DEVELOPMENT OF A PRECISION METERING SYSTEM FOR PREGERMINATED SEED

By

STEPHEN W. SEARCY

Bachelor of Science in Agriculture
University of Missouri, Columbia
Columbia, Missouri
1974

Bachelor of Science in Agricultural Engineering
University of Missouri, Columbia
Columbia, Missouri
1976

Master of Science
University of Missouri, Columbia
Columbia, Missouri
1976

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Thesis Approved:

Lawrence D. Roth
Thesis Adviser

David G Batchelder

Gerald H. Brusewitz

James E Motes

Norman N. Durham
Dean of Graduate College

PREFACE

The following study was concerned with the development of a precision metering system for pregerminated seed. The primary objective was to develop a system capable of accurately singulating and spacing germinated seed. The resulting system is reported as developed along with data on the efficiency of the system.

I would like to express my appreciation for the excellent guidance provided by my major advisor, Dr. Lawrence O. Roth, throughout my doctoral program. I would also like to thank the other members of my advisory committee for their assistance at various times during the course of my studies, Mr. David G. Batchelder, Dr. Gerald H. Brusewitz and Dr. James E. Motes.

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NOMENCLATURE

b - correction factor for Rabinowitsch equation

b_t - thixotropic constant

d - distance from axis of rotation

f_x - frequency of spacings equal to x

k - viscosity constant

k_1 - torsional spring constant

k_2 - bob shear stress constant

k_3 - bob-cylinder combination shear rate constant

L - cylinder length

L_c - length of capillary tubing

n - viscosity exponent

N_0 - total number of seed spacings

N_x - number of spacings greater than x

P - pressure in capillary tubing

Q - volumetric flowrate

R_c - radius of capillary tubing

R_i - radius of inner cylinder

R_o - radius of outer cylinder

x - seed spacing distance

γ - shear rate

γ_w - shear rate at capillary wall

θ - viscometer dial reading

λ - spacing density constant

μ - apparent dynamic viscosity

μ_0 - apparent dynamic viscosity at time=Ø

τ - shear stress

τ_w - shear stress at capillary wall

ω - angular velocity

CHAPTER I

INTRODUCTION

The production of vegetables for commercial processing and fresh market sales is an increasingly large part of the agricultural production of the United States. In 1977 the estimated total value of the twenty two principal vegetables and melons grown for fresh market was $2,405,500,000, seven percent higher than the previous year. This production involved a total harvested area of 1.7 million acres. The estimated value of the thirteen major commercial processing vegetables was $1,059,000,000. This gives an estimated total value of vegetable and melon crops grown in the United States in 1977 of nearly 3.5 billion dollars (USDA, 1977).

The production of vegetables has traditionally been very labor intensive, particularly in the crop thinning and harvesting operations. A great deal of research work has been done in recent years in an effort to mechanize vegetable production. Much of this work has concentrated on harvesting and as a result successful harvesters have been developed for many crops. Mechanical harvesters require a full plant stand with uniformly matured fruit for optimum performance. This has increased the importance of accurate plant stand establishment and rapid emergence.

Vegetable crops have traditionally been established by two methods, transplanting or direct seeding. Both of these methods result in relatively high costs for crop establishment. Transplanting involves growing seedlings in a greenhouse or field and transplanting the seedlings into the field. In recent years field transplanting has been mechanized but most of these machines still require that each seedling be handled individually. Direct seeding involves the placing of dry vegetable seed directly into the field. Because of the many variables affecting the final emergence, the number of seed planted is often two to ten times the desired plant stand. The plants are then thinned, either by hand or with a mechanical thinner, back to the desired spacing.

The need for a method of precision planting of vegetable seed with assured emergence is evident. Many of the vegetable seed frustrate efforts in this area due to their small size and odd shapes. Many researchers have attempted to alleviate these problems by processing the individual seed to make them easier to meter. While these efforts were often successful in achieving accurate metering, the cost of planting was increased and the problem of insuring seedling emergence was not solved.

The planting of pregerminated seed is one possible solution to the problem of seedling emergence. Seed are germinated in an artificial environment until the radicle

emerges through the seed coat. The viable seed can then be sorted from the nonviable seed before planting. This method avoids many of the causes of nonemergence and results in a much higher percentage of seedling emergence. The planting of pregerminated seed incorporates the major advantages of both transplanting and direct seeding. A live plant is placed in the soil and the seed can be planted by a machine with little hand labor required.

While the use of pregerminated seed can help solve many of the problems associated with the production of vegetable crops, there is still a need for a planter which can accurately plant the pregerminated seed. Planters currently in use either do not have the capability of handling the fragile pregerminated seed without damage or do not have an adequate means of precision metering the seed. Any such planter would have to overcome several difficulties including identification, singulation and handling of the fragile seed. It should be able to meter and accurately space within the row a number of seed with different sizes, shapes and spacing requirements.

The objectives of this research were to:

1. Determine an acceptable means of transporting the pregerminated seed with respect to seed protection, facilitation of planting operation and ease of handling.

2. Design, construct and evaluate a mechanism capable of precision planting pregerminated seed of various sizes, shapes and intra-row spacings at acceptable field planting rates.

CHAPTER II

LITERATURE REVIEW

Plant Stand Establishment

For many years horticulturalists have known that variations in plant population could have drastic effects on the final yield (Nonnecke, 1974 and Becker, 1969). This knowledge has resulted in much work on the determination of the optimum plant population for individual crops under given sets of environmental conditions. This in turn necessitated the ability to accurately control the plant population. This ability is referred to as precision planting. The term "precision planting" has been used to refer to many things including metering accuracy (Johnson and Warren, 1969), depth control (Giannini et al., 1967), longitudinal seed spacing (Short & Huber, 1968), seed singulation (Harriott, [illegible]) and lateral seed placement (Wanjura and Hudspeth, [illegible]). However, the most commonly known and understood use of the term would be for longitudinal intra-row seed spacing. This meaning for precision planting will be used throughout this publication. Other than emergence, the ability to place a seed in the desired location along the row has the most effect on the relative plant population. Although a field may have the desired overall plant

population, unless the plant spacings are accurate, each plant will experience a different effective population depending on the spacing of the adjacent plants.

Most plant establishment systems involve three separate operations: the selection of a single seed or plant, the placing the seed or plant in the desired target location, and the emergence of the seedling or the survival of the transplant (Rohrbach et al., 1971). The last part of the plant establishment procedure is usually the result of uncontrollable events that occur after the planting and as such are not generally considered in evaluation of a particular planter. The selecting of a single seed or plant and the resulting transfer of that seed or plant to the soil are both very much a function of the design of the planter or transplanter being used. Several factors can combine to affect the precision of a planter. These can include seed type, seed uniformity, machine vibration, machine adjustment and operating speed. Each different planter design will be affected differently and will have its own probability distribution for the selection of zero, one, or multiple seed as a result. In addition, the transfer of the seed or plant from the metering device to the soil can add more randomness to the ultimate seed location. Rohrbach et al. (1971) illustrated the effects of random factors on a generalized plant spacing device (Figure 1). The figure shows a general probability distribution around the seed target sites.

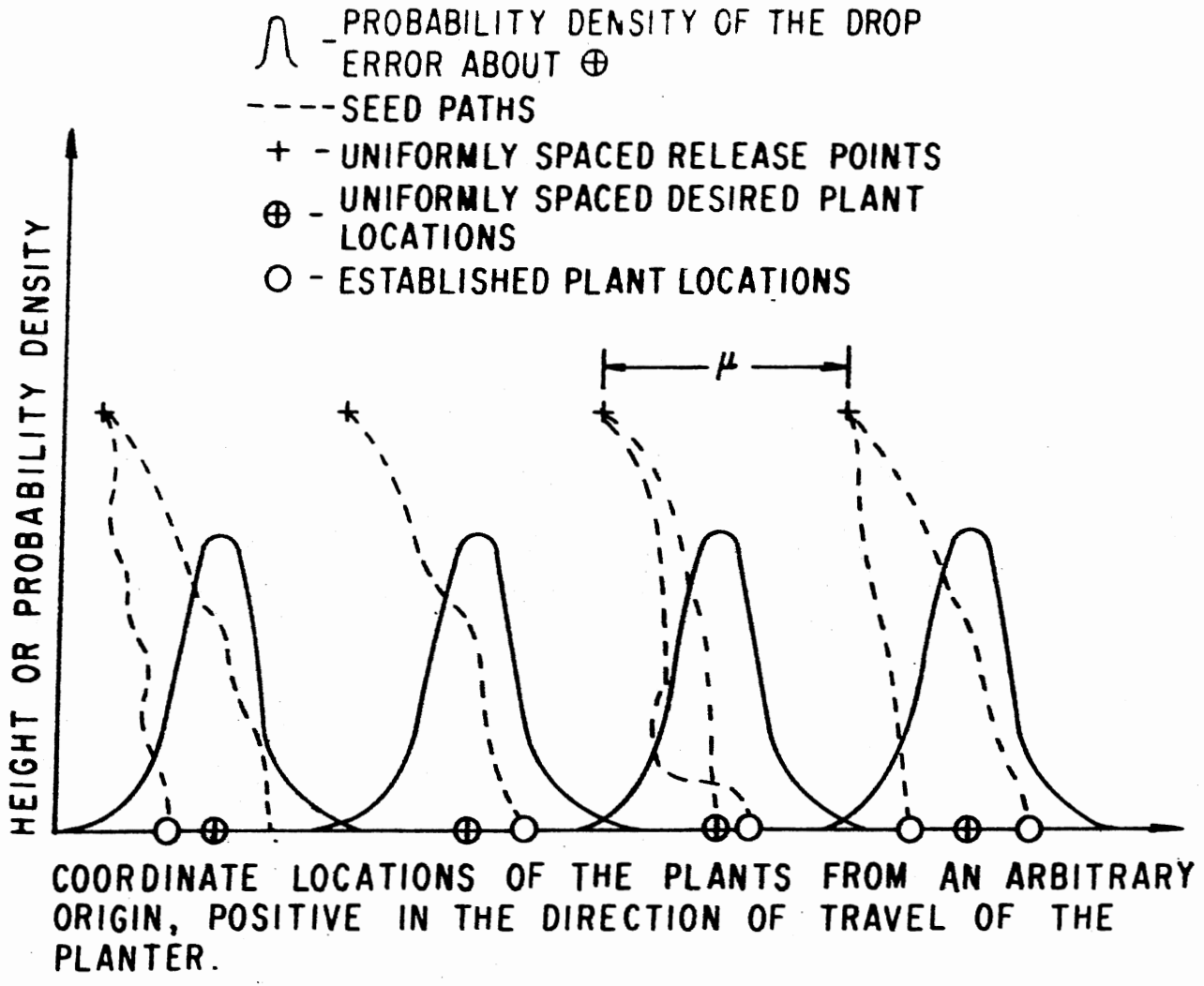


Figure 1. Effects of Random Factors on Seed Spacing (Rohrbach et al., 1971)

Two distinct methods are currently being used in commercial vegetable production, transplanting and direct seeding. Transplanting is most often used with high value crops, crops that germinate poorly, and in colder regions where it gives a longer effective growing season. Considerable labor and expense is required to grow the seedlings for transplanting. Direct seeding uses a planting mechanism to meter and place the dry seed in the soil. Because of a lack of accurate metering and other factors affecting emergence, an area is generally seeded at two to ten times the desired plant population and later thinned.

Transplanting

Transplanting is the process of placing live seedlings in the growing area at the desired plant population. The seedlings are grown in another location, usually a greenhouse, and transported to the field for planting, either as bare-root stock or in the growing container. The process of growing and transplanting seedlings is very energy and labor intensive and as a result the costs are quite high. When labor is available, the transplanting of the seedlings is often done by hand. However labor is becoming less available and growers are increasingly turning to mechanized means of transplanting their crops.

Much of the mechanization of transplanting operations has occurred in the tobacco and forestry industries. Tobacco growers have been forced to transplant seedlings

because the minute size of the tobacco seed makes direct seeding practically impossible. The forestry industry uses transplanting to rapidly reestablish large areas that have been cut.

Many transplanters now in operation are manually loaded with bare-root seedlings. These machines often require two persons per row (in addition to the driver) for optimum operation. C. W. Suggs (1979) developed a transplanter with multiple loading stations to increase the efficiency of the machine operator. The increased efficiency results from providing the operator with multiple loading stations that can be filled with seedlings before they are actually needed by the machine. The transplanter consisted of a chain with plant clips attached at appropriate intervals, a loading table and a furrow opener. When the clips were present before the operator, they opened to accept a plant. As they moved into position to place the seedling in the soil, the clips were closed, holding the seedling in position. As the clip passed through the furrow it opened up again, leaving the plant in the furrow.

The multiple loading transplanter was successful in increasing operator efficiency. With planting rates adjusted to two percent misses, the modified transplanter averaged 78.9 plants/min while a conventional transplanter with two operators achieved 72.3 plants/min and with one operator achieved 54.4 plants/min. Although this was a sig-

nificant increase in operator performance, a high labor requirement was still present.

In studies of transplanted tobacco and cabbage crops, Huang and Splinter (1968) listed the following disadvantages of conventional hand transplanting of bare-root stock:

1. High labor requirements in a short period of time.
2. Weather hazards often cause growers to miss the optimum transplanting period, thus reducing yields.
3. Plant losses occur due to handling of the transplants, thus requiring extra labor to fill in the skips.
4. Unavoidable human error results in nonuniformity of stands and missing plants which consequently affects mechanical harvesting.
5. Human error increases exponentially with planting rate and from a human engineering standpoint, transplanting speed is limited to less than 1.5 miles per hour.

These reasons plus the unavoidable root damage which occurs when the seedling is pulled from the growing bed convinced Huang and Splinter that an automatic transplanting system with each seedling grown in its own container was necessary. Growing each seedling in an individual container minimized the root damage during the transplanting operation and gave the additional advantage of facilitating gravitational transfer of the seedling to the soil. The greater weight of the potting container and the parachuting effect of the seedling leaves allowed the plant to be

dropped into position and still remain upright. The impact of the container with the soil resulted in close contact between the two. The impact force could be controlled by drop height, weight and size of the container. In an investigation of various fiber containers, the researchers found peat to yield the greatest amount of tops and roots.

The researchers developed a system of growing the seedlings in wooden grids, with the number of seedlings per grid controlled by the size of the peat containers. The automatic transplanter was constructed to accept and meter the seedlings directly from wooden grids similar to the growing grids. The seedlings were rapidly transfered to the transplanter by placing the growing grid over the transplanter grids and removing the bottom. This allowed the seedlings to fall into the transplanter grids. The seedlings were transfered to the soil by allowing them to fall through drop tubes to the ground. The tubes were equipped with a suction device to accelerate the fall of the plant. The furrow for the plants was opened with a spiked opener to provide a soft landing zone for impact absorbtion and to prevent tumbling. Two press wheels set at 45 degree angles closed the furrow around the seedlings.

Huang and Splinter (1968) reported that high livability and a uniform stand were achieved with the automatic transplanting system. However there was no mention of transplanting rates for the system.

Other transplanters which utilize container grown seedlings have been developed for use in the forestry industry. The transplanting of containerized stock is being rapidly increased as new developments make it increasingly feasible for replacing direct seeding and bare-root transplanting. Moden et al. (1977) developed a containerized transplanter which loaded the seedlings vertically into a planting shoe traveling in a furrow. At the appropriate time a piston forced the container horizontally out of the rear of the shoe at a rate equal to the forward speed of the transplanter. This made the seedling stationary relative to the ground, and allowed it to remain vertical as the press wheels closed the furrow around it. The transplanter used hand-loaded seedling cartridges and required both a driver and operator.

Moden et al. (1978) developed an intermittent dibble type container transplanter. The dibble was a device which punched holes in the soil. The transplanter was towed behind a tractor and placed seedlings in the punched holes rather than in furrows. The seedlings were hand fed by an operator into the dibbles and were left in the soil after the hole was punched by means of a trap door in the dibble. The transplanter could be rapidly changed for different sized containers and showed planting success rates up to 92 percent.

Direct Seeding Methods

Direct seeding is the process of planting dry seed directly in to the field. Direct seeding is by far the most widely used method of planting agricultural crops. It does however have several disadvantages, particularly for weak seedlings or crops which need to be precision planted. Many limiting factors are sometimes present and may reduce seedling emergence to 30 percent (Harriott, 1970). These factors include lack of uniform seedbeds, poor seed depth control, high or low temperature dormancy of the seed, lack of seedling vigor, soil crusting and insect damage. Because of these obstacles, growers often overplant by many times the desired plant population. The stand then has to be thinned, either mechanically or by hand. With this situation it is obvious that a great deal of money could be saved in seed and labor if an accurate planter could be developed.

