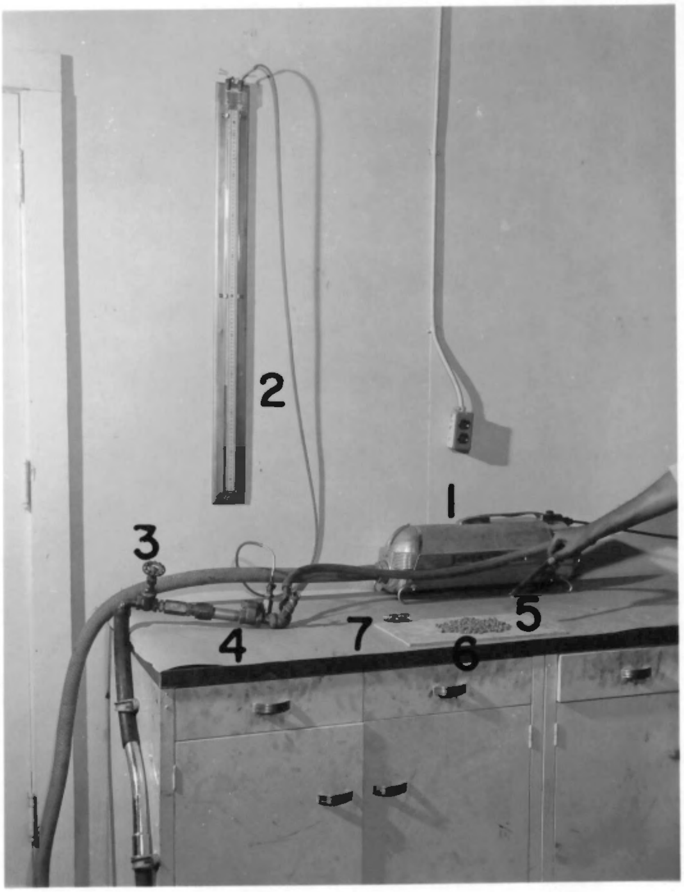
To ascertain the possibility of separating a single bean seed from a group of seeds with the use of vacuum air pressure, different sizes and shapes of seed cells to hold beans were devised. Some of these are shown in Figure 1. To test whether the beans could be held by these cell pockets under vacuum pressure, an ordinary household vacuum cleaner (one "Electroflux" cleaner having 1-1/4 in. diameter suction hose, opening operating on 110 Volts 60 cycle electric supply) was used. The vacuum cleaner was connected to one of the cell pockets through an 1-1/4 inch non-collapsible rubber hose, a gate valve to control vacuum pressure, and a quick shut-off valve to make or break the vacuum line from the vacuum cleaner to the cell pocket. The vacuum pipe line was reduced to one-half inch and connected to the cell by a suitable rubber hose and a piece of metal tubing. A valve to release vacuum when desired and a connection to a mercury manometer for measuring the vacuum pressure were inserted between the seed-cell and shut-off valve. The equipment is shown in Figure 2. All of the joints were made air tight by using jointing material for pipes and some cellophane tape.

This device was tested for the possibility of



(a),(b),(c) made of brass rods.
(d) made of copper tubing.

Figure 1. Shapes and sizes of seed cell pockets designed for preliminary testing.



(1)	Vacuum Cleaner	(5)	A Bean in the Seed Cell
(2)	Mercury Manometer	(6)	Heap of Beans
(3)	Gate Valve	(7)	Seed Cells
(4)	Quick Shut-Off Valve		

Figure 2. Preliminary testing equipment used to separate bean seeds.

catching a single seed from a group of bean seeds. A heap of snap bean seeds was placed on the table, the vacuum pump switched on, and the seed-cell held at the top of the heap of beans. Then gradually the seed cell was brought closer to the seeds, It was observed that a bean was separated from the heap and held by the vacuum-air pressure in the cell each time it was brought near the surface of beans in the heap. When the quick shut-off valve was closed, disconnecting the vacuum from the seed-cell to the pump, the bean fell off from the cell due to the bean's own weight. It was noted on the manometer that a vacuum (gauge) pressure of two to four inches of mercury was required to hold the beans in the cell. In using the larger cell pockets sometimes two or three seeds were picked up from the heap, while smaller cells picked up mostly one seed at a time. It was also observed that when vacuum pressure was six or seven inches of mercury the larger cell invariably picked up more than one seed.

From the above preliminary testing it was concluded that it was possible to separate a single seed from a heap with vacuum pressure and suitable metal cell pockets. No rubber sealing on the cell facing was found necessary to hold beans in the cells provided the vacuum was present.

Pneumatic Seed Metering Equipment

Using the basic principle of collecting seeds by vacuum air pressure, a metering device for snap beans was designed and developed. The seed metering device which was planned to be ultimately adopted for snap bean planting, designed for laboratory testing is shown in a schematic diagram in Figure 3.

The equipment mainly consisted of a seed metering disc with radial holes drilled on the peripherial surface which hold replaceable cell pockets. The seed metering disc and the cell pockets were made of plexiglass. One inch thick plate for the metering disc and 3/4 inch diameter plexiglass rods for machining the cell pockets were used. This enabled one to observe the movement of seeds in the cells. At the center of this metering disc, a metal housing fabricated into a boss for the disc to rotate over was devised with two plate type bushings, joining from either end to hold the metering disc in the center. The inside area of this housing was so designed to have open contact with the radial holes in the metering disc all-around. Two arc type metal strips welded at the inner face, one to each plate bushing to match against each other when assembled, thus separating the central housing area into two zones. A rubber gasket and a sealing material, "Permatex", was used between these arc strips to make the two zones air right. Two pieces of pipes about 4 inches long were welded to one of the bushing plates projecting outside and making a through connection to the two zonal areas. A 3/4 inch diameter pipe and a 3/8

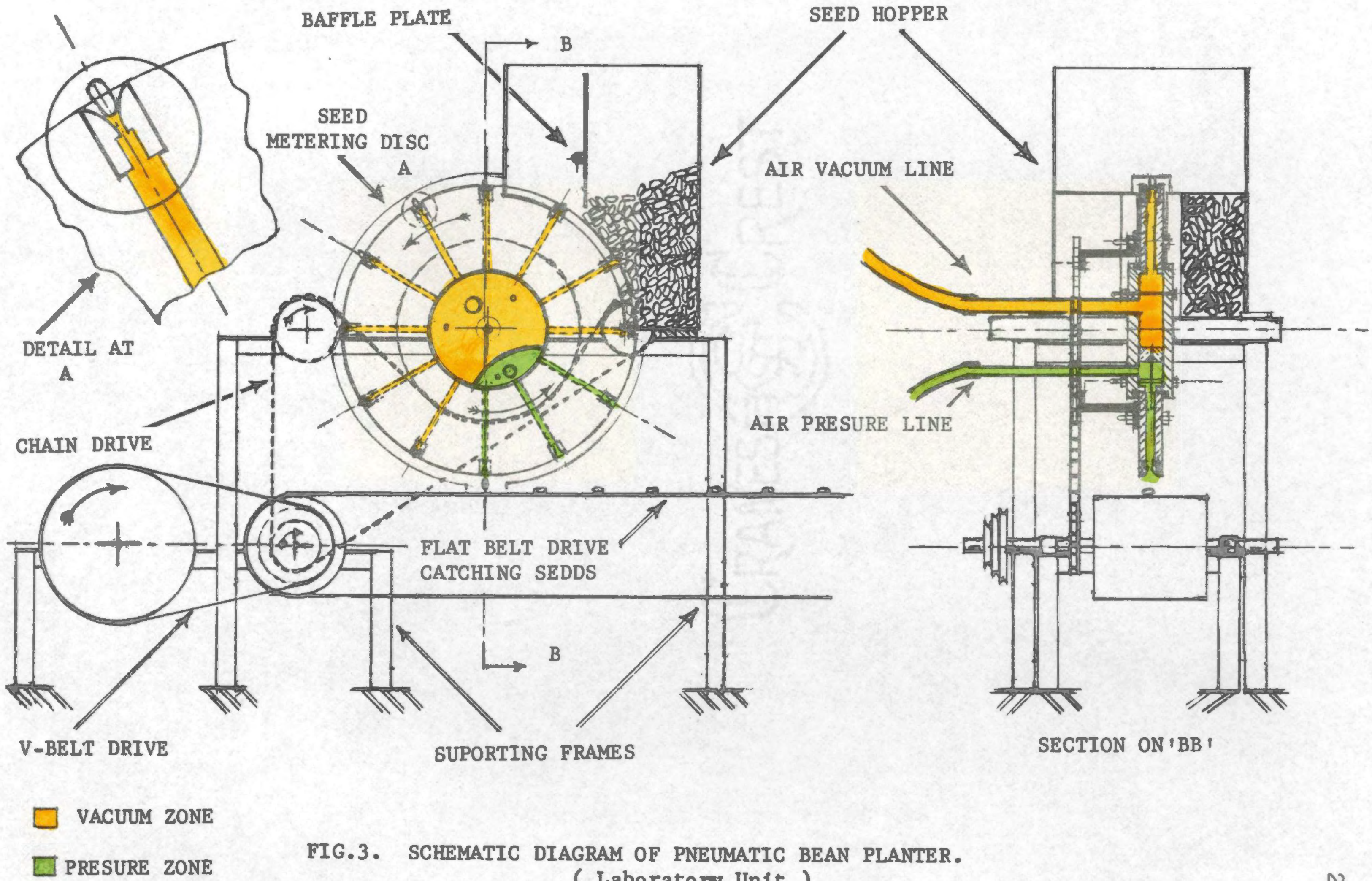
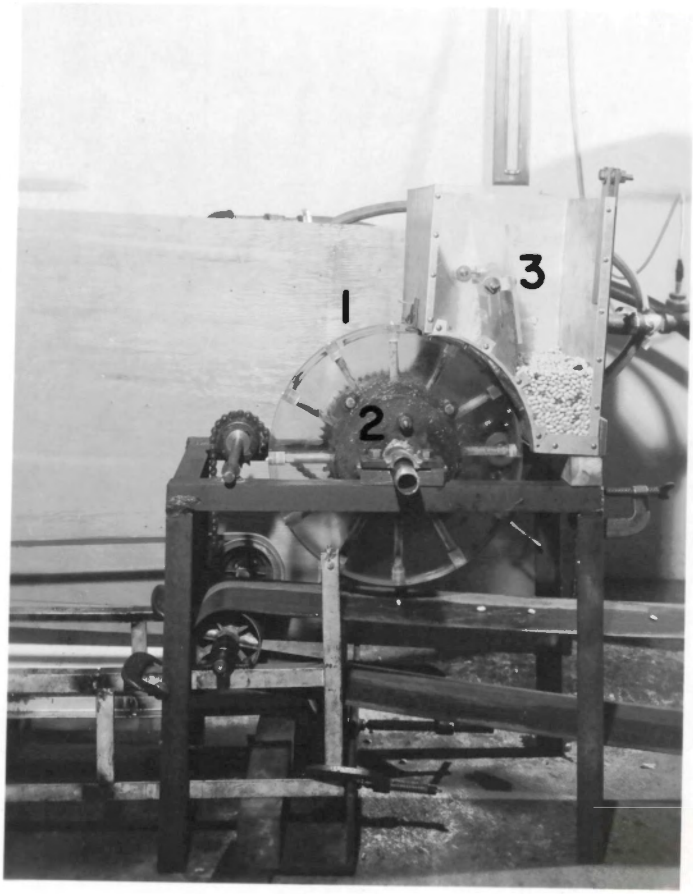