Efforts to improve planters have focused in many different areas over the years. There have been many attempts to improve the performance of the planter by using various schemes to meter the seed. Attempts have been made to improve the metering properties of the seed by pelleting, wafering, placing seed in a tape, etc. And there have been efforts to improve the quality of the seedbed in order to improve seedling emergence.

Cell Type Planters. This type of planter has traditionally been used for most agricultural crops. It consists of a plate or drum with cells, normally around the outer edge, that rotate through a hopper containing the seed to be metered. As the cells pass through the hopper they are filled, one seed per cell, and then transfered to an outlet and dropped to the ground. Under laboratory conditions with uniformly sized, symmetrical particles this can be a very rapid and accurate meter. However under actual practice this type of meter has proven to be lacking as a precision meter.

Much testing has been done on both horizontal and vertical plate planters and several factors have been identified which limit the performance of cell type seed meters (Barmington, 1948; Bainer, 1947; Wanjura and Hudspeth, 1968; and Rohrbach et al., 1971). Agricultural seed and vegetable seed in particular are seldom symmetrical or uniformly sized. This variation in size and shape results in some cells being left open and others containing multiples. Even with uniform symmetrical particles, small differences in construction can affect the accuracy of cell plate planters. Wanjura and Hudspeth report that variations in metering cotton seed were found to be due to the geometry of the hopper bottom, cell plate speed and the plates themselves. They report that seed spacing along the row is random and unsuitable for precision planting. Bainer also found some varia-

tion in seed spacing due to the type of seed drop tubing used to transfer the seed from the meter to the furrow.

Pnuematic Planters. In an effort to overcome some of the shortcomings of the cell type planter, several researchers have attempted to develop pnuematically controlled meters. Most of these involve blowing or drawing seed into position at the proper time. In general, pnuematic planters suffer the same vulnerability to variations in seed size and shape as the cell type planter. Giannini et al. (1967) listed some of the problems associated with vacuum type seed-selection units:

1. Seed are small, making allowable orifice sizes very small. This results in a very small gripping force and a tendency to be easily cogged by dirt and chaff.

2. The small gripping forces allow seed to be easily dislodged at inappropriate times.

3. Some vegetable seed have pointed ends. This allows a single orifice to hold multiple seed if they are held by the points.

Sial and Persson (1979) listed five separate operations in the pnuematic metering of seed. These include seed orientation, seed pickup, seed holding and transport, brush off of extra seed, and seed ejection. They then studied each operation theoretically and experimentally. Several alternative methods were investigated for each operation and the best combination was determined for cabbage seed. The researchers did not attempt to evaluate their design in a field type application.

Giannini et al. (1967) developed a vacuum type planter for lettuce seed that opened a furrow, placed single seed at intervals greater than 51 mm (2 in), covered the seed with a non crusting soil amendment, and pressed the soil and soil amendment around the seed. The planter used modified syringe needles for the pick up nozzles and a cam-type apparatus to distribute the vacuum among the nozzles at the proper time. The planter was field tested and compared with a bulk metering planter normally used for lettuce. The vacuum planter showed several advantages over the bulk metering planter, including using one-tenth the seed of the bulk meter, increasing emergence percentage by greater than a factor of two, a 45 percent reduction in thinning time and an increase in the number of harvestable heads. Although the vacuum planter was a great improvement over the bulk meter, it still experienced operational problems. These included a high sensitivity to seed size and a tendency to plug the nozzles under certain conditions.

Short and Huber (1970) developed a vacuum planter for cucumbers which utilized modified grease fitting for nozzles. The meter used a planetary type motion which allowed a zero relative velocity between the nozzles and the seed at the time of pickup. The researchers tested the planter within a nozzle air velocity range of 30.5 to 91.5 m/sec (100 to 300 ft/sec). The percentage of theoretical seed drop was very dependent on the nozzle air velocity,

ranging from less than 60 percent to greater than 140 percent. In the best test run, a nozzle air velocity of 54.9 m/sec (180 ft/sec) was used. The percent of theoretical seed drop was 120 with 80 percent of the nozzles having a single seed and 20 percent having multiple seed. The percent of theoretical seed drop was only slightly affected by seeding rate in the 1.5 to 6 seed/sec range.

Other types of pnuematic planters have been developed on principles other than the vacuum nozzle. Moden et.al. (1974) reported on development of a pnuematic planter which used a rotating drum with orifices around the perimeter. As the drum rotated, both vacuum and positive pressure were used. For 300 degrees of rotation a vacuum was placed in the drum to adhere the seed to the orifices. From 300 to 330 degrees the vacuum was off to allow the seed to drop out of the orifices. At 330 degrees a positive pressure was applied to the drum to remove any foreign material and seed which may have remained in the orifices. The major deficiency of the planter was the large number of multiple seed which occurred. The percentage of orifices with only one seed ranged from 89.4 for Ponderosa Pine with a 51 mm (2 in) spacing to 37.4 for Douglas Fir with a 102 mm (4 in) spacing. Multiple seed were the largest cause of error, being up to 96 percent of the error for Douglas Fir.

Some researchers have attempted to use fluidics to precision meter seed. Walters (1971) reported on an attempt to meter Douglas Fir seed with a fluidic device. Although

the fluidic system had several desirable properties, such as rapid rate of switching, no moving parts, and self-cleaning abilities, it was unsuccessful due to a lack of uniformity in the size and shape of the seed. Rohrbach and Kim (1972) developed a fluidic device for singulating small particles. The device was extremely accurate, with an error rate of 1.7 percent at a 24 particle /sec rate. However the particles used were 2.87 mm (Ø.113 in) diameter plastic beads. No attempt was made to test the device with seed.

Dibble-Type Planters. Another type of experimental planter is the dibble type. These planters use punches of various types to make holes or depressions in the ground. The seed are then dropped into the holes, which are equally spaced along the row. This requires a mechanism which can place the seed accurately into the holes. Dibble planting allows the seedlings to avoid harsh environments. Environmental factors known to harm emergence are soil crusting, salt accumulations, low moisture availability, soil compaction, low light intensity, low oxygen availability and temperature extremes (Cary, 1967; Wilkins et al., 1979).

Jafari and Formstrom (1972) developed a precision punch planter for use with sugar beets. The planter consisted of a wheel to punch holes in the soil, a seed metering device to place the seed in the soil indentations and a seed pickup device to move seed from the hopper to the metering device.

The hole punching wheel had six 38 mm (1.5 in) high 90 degree cones mounted on the circumference. As the planter moved forward, the holes would be equally spaced. The wheel was built to give a concave shaped seedbed. The seed meter consisted of a grooved rotating plate which gave the seed a rearward velocity equal to the forward ground speed. This theoretically allowed the seed to have zero velocity relative the the holes and to fall directly into the holes. The seed were fed into the meter through a tube suspended from the hopper. The seed pickup mechanism kept the seed tube full by rotating a metal finger in the bottom of the hopper. The finger kept the seed agitated so that they could feed freely down the seed tube.

The planter was field tested at 4.83, 6.44 and 8.05 km/hr (3, 4 and 5 mi/hr) forward speed with no significant differences in seed spacing caused by the speed. The planter successfully placed from 94 to 97 percent of the seed in the punched holes. Although the planter was successful in placing seed in the wide shallow holes that were punched, it's design limited the advantages achieved by punch planting. Because the seed were only dropped on the soil, a press wheel was necessary to provide sufficient contact with the soil. The major advantages of punch planting are due to placing the seed deeper in the soil than normal and having no soil covering the seed. This planter was not designed to take advantage of these properties.

Two machines were developed by Heinemann et al. (1973) for planting seed which have physically weak seedlings such as carrot, lettuce, onion and beets. Both used the same principles but employed a different means of punching holes in the soil. The first machine used a pneumaticly actuated punch to form vertical holes in the soil 8 mm wide, 13 mm long and 38 mm deep. The punch was triggered by magnets located on a ground wheel, resulting in equally spaced holes regardless of forward speed. The second planter used a wheel with a series of punches mounted on it and an endless belt with holes punched to match the punch spacing. The belt stablized the soil around the punched hole and aided in placing the seed into the punched hole. In both cases a plate type seed meter was rotated through the seed hopper. Proper timing between the seed drop mechanism and the punched holes was used to place the seed into the holes. This timing made a uniform ground speed a critical factor.

The pneumatic planter was field tested at 1.6 km/hr (1 mi/hr). Fifteen percent of the holes did not contain a seed due to missing of the hole or failure to release a seed. After accounting for seed lot viability, less than 50 percent of the properly planted seed emerged. The authors suggest punch planting would be more successful with a convex shaped seedbed and use of a soil stabilizer to hold the punched hole's shape until the seedling emerges.

Wilkens et al. (1979) developed a dibble planter which punched the seed into the soil rather than dropping them into a hole. The planter used magnetism to hold the seed and place them in the soil. The seed were coated with a compound containing iron oxide which made the seed attractive to the magnetic punches. The punches were mounted on a punch wheel and remained vertical by means of an eccentric disc. Seed were singulated by a vertical notched seed wheel and carried out of the hopper to meet the punches. After the seed transferred to the punch, it was carried along on the bottom of the punch until it was forced into the ground. The strength of the soil surrounding the seed was expected to hold the seed while the punch was removed.

The planter achieved good success in singulating the coated seed. At travel speeds of 1.6 km/hr, 98.3 percent of the holes contained one seed and there were no doubles. At 3.2 km/hr the percentage of holes with one seed dropped to 88. In a comparison with a Stanhay planter, the magnetic punch planter greatly decreased the time from planting to emergence. The time to 70 percent emergence of lettuce seedlings was 4.5 days for the punch planter and 7.5 days for the Stanhay planter. The rate of emergence was also faster for the punch planter. From 20 to 70 percent emergence took 15 hours versus 40 hours for the Stanhay planter.

Preplanting Seed Treatments. Many of the metering mechanisms previously discussed have incorporated the use of seed modification to improve the accuracy of the mechanism. This generally has involved pelletizing or coating the seed to result in a uniform sized symmetrical particle. In most cases this was done strictly to improve the handling and metering properties. Many different seed coating materials have been used with varying degrees of succcess. Many researchers have reported decreased emergence of coated seed. This decrease is most often associated with lowered oxygen diffusion through the coating material (Sooter and Millier, 1978). As the practice of seed coating has evolved, several companies have developed coating materials and techniques. Robinson et al. (1975) evaluated seed coatings from several different firms. Lettuce seed were sent to seven commercial seed coating firms. Nine different coating types were field tested. A Stanhay belt planter equiped as specified by the companies for each coating was used to plant the seed. Although there were significant differences in percent emergence between the different coatings, all of the coatings provided an adequate stand for thinning to the final plant population.

Other seed preparations have been investigated in an effort to provide more than just increased metering accuracy. Harriott (1970,1974) developed a system of placing seed in vermiculite tablets. In addition to easy

metering, the tablet provided a more desirable growing medium for the weak young seedlings. A planter was developed to singulate and precision place the tablets, which required a vertical orientation for optimum emergence. This seed tablet system has been sucessfully used with many crops including cabbage, carrot, celery, broccoli, cauliflower, lettuce, onion and tomato.

In an attempt to increase the plant stand by increasing seedling emergence, plug mix planters were developed to place material in the furrow along with the seed to aid in seedling growth. In these planters, the seed was mixed with a soil medium which had been specially prepared to encourage seedling growth. These planters could only meter the soil mix, not the seed which were mixed in the soil. This lack of metering capability generally made the plug mix planters unacceptable for precision planting of seed.

Practically all planters, experimental and conventional, have been designed to select and plant the seed while moving through the field. In an effort to separate these functions, Chancellor (1969) devised a system of placing the seed in a water soluble tape prior to planting. In this method, seed metering can take place in a constant controlled environment with relative freedom from the dust, moisture and vibrations that limit most field planters. After the seed is attached to the tape, the only operation left is to transfer the seed from the reel to the soil. Some difficulties still remain however. Field tests

indicate a 58 percent emergence can be expected from seed of 92 percent germination.

Fluid Planters. Planters have been developed which utilize water or water soluble gels to aid in planting or to promote seedling emergence. One advantage of the fluid planters was that fertilizers, pesticides or other chemicals could be accurately metered into the furrow along with the seed by disolving the chemicals in the liquid or gel before planting. By suspending the seed in water or gel they can be handled more gently, allowing the sowing of soaked or germinated seed. Gatzke et al. (1967) described a planter which metered seed suspended in water. The seed/water mixture was held in a tank and metered by a plate with cells on the circumference. As the cells aligned with the outlets, head pressure from the tank washed the seed out of the cells and into the furrow.

Phillips and Scott (1967) developed a planter in which the seed could be suspended in a cellulose based gel and extruded into the furrow intermittently or continuously. This is similar in function to planters designed by Fiedler and Summers (1972) and Fluid Drilling Limited (1978). The Fiedler and Summers planter pumped the seed/gel mixture from a large tank using flexible vane pumps. The Fluid Drilling planter was developed and sold as part of a system for planting pregerminated seed. It uses a peristaltic-type pump to transfer the seed/gel mixture to the ground. These planters can give accurate overall plant populations by

mixing a certain number of seed in a known volume of gel and extruding it at a known rate. However the intra-row spacing is completely random.

A theoretical analysis of the seed spacing of a fluid drill was conducted by Richardson and O'Dogherty in 1972. Their analysis showed that the cummulative distribution of seed spacings from a completely mixed seed/fluid mixture extruded from a fluid planter would have the form of a Poisson distribution. They concluded that this distribution would be unsuitable for precision seeding of row crops and that fluid drilling would be most applicable if a method of precision seed placement was developed. According to the authors, the only time in which fluid seeding without precision metering would be useful would be when a biological advantage outweighs the effects of poor seed spacing.

Seed Identification Methods

Practically all of the planters previously discussed have used methods of metering which rely on the seed filling the metering mechanism based on the physical presence of a large nmmber of seed. While this may be acceptable for some crops and planters, for most seed it will not provide the precision necessary for planting directly to the desired plant population (planting to stand). Some means of identifying individual seed is required to satisfy the needs of

precision planting. Several methods have been developed to identify individual particles.

Kim and Rohrbach (1972) used fluidics to detect a particle as it passed through a straight circular pipe. The authors passed plastic beads through a turbulent flow field that had been developed in the pipe. The use of fluidic devices accurately detected the particle presence. The system was used strictly for detection and did not try to control the particle in any way. LePori et al. (1974) described a fluidic method of detecting and filling seed skips. The system was designed to operate on a pneumatic planter that used a pressurized drum with holes around the outside. As the drum rotated, air pressure would force the seed into the holes, from which they were later transfered to the soil. A detection system was devloped which recognized missing seed and replaced them from a secondary source. Assuming a 90 percent accuracy of the initial planting system, the additional detection circuitry could increase accuracy to 99 percent.

An alternative method of determining seed presence is with photodetection. Seed can be passed through a light beam and the interrupted signal from a phototransistor will indicate the seed's presence. This method was used by Reid et al. (1976) in development of a seed counter. Seed were allowed to fall from a vibratory bowl and break the light beam from an incandescent lamp. The seed counter was accu-

rate to 1.5 percent of the total count for a range of seed types and sizes. Reid and Buckley (1974) developed a similar type seed counter which utilized a laser as the light source. The laser was used because it could be focused down to a very fine light beam. This was necessary for counting extremely small seed (1 mm or less). The device was successful in counting seed to an accuracy of five percent of the total count or less for most seed. Loss of accuracy in the device was due to the path taken by the seed as they travelled though the light beam rather than the detection system.

Pregerminated Seed Research

Much of the research on vegetable crop establishment has concentrated on the development of systems to give uniform plant stands and ultimately a higher quality and quantity of the crop at harvest. This has also been the case for the pregerminated seed concept. The majority of work with pregerminated seed has been done in England at the National Vegetable Research Station. After some unsuccessful attempts to use pelleted seed, soluble tape, and other methods of providing artificial environments for germination, attempts were made to use pregerminated seed. This effort began in 1972 using a fluid drill designed by the Weed Research Organization (Currah, 1978).

The fluid drill was originally designed to reestablish pastures by sowing seed suspended in an aqueous medium. The drill used positive volumetric displacement to extrude the seed-fluid mixture into the soil. The procedure showed promising results when pregerminated seed were planted with the drill. There was no advantage over conventional methods when planting dry seed unless the soil did not contain adequate moisture (Anon. 1966). This fluid drill was later adapted for use with vegetable seed.

Two methods were developed for providing large quantities of pregerminated seed. The first method provided continuous aeration and moisture while the second supplied air and water intermittently. For the first method seed were placed in a column of water and were provided with ambient conditions suitable to stimulate growth. Air was bubbled into the column to aerate the seed and to keep them suspended in the water (Darby and Salter, 1976). The second method consisted of placing the seed in partially filled nylon bags. The bags were then alternately soaked in clean water and placed in a spin drier to remove the excess water and entrained air among the seed (Currah et al., 1976). The first method was used most often due to the amount of handling required with the second method.

During the germination procedure not all of the seed germinated. The entire mass of seed was sorted into viable and nonviable fractions by using a solution of the proper

density. As the radicle grew, the seed density was decreased. Taylor et al. (1977) used a sucrose solution to separate germinated celery and pepper seed. The separated seed had 95.2 and 97.6 percent emergence as compared to 72.8 and 73.6 percent for nonseparated celery and pepper seed.

After germination the seed growth must be stopped or reduced if the seed cannot be planted immediately. This growth stoppage was achieved for up to two weeks by cooling the seed to nearly 0 degrees C (Currah, et al., 1976). Taylor (1977) reported that pregerminated seed of asparagus, carrot, celery, and onion were not significantly affected by cold storage (1 degree C) up to 6 days. However, pepper and tomato seed experienced decreased percentage emergence when stored at 5 degrees C for 3 or 6 days.

Planting pregerminated seed accelerated seedling emergence in almost all vegetables (Currah et al., 1974; Biddington et al., 1975; Gray, 1976 and Gray, 1974). During germination, conditions which cause delayed emergence in the soil could be avoided. These could include lack of light, low or high temperature dormancy, and improper moisture availability. In addition, artificial environments were used to an advantage for some crops. The amount of water absorbed by seed was controlled by suspending them in an osmotic media (Heydecker et al., 1973). This brought all the seed to the brink of germination simultaneously. They were then germinated and planted sychronously, leading to a more uniform emergence and more uniformity at harvest. Cur-

rah et al. (1974) reported that celery seed germinated with sufficient light in the laboratory gave a 60 percent stand compared with dry seed which gave a 2 percent stand.

The seed of some species will not germinate at low temperatures although the seedlings can grow satisfactorily at those temperatures. In soils below 10 to 12 degrees C young cucumbers, sweet corn, and tomatoes can grow, but the seed will not germinate. Fluid drilled pregerminated tomato seed yielded up to 60 percent more fruit than dry sown seed (Currah, 1978). The earlier emergence of the pregerminated seed allowed them to utilize more of the short British growing season, resulting in a large increase in yield. Bussell and Gray (1976) found that in soils at 10 degrees C, pregermination of tomato seed reduced the time of emergence to 17 days compared with 41 days for dry seed. With soil temperature of 18 degrees C emergence time was reduced from 11 days to 5 days by using pregerminated seed. In research on the effects of time to emergence, Gray (1976) found that 60 to 90 percent of the variation in mature lettuce head weight and the date of head maturity could be accounted for by variation in the date of seedling emergence. Pregerminated seed sown with a fluid drill emerged within 5 days after planting compared to a 10 day span for the dry seed.

CHAPTER III

EXPERIMENTAL EQUIPMENT AND PROCEDURES

Experimental Equipment

Viscosity Measurement

In the process of analyzing various gels for use in a pregerminated seed meter, one of the criteria was the gel's viscosity characteristics. For this purpose three different viscometers were used, two Couette types (rotational flow between concentric cylinders) and a Poiseuille type (capillary flow) viscometer. The Couette viscometers were the commercially available Fann V-G meter and the Brookfield Model RVT Synchro-Lectric Viscometer. The Poiseuille viscometer was a custom made piston extrusion type.

The Fann viscometer (Figure 2) consisted of a constant speed synchronous motor, a torsional calibrated spring, a bob and a rotating cylinder. The bob was connected to the housing through the calibrated spring. The cylinder could be driven at 3, 6, 100, 200, 300, and 600 rev/min. The bob was suspended inside the rotating cylinder and the amount of viscous drag was measured by reading a dial located on the top of the drive housing. The range of the viscometer was determined by the torsional spring and the cylinder-bob com-

bination. Only one spring and one cylinder-bob combination were available for this work. The spring used was rated at 0.386×10^{-4} Nt-m/degree. The cylinder had an inside radius of 18.415 mm and the bob was 17.245 mm in radius and 38.0 mm long.

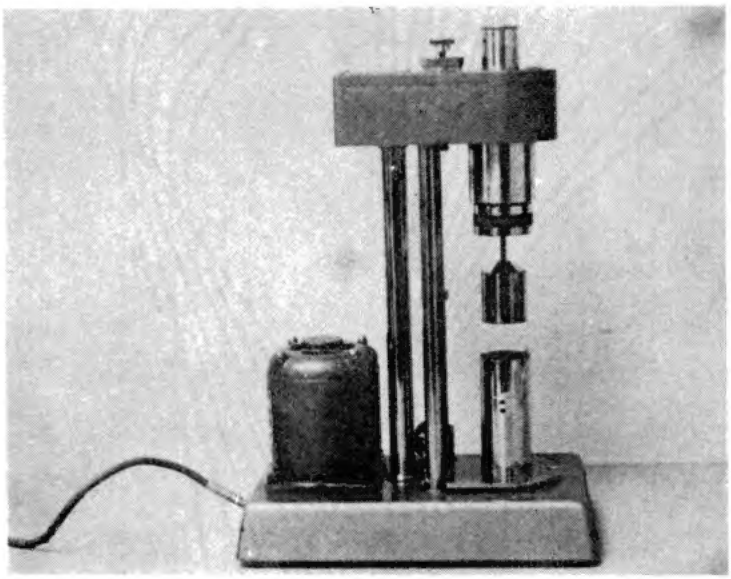


Figure 2. Fann V-G Meter

Equations for calculating shear stress and shear rate were provided by the manufacturer (Onufer, 1978). The constant values were also provided for each torsional spring and cylinder-bob combination. From each set of shear stress and shear rate values, the apparent dynamic viscosity could be determined.

$$\tau = k_1 k_2 \Theta \quad (1)$$

$$\gamma = k_3 \omega \quad (2)$$

$$\mu = \tau/\gamma \quad (3)$$

τ - shear stress

k_1 - constant for torsional spring

k_2 - shear stress constant for bob

Θ - dial reading

γ - shear rate

k_3 - shear rate constant for cylinder-bob combination

ω - cylinder angular velocity

μ - apparent dynamic viscosity

The Brookfield Synchro-Lectric Viscometer Model RVT (Figure 3) is very similar in principle to the Fann viscometer. It consisted of a synchronous motor, a calibrated torsional spring, a dial for reading angular displacement of the spring and a series of cylinders of various sizes. The model RVT was capable of rotating at .5, 1, 2.5, 5, 10, 20, 50, and 100 rev/min. The viscosity measuring range was changed by attaching the different cylinders. The cylinders were driven by the motor through the torsional spring. The spring measured the viscous drag as the cylinder rotated in a stationary container. The full scale torque of the Model RVT torsional spring was 0.7187×10^{-3} Nt-m. The cylinders

vary in diameter from 3.18 to 18.84 mm. The manufacturer recommended using a standard 600 ml Griffin beaker to contain the liquid being measured. Brookfield (1966) lists the following formula for determining shear rate and shear stress.

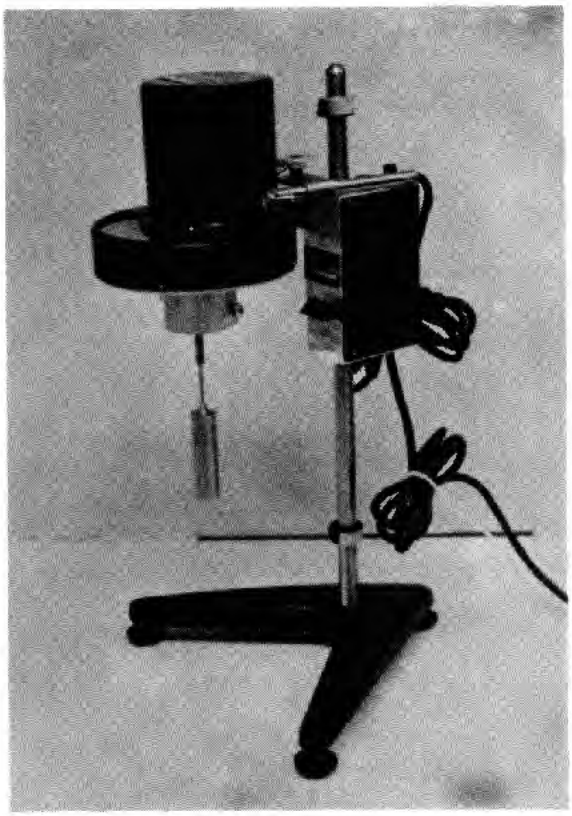


Figure 3. Brookfield Sychro-Electric Viscometer

$$\tau = \frac{\theta\, k_1}{2\pi\, R_i^2\, L} \tag{4}$$

$$\gamma = \frac{2\omega\, R_o^2\, R_i^2}{d^2 (R_o^2 - R_i^2)} \tag{5}$$

R_o - outer cylinder radius

R_i - inner cylinder radius

d - distance from the axis of rotation where shear rate is measured

L - cylinder length

The capillary viscometer was constructed to provide a higher shear rate than was achieved with the rotational viscometers and to provide a viscosity measurement in an arrangement more nearly like that to be used in the seed meter design. The capillary viscometer is shown in Figure 4. A Graham variable speed drive unit was used to drive the piston through a rack and pinion gear arrangement. The inside diameter of the cylinder was 25 mm. A funnel and ball valve assembly attached to the cylinder was used to load the gel. The capillary tube consisted of a 9.5 mm inside diameter section of Tygon tubing. The pressure drop across a 3.84 m length of tubing was recorded by a strain gage type pressure transducer and a millivolt recorder. The pressure transducer was located 380 mm from the entry point of the tubing, in order to eliminate any error due to

turbulence at the tubing inlet. The gel was allowed to exit the tubing at ambient conditions.

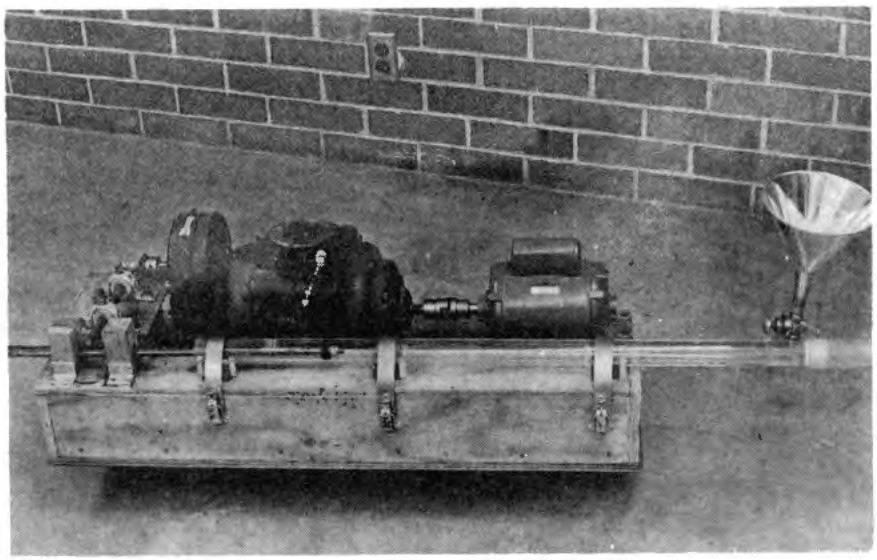


Figure 4. Capillary Viscometer with Loading Funnel and Valve

Von Wazer et al. (1963) lists a number of conditions which should be met by capillary viscometers for accurate measurement of non-Newtonian fluids. These include:

1. the flow must be steady
2. there are no radial or tangential components of the velocity
3. the axial velocity is a function of the distance from the axis alone
4. there is no slippage at the wall
5. the tube is sufficiently long to make end

effects negligible

6. the fluid is incompressible

7. there are no external forces

8. isothermal conditions prevail throughout

9. viscosity does not change appreciably with the change in pressure down the tube

Points one, two, three, five, seven and eight were met by the physical design and layout of the viscometer. Point four was fulfilled by insuring that only gel was allowed in the system during use and points six and nine were met by the properties of the gels.

The development of equations of shear stress and shear rate for capillary flow has been well documented (Van Wazer et al., 1963, and Alves, 1948) and will not be repeated here. The equations are as follows:

$$\tau_w = (\Delta P \cdot R_c)/(2 \cdot L_c) \tag{6}$$

$$\gamma_w = \{(3+b)/4\}(4Q/\pi R_c^3) \tag{7}$$

τ_w - shear stress at the capillary wall

P - pressure in the capillary

R_c - capillary radius

L_c - capillary length

γ_w - shear rate at the capillary wall

b - correction factor

Q - volumetric flowrate

In equation (7), the term in the first brackets is known as the Rabinowitsch correction factor. For Newtonian fluids, this term will be one and it will increase or decrease with the degree in which the fluid is non-Newtonian. The correction factor b can be determined from the slope of the log-log plot of $4Q/\pi R_c^3$ versus τ_w.

Seed Germination and Separation

For use in the development work of the pregerminated seed planter, a convenient source of pregerminated seed was necessary. This was provided by germinating the seed on location using germinating columns. The germinating apparatus consisted of a compressed air source, a water bath, a series of needle valves and plexiglass columns. The compressed air was bubbled through the water bath to remove any oil or other foreign material and to insure a high moisture content in the air. The plexiglass columns were filled with water and air was diffused through them by using an airstone in the bottom of the column. Each column had an individual valve for air flow control. The seed were added to the columns of water and allowed to gently agitate until they reached the desired stage of germination.

For most of the development work being reported here, the seed lot germination percentage was high enough for use without sorting out the nonviable seed. However in some cases the seed were sorted to give a higher germination percentage. The seed separation technique used was developed

by Taylor et al. (1977). A large glass column with a funnel shaped bottom (Figure 5) was filled with a sucrose solution mixed to a predetermined specific gravity. Table I lists the specific gravities used for separation of the vegetable seed used in this study (Taylor, 1978). The germinated seed were placed in the sucrose solution and allowed to separate. After about 30 seconds most of the nongerminated seed settled to the bottom of the column. They were then removed by allowing the sucrose mixture and seed to drain out the bottom. After the unwanted seed were removed, the remainder of the seed and sucrose was drained from the column. The seed were removed from the sucrose solution by straining and were thoroughly rinsed to remove any sucrose residue.

TABLE I

SPECIFIC GRAVITIES USED FOR SEED SEPARATION

SEED TYPE	SPECIFIC GRAVITY
Tomato	1.10
Cabbage	1.09
Cucumber	1.12
Lettuce	1.06

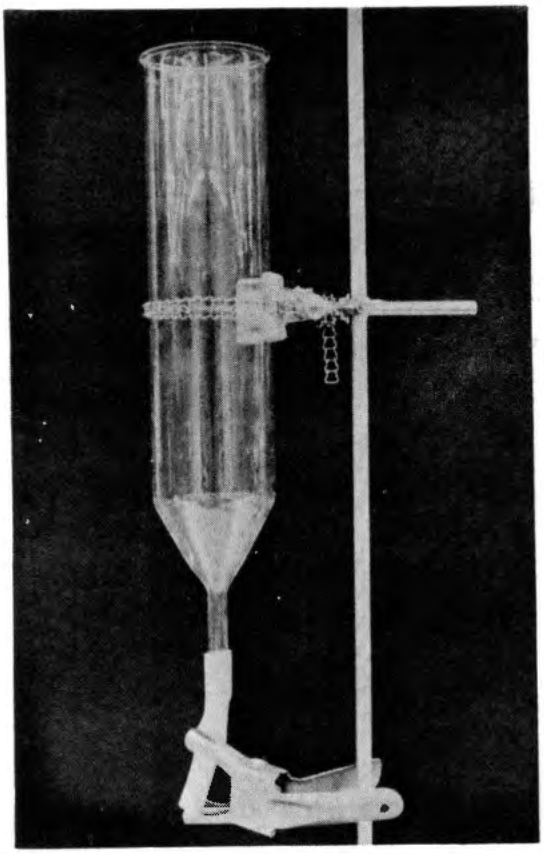


Figure 5. Seed Separation Column

Seed Suspension Tests

In order to test the ability of the prospective gels to hold the seed in suspension, an All American Model 25 HAT horizontal vibration table was used. Four plexiglass containers were constructed and clamped to the top of the vibrating table by means of an aluminum plate (Figure 6). After being filled with the appropriate seed/gel mixture,

the four containers were all attached to the table and vibrated simultaneously.