FIG.3. SCHEMATIC DIAGRAM OF PNEUMATIC BEAN PLANTER.
(Laboratory Unit)

inch diameter pipe were used for the vacuum zone and the pressure zone, respectively. The vacuum zone was made larger extending over to nine cells while the pressure zone was restricted to an area of three cells. There was a total of twelve cell pockets provided in the equipment. Two metal rings 3/4 inch wide and 1/4 inch thick were screwed one on each side of the metering disc at the boss to provide greater wear surface of contact with the plate bushing and to keep the disc in alignment. Heavy grease was applied on these rings to seal any leakage of vacuum pressure from the central zone of the plate bushings. Two one inch diameter pipes eight inches long were welded to the center of each of the plate bushings thus projecting outside to form dummy trunions. The entire metering disc assembly was mounted on a suitable designed iron frame.

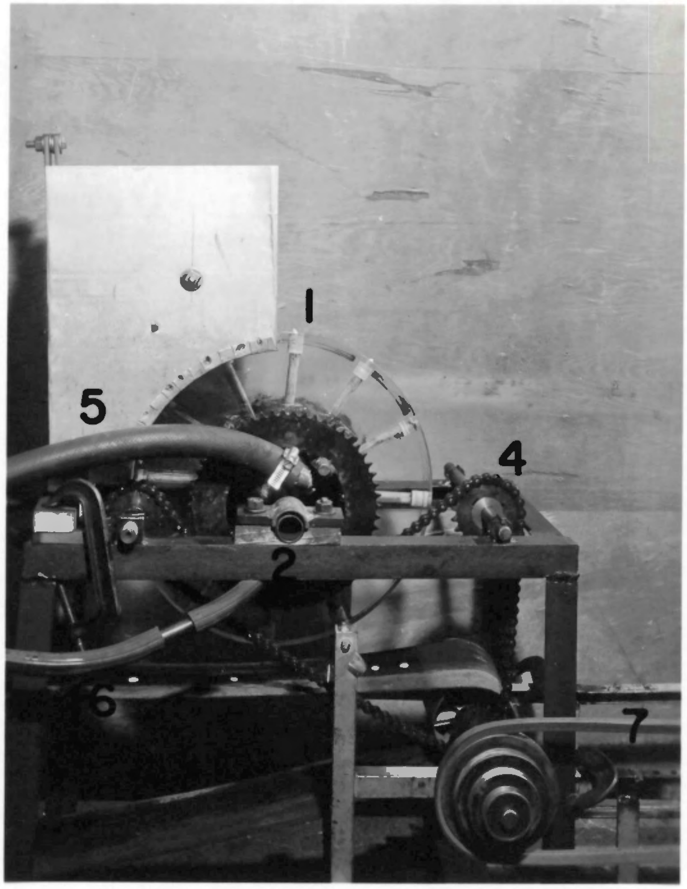
A seed hopper was fabricated out of 26 gauge sheet metal with one side wall of plexiglass (see Figure 4). A slit was made at the bottom of the hopper to coincide with the metering disc arc. Two rubber strips were riveted on both sides along the slit to give a smooth contact to the rotating metering disc. A sprocket and chain used for driving the metering disc was attached on one side with suitable bolts and iron brackets (see Figure 5).

To catch seeds from the metering disc a 20 foot flat belt six inches wide was used as a conveyor for seeds (see Figure 6). The distance between the bottom peripheral



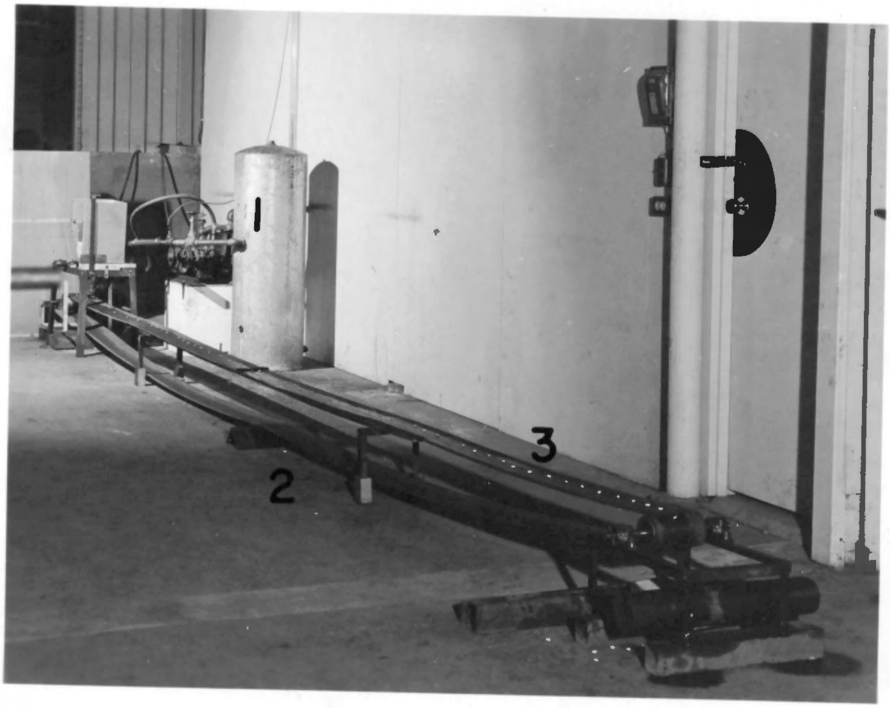
(1) Seed Metering Disc
(2) Metal Plate Boss Unit
(3) Seed Hopper

Figure 4. A side view of seed metering unit.



(1) Seed Metering Disc
(2) Dummy Trunion
(3) Sprocket on Metering Disc
(4) Chain Drive
(5) Vacuum Hose
(6) Pressure Hose
(7) V-Belt Drive

Figure 5. Side view of seed metering unit showing driving mechanism.

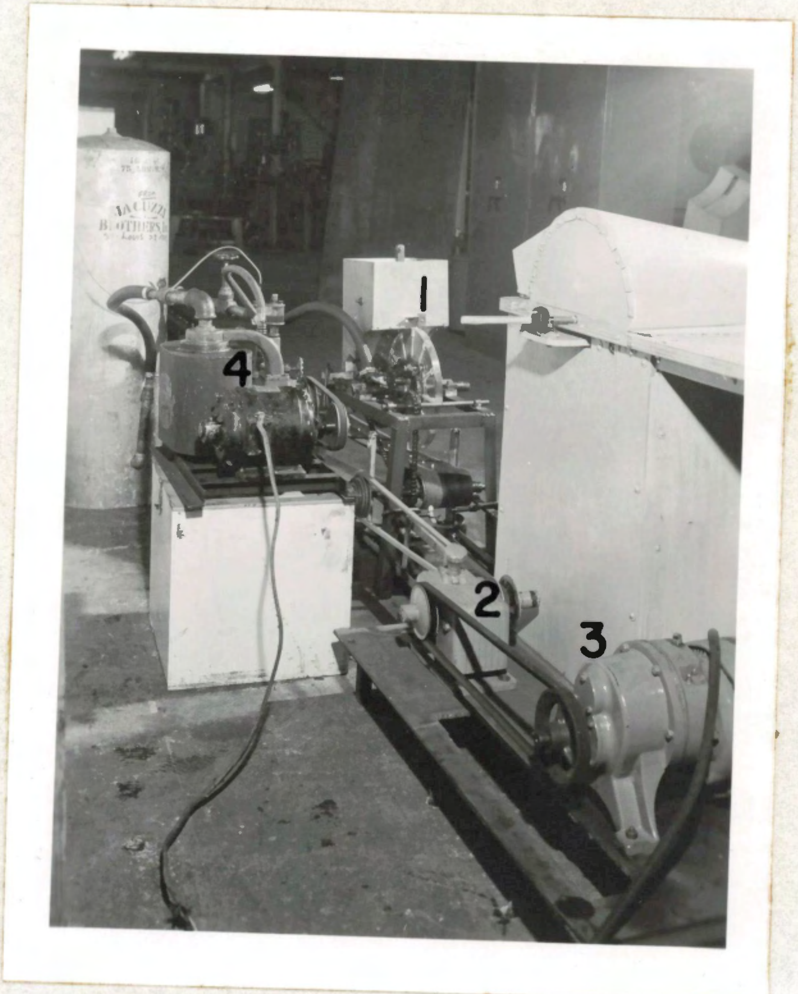


(1) Vacuum Storage Tank
(2) Conveyor Belt
(3) Bean Seeds

Figure 6. Testing equipment in operation.

surface of the metering disc and the flat belt surface was kept to a minimum of one inch. This ensured graviational force of falling seeds to be a minimum and reduced scatter of seeds. The metering disc and the seed catching belt drive pulley were made to rotate in opposite directions by connecting them on opposite sides of an endless chain, shown in Figure 5, page 32. Idler guide sprockets were used on each side of the metering disc sprocket to ensure proper contact and allow for any adjustment of the chain alignment. The whole unit was powered by a V-grooved pulley fixed on the end of the flat belt drive pulley. This was driven externally by a one horsepower electric gear motor. A variable V-sheave drive was fixed between the electric motor and the V-grooved pulley on the flat belt drive shaft (see Figure 7). This enabled variation of speeds of the planting unit. The sprockets on the metering disc and flat belt drive were proportioned to have nearly a zero relative speed between the flat belt and the metering disc periphery. This ensured reduction of scatter of seeds under field conditions. A 55 tooth sprocket on the 15 inch diameter metering disc and a 16 tooth sprocket connecting to the four inch diameter flat pulley were used. This eliminated the likely drag and dispersion of seeds on the flat belt as the seeds were discharged from the metering unit.