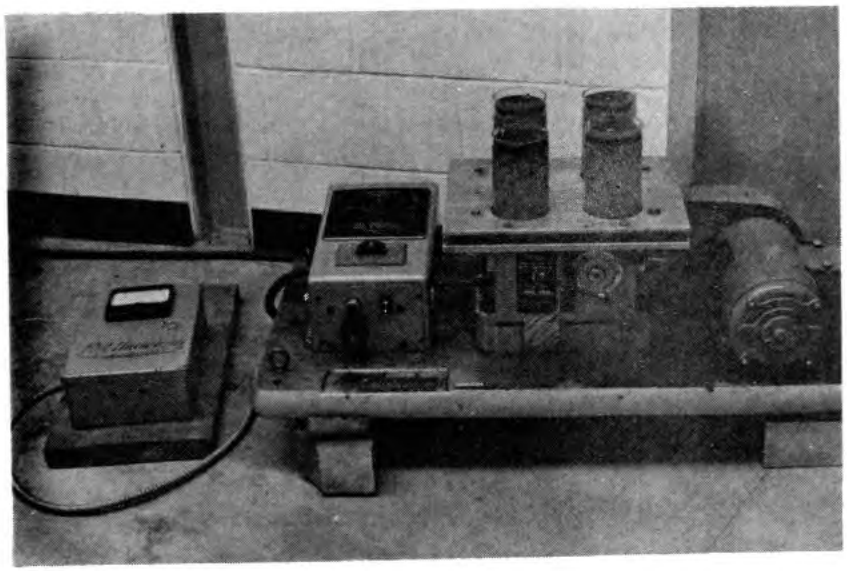


Figure 6. Seed/Gel Suspensions Mounted on the Vibrating Table

Both before and after the suspension tests, each mixture was sampled with the apparatus shown in Figure 7. The sampler consisted of two plexiglass tubes, a pipetting bulb and connecting tubes. Each column was sized to remove five percent of the total volume of the seed/gel container. The tubes were etched in thirds to aid in removing the samples from the tube properly.

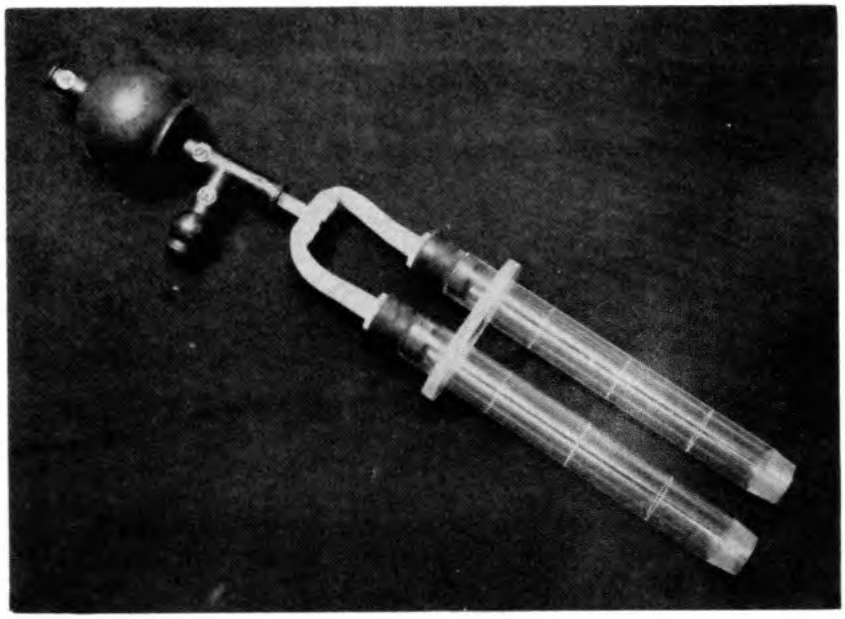


Figure 7. Sampling Apparatus for Seed Suspension Tests

Seed Spacing Distribution Analysis

To evaluate the effectiveness of the metering system, seed spacings were recorded on high speed film. A Fastax Model WF3 high speed camera with 16 mm Kodak 4-X (ASA 400) black and white reversal film was used for the unmetered spacing tests. A Bolex movie camera with 16 mm Kodak Tri-X (ASA 200) black and white reversal film was used with metered seed spacing distributions because they did not require the high speed camera. In both cases the seed were extruded onto a continuous belt and passed before the movie camera. Included in the framing area of the camera was a linear scale marked every 5 mm. The seed passed beneath the

scale, allowing for accurate measurement of the seed spacing.

For development of the metering system, a planter test stand was used. The test stand consisted of an endless belt and a Graham Model 250 S2.8 variable speed drive unit. By varying the drive unit, belt speeds of 0 to approximately 20 km/hr could be obtained. The belt was painted white and marked every 200 mm to aid in the determination of the seed spacing.

After the seed spacings were recorded on film and the film developed, the spacing distribution was measured using a film analyzer. This allowed the film to be viewed one frame at a time. Each frame was projected onto a screen and the operator controlled the film motion. The individual spacings were determined from the scale in the picture.

Experimental Procedure

Gel Evaluation

For development and testing of the metering system, a medium was needed which could both carry and protect the fragile seeds. These functions seemed to be best met by gel type fluids. Most gels have the advantage of high viscosity which aids in seed suspension and protection. The following is a list of requirements that an ideal gel would meet:

1. Economical and readily available
2. Provide adequate seed suspension under field conditions

3. Easily prepared, handled and cleaned up after use

4. Have no corrosive effects on equipment

5. transmit light readily

6. Have a low sensitivity to salts

7. Have no phytotoxic or growth inhibitory effects on seeds

The gels tested for use in this work were all water swellable gels. When mixed in water, they absorbed many times their weight and would result in highly viscous fluids. Most of these compounds were both economical and easily available. All the gels had at least some seed suspension qualities. A wide range in the ease of preparation and handling was experienced and this was an important factor in determining a gel for use in this study. Corrosive effects of the gels were not specifically studied. However, none were noticed to be visibly more corrosive than water. A high light transmisivity was desirable in order to allow the use of photoelectric devices for seed detection. Salt sensitivity was important because it could be very desirable to include fertilizers, pesticides or growth regulating compounds in the gel. Salt sensitivity ranged from highly sensitive to practically no sensitivity (Taylor, 1978). Any growth inhibitory effect in the gels would be defeating the reason for using pregerminated seeds, i.e. faster and more uniform seedling emergence.

Six different gels were evaluated for use in the metering system development. Table II lists the different

gels that were obtained and tested for use.

TABLE II

GELS EVALUATED FOR USE IN METERING PREGERMINATED SEED

GEL TRADE NAME	MAJOR COMPONENT
CLD	Cellulose
SGP	Starch
Viterra II	Polyacrylamide
Polymer 35-B-100	Starch
Starpol 100	Starch
Gum Blend	Gum

These gels were analyzed for ease of mixing, consistency of gel after mixing and ease of clean up after mixing. Although only a subjective evaluation was made of these characteristics, there were large differences between the gels. Some, such as SGP and Starpol 100 were difficult to mix into suspension. They formed clumps of material which were hard to disperse. Gum Blend was subject to enzymatic action and required denaturing if it was not used rapidly. Other gels had varying degrees of light transmissivity, salt sensitivity and phytotoxic effects (Taylor, 1978). Two gels (CLD and Viterra II) were initially identified for use with the seed meter. Both of these gels were evaluated for their viscosity and seed

suspension qualities.

Viscosity Determinations

Viscosity measurements were taken for Viterra II and CLD using both rotational and capillary viscometers. The gels were mixed to the desired concentration (percentage by weight) in demineralized water using a propeller type laboratory stirrer. The mixtures were stirred until mixing appeared to be complete. The gel was then allowed to stand approximately thirty minutes to obtain its full viscosity. All tests were conducted at ambient temperature (23-25 degrees C).

Initial viscosity tests on Viterra II were conducted with both the Brookfield and Fann rotational viscometers. Measurements for CLD were taken only with the Brookfield viscometer. The gels were placed in standard 600 ml Griffin beakers for the tests. This container was recommended by the manufacturer for use with the Brookfield viscometer. Due to the configuration of the Fann viscometer, container size was not important as long as a sufficient depth of fluid was maintained.

For each measurement, the rotating cylinder or bob was lowered into the gel to the recommended depth. The desired rotation speed was selected and the viscometer turned on. The cylinder or bob was then allowed to rotate until an equilibrium reading appeared to have been achieved, normally about 30 sec. In addition to the equilibrium viscosity

tests, a determination was made of Viterra II visocity as a function of time at a constant shear rate. In this case the viscometer was allowed to rotate for an extended length of time and readings were taken periodically.

Viscosity measurements were also taken for both gels using the capillary viscometer. The gels were mixed in a manner identical to that for the rotational viscometers but in larger quantities. After mixing, the gel was loaded into the viscometer by means of the funnel and ball valve on the cylinder. The ball valve was opened, the piston drawn back and the gel filled the cylinder. After purging all air from the cylinder and tubing, careful loading allowed the system to remain bubble free. After loading, the variable speed drive unit was set to the desired piston speed, the millivolt recorder was turned on and the piston was started. The cylinder of gel was extruded and the pressure in the tubing was recorded. Tests were conducted for each gel at a number of concentrations and gel velocities.

Data from all of the viscosities tests were analyzed for shear stress and shear rate. The data reduction methods suggested by Van Wazer et al. (1963) were used to determine the relationships between shear stress, shear rate and dynamic viscosity. The regression procedure of the Statistical Analysis System (SAS) was used in this analysis.

Seed Suspension Tests

Seed suspension tests were conducted for both CLD and

Viterra II. Germinated seed were mixed in the gels and vibrated to determine if the seeds would settle to the bottom of the container. Cucumber seed were used in these experiments because they were the densest seed to be used in testing the metering system. A randomized block experimental design was used with gel concentration as the treatment. Each treatment was replicated twice and each replication was sampled twice.

After mixing the gel concentrations, 700 germinated cucumber seed were added to the gel at a one seed/ml rate. The seed were mixed as uniformly as possible into the gel and the mixture was placed in a container to be clamped to the vibration table. Two samples were taken from the container before vibration. Each sample contained five percent of the total and was separated into three parts, upper, middle and lower thirds. The number of seed in each third was counted. This sampling procedure was conducted immediately after the mixture was placed in the container, allowing no time for seed settling prior to sampling. A lid was placed over the gel and allowed no air space above the gel. This eliminated any wave action and the resulting seed movement. Four different gel concentrations were placed on the vibration table and vibrated at 15 and 50 Hz with a 3.8 mm amplitude for one hour (Viterra II was only vibrated at 15 Hz). After one hour the containers were removed and samples were taken again by the same method. After the seed were counted, each value was divided by 0.9 (Weeks, 1978). This cor-

rection factor was used because the before vibration samples were taken without replacement. This meant that the after vibration samples were taken from only 90 percent of the original seed/gel mixture.

Unmetered Seed Spacing Determination

Richardson and O'Dogherty (1972) predicted that the cumulative spacing distribution between seed uniformly mixed in a fluid would have a Possion type distribution upon extrusion of the mixture. This prediction had not been proven experimentally however. In an attempt to determine the amount of improvement in seed spacing that was actually needed, tests were conducted to determine the spacing distribution from a uniform gel/seed mixture.

Tests were conducted with cucumber seed to determine the effects of gel to seed ratios and outlet speed on the spacing distribution. The gel/seed mixture was forced through a funnel to a tubing with an inside diameter of 5 mm, slightly larger than the seed width. This placed the seed in a single file manner on the belt. The extrusion tube was made to flow full at all times and the gel exited the tubing at the same velocity as the belt it was extruded on. Pressure in the holding tank was varied in order to keep the belt and gel exit velocities equal.

Cucumber seed were mixed to the desired seed to gel concentration in a one percent Viterra II gel. The mixture was stirred by hand until the seed were as uniformly mixed

as possible. It was then placed in a tank to be pressurized with compressed air. The gel was extruded onto a continuous belt and carried past a high speed movie camera. Spacing data was visually taken from the developed film and recorded manually.

Tests were conducted at travel speeds of 1, 3, 5 and 7 km/hr. Gel/seed ratios used were 1, 2, 3, 4 and 5 ml/seed. The spacing distribution equations were determined using SAS regression routines. The resulting equations were compared to the predicted equations to determine the accuracy of the predictions. The gel to seed ratio and travel speed variables were examined for their effect on the spacing distribution. Based on the distribution prediction equation, an estimate of the distribution mean was derived.

Metered Seed Spacing Determination

Tests were conducted with the seed metering system to determine the accuracy of the spacing it produced. Four different seed types were used in the testing. The seed used included cabbage, a spherical seed approximately 3.5 mm in diameter; tomato, a round, flat seed about 3.0 mm in diameter; lettuce, a long, round seed about 5 mm long and 2 mm in diameter; and cucumber a large seed with an oval cross-section, approximately 15 mm long and 5 mm wide. The majority of tests were conducted with cabbage seeds. As a spherical seed of average size it was the seed most easily metered by the system. The other three seed were used to

determine the metering mechanism's ability to handle various seed sizes and shapes.

Seed used in testing were germinated in aeration columns at the Agricultural Engineering Laboratory. The seed were germinated to the point where the radicle had a length of 1 to 2 mm. An approximate seed count was determined by weighing and the desired number of seed was mixed into a previously prepared 1.0 percent concentration of Viterra II. The seed were mixed in the gel as uniformly as possible with a spatula. Gel/seed ratios of 4.0, 3.0, 2.0 and 1.0 ml/seed were mixed and tested in the system. The mixtures were poured into the seed/gel tank and pressurized. A 0.5 percent mixture of Viterra II was placed in the gel tank and also pressurized.

The spacing distribution tests were conducted on the planter test stand in a manner similar to the unmetered spacing tests. At each gel/seed ratio, all metering rates were tested from the same tank mixture. For each gel/seed ratio, the metering system was started up and adjusted at the slowest metering rate. The tank pressures and the PDELAY time delay were adjusted to achieve the optimum system performance. By causing the seed to be caught at different locations in the input cells, the output of the mechanism was affected. After the system had been adjusted to the point where the spacing appeared to be the most uniform, results were recorded for metering rates of 0.5, 1.0, 2.0 and 3.0 seeds/sec. In addition rates of 4.0 and 5.0

seeds/sec were taken at the 2.0 ml/seed ratio. The only change between tests at a single gel/seed ratio was in the speed of the belt which increased the metering rate. All tests were recorded on film and spacing data was taken with methods similar to those used for the unmetered tests.

After the data had been recorded, each combination of gel/seed ratio and metering rate was analyzed for metering error and spacing uniformity. A skip was defined as any spacings greater than 150 percent of the desired spacing. Any spacing less than 50 percent of the desired spacing was called a double. Skips and doubles were considered metering errors. The percentages of skips and doubles were determined by dividing the number of skips and doubles by the theoretical number of spacings. The theoretical number of spacings represented the number of spacings which would have been seen if the distribution had been perfect and was calculated by adding the number of skips and subtracting the number of doubles from the actual number of spacings recorded.

The metering uniformity was considered for all spacings within 50 to 150 percent of the desired spacing. All other spacings were called metering errors and were not included. The distribution means and variances were used as measures of uniformity.

CHAPTER IV

DESIGN OF METERING SYSTEM

Design Objectives

In the development of a concept for a precision planter of pregerminated seed, certain objectives were identified which the planter should meet. These included:

1. Damage to the pregerminated seed must be less than one percent of the seed planted.
2. Metered seed must follow a continuous, identical path from the meter to the furrow.
3. The metering system must be portable and achieve metering rates of ten seed per second or greater.

The primary reason for precision planting of pregerminated seed was to plant directly to the desired plant population, thus eliminating overplanting and thinning. It was necessary that each seed planted be viable and grow into a healthy plant. Because of the fragile nature of the seed after germinating, it was desirable to handle, transport and meter the seed with as little mechanical contact as possible. Other researcher's work (Currah et al., 1974; Fiedler and Summers, 1972; Lickerish and Darby, 1976) has shown that suspending the seed in a gel or fluid is extremely successful in protecting the seed from

damage. In order to utilize the protection of gel suspension, a metering method was developed which sensed the seed's presence in the gel and metered it without physically handling the seed itself.

A major cause of randomness in most dry seed meters is the path or trajectory that a seed follows from the meter to the furrow. Because on most planters the seed path is never the same for adjacent seed, even seed from a perfect metering device would have a random factor in their spacing distribution. To correct this problem the seed must be made to follow the same path at the same rate. By utilizing a continuous flow of gel from the meter to the furrow, the proposed metering system forced the metered seed into identical paths.

The reasons behind the third design objective are reasonably clear. If a planter is to be successful it needs to be capable of use in the field and at a reasonable rate. A machine to precision meter seed suspended in water has been developed (Fluid Drilling Limited, 1978b), but it is too large and slow for field use and is used strictly for stationary greenhouse work. A metering rate of ten seed/second was considered a reasonable target rate. At 150 mm seed spacings, this would allow a ground speed of 5.4 km/hr.

Metering System Components

The seed metering system consists of five major parts

and is illustrated in Figure 8. The major components were a holding tank for the seed/gel mixture, a holding tank for gel only, a device to force the seed into a single file, the seed metering mechanism and a microcomputer to control the meter and its inputs. Figure 9 shows the physical layout of the metering system and the planter test stand used for evaluation.

Holding Tanks

Two similar tanks were built to hold the gel and seed/gel mixtures necessary for the operation of the seed meter. Each tank was constructed to hold internal pressures up to 350 kPa. The tanks were cylindrical with a cone shaped bottom to aid in removing all the gel. The material was loaded in the top of the tanks and the lids were fastened with bolts mounted on the tank. The tanks were pressurized with compressed air and each had a regulator and pressure gauge for independent pressurization. The gel flow rates through the meter were controlled by tank pressure.

Single File Device

In order to meter individual seed a means of placing the seed in single file was necessary. The longitudinal spacing between seed was not as critical as the need for single seed as they entered the metering device. Figure 10 shows one of the single file devices used. The devices were machined out of plexiglass rod to allow a visual check of

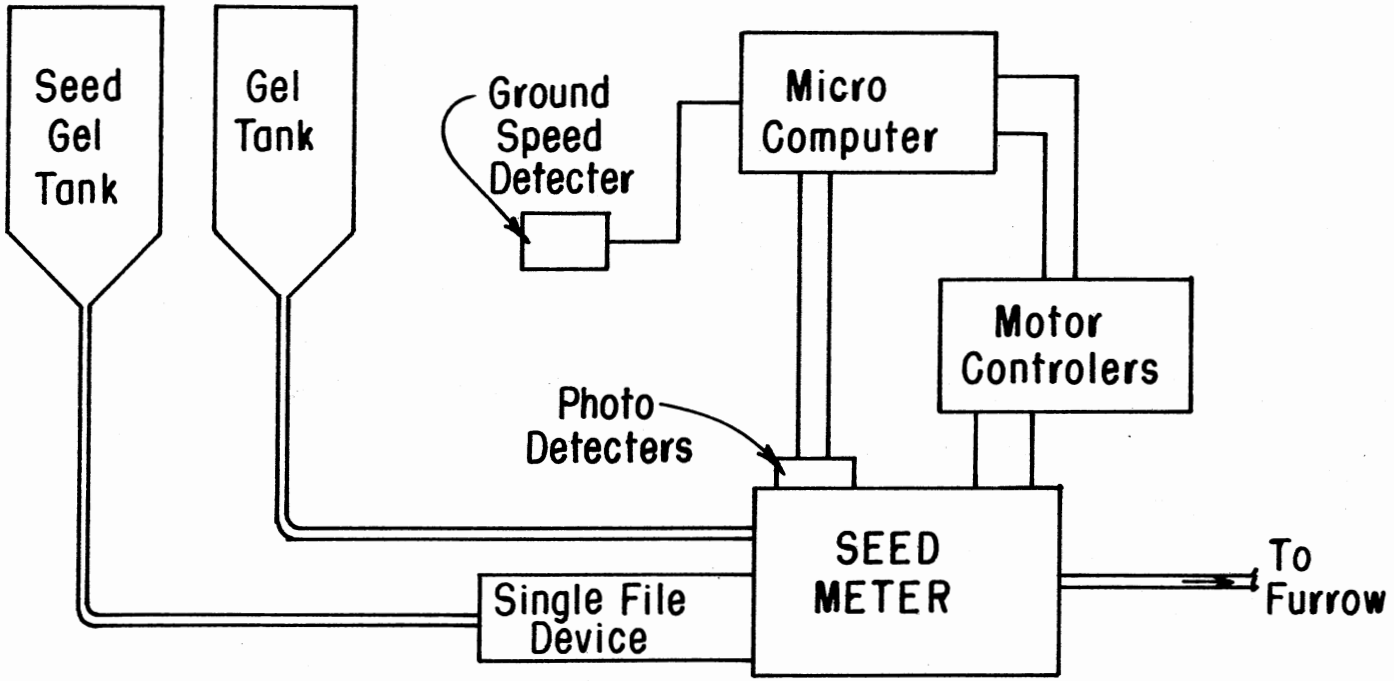


Figure 8. A Schematic of the Metering System for Pregerminated Seed

the seed as they flowed through the device. A gradual taper down to the diameter of the seed was used to force the seed to exit one at a time. The lower end of the single file device was threaded to be accepted by the metering mechanism. Because of it's shape and function, the device was referred to as a seed funnel.

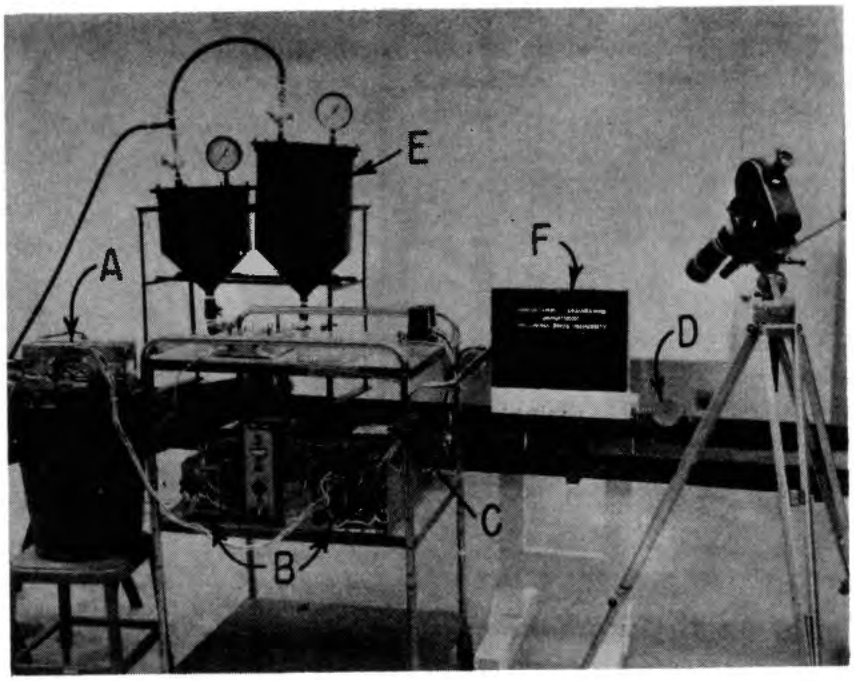


Figure 9. The Physical Layout of the Metering System as used. A) Metering Mechanism B) Motor Controllers C) Microcomputer D) Encoder E) Gel Tanks F) Filming Scale

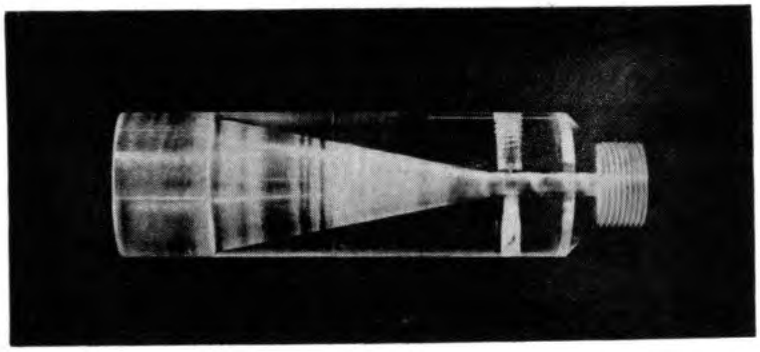


Figure 10. A Seed Funnel to Place Seed in Single File.

Metering Mechanism

The metering mechanism performed the most difficult task in the metering system. It was required to transform a random seed input to a fixed output. As the seed emerged from the seed funnel, the metering mechanism had to be capable of trapping the individual seed, holding the seed in readiness and releasing the seed at the necessary time. The mechanism consisted of several parts including: an aluminum mounting frame, an input disk and housing, a transfer block, an output disk and housing, two photoelectric detectors and two stepping motors. Appendix A contains detailed drawings of the various parts.

The mounting frame was carefully milled from a solid block of aluminum. This was done to provide mounting surfaces that were as nearly parallel as possible. The disks and housings were constructed with close tolerances and required that mounting surfaces be parallel in order to reduce the drag on the disks while they rotated. The disks were mounted inside the frame in an offset manner. The driving motors were mounted outside the frame on opposite sides.

The disks, disk housings and the transfer block were constructed of plexiglass. The plexiglass parts are shown in Figure 11. Plexiglass was chosen for part construction because of several qualities: visual clarity, lightweight, easy machining and relatively low coefficient of friction.

Figure 12 shows the input disk. It had twenty cells of 6 mm diameter around the outer edge. The cells were spaced evenly around the disk with 8 mm between the cells. This arrangement allowed the disk to rotate half way between the cells and shut off the flow of the seed/gel mixture. The disk was contained in a housing with a 0.04 mm average clearance between the disk and housing. This allowed the disk rotation to effectively cut off the seed/gel flow. One of the photo-electric detectors was mounted in the housing 5 mm before the edge of the disk. This allowed the seed to be detected just prior to entering the cell. This location of the seed detection device close to the disk helped to eliminate the trapping of multiple seed.

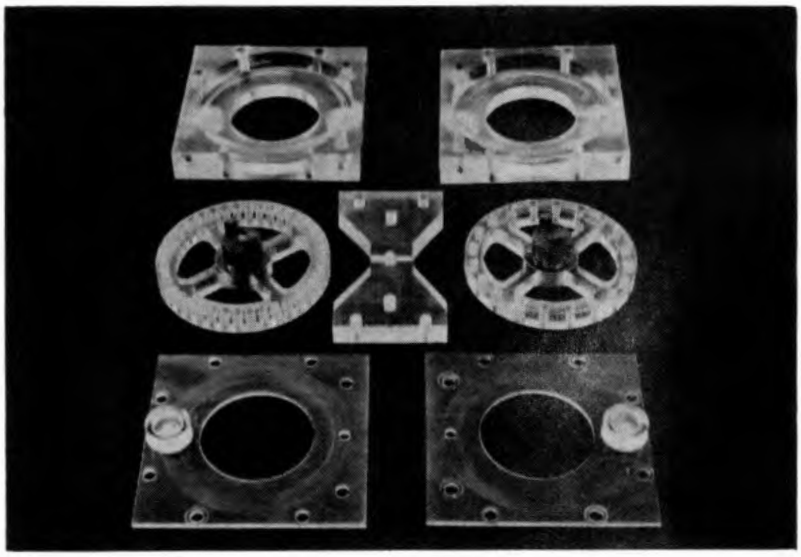


Figure 11. Metering Mechanism Parts

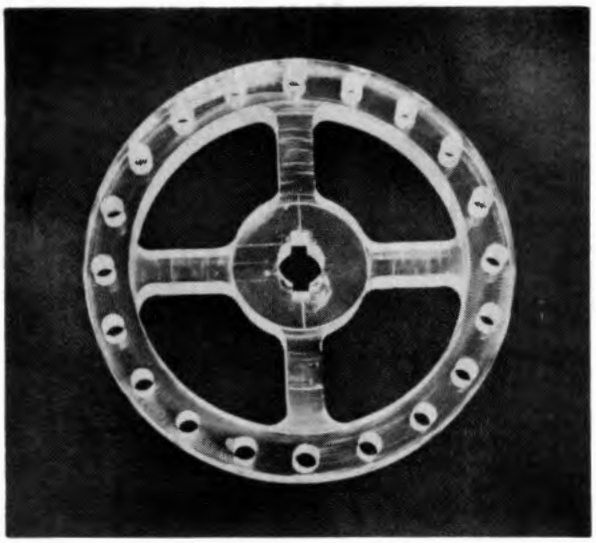


Figure 12. Plexiglass Input Disk from Metering Mechanism.

The output disk was similar to the input disk but with twice the number of cells. This number of cells was necessary because of the function of the disk. One of the objectives of the metering system was to provide a continuous output. By placing the cells close together on the output disk, the gel flow was never entirely cut off. As one cell was being closed off, an adjacent cell was being opened. This provided the necessary flow to keep the seed moving towards the outlet. The output disk was contained in a similar housing to that of the input disk, but without the photoelectric detector.

Two transfer blocks were constructed, one with a 3.5 mm opening for small seed and one with a 5 mm opening for larger seed. A transfer block was mounted between input and output housings. The second photoelectric detector was mounted in this block. The block had only a single passageway for seed to move from the input to the output disk. As the seed passed between the light source and the photo-transister, it was sensed and a timing function was initiated.

The rotational motion of the disks was supplied by stepping motors. The disks needed to be rotated a fixed angular displacement in order to keep the cells properly aligned. Superior Electric Model M092-FD310 stepping motors were used to supply this motion. These electrical motors have 1.8 degree steps or 200 steps per revolution. This allowed five steps between the cells on the output disk and ten steps between cells on the input disk. Each motor was

driven by a separate controlling unit. These controllers accepted a negative logic input with each pulse causing the motor to rotate one step. The amount of disk rotation could be easily controlled by the number of pulses input to the controllers. Figure 13 shows the metering mechanism assembled including the stepping motors.

Travel Speed Detection

In order for the metering system to perform accurately, a means of detecting travel speed was necessary. The rate of travel needed to be rapidly detected in order for the metering mechanism to be able to adjust to any changes. An additional requirement of the detector was that it have a digital output in order to interface with the microcomputer. An optical encoder was used to detect the travel speed. Through use of a photoelectric cell and proper circuitry, the encoder translated the rotation of a shaft into a series of pulses with a constant relationship between distance traveled and the number of pulses. For use with the metering system, the encoder was set to provide one pulse for every ten mm of travel.

Microcomputer

The concept of precision planting neccesitated the identification of individual seed in order to control their spacing. This emphasis on identification of the seed before metering required that some type of monitoring and decision

making device be included in the system. Conventional planters rely on the probability that a seed will be metered and so require no decision making ability. Although this makes a much simpler mechanism, it will inherently have errors in the output.

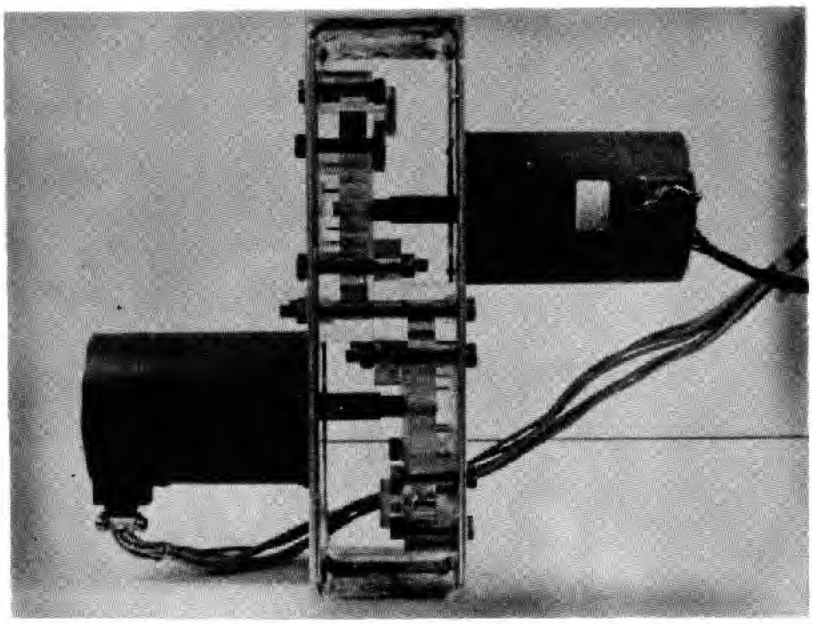


Figure 13. The Assembled Metering Mechanism.