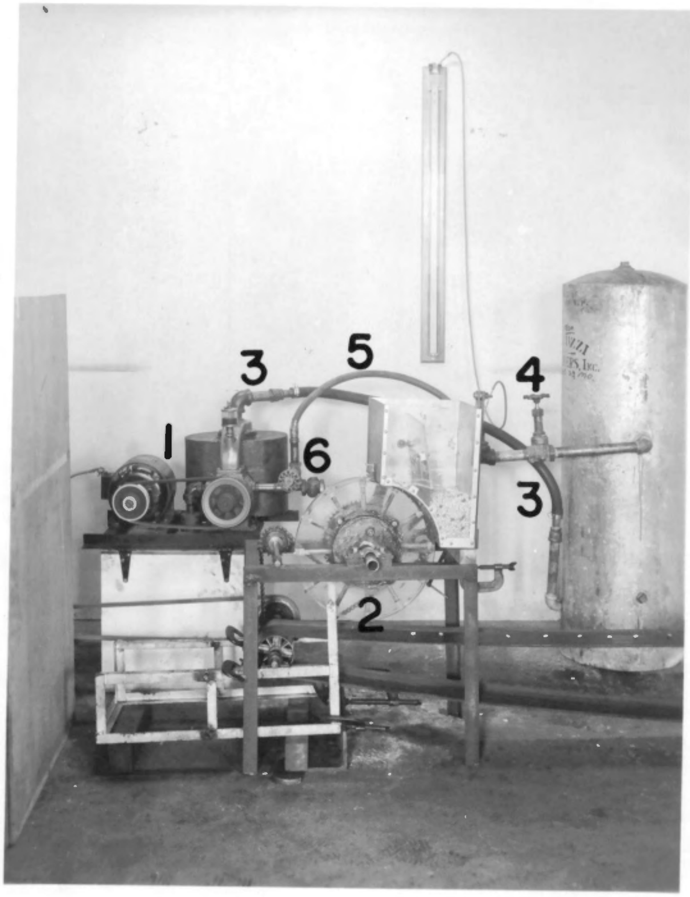
A milking machine vacuum pump was used to provide the vacuum air pressure supply and was connected to the vacuum



(1) Planter Unit
(2) Variable V-Sheave
(3) Electric Motor
(4) Vacuum Pump Unit

Figure 7. Planter unit and variable V-sheave drive arrangement.

zone pipe of the metering disc (see Figure 8). A steel storage tank (16 inch diameter by 48 inch high) was used in the vacuum line to maintain the vacuum without a rapid decrease. A gate valve, a Tee-connection and a mercury manometer were fixed on the vacuum line to control the vacuum to the metering unit and to record the vacuum, respectively. One inch diameter non-collapsible rubber hose and standard pipe fittings were used to connect the line. The discharge from the vacuum pump was employed to supply air pressure for the pressure zone on the delivery side of the metering unit. A half inch pipe connection was attached to the discharge end of the vacuum pump and connected through a gate valve to control the amount of pressure exerted. A rubber hose and half inch pipe fittings were used to complete the line (see Figures 4, p. 31; 5, p. 32; 6, p. 33; 7, p. 35; 8, p. 37).



(1) Vacuum Pump
(2) Planter Unit
(3) Vacuum Hose Connection to Storage Tank
(4) Gate Valve on Vacuum Line
(5) Pressure House to Planter Unit
(6) Gate Valve on Pressure Line

Figure 8. Planter unit with vacuum pressure system.

CHAPTER V

PROCEDURE

In the present investigation the variables involved were:

(1) The size of vacuum nozzles connecting cell pockets and the size and shape of the cell pockets.

(2) The extent of cell and seed contact available in the hopper for picking seeds.

(3) The amount of vacuum pressure exerted on the nozzle cell pockets to catch and retain seeds until discharged.

(4) The radial distance of cell pockets to the center of seed metering disc or the diameter of seed metering disc.

(5) The amount of air pressure exerted on the discharge end for ejection of seeds from the cells.

(6) The speed of the rotating seed metering disc or the peripheral speed of the cell pockets.

These were kept constant except for the speed of the seed metering disc. Seed cell pockets having a cross section, as shown in Figure 2, detail (b), page 25, were used. The distance through which the cell pockets remained in contact with the seeds in the hopper was also held constant by using a baffle plate in the hopper and maintaining a constant depth of beans in the hopper before each series of observations were made. The amount of vacuum pressure could not be held constant, but was maintained within the limits of the vacuum found necessary to catch beans and carry them to the delivery side. The vacuum pressure was maintained between 1-1/2 to 2-1/2 inches of mercury at the lower cell speed of 150 feet per minute, while a vacuum of four to five inches was maintained to hold the beans at 240-300 feet per minute. The adjustment of pressure was accomplished by manupulating the gate valve provided for that purpose. The radial distance of cell pockets to the center of metering disc remained constant since the same metering disc of 15 inches diameter was used. The amount of air pressure was adjusted just sufficiently to eject beans from the cell pockets without unduly forcing them out and to cause scatter.

The speed of the metering disc was adjusted to the desired R.P.M. by adjusting the variable V-sheave connected on the drive system between the electric motor and the metering unit. The V-sheave was locked in position for each set of observations.

Keeping only four cell pockets in action at right angles to each other, the other eight were closed by the use of a cellophane tape pasted on the peripheral face of the metering disc against cell openings.

After fixing the speed of the metering disc and locking the variable V-sheave in position, the speed of seed belt pulley drive shaft was recorded by a tachometer and a stop watch. The vacuum pump was switched on and vacuum was accumulated and stored in the system, while the gate valve connecting to seed metering disc was kept closed. The drive unit was switched on and the air pressure adjusted just sufficiently to eject beans. The vacuum pressure required to catch and hold the beans was noted on the mercury manometer connected to the system. A thin coat of cup grease was applied on the outside surface of the seed conveying belt. Most of the seeds were unloaded at the end of this conveyor belt into a tray kept for the purpose. Some beans which remained on the belt were brushed off by a mild steel bar positioned across and below the moving belt. The vacuum pump was switched on with the gate valve, connecting to the seed metering unit, closed. The metering unit was switched on. Then the gate valve was slowly opened and air vacuum allowed to act on the cell pockets which resulted in picking up beans as the cells passed through seeds in the hopper. The beans held in the cells were automatically ejected by air pressure when they reached the delivery point. As the beans were dropped they were caught on the greased belt and conveyed forward. For recording measurements of distances of beans metered, when about ten to twleve feet length of belt carried beans delivered from the metering disc, the drive unit was electrically disconnected to stop the movement of unit. The unit was found to move through a distance of one to two feet after being switched off before it stops. The seed spacings were measured from the farther end of the metering unit to a mark made on the seed belt just below the seed delivery point when the drive unit was switched off each time.

The distances of seeds from a starting point on the belt were measured with a steel tape. The readings were taken to the center of each single bean and to the middle point of seeds when more than one seed was dropped by a single cell. The number of cells filled with two or more seeds were recorded by counting such groups of beans found on the belt. The skips or the cells not filled were recorded by observation. The number of skips were counted on the belt and this number was counter checked by computation of distances between seeds delivered.

The experiment was repeated to record eight replications for cell speeds of 150, 190, 243 and 300 feet per minute which had corresponding planting speeds of 1.57, 1.97, 2.53 and 3.10 miles per hour, respectively.

The experiment was also repeated with all twelve cell pockets opened and data were recorded at the speeds mentioned above.

Computation of Results

The distance between seeds was computed by deduction of the lower value from the higher value of distances of seeds measured from a starting point. Referring to the data on Table IX, shown in the Appendix, the distance between the first two beans under Replication 1 was given by

19.8 - 10.1 = 9.8 inches.

Similarly the distance between the second and the third beans was

31.2 - 19.0 = 11.2 inches.

The percent cell fill was computed by the number of cells passed and the number of cells filled. For example, referring to Replication 6 in the same Table, it was noted:

No. of cells passed = 10

No. of cells filled = 9

No. of cells filled with two or more seeds = 2

Per cent cell fill $= \frac{9}{10} \times 100 = 90$

Per cent cell fill with two or more seeds per cell =

$\frac{2}{10} \times 100 = 20$

The mean seed spacing was computed by adding the individual distances between seeds and dividing the sum by the number of spaces added. But in order to have a clear understanding of the deviation from the theoretical seed spacing and deviation of the mean, the distances between seeds which included skips or cells not filled were omitted for calculating the mean seed spacing and the coefficient of variance. For example the distance between seeds measuring 22.3 inches shown in Table IX, Replication 6, was not taken into account in computing either the mean seed spacing or the coefficient of variance.

The coefficient of variance was calculated as follows:

Taking the measurements recorded in Table IX, Replication 6, shown in the Appendix, the sum of seed spacings and the squares of seed spacings were computed and have been shown in Table I.

Then,

No. of distances between seeds included, $n = 7$

Sum of the distances, $\Sigma x = 78.5$ inches

Square of the sum of distances, $(\Sigma x)^2 = (78.5)^2 = 6162.25$

Sum of squares of distances, $\Sigma x^2 = 884.77$

Standard deviation of the mean, $s = \sqrt{\dfrac{\Sigma x^2 - \dfrac{(\Sigma x)^2}{n}}{n - 1}}$

$$s^2 = \frac{884.77 - \frac{6162.25}{7}}{7 - 1}$$

$$= \frac{884.77 - 880.32}{6} = .7415$$

$$s = \sqrt{.7415}$$

$$= .8610 \text{ inch}$$

Mean distance between seeds $= \dfrac{78.5 \text{ inch}}{7} = 11.21$ inch

Coefficient of variance $= \dfrac{\text{Standard Deviation}}{\text{Mean}}$

$$= \frac{.8610 \text{ inch}}{11.21 \text{ inch}} = .07698$$

Per cent coefficient of variance $= .07698 \times 100 = 7.698$,

or 7.70

The theoretical distance between the seeds was calculated by the computation of the speed of the metering disc, its

TABLE I

DISTANCE BETWEEN SEEDS AND SQUARES OF THE DISTANCES BETWEEN SEEDS PERTAINING TO DATA ON TABLE IX, REPLICATION 6, FOUND IN THE APPENDIX

Distance of seeds from a starting point (1)	Distance between seeds (2)	Squares of distances in column (2) (3)
inches	inches	
10.0		
21.8	11.8	139.24
32.1*	10.3	106.09
44.4	12.3	151.29
54.9	10.5	110.25
65.8*	10.9	118.81
--**		
88.1	22.3***	407.29***
98.6	10.5	110.25
110.8	12.2	148.84
Totals	78.5	884.77

*Denotes cell filled with two seeds.

**Denotes cell not filled.

***Denotes data not used in computation of totals diameter or circumference, the number of cell pockets and the relative speed of the seed collecting belt.