An Intel model MCS 85 microcomputer was used for monitoring and controlling the metering system. The MCS 85 was based on Intel's 8085 central processing unit integrated circuit and was equipped with 2000 bytes of Read Only Memory (ROM), 256 bytes of Random Access Memory (RAM), a six digit

LED display unit and a keypad for data input. The microcomputer in its standard form had insufficient memory for program storage, so a 2000 byte Erasable Programmable Read Only Memory (EPROM) was added.

Metering System Operation

Metering Mechanism Operation

Figure 14 shows the path that a seed must travel through the meter. As seed came through the seed funnel, they were placed in single file. In this way the seed passed the first photoelectric detector individually. After being detected, a time delay allowed the seed to move into a cell of the input disk. The disk then rotated, trapping the seed in the cell. The input disk initially rotated halfway between the cells. It remained in this position, with the seed/gel flow blocked, until time for a seed output. The disk then rotated until a new cell was aligned and the seed/gel flow was resumed.

At the same time seed moved into the cells of the input disk, the previously trapped seed were exiting the cells on the opposite side. Because the input disk had an even number of cells, both inlet and outlet cells were aligned at the same time. Gel from the second tank forced the seed past the second photoelectric sensor and into a cell on the output disk. The sensor triggered a timing circuit which trapped the seed in the output disk. The output disk also had an even number of cells so that as a seed was trapped on

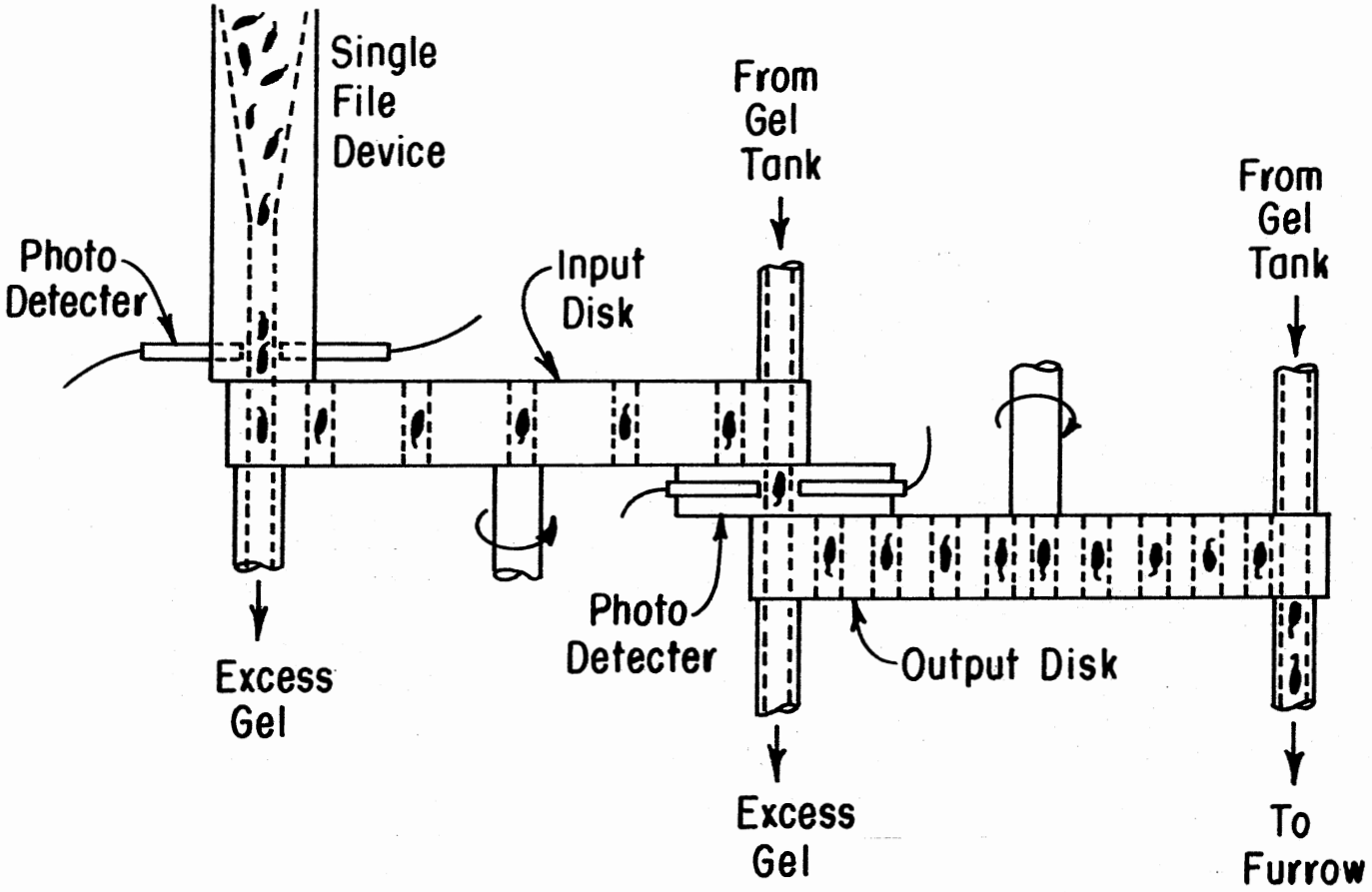


Figure 14. An Illustration of the Seed Path Through the Metering Mechanism

one side of the disk, another seed was released at the outlet side. The cells on the outlet disk were spaced closely together so that the output gel flow was never halted. This provided the metered seed with a continuous flow to the furrow.

The disks rotated independently in order to achieve a seed spacing output that was independent of the input. The input disk rotated on the availability of seed. When a seed was detected, the disk advanced to cut off the seed/gel flow. When a seed output was required, the input cell rotated so that a trapped seed would transfer to the output disk. While trapping the seed, the output disk also released another seed to the furrow.

Control System Development

A programmable microcomputer was used as the basis of a controlling system for the seed meter. The program for the microcomputer was responsible for monitoring two photoelectric detectors and an optical encoder and for controlling two stepping motors in response to the inputs. Figure 15 lists the events that the control system needed to monitor and regulate during a seed's movement through the metering mechanism.

The metering sequence was intiated when the first photoelectric detector determined that a seed was present. This signal started a previously programed time delay which allowed the seed time to move into a cell on the disk. At

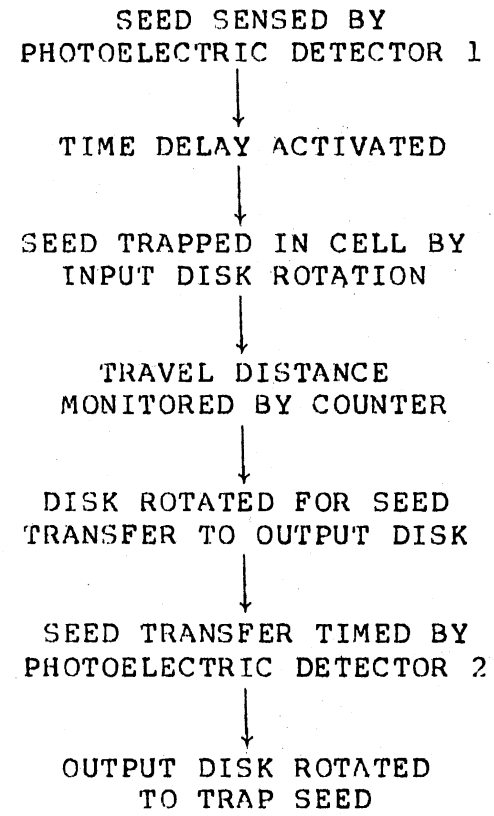


Figure 15. The Order of Events That the Micro-computer Controls.

the end of the time delay, the input disk was rotated to trap the seed. The spacing between seed was determined by programing a counter which counted pulses from the optical encoder. When the desired count was achieved, the input disk was rotated so that a seed could transfer to the output disk. At this point two events were occurring simultaneously. A seed was transfering to the output disk and the input disk was waiting to trap another seed. The seed

transfer was timed by the second photoelectric detector. After the input disk was rotated, a counter began counting up. The count continued until the seed blocked the light from the detector. After the light path was blocked, the counter started back down. When zero was reached, the output disk was rotated to trap the seed. After half the cells were filled, a seed was released from the mechanism whenever a new seed was trapped.

During initial development of the controlling functions, it was recognized that the microcomputer could not monitor both travel speed and seed movement. Although seed movement was intermittent, the distance traveled needed to be determined continuously. For this reason an independent counting circuit was developed for monitoring travel speed (Figure 16). The major building block of the circuit was an Intel 8253 programmable counter. The count value and counting mode were programmed by the microcomputer prior to use. The square wave pulses from the optical encoder were conditioned with a 555 timer integrated circuit operating in a monostable mode. This signal conditioning was necessary due to the high sensitivity of the counter. Without the signal conditioning, a single encoder pulse would be counted as two or three due to transient peaks at the logic Ø to logic 1 transition point.

After being programmed with the counting mode and count value via the eight data lines, the operation was completely independent of the microcomputer. In the chosen operating

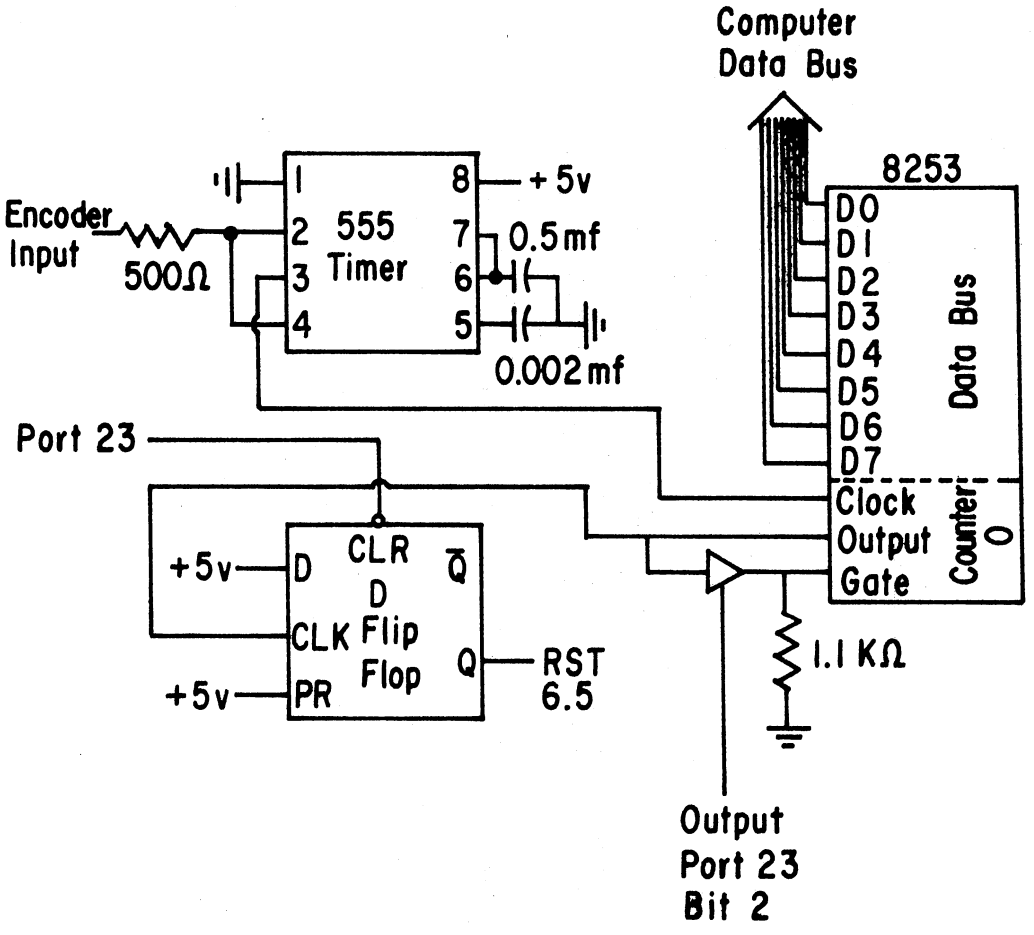


Figure 16. Encoder Pulse Counting Circuit.

mode, the counter counted down to zero and then set the output pin to logic 1. A high level on the output pin did two things: 1) caused a signal to be sent to the microcomputer's interrupt system and 2) reset the counter following the next encoder pulse. Because of this dual purpose, a D type flip-flop memory was used to hold the interrupt signal high. When the counter was reset, the output pin returned to a logic Ø state. If this had occurred before the micro-

computer program had recognized the interrupt signal, it would have been lost. The flip-flop held the signal high until a signal from the microcomputer indicated that the interrupt had been recognized.

With the travel distance monitored by a separate circuit, the microcomputer was freed to control the seed movements through the metering mechanism. This responsibility consisted of recognizing seed presence, controlling the stepping motors and periodically servicing the interrupt. A program was written in Intel's assembly language to perform these tasks in the proper sequence. After being assembled, the program was stored in the EPROM which had been added to the microcomputer. Figure 17 shows the flow charts for the main program and interrupt service routine.

The main program began by initializing the counting circuit and the computer's on-board input/output ports. The program used three of the six available ports, one for input and two for output. To begin operation of the mechanism, the interrupt system was enabled. A polling loop was then entered. Program control kept checking photoelectric detector one until a seed was indicated. Control then moved to the SEED routine (Figure 18). If an interrupt was encountered before a seed, control immediately jumped to the interrupt service routine. After resetting the flip-flop memory in the travel counting circuit, the routine determined if a seed had been previously detected. If a seed had been detected, program control jumped to the SEED routine

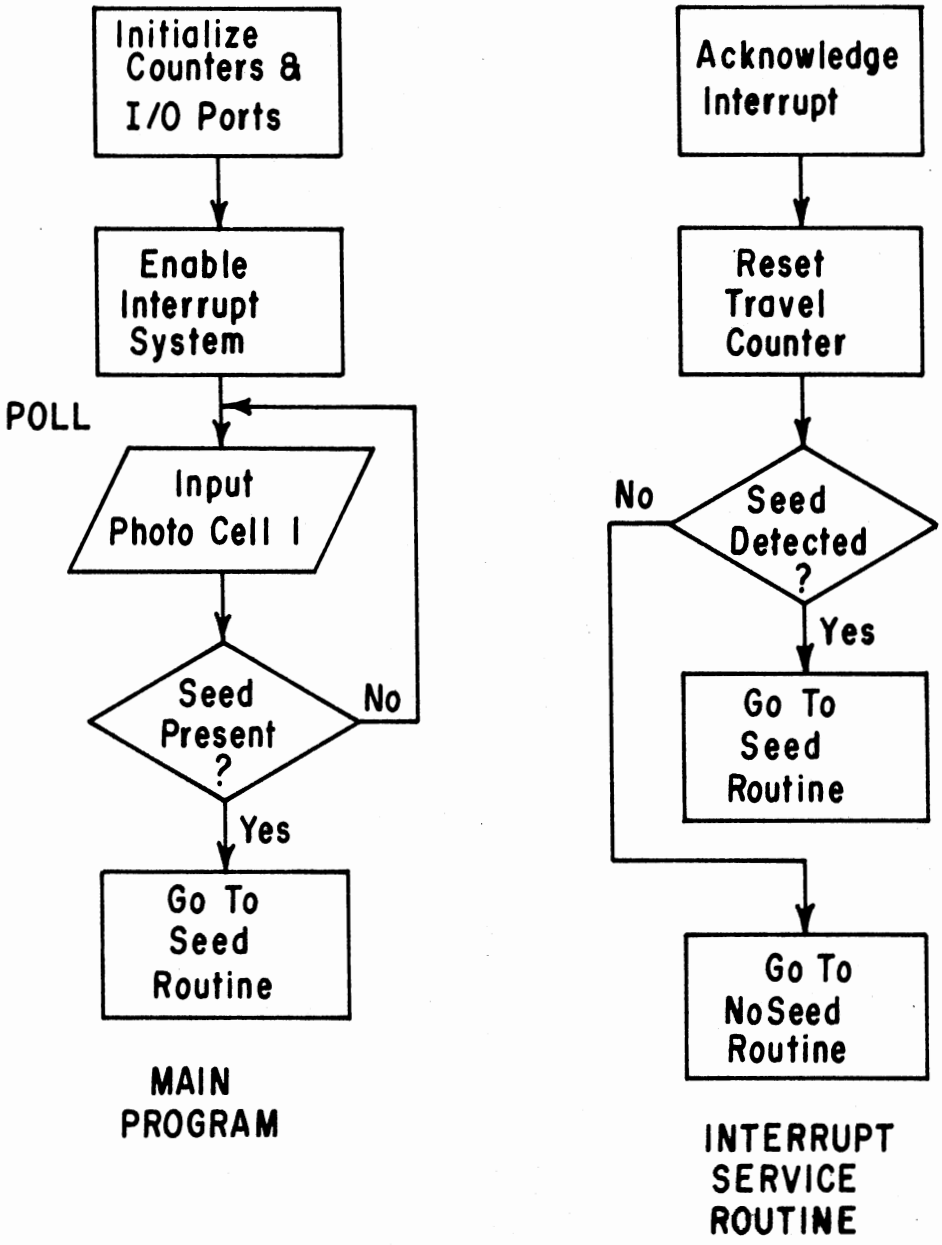


Figure 17. Flowcharts of the Main Program and Interrupt Routine for the Seed Metering System.

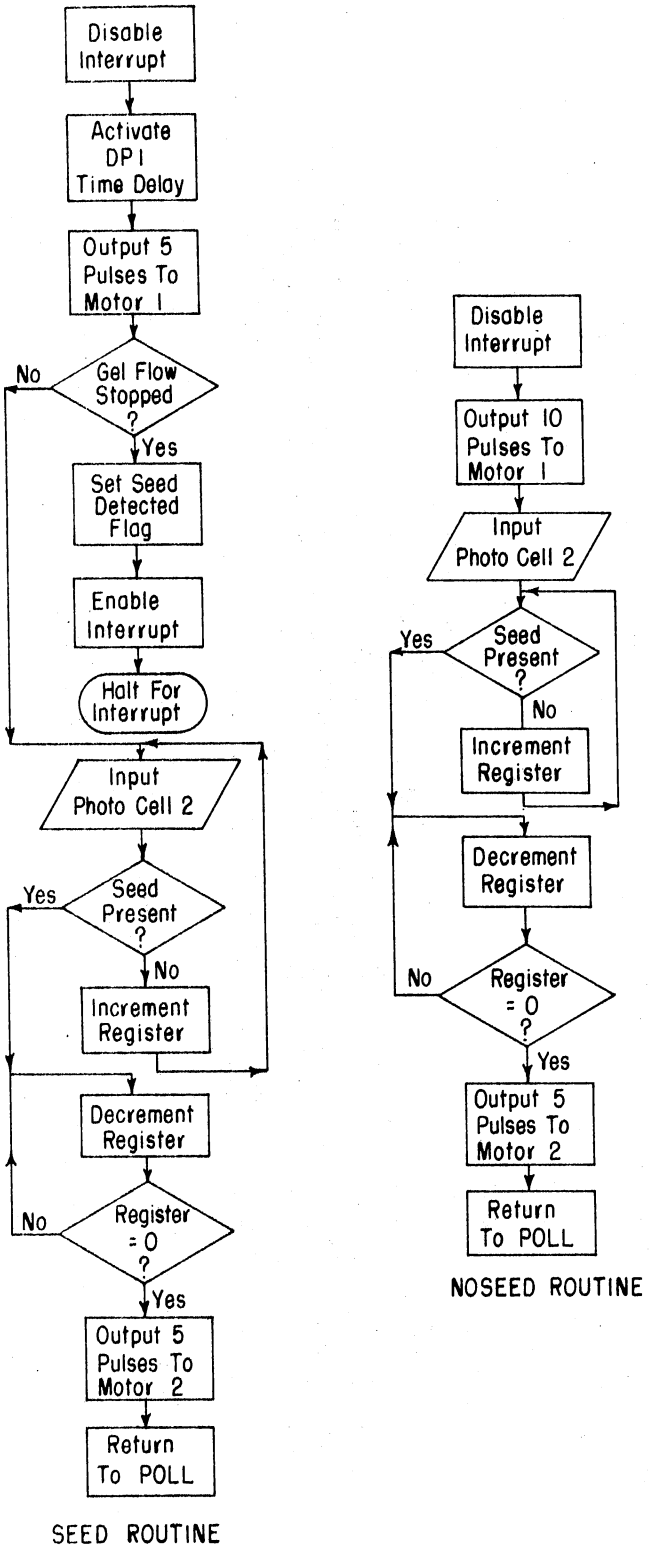


Figure 18. Flowcharts of the SEED and NOSEED Routines of the Controlling Program

and if not, control transferred to the NOSEED routine.

The SEED routine was entered from two locations in the program and worked differently in each case. If control came from the main program, the SEED routine's function was to capture the moving seed in the input disk and wait for the interrupt. If the routine received control from the interrupt service routine, then a seed had previously been trapped. In this case the routine rotated the input disk so that a seed would transfer to the output disk. It then monitored the second photoelectric detector, timed the seed movement and trapped the seed in the output disk. The NOSEED routine had a function similar to the second function of the SEED routine. Since no seed had been trapped, the input disk was rotated ten steps so that the next cell aligned. This allowed a seed to transfer to the second disk. Program flow for the seed transfer functions was identical in the two routines.

The first action taken by the SEED routine upon transfer from the main program was to disable the interrupt system. In this way the interrupt was allowed to function only at the appropriate time. If the interrupt was allowed to occur while pulses were being sent to the motors, the disks would become irretrievably misaligned. The DP1 time delay was then produced to allow the seed to move into the cell. After the time delay, five pulses were sent to the first stepping motor. At this point a flag was checked to see if this movement had blocked the gel flow. If it had, a seed

detected flag was set for the interrupt routine and the interrupt system was enabled again. Program control then went into a halt state, waiting for the interrupt to occur.

If program control had come from the interrupt routine, then a jump was made to the section that timed the seed transfer from the first to the second disk. A polling routine was entered which checked photoelectric detector two for the seed's presence. With each pass through the polling loop, a register was incremented. When the seed passed the detector, another loop was entered to decrement the same register. When the register equaled zero, five pulses were output to the second motor in order to catch the seed. After sending the pulses, control was transferred back to the main program.

The NOSEED routine was used only when the desired spacing had been traveled and no seed had been detected entering the meter. This situation resulted in a skip in the seed output, but because of the disk rotations the skip was delayed for thirty spaces. The NOSEED routine was very similar to the SEED routine except that ten pulses were sent to motor one and the routine did not halt for an interrupt. Since the routine itself was prompted by the interrupt signal, both motors were rotated and control was transferred back to the main program as rapidly as possible.

Control System Revision

During testing of the metering system, it became appar-

ent that the use of the microcomputer for both seed monitoring and motor pulse output was disadvantageous. The microcomputer was limited in its monitoring and outputing capacity. It could do only one operation at a time. With the metering mechanism as designed, often two events needing attention occurred simultaneously. This was especially true with the input disk. Figure 19 shows a timing diagram for the program. The encoder pulses indicated the travel rate, and frequency varied in direct proportion to the travel speed. The interrupt signal moved to logic 1 when the counter reached zero. The typical metering cycle began with a pulse from the first photoelectric cell. After receiving the pulse, the computer timed a delay, DP1, and sent five pulses to rotate the input disk. The program then halted for the interrupt. This waiting period was variable depending on when the seed was originally encountered, the desired seed spacing and travel speed. After the interrupt, the computer took 15 msec to rotate the first disk, waited a minimum of 50 msec for the seed transfer and took another 15 msec to rotate the output disk. After the input disk was rotated, two events were occurring. The trapped seed was being transferred from the input to the output disk, and seed from the seed/gel tank were entering the opposite side of the disk. Both events required monitoring by the computer, but only the seed transfer could be observed. This left a minimum of 65 msec that the seed could escape through the disk without detection. This minimum time

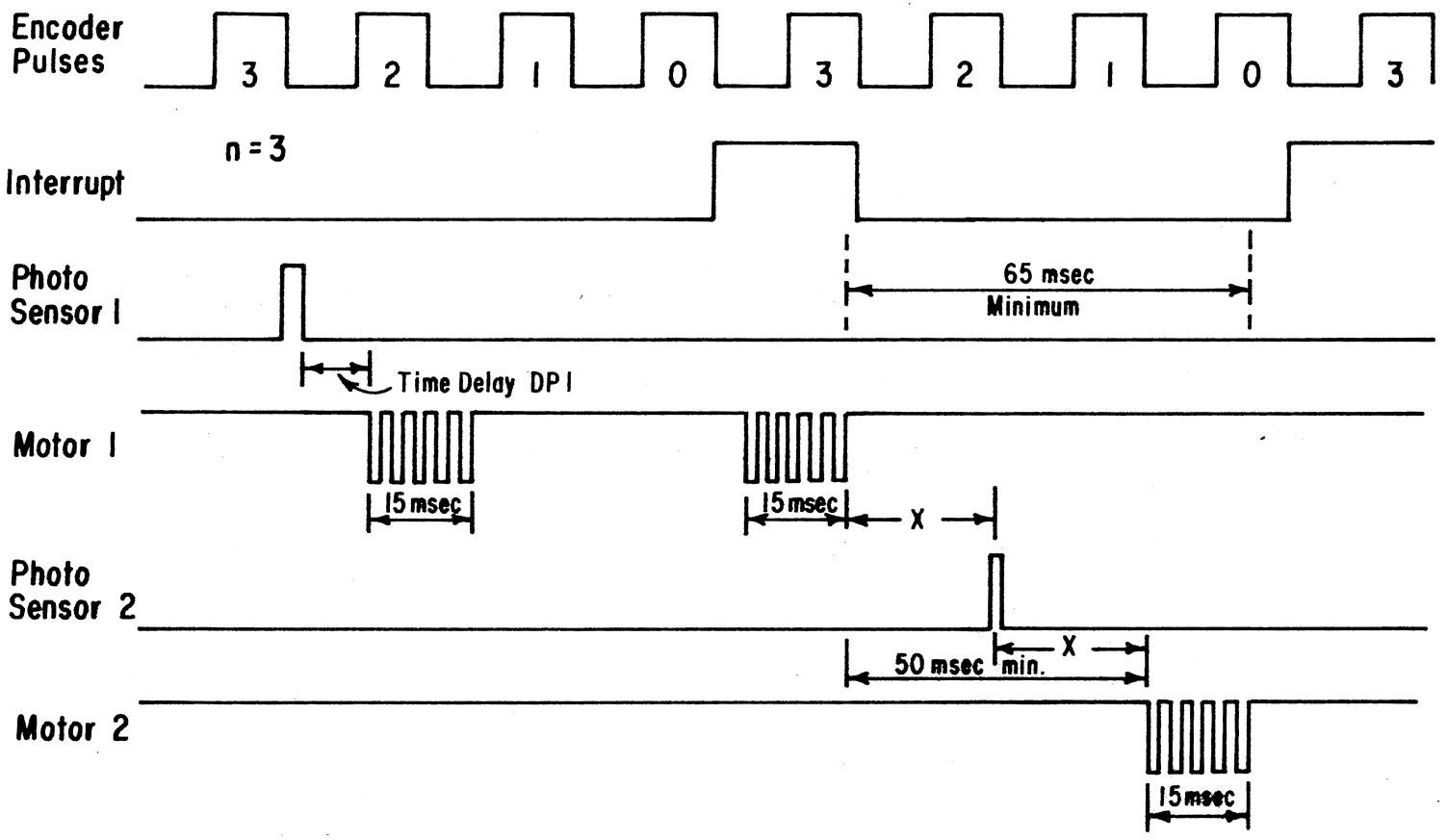


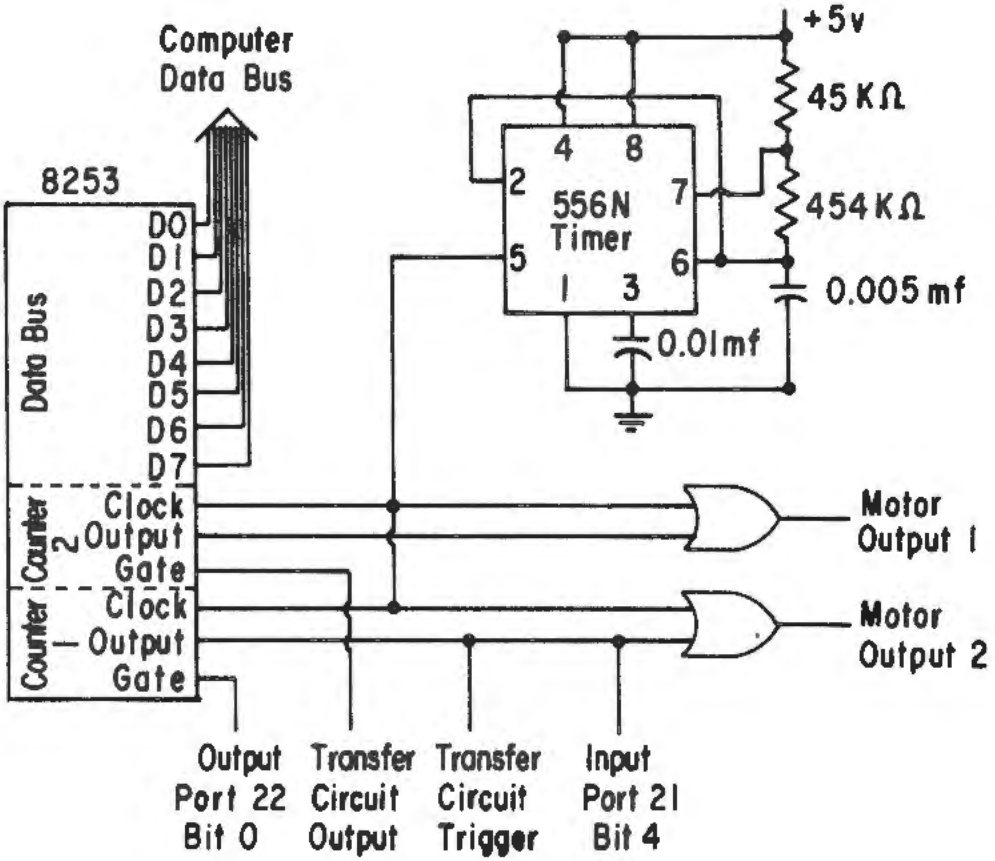
Figure 19. Timing Diagram for Operation of the Metering Mechanism with the Original Microcomputer Program

period was determined by the maximum speed at which the seed could move and still be trapped in the cells. In actual practice the time period was much longer. Another difficulty encountered was that the time delays and motor pulse outputs are fixed values. Regardless of the travel speed or desired spacings, these events require the same amount of time. As the interrupt frequency increased, due to increased travel speed or decreased spacing, the time available for waiting on and servicing the interrupt decreased. During testing it was determined that the maximum seeding rate with the original program was 1.5 seed/sec. This was the maximum speed at which the interrupts could be recognized and serviced.

The use of the microcomputer for measuring time delays was extremely inefficient. The microcomputer could operate very rapidly (the MCS-85 had a clock cycle of 320 nanoseconds) and accurately in a decision making role. The elimination of the time delays from the microcomputer's responsibility allowed it to operate more efficiently and devote a much larger portion of time to the primary responsibility of monitoring seed movement. This change was accomplished by the use of independent circuits. With independent circuits to produce the time delays, the microcomputer had only to output a brief pulse and return to monitoring. After an initial triggering pulse, the circuits were designed to rotate the motors and time the seed without further input from the microcomputer.

Figure 20 shows the wiring schematic and timing diagram for the circuits designed to drive the stepping motors five steps. The circuits consisted of one timer from a 556N dual timer integrated circuit, the two previously unused counters on the 8253 programmable counter and two "OR" gates. The timer was used to create a square wave clock signal with a period of approximately 3 msec. This clock signal was common to both counters and was also used as the source for the motor pulses. The counters, one for each motor, were programmed in a retriggerable one shot mode. The counter outputs and the clock signal were combined in an "OR" operation to produce the motor pulses. The timing diagram illustrates the circuit operation. Each counter sampled the gate pin on rising clock edges. After the counter recognized a change in the gate pin from low to high, the output pin was set low and the count was decremented on falling clock edges. When the output pin was set low, the "OR" output was allowed to follow the clock pulses. The Boolean Algebra "OR" operation sets the output high if either or both of the inputs is high. In this manner the output pin of the counter acted as a switch. When five falling clock edges had been counted, the signal to the motor was set high. This matched the motor controller's requirements of negative logic input.