These calculations showed that the mean spacing of seeds metered was 11.21 inches as compared to its theoretical spacing of 10.80 inches. The coefficient of variance was 7.698 per cent which indicated that the seeds are more evenly distributed. As coefficient of variance approaches zero value, the planter attains perfections and results in complete accuracy in seed spacing.

CHAPTER VI

RESULTS AND DISCUSSION

The observations recorded during the course of the investigations are shown in Appendix Tables IX through XVI. The measurements of seed spacings were taken for four different cell speeds of 150, 190, 243 and 300 feet per minute. These cell speeds had corresponding planting speeds of 1.57, 1.97, 2.53 and 3.10 miles per hour. The data were recorded from the observations for four cell pockets as well as twelve cell pockets.

The cells which carried more than two seeds included cells filled with three or four seeds. Most of these were with three seeds per cell, though rarely a cell was filled with four small seeds. There was no instance when a cell carried more than four seeds.

The percent of cell fill is shown in Tables II and III. These results indicated a drop of cell fill from an average percent of 97.50 to 52.78 at all speeds of 150 feet per minute and 300 feet per minute, respectively, when only four cell pockets were open. The per cent cell fill for the same speeds was 87.09 and 30.32, respectively, when twelve cell pockets were open. During the course of the experiment it was noticed that there was greater fluctuation of vacuum pressure as noticed from the mercury manometer at higher cell

TABLE II

PER CENT CELL FILL WITH FOUR CELL POCKETS OPEN ON METERING DISC AT DIFFERENT CELL SPEEDS

Replication No.	Cell speeds in feet per minute			
	150	190	243	300
1	100	100	80	55.56
2	100	90	60	55.56
3	100	80	70	55.56
4	100	100	50	44.45
5	90	100	80	44.45
6	90	100	80	66.67
7	100	90	80	55.56
8	100	100	70	44.45
Mean	97.50	95.00	71.25	52.78

TABLE III

PER CENT CELL FILL WITH TWELVE CELL POCKETS OPEN ON METERING DISC AT DIFFERENT CELL SPEEDS

Replication No.	Cell speeds in feet per minute			
	150	190	243	300
1	86.67	83.34	50.00	23.06
2	90.00	70.00	50.00	23.06
3	83.34	63.34	53.34	25.00
4	86.67	56.67	53.34	35.71
5	93.34	86.67	46.67	25.00
6	86.67	73.34	53.34	32.14
7	93.34	63.34	43.34	35.71
8	76.67	80.00	50.00	42.86
Mean	87.09	72.09	50.00	30.32

speeds than at lower speeds. The fluctuation of the vacuum pressure was also observed to be greater with all the twelve cells opened as compared with four cells in action. This was perhaps due to the greater number of nozzles required to be supplied with the vacuum action in the same interval of time at higher speeds than at lower speeds. Since there was no means of maintaining the vacuum pressure constant in the system set up except simultaneous manipulation of control valve in the line, the vacuum could not be held steady. Even though the results in the present investigations showed a drop of per cent cell fill at higher speeds it might be possible to have 100 per cent cell fill by adjustment and proper control of vacuum pressure.

The per cent of cells which carried two or more seeds was 11.25 and 9.30 at a speed of 150 feet per minute with four and twelve seed cells, respectively. No cells carried two or more seeds at the speed of 300 feet per minute (see Figure 9). It was also observed that there was a greater number of cells carrying two or more seeds when the vacuum pressure was increased beyond a particular value. This indicated a possibility of eliminating cells carrying two or more seeds when proper vacuum pressure is used with a suitable cell pocket size. No beans were carried by the metering disc at a cell speed of 150 feet per minute when the vacuum pressure was cut off from the system. Further investigation with the use of different sizes and shapes

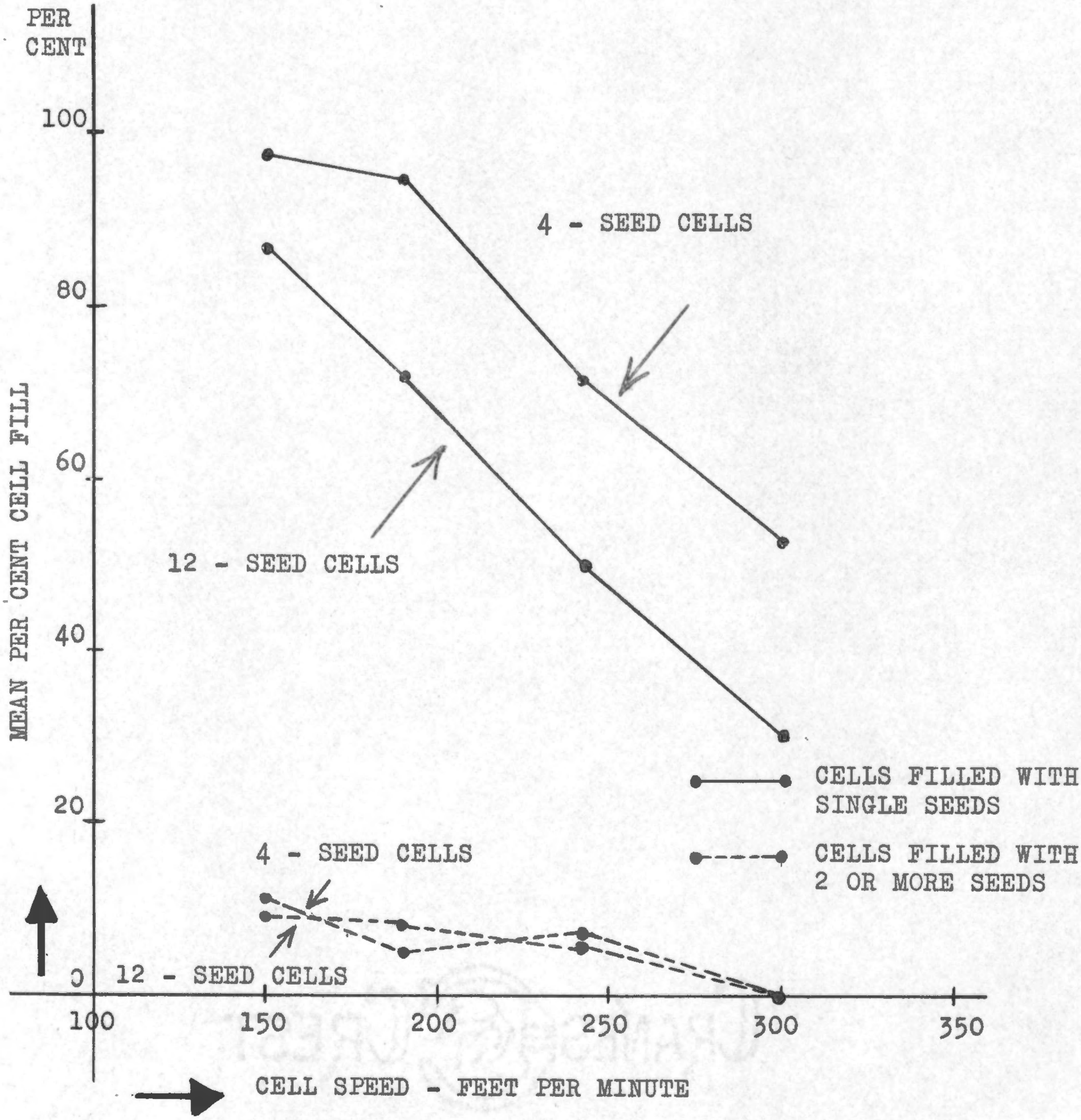


Figure 9. Effect of cell speed on mean per cent cell fill.

of cell pockets appeared necessary.

The mean distance between seeds is shown in Tables IV and V for four and twelve cells in operation. The over all mean distances (excluding the distances at skips) were 11.06, 11.07, 11.81 and 11.51 inches at cell speeds of 150, 190, 243 and 300 feet per minute, respectively. The theoretical distance between seeds was 10.80 inches in all the cases with four cell pockets open. The mean spacings were 3.63, 3.67, 3.69 and 3.50 inches, respectively, at the cell speeds indicated above as compared to a theoretical spacing of 3.6 inches with twelve cell pockets. This is graphically shown in Figure 10.

The coefficient of variance for different cell speeds are recorded in Tables VI and VII. The per cent coefficient of variance fluctuated in both cases of four and twelve cells. It ranged from 3.64 per cent to 12.45 per cent with four cells open while the range was between 11.73 to 20.49 per cent with 12 cells open. These results are graphically shown in Figure 11.

An overall view of cell speeds, planting speeds and the corresponding results of cell fill, coefficient of variance, etc. are shown in Table VIII. No damage to beans was noticed to occur through the metering unit.

Some of the observations made during the course of the present investigations are noted below:

(1) The drop of per cent cell fill appeared greater

TABLE IV

MEAN DISTANCE BETWEEN SEEDS AT DIFFERENT CELL SPEEDS WITH FOUR CELLS OPEN ON METERING DISC*

Replication No.	Cell speeds in feet per minute			
	150	190	243	300
	All measurements in inches			
1	10.93	11.06	10.58	11.50
2	11.01	10.79	12.60	11.20
3	11.09	11.12	11.60	11.20
4	11.09	11.10	11.30	11.90
5	11.03	11.06	11.35	10.95
6	11.21	11.18	13.00	12.83
7	11.03	11.04	12.40	11.17
8	11.11	11.17	11.65	11.35
Over-all mean	11.06	11.07	11.81	11.51
Theoretical distance between seeds	10.80	10.80	10.80	10.80

*The distances between seeds where cells were not filled were omitted in computing the mean distances.

TABLE V

MEAN DISTANCE BETWEEN SEEDS AT DIFFERENT CELL SPEEDS WITH TWELVE CELLS OPEN ON METERING DISC*

Replication No.	Cell speeds in feet per minute			
	150	190	243	300
	All measurements in inches			
1	3.79	3.72	3.85	--**
2	3.68	3.49	3.43	--**
3	3.52	3.84	3.47	2.70
4	3.68	3.87	3.60	2.90
5	3.64	3.63	4.06	4.00
6	3.52	3.60	3.58	3.45
7	3.49	3.72	4.06	4.03
8	3.72	3.47	3.48	3.92
Over-all mean	3.63	3.67	3.69	3.50
Theoretical distance between seeds	3.60	3.60	3.60	3.60

*The distance between seeds where cells were not filled were omitted in computing mean distance.

**Data available was inadequate to compute the value.

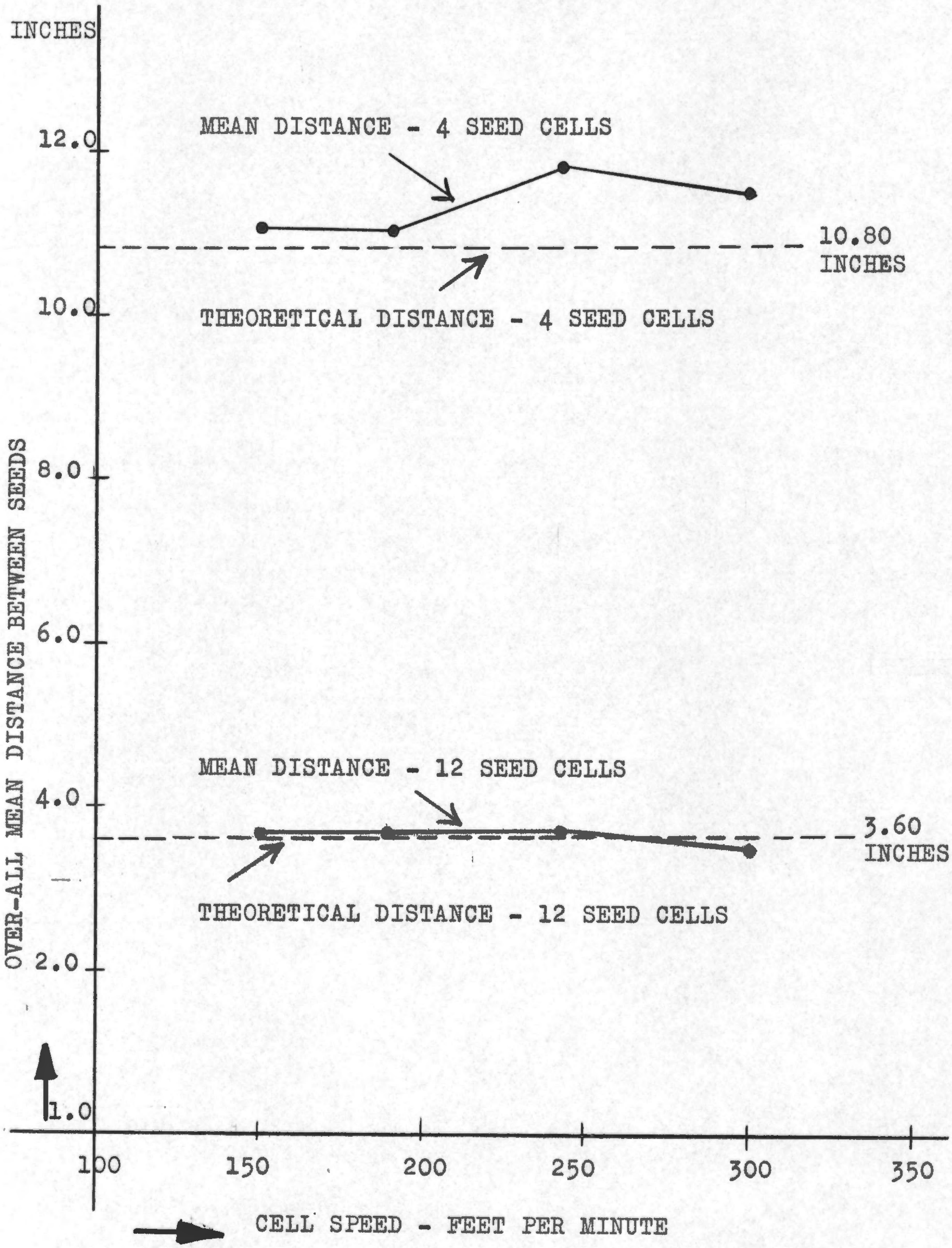


Figure 10. Effect of cell speed on over-all mean distance between seeds.

TABLE VI

PER CENT COEFFICIENT OF VARIANCE AT DIFFERENT CELL SPEEDS WITH FOUR SEED CELLS*

Replication No.	Cell speeds in feet per minute			
	150	190	243	300
1	29.59	7.15	4.70	2.46
2	5.96	1.10	2.72	1.27
3	3.99	2.05	8.33	0.00
4	4.13	4.52	2.50	--**
5	2.13	3.81	3.15	32.85
6	7.70	2.68	22.90	35.80
7	1.30	5.75	44.90	1.42
8	5.41	2.05	10.40	8.08
Mean	7.53	3.64	12.45	11.84

*The distances between seeds where cells were not filled were omitted in computing the coefficient of variance.

**Data available was inadequate to compute the value.

TABLE VII

PER CENT COEFFICIENT OF VARIANCE AT DIFFERENT CELL SPEEDS WITH TWELVE SEED CELLS*

Replication No.	Cell speed in feet per minute			
	150	190	243	300
1	18.81	12.61	18.67	--**
2	15.37	22.00	7.43	--**
3	21.07	14.77	12.66	--**
4	15.13	11.10	5.83	--**
5	26.50	22.38	8.26	7.07
6	25.09	18.51	6.96	32.31
7	24.31	25.87	14.04	20.41
8	17.63	27.83	19.95	14.95
Mean	20.49	19.38	11.73	18.68

*The distances between seeds where cells were not filled were omitted in computing the coefficient of variance.

**Data available was inadequate to compute the value.

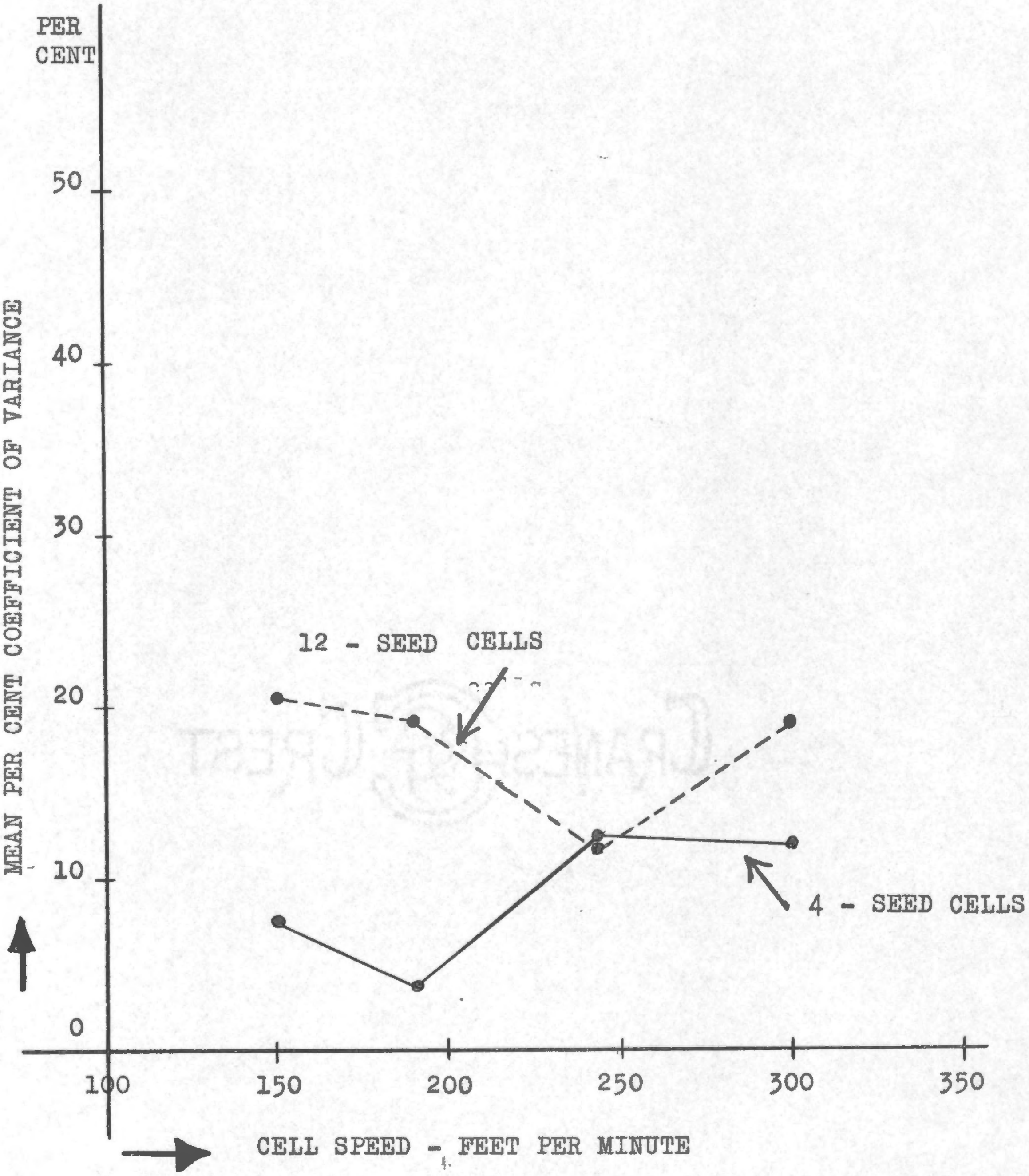


Figure 11. Effect of cell speed on mean per cent coefficient of variance.

TABLE VIII

SUMMARY OF PLANTING SPEEDS CORRESPONDING TO CELL SPEEDS, MEAN CELL FILL AND MEAN COEFFICIENT OF VARIANCE

Cell speeds	Planting speeds	Cell fill	Cells filled with two or more seeds	Coefficient of variance*
Feet/min.	miles/hr.	Average per cent		
With four cells				
150	1.57	97.50	11.25	7.53
190	1.97	95.00	5.00	3.64
243	2.53	71.25	7.50	12.45
300	3.10	52.78	0.00	11.84
With twelve cells				
150	1.57	87.09	9.30	20.49
190	1.97	72.09	8.34	19.38
243	2.53	50.00	5.84	11.73
300	3.10	30.32	0.00	18.68

*The distances between seeds where cells were not filled were omitted in computing coefficient of variance.

when the vacuum pressure fell below a particular value. Optimum vacuum required for best results is to be established at different cell speeds.

(2) While the seed metering disc was run at higher speeds, some beans were found to be thrown out of the cell pocket as it was being carried out of seed hopper and before the cell reached delivery point. This indicated that the weight of the beans has something to do with cell fill, proper conveyance of seed in cells, and the vacuum pressure required. The centrifugal force due to the weight of seed appears to act against the amount of vacuum pressure acting on the seed cell.

(3) The fluctuation of the vacuum pressure in the system appeared to be mostly due to insufficient capacity of the vacuum pump to move a sufficient volume of air through the seed cell openings, A higher capacity pump is likely to keep down the variation in the vacuum pressure.

(4) Increased vacuum pressure appeared to improve the cell fill, but the use of increased vacuum needed increased air pressure to eject the seeds at the delivery point.

(5) The size of nozzles connecting the cell pockets seem to have some effect on the vacuum and air pressure needed in the planting unit.

However, with further investigations on some of the aspects noted above, it may be possible to develop a compact planter unit to plant seeds of any kind at greater speeds and more accurately than with the conventional plate type planters that are now used. The only disadvantage with this type of planter which appeared to the author is the method of supplying continuous vacuum pressure for carrying seeds and air pressure to eject them. This may lead to the design of a suitable vacuum pumping unit for adoption on such type of planters driven by tractors. There could be a possibility of limiting the vacuum zone only to the extent of separating the seed from the hopper and then carry the seed in the cell with guide plates without the need for a vacuum to hold the seed continuously. In such a case a small piston pumping device suitably housed at the center of metering disc is likely to meet the requirement, but this needs to be investigated. There is also a possible way of using pneumatics for metering seeds from a hopper only to the extent of separating a seed and feeding a conveying system of a planting unit to the ground. Some sort of a seed catching device utilizing a make and break system with pneumatics and a double belt or a chain conveyor is also likely to satisfy this requirement.

CHAPTER VII

LIMITATIONS OF THE PRESENT STUDY AND SUGGESTIONS FOR FUTURE RESEARCH

Limitations

There were certain limitations in the equipment set up for the present investigations. The vacuum pressure could not be held constant during an observation due to the insufficient capacity of the pump. The air pressure required for proper ejection of seeds was not measured. Only one type of seed cells was used. As a result of such limitations in this study further investigations are necessary.

Suggestions for Future Research

Further research on the following aspects is suggested for future investigations:

(1) An investigation of the result of cell fill at various vacuum pressures and at different speeds.

(2) The effect of various sizes and shapes of nozzles and cell pockets on the metering accuracy and vacuum pressure requirement.

(3) The optimum air pressure needed to completely discharge seeds from the cells without scattering.

(4) The possibility of employing vacuum pressure only to separate single seeds from the hopper and then

carry the seeds through conventional means.

(5) The design of a suitable vacuum pumping system for adoption on such planters run by tractor power.

CHAPTER VIII

SUMMARY AND CONCLUSION

The accuracy of planting equipment in conventional plate type planters depends upon several factors such as cell speed, cell size, planting speed, seed path and travel, cut-off devices, ejection devices, the variation in seed size, shape and other physical characteristics of the seeds. The large variation in size and shape of different crop seeds and the variation of physical characteristics within the seeds of a particular crop and variety, have lead to the use of different types of planters and metering plates. In most cases the seeds are required to be graded to obtain fairly precise seed distribution. The conventional planters were greatly modified with respect to corn and sugar beet planting before they became precision planters. Planting of single seeds at uniform distances is desired in most vegetable crops. Snap beans is one of those crops which require uniform planting of single seeds.

The use of vacuum air pressure for picking one seed at a time from a seed hopper seemed feasible to solve the problem of planters with regard to the size and shape of the seeds. Accordingly a preliminary investigation of the use of pneumatic vacuum pressure for separating single seeds from a group was found possible through a vacuum seed cell system. The cell system involved a seed cell connected to a vacuum pressure source through a nozzle. No lining of seed cells to form a seal was found necessary when the system was connected to a vacuum.

A metering device having a number of cells on the periphery of a rotating disc with a vacuum air pressure connected to every cell through a suitably designed vacuum cell system was designed and constructed for testing under laboratory conditions for snap beans. Four open seed cells 90° apart around the periphery of the metering disc were used in one set of observations. In a second series of tests twelve seed cells equally spaced were used around the entire periphery of the metering disc. A milking machine vacuum pump with a vacuum storage tank was used to supply vacuum pressure to the metering disc. The pressure discharge side was tapped from the same vacuum pump to supply air pressure to eject seeds from the seed metering disc. A greased flat belt conveyor system was used to carry the seeds delivered from the metering unit. The entire unit was powered by an electric gear motor through a variable V-sheave belt and sprocket-chain drive system in combination.

The variations in seed distribution measured as a factor of coefficient of variation relating to the distance between seeds were computed at various cell speeds.

The cell fill dropped from 97.50 to 52.78 per cent in a four cell system when the cell speed was increased from 150 to 300 feet per minute. The percentages of cell fill were 87.09 and 30.32 when a twelve seed cell system was operated at the cell speeds mentioned above. The vacuum pressure fluctuated during the course of metering the seeds. Perhaps this fluctutation of vacuum pressure partly accounted for the drop in cell fill. No seeds were carried in the cells when the unit was operated without a vacuum pressure. The percentage of two or more seeds filling a cell was ranged from 11.25 to zero and 9.3 to zero for four and twelve cell systems, respectively. The zero values corresponded to the higher cell speed of 300 feet per minute while lower values were at 150 feet per minute cell speed.

It was concluded from these investigations that the use of pneumatics was feasible for improving the accuracy of planting snap beans. The author is of the opinion that a precision planter could be developed with the effective use of pneumatic vacuum to separate single seeds from a hopper and air pressure to discharge the seeds at the delivery point irrespective of the size and shape of seeds.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Autry, J. W., and E. W. Schroeder. "Design Factors for Hill-Drop Planters," Agricultural Engineering, 34:525-531, August 1953.

2. Barmington, R. D. "The Relation of Seed, Cell Size, and Speed to Beet Planter Performance," Agricultural Engineering, 29:530-532, December 1948.

3. ________. "Metering Devices and Test Results of Some Foreign and Domestic Sugar Beet Planters," Journal of the American Society of Sugar Beet Technologists, 9:44-50, April 1956.

4. ________. "Planting Equipment for Manogerm Seed," Journal of the American Society of Sugar Beet Technologists, 10:48-52, April 1958.

5. Bruhn, H. D. "A Procedure for Determining and Setting-forth the Accuracy of Seed Distributing Equipment," Paper No. 60-326 (Unpublished) presented to the 1960 Annual Meeting,American Sciety of Agricultural Engineers held at Ohio State Univesity, Columbus, Ohio, June 12-15, 1960.

6. Bjerkan, Arthur J. "Precision Planting," Agricultural Engineering, 28:54, 57, Feb. 1947.

7. Bainer Roy, R. A. Kepner, and E. L Barger. Principles of Farm Machinery, New York: John Wiley Inc., pp. 221-256, 1963.

8. Bainer Roy. "Precision Planting Equipment," Agricultural Engineering, 28:49-54, Feb. 1947.

9. Brandt, Roy G. and Zdenek Fabian. "Developing a High Speed Precision Planter," Agricultural Engineering, 45:254-255, May 1964.

10. Colliers Encyclopedia. "Farm Machinery," 7:583-589. New York: P. F. Collier and Son Corporation, 1958.

11. Encyclopedia Britannica. "Agriculture," "Sowing," Eleventh Edition, 25:388, 523. New York: University Press, 35 West 32nd Street, 1911.

12. Futral J. G. and R. L. Allen. "Development of High-Speed Planter," Agricultural Engineering, 32:215-216, April 1951.

13. Guelle C. E. "Precision Planting of Beets and Corn," Agricultural Engineering, 28:56-57, February 1947.

14. Gittins, Bert S. Land of Plenty, Chicago, Illinois: Farm Equipment Insitute, Second Edition, 1959.

15. Hansen H. V. "Time and Labor-Saving Possibilities of a High-Speed Drill Planter," Agricultural Engineering, 25:387, 392, October 1944.

16. Hudspeth E. B. and W. C. Hulbert. "Review of Research on Equipment for Effective Seeding Practices," Paper (Unpublished) presented at the 50th Annual Meeting of the American Society of Agricultural Engineers in East Lansing, Michigan, June 26, 1957.

17. Minges P. A. and J. F. Harrington. "What You Should Know About Growing Snap Beans," University of California Agricultural Extension Service Bulletin, March 1954.

18. Minton, Willard H. and George B. Byers. "Labor, Other Costs, and Management Practices in Producing and Marketing Snap Beans in Southeastern Kentucky," Lexington: University of Kentucky Agricultural Experiment Station, Bulletin 687, March 1964.

19. McBirney, S. W. "The Relation of Planter Development to Sugar Beet Seeding Emergence," Agricultural Engineering, 29:533-536, December 1948.

20. Morton C. T. and W. F. Buchele. "Development of Commercial Beet Planters," Paper presented at the 10th Eastern Regional Meeting of the American Society of Sugar Beet Technologists at Chatham, Ontario, Canada, 1959.

21. Partridge R. L. "Some Experiences with Beet Drills," Agricultural Engineering, 28:55-57, February 1947.

22. Roth, L. O. and J. G. Porterfield. "Some Basic Performance Characteristics of Horizontal Plate Seed Metering Device," Transactions of the American Society of Agricultural Engineers, 3:105-107, 1960.

23. Sandmark A. C. "Checkrow Planting at Higher Speeds," Agricultural Engineering, 25:386, October 1944.

24. Wright, A. H. "Seed Corn Grading in Relation to Planting," Agricultural Engineering, 22:18-24, January 1941.

25. Weller, K. Ing. "Sowing by Pneumatically Operated Equipment," Landtechnische Forschung (German) 8, No. 1:1-9, 1958.

APPENDIX

TABLE IX

CELLS FILLED AND SEED SPACINGS USING FOUR CELLS ON THE METERING DISC AT A CELL SPEED OF 150 FEET PER MINUTE

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
10.0		10.0		10.0		10.0	
19.8	9.8	21.8	11.8	21.0	11.0	22.1	12.1
31.0	11.2	31.9	10.1	32.6	11.6	32.6	10.5
48.4	17.4	42.8	10.9	43.6	11.0	43.5	10.9
53.0*	4.6	53.9*	11.1	54.5	10.9	54.5*	11.0
64.3	11.3	66.1	12.2	65.6*	11.1	65.5	11.0
75.3	11.1	76.5	10.4	76.5	10.9	76.5*	11.0
86.4	11.0	87.4	10.9	88.1	11.6	87.8	11.3
97.6	11.2	98.6	11.2	98.3	10.2	98.5	10.7
108.4	10.8	109.1	10.5	109.8	11.5	109.8	11.3
Replication 5		Replication 6		Replication 7		Replication 8	
10.0		10.0		10.0		10.0	
20.8	10.8	21.8	11.8	20.9	10.9	22.0	12.0
32.0	11.2	32.1*	10.3	32.0	11.1	32.1	10.1
----***		44.4	12.3	43.3	11.3	43.6	11.5
54.3	22.3	54.9	10.5	54.4	11.1	54.8*	11.2
65.3	11.0	65.8*	10.9	66.0	11.6	65.3	10.5
76.5	11.2	----***		77.3	11.3	77.0	11.7
87.5	11.0	88.1	22.3	87.3	10.0	87.8	10.8
98.0	10.5	98.6	10.5	98.5	11.2	98.9	11.1
109.5*	11.5	110.8	12.2	109.3	10.8	110.0	11.1

*Denotes cell the fill with two seeds.
***Denotes cells not filled.

TABLE X

CELLS FILLED AND SEED SPACINGS USING FOUR CELLS ON THE METERING DISC AT A CELL SPPED OF 190 FEET PER MINUTE

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
10.0		10.0		10.0		10.0	
20.4	10.4	18.6	8.6	21.1	11.1	20.9	10.9
31.8	11.4	29.4	10.8	32.1	11.0	32.4	11.5
43.1	11.3	40.6	11.2	43.6	11.5	42.9	10.5
53.8**	10.7	52.3	11.7	----***		55.0*	12.1
65.3	11.5	62.3	10.0	65.5	21.9	65.5	10.5
75.1	9.8	74.0	11.7	----***		76.5	11.0
85.5	10.4	84.1	10.1	87.9	22.4	87.5**	11.0
98.0	12.5	96.3	12.2	99.0	11.1	98.6	11.1
109.5*	11.5	----***		109.9	10.9	109.9	11.3
Replication 5		Replication 6		Replication 7		Replication 8	
10.0		10.0		10.0		10.0	
21.4	11.4	21.1	11.1	20.8*	10.8	21.4	11.4
32.1	10.7	37.9	16.8	----***		32.8	11.4
43.1	11.0	42.8	4.9	43.3	22.5	43.6	10.8
54.3	11.2	54.6	11.8	53.3	10.0	54.8	11.2
65.4	11.1	65.6	11.0	65.4	12.1	65.8	11.0
77.3	11.9	77.0	11.4	76.4	11.1	76.8	11.0
87.9	10.6	88.0	11.0	87.5	11.0	87.9	11.1
98.9	11.0	99.0	11.0	98.4	10.9	99.4	11.5
109.5	10.6	110.5	11.5	109.8	11.4	110.5	11.1

*Denotes cell the fill with two seeds.
**Indicates cell filled with more than two seeds.
***Denotes cell not filled.

TABLE XI

CELLS FILLED AND SEED SPACINGS USING FOUR CELLS ON THE METERING DISC AT A CELL SPEED OF 243 FEET PER MINUTE

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
10.0		10.0		10.0		10.0	
20.5	10.5	----***		23.0	13.0	21.1	11.1
32.0	11.5	29.5	19.5	----***		----***	
43.1	11.1	44.6	15.1	39.1	16.1	42.5*	21.4
----***		53.3	8.7	49.9	10.8	----***	
64.1	21.0	67.3	14.0	61.1	11.2	----***	
----***		----***		----***		----***	
87.5	23.4	----***		----***		87.6	45.1
98.9	11.4	97.3	30.0	94.0	32.0	99.1	11.5
109.3	10.4	----***		105.4	11.4	----***	
Replication 5		Replication 6		Replication 7		Replication 8	
10.0		10.0		10.0		10.0	
23.6	13.6	22.6	12.6	15.3	5.3	----***	
34.9	11.3	32.6	10.0	33.0	17.7	32.1	22.1
45.9	11.0	----***		----***		----***	
----***		54.6	22.0	51.5	18.5	----***	
68.0**	22.1	65.8	11.2	67.8*	16.3	62.8*	30.7
79.1	11.1	----***		----***		76.1	13.3
89.8	10.7	81.8	16.0	87.9	20.1	87.9	11.8
100.3	10.5	99.1	17.3	95.5*	7.6	98.5	10.6
----***		110.0	10.9	110.6	15.1	109.4	10.9

*Denotes cell the fill with two seeds.
**Indicates cell filled with more than two seeds.
***Denotes cell not filled.

TABLE XII

CELLS FILLED AND SEED SPACINGS USING FOUR CELLS ON THE METERING DISC AT A CELL SPEED OF 300 FEET PER MINUTE

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
10.0		10.0		10.0		10.0	
----***		----***		----***		----***	
----***		32.3	22.3	26.6	16.6	31.1	21.1
43.1	33.1	----***		37.8	11.2	43.0	11.9
54.4	11.3	54.4	22.1	49.0	11.2	----***	
66.1	11.7	65.5	11.1	----***		65.3	22.3
----***		----***		70.9	21.9	----***	
----***		----***		----***		89.8	24.5
99.1	33.0	98.6	33.1	93.1	22.1	----***	
----***		109.9	11.3	----***		----***	
Replication 5		Replication 6		Replication 7		Replication 8	
10.0		10.0		10.0		10.0	
----***		25.0	15.0	----***		----***	
----***		----***		----***		----***	
----***		48.8	23.8	40.3	30.3	43.1	33.1
54.3	44.3	59.6	10.8	51.3	11.0	55.1	12.0
----***		----***		----***		65.8	10.7
77.0	23.7	----***		----***		----***	
85.4	8.4	91.4	31.8	84.3	33.0	----***	
98.9	13.5	104.3	12.7	95.6	11.3	----***	
----***		----***		106.8	11.2	----***	

***Denotes cell not filled.

TABLE XIII

CELLS FILLED AND SEED SPACINGS USING TWELVE CELLS ON THE METERING DISC AT A CELL SPEED OF 150 FEET PER MINUTE

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
10.0		10.0		10.0		10.0	
14.3	4.3	14.3	4.3	----***		13.6	3.6
17.8	3.5	17.8	3.5	18.3	8.3	16.6	3.0
20.0*	2.2	21.3	3.5	21.9	3.6	20.8	4.2
23.6	3.6	25.3	4.0	25.4	3.5	24.1	3.3
27.4	3.8	28.9**	3.6	29.1	3.7	27.8**	3.7
31.9	4.5	32.5	3.6	32.8**	3.7	31.3**	3.5
36.4	4.5	3.58	3.3	36.8**	4.0	----***	
38.6	2.2	----***		40.3	3.5	37.9	6.6
----***		----***		43.0	2.7	42.4	4.5
45.9	7.3	47.1	11.3	47.5	4.5	46.5	4.1
----***		50.6	3.5	51.4	3.9	49.5	3.0
53.9**	7.5	54.8	4.2	55.0	3.6	----***	
57.4	4.0	58.0	3.2	----***		56.4	6.9
----***		62.1	4.1	----***		61.4	5.0
64.5	7.1	65.5*	3.4	65.6	10.6	64.9	3.5
68.4	3.9	70.3	4.8	69.6	4.0	68.3	3.4
72.0	3.6	73.5	3.2	----***		71.3	3.0
75.9	3.9	77.0	3.5	77.4	7.8	75.5	4.2
79.5**	3.6	80.6	3.6	80.5	3.1	79.1	3.6
83.6	4.1	83.9	3.3	84.9	4.4	82.5	3.4
86.9	3.3	----***		87.6	2.7	87.1	4.6
89.8	2.9	91.6	7.7	91.5*	3.9	89.9	2.8
94.0	4.2	95.3	3.7	----***		----***	

TABLE XIII (continued)

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
			All measurements in inches				
97.8	3.8	99.0	3.7	98.3	6.8	----***	
101.8	4.0	102.6	3.6	103.0**	4.7	101.5	11.6
107.3	5.5	105.4	2.8	106.8	3.8	104.9	3.4
111.4	4.1	109.0	3.6	109.8	3.0	108.6	3.7
115.3	3.9	114.4	5.4	113.8	4.0	112.3	3.7
----***		117.4	3.0	117.6	3.8	116.0	3.7
Replication 5		Replication 6		Replication 7		Replication 8	
10.0		10.0		10.0		10.0	
12.5	2.5	13.3	3.3	13.9	3.9	13.5	3.5
16.8*	4.3	18.1	4.8	17.4	3.5	17.1	3.6
20.1**	3.3	20.8	2.7	20.8	3.4	----***	
23.4	3.3	----***		24.9	4.1	24.9	7.8
27.1	3.7	----***		30.0	5.1	29.0	4.1
31.6	4.5	32.3*	11.5	32.3	2.3	32.0	3.0
34.9	3.3	35.8*	3.5	35.6	3.3	36.0	4.0
38.9	4.0	40.8	5.0	39.4*	3.8	39.8	3.8
42.3	3.4	44.1	3.3	43.4	4.0	43.5	3.7
44.8	2.5	46.3	2.2	47.1	3.7	----***	
49.5	4.7	50.3*	4.0	49.0	1.9	50.3	6.8
53.0	3.5	54.6	4.3	50.8*	1.8	54.4	4.1
----***		57.0	2.4	54.1	3.3	----***	
60.5	7.5	58.6	1.6	57.3	3.2	----***	
65.0	4.5	61.8**	3.2	60.3	3.0	65.0	10.6
68.0	3.0	65.6	3.8	----***		68.3	3.3
----***		70.0	4.4	65.9	5.6	72.4	4.1

TABLE XIII (continued)

Replication 5		Replication 6		Replication 7		Replication 8	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
75.6	7.6	73.0	3.0	----***		75.9	3.5
79.0	3.4	77.0	4.0	72.6	6.7	79.8	3.9
80.9	1.9	80.3	3.3	76.1	3.5	83.8	4.0
83.1	2.2	84.6	4.3	79.9	3.8	87.0	3.2
86.6	3.5	87.5	2.9	84.0	4.1	90.3	3.3
89.9	3.3	----***		86.9	2.9	----***	
94.4	4.5	95.4	7.9	90.4	3.5	96.0	5.7
97.8	3.4	99.3	3.9	95.4	5.0	98.5*	2.5
104.4	6.6	101.8	2.5	97.5	2.1	----***	
108.6	4.2	106.4	4.6	102.1	4.6	----***	
111.8	3.2	110.4	4.0	105.6	3.5	109.4	10.9
116.0	4.2	----***		109.5	3.9	113.1	3.7

*Denotes cell the fill with two seeds.
**Indicates cell filled with more than two seeds.
***Denotes cells not filled.

TABLE XIV

CELLS FILLED AND SEED SPACINGS USING TWELVE CELLS ON THE METERING DISC AT A CELL SPEED OF 190 FEET PER MINUTE

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
10.0		10.0		10.0		10.0	
14.0	4.0	----***		14.8	4.8	14.5	4.5
17.8*	3.8	17.9	7.9	18.1	3.3	18.5*	4.0
21.3	3.5	21.3	3.4	21.5	3.4	----***	
25.5	4.2	----***		----***		----***	
29.6	4.1	28.6	7.3	29.8	8.3	29.0**	11.5
32.0**	2.4	30.1	1.5	----***		----***	
36.0**	4.0	32.5	2.4	36.4	6.6	36.8	7.8
39.9	3.9	----***		39.9*	3.5	39.9	3.1
----***		39.5	7.0	----***		44.0	4.1
47.1	7.2	43.0*	3.5	47.6	7.7	48.0	4.0
50.5	3.4	47.0	4.0	51.3	3.7	----***	
54.3	3.8	51.1	4.1	----***		----***	
58.1	3.8	54.5	3.4	----***		58.6	10.6
----***		58.1	3.6	62.1	10.8	62.3	3.7
65.0	6.9	62.0	3.9	65.8*	3.7	----***	
69.3	4.3	----***		----***		----***	
72.3	3.0	----***		73.5*	7.7	----***	
----***		72.9	10.9	77.4	3.9	----***	
79.5**	7.2	76.9	4.0	80.8	3.4	80.8	18.5
83.9	4.4	----***		84.1	3.3	84.5	3.7
87.5	3.6	83.3	6.4	----***		87.8	3.3
----***		87.3	4.0	91.5	7.4	92.1	4.3

TABLE XIV (continued)

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
95.4	7.9	91.5**	4.2	----***		96.1	4.0
98.6	3.2	----***		----***		----***	
102.5	3.9	99.0	7.5	----***		102.5	6.4
106.0	3.5	102.3	3.3	106.1	14.6	----***	
109.6	3.6	----***		110.5	4.4	110.5	8.0
113.5	3.9	109.9	7.6	115.3	4.8	----***	
----***		----***		----***		116.3	5.8
Replication 5		Replication 6		Replication 7		Replication 8	
10.0		10.0		10.0		10.0	
----***		----***		----***		13.5	3.5
17.6	7.6	17.0	7.0	17.1	7.1	17.5	4.0
21.8	4.2	21.0	4.0	----***		22.8*	5.3
----***		24.5*	3.5	----***		24.8*	2.0
28.9	7.1	28.3	3.8	27.1*	10.0	----***	
32.4	3.5	31.9	3.6	----***		31.6	6.8
38.3	5.9	35.1	3.2	----***		----***	
39.8	1.5	37.1*	2.0	36.3	9.2	39.0	7.4
41.5	1.7	39.6	2.5	----***		----***	
43.8	2.3	43.4	3.8	43.4	7.1	47.0	8.0
47.0	3.2	46.6	3.2	46.6	3.2	50.4	3.4
51.3	4.3	----***		----***		53.8	3.4
55.0	3.7	53.5	6.9	53.9	7.3	57.3	3.5
58.4	3.4	57.4	3.9	59.6	5.7	60.8	3.5
62.9	4.5	60.9	3.5	61.5	1.9	64.3	3.5
65.6	2.7	----***		65.3	3.8	67.0*	2.7

TABLE XIV (continued)

Replication 5		Replication 6		Replication 7		Replication 8	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
----***		68.4	7.5	----***		71.8	4.8
73.6	8.0	72.4	4.0	72.5	7.2	----***	
76.5	2.9	76.0*	3.6	----***		----***	
80.6	4.1	79.8	3.8	80.1	7.6	83.8	12.0
82.6	2.0	----***		83.5	3.4	----***	
87.0	4.4	87.6	7.8	87.8	4.3	89.5	5.7
91.9	4.9	92.1	4.5	----***		93.6	4.1
94.3	2.4	96.8*	4.7	----***		98.0	4.4
----***		----***		98.6	10.8	101.9	3.9
102.8	8.5	----***		102.4	3.8	103.4	1.5
106.6	3.8	----***		105.6	3.2	105.6	2.2
109.6	3.0	----***		109.6	4.0	108.4	2.8
113.8	4.2	113.4	16.6	113.5	3.9	112.4	4.0

*Denotes cell the filled with two seeds.
**Indicates cell filled with more than two seeds.
***Denotes cell not filled.

TABLE XV

CELLS FILLED AND SEED SPACINGS USING TWELVE CELLS ON THE METERING DISC AT A CELL SPEED OF 243 FEET PER MINUTE

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
10.0		10.0		10.0		10.0	
14.3	4.3	13.5	3.5	----***		13.9*	3.9
----***		----***		17.4	7.4	----***	
----***		20.8	7.3	----***		21.1	7.2
25.0	10.7	----***		24.8	7.4	24.8	3.7
28.9	3.9	----***		28.5	3.7	28.5	3.7
32.5	3.6	----***		----***		----***	
36.5	4.0	----***		----***		35.6	7.1
----***		39.1*	18.3	39.6	11.1	----***	
----***		42.5	3.4	42.9*	3.3	----***	
47.5	11.0	----***		46.8	3.9	47.0*	11.4
----***		----***		50.4	3.6	50.5	3.5
----***		54.4	11.9	54.4	4.0	54.0	3.5
58.6*	11.1	57.8	3.4	----***		----***	
----***		----***		61.3	6.9	61.4	7.4
----***		66.4	8.6	65.1	3.8	----***	
69.4	10.8	----***		69.1	4.0	68.6	7.2
73.4	4.5	72.8	6.4	72.6*	3.5	----***	
78.1	4.2	76.0	3.2	76.1	3.5	75.4	6.8
80.3*	2.2	79.9*	3.9	----***		----***	
84.4	4.1	83.4	3.5	82.0	5.9	----***	
----***		----***		84.4	2.4	----***	
----***		----***		87.6	3.2	90.8	15.4
----***		----***		91.0	3.4	----***	

TABLE XV (continued)

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
----***		98.4	15.0	94.4	3.4	----***	
103.1	18.7	----***		----***		102.0	11.2
----***		106.5	8.1	103.2	8.8	105.3	3.3
----***		109.6	3.1	106.1	2.9	----***	
----***		----***		----***		113.1	7.8
115.0	11.9	116.8	7.2	----***		----***	
Replication 5		Replication 6		Replication 7		Replication 8	
10.0		10.0		10.0		10.0	
14.0*	4.0	----***		----***		----***	
----***		----***		----***		----***	
----***		----***		19.0	9.0	21.0	11.0
----***		----***		22.9	3.9	----***	
27.8	13.8	26.4	16.4	----***		27.8	6.8
32.1*	4.3	----***		30.0	7.1	----***	
----***		32.1	5.7	34.3*	4.3	----***	
39.6	7.5	35.4	3.3	----***		----***	
43.3	3.7	----***		----***		42.0	14.2
47.1	3.8	43.0	7.6	----***		----***	
----***		46.6	3.6	----***		48.1	6.1
----***		50.6	4.0	52.1	17.8	51.8*	3.7
58.3	11.2	----***		----***		54.8	3.0
----***		58.3	7.7	----***		57.5	2.7
65.4**	7.1	----***		63.1	11.0	61.0	3.5
----***		65.6	7.3	67.1	4.0	----***	
74.1	8.7	----***		----***		67.8*	6.8

TABLE XV (continued)

Replication 5		Replication 6		Replication 7		Replication 8	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
----***		----***		73.6	6.5	72.3	4.5
----***		76.6	11.0	----***		----***	
84.1	10.3	----***		----***		79.6	7.3
----***		----***		----***		----***	
91.5	7.1	88.0	11.4	----***		86.8	7.2
96.0	4.5	91.4	3.4	----***		----***	
----***		95.1	3.7	96.8	23.2	----***	
102.6	6.6	----***		----***		----***	
----***		103.0	7.9	103.9	7.1	99.0	12.2
----***		106.5	3.5	107.8	3.9	----***	
----***		----***		112.0	4.2	----***	
----***		113.1	6.6	----***		----***	

*Denotes cell the filled with two seeds.
**Denotes cell not filled.
***Indicates cell filled with more than two seeds.

TABLE XVI

CELLS FILLED AND SEED SPACING USING TWELVE CELLS ON THE METERING DISC AT A CELL SPEED OF 300 FEET PER MINUTE

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
10.0		10.0		10.0		10.0	
----***		----***		13.3	3.3	----***	
----***		----***		----***		16.4**	6.4
----***		----***		----***		20.0	3.6
24.8*	14.8	25.0	15.0	----***		----***	
----***		----***		29.8	16.5	27.5	7.5
32.5	7.7	----***		----***		----***	
----***		----***		----***		----***	
40.1	7.6	----***		----***		----***	
----***		----***		----***		42.3	14.8
----***		----***		----***		45.9	3.6
----***		----***		----***		49.6	3.7
----***		----***		----***		----***	
----***		----***		----***		----***	
59.5	19.4	57.9	32.9	58.4	28.6	57.8	8.2
----***		----***		62.3	3.9	----***	
----***		65.1	7.2	----***		64.4	6.6
69.0	9.5	----***		----***		----***	
----***		----***		----***		----***	
----***		----***		76.8	14.5	----***	
----***		----***		----***		79.4	15.0
----***		81.4	16.3	84.3	7.5	----***	
----***		----***		88.0	3.7	87.0	7.6
----***		----***		----***		----***	

TABLE XVI (continued)

Replication 1		Replication 2		Replication 3		Replication 4	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
----***		----***		----***		----***	
----***		95.6	14.2	97.1	9.1	97.6	10.6
102.4	33.4	----***		102.3	5.2	----***	
----***		----***		----***		----***	
----***		105.0	9.4	108.5	6.2	108.9	11.3
----***		----***		----***		----***	
Replication 5		Replication 6		Replication 7		Replication 8	
10.0		10.0		10.0		10.0	
----***		----***		----***		----***	
----***		----***		17.6	7.6	----***	
----***		----***		----***		----***	
----***		----***		----***		24.9	14.9
----***		----***		----***		----***	
32.8	22.8	32.0	22.0	----***		----***	
37.0	4.2	----***		35.6	18.0	35.8	10.9
----***		39.8	7.8	----***		----***	
----***		----***		----***		----***	
----***		46.5	6.7	----***		47.1	11.3
51.6	14.6	----***		----***		----***	
----***		----***		54.6	19.0	54.9	7.8
----***		----***		----***		----***	
----***		----***		62.5	7.9	61.8	6.9
----***		65.1	18.6	----***		----***	
70.0	18.4	68.8	3.7	----***		----***	
73.8	3.8	----***		72.0	9.5	73.0	11.2
----***		----***		----***		----***	

TABLE XVI (continued)

Replication 5		Replication 6		Replication 7		Replication 8	
Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds	Distance of seeds from a starting point	Distance between seeds
All measurements in inches							
----***		----***		----***		80.1	7.1
----***		----***		----***		----***	
----***		----***		87.6	15.6	----***	
----***		91.4	22.6	90.3	2.7	----***	
----***		----***		----***		92.5	12.4
99.8	26.0	----***		----***		95.4	2.9
----***		----***		----***		----***	
----***		105.5	14.1	----***		----***	
----***		108.8	3.3	----***		106.1	10.7
----***		----***		----***		----***	
----***		115.4	8.6	----***		113.1	7.0

*Denotes cell filled with two seeds.
**Indicates cell filled with more then two seeds.
***Denotes cell not filled.