An additional circuit was designed to monitor the transfer of seed from the input to the output disk. The use of this circuit allowed the movement of seed on both sides of the input disk to be monitored simultaneously. The



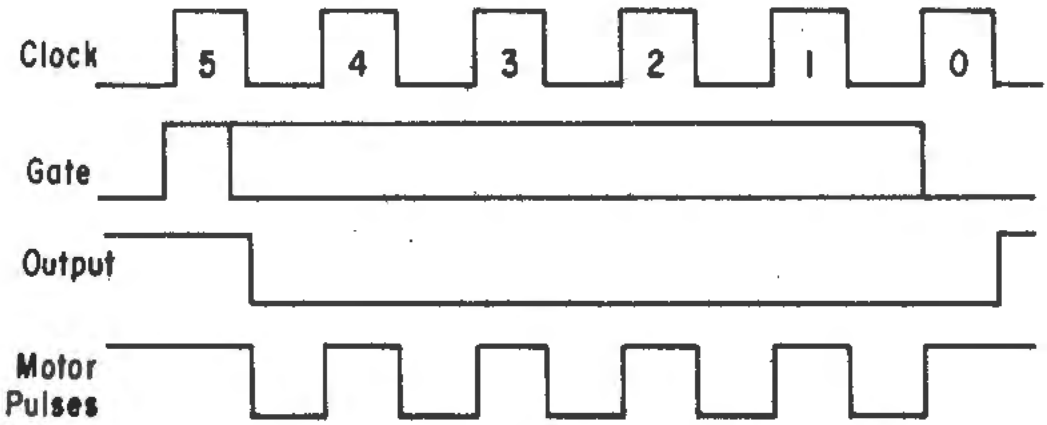


Figure 20. Wiring Schematic and Timing Diagram for Motor Pulse Generating Circuits.

duties of the transfer circuit were to start counting up after being triggered by the pulse generating circuit for motor one, stop counting when the seed blocked the light beam of the photoelectric detector, start counting down after the seed passed out of the light beam and trigger the rotation of the output disk after reaching zero. Figure 21 shows the configuration used to achieve these responsibilities. The integrated circuits used included a dual J-K flip-flop memory (74LS76N), two four bit up/down counters (74LS169N and 74-4029), one half of a dual timer (556N), three inverters and an "OR" gate. The up/down counters were cascaded to provide an eight bit counter.

The circuit had three inputs and one output. The inputs included an enable signal from the microcomputer, a triggering signal from the motor one driving circuit and the second photoelectric detector. The enable signal was necessary because the input disk rotated five steps twice between each operation of the transfer circuit. The first rotation trapped a seed and since a transfer was not occurring, the circuit was disabled. On the second rotation a seed would transfer and the circuit was enabled before the motor one drive circuit was triggered. The single output was used to trigger the rotation of the output disk.

The external resistance and capacitance values for the timer were adjusted to give a clock frequency of approximately 5 kHz. As previously mentioned the circuit had two inputs which were required to begin counting, the enable

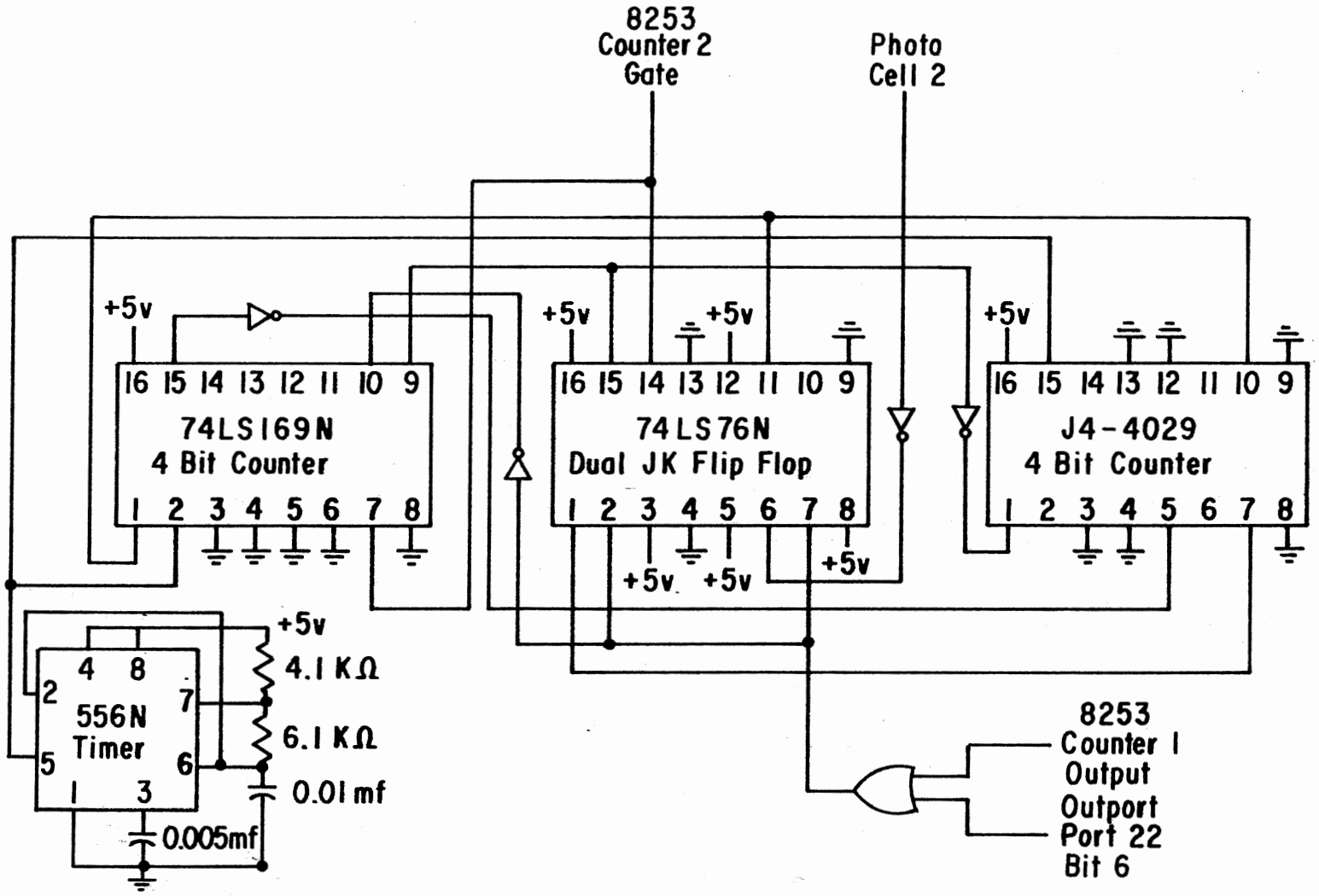


Figure 21. Wiring Schematic for the Seed Transfer Circuit

signal from the microcomputer and the trigger from the motor one circuit. These two signals were combined in an "OR" operation to create a single trigger which could enable counting. The falling edge of this trigger initiated counting. At this point, the count was started at the value currently on the counter input pins. To insure that the count always began at zero, all eight input pins were grounded.

The two flip-flop memories were used to hold the counter inputs at the proper values. In this manner, the width of the circuit triggering pulse was unimportant. One of the flip-flops was used to control the output signal to the motor circuit and the other controlled the counting direction input. Each memory had one input in addition to the initial trigger. The count direction memory was connected to the photoelectric detector. When it detected a seed, the count direction was changed. The output signal flip-flop was tied to the output of the J4-4029 counter. This counter was responsible for the end of count signal. When the count returned to zero, the output signal to the motor circuit was returned high.

The actual timing of the various signals occurred in the following sequence (Figure 22). A counting trigger was generated by combining the circuit enable and counter one output pin in an "OR" gate. On the falling edge of the pulse, the count was loaded and the count direction was set as up. On the rising edge, counting was enabled and the count was incremented on each clock pulse. Counting contin-

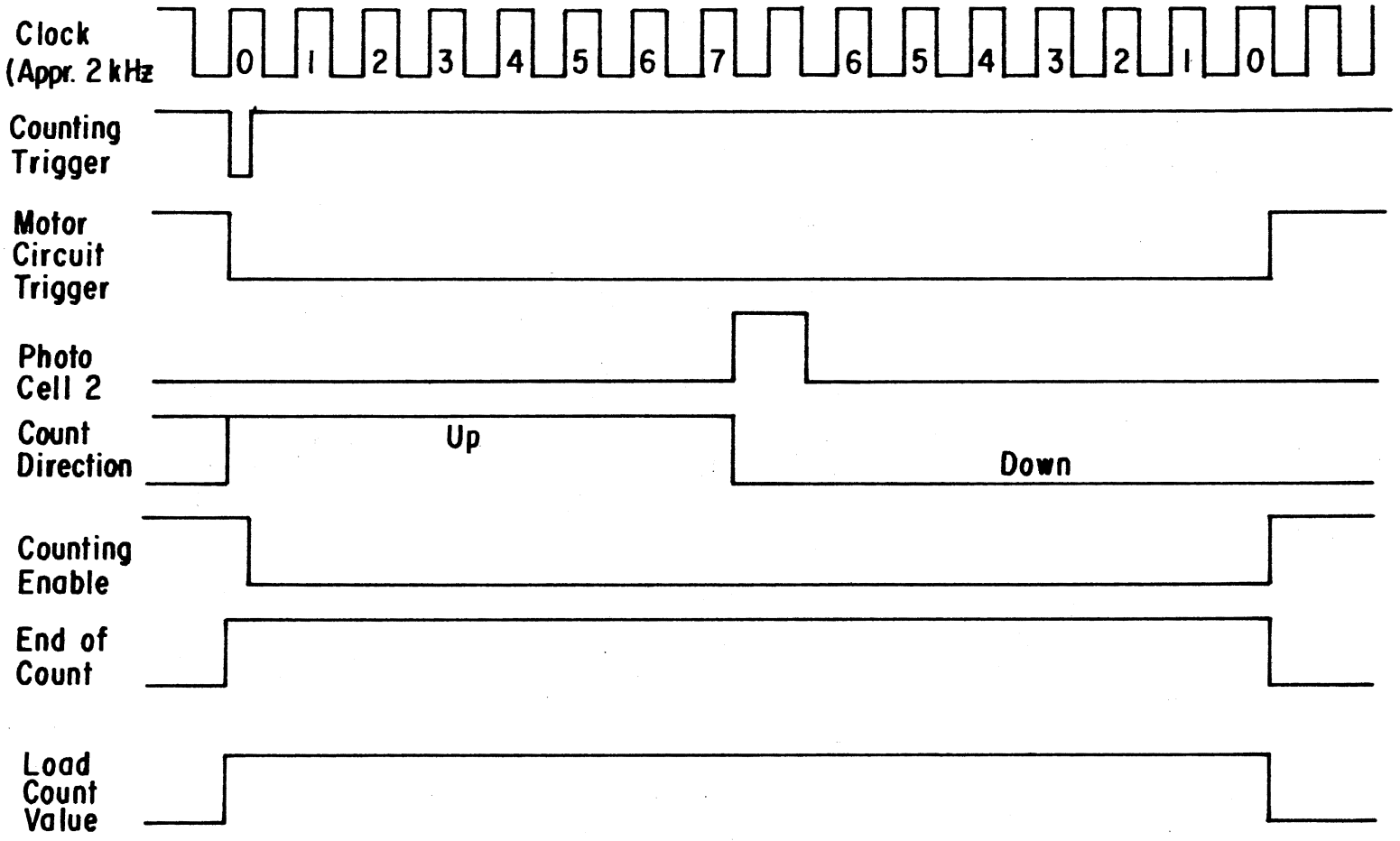


Figure 22. Timing Diagram for the Transfer Circuit

ued until the rising edge of the signal from the second photoelectric detector. This changed the counting direction. The count then decremented to zero. Upon reaching zero the end of count signal went low, causing the motor circuit trigger to go high. This high signal caused the output disk to be rotated.

Figure 23 illustrates the controlling program flow as revised to include the independent circuits. Appendix B lists both the revised and original controlling programs. The program was very similar to the original program up to the point where the DP1 time delay was activated. Instead of jumping to a routine which outputs a series of pulses, the program sends a single signal to the motor controlling circuit. The program paused to insure that the circuit received the signal, set the proper flags and moved into a halted condition to await the interrupt. The width of the pulse varied up to a maximum of 3 msec depending on the state of the circuit's clock at the beginning of the pulse.

After receiving the interrupt signal, the circuit for motor one was started again. Since the flags indicated a seed was trapped, an enabling signal was sent to the transfer circuit. After enabling the circuit, control was transferred back to the polling loop before the stepping motors could finish rotation. In this way the microcomputer was always ready to monitor seed movement.

The interrupt service routine was modified to eliminate the NOSEED routine. If a seed had not been trapped between

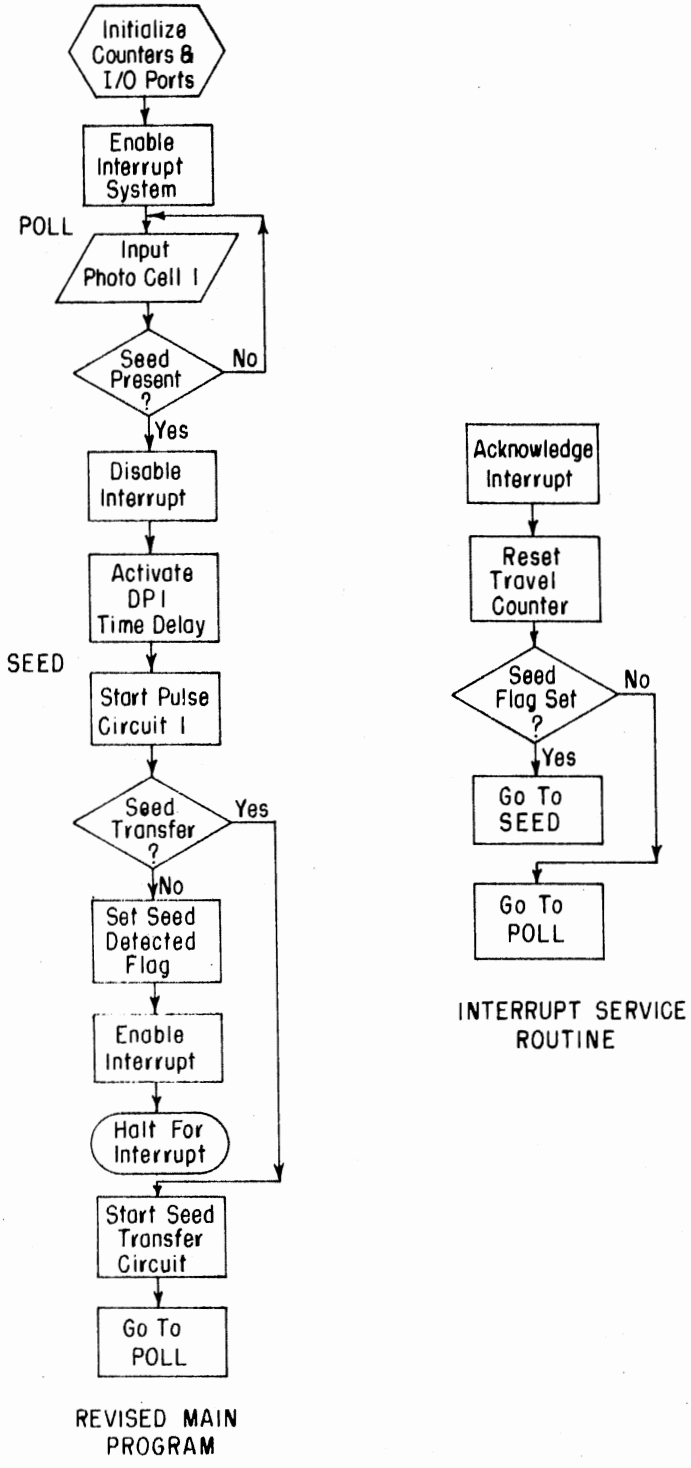


Figure 23. Flow Charts for the Revised Metering System Controlling Program and Interrupt Routine

consecutive interrupt signals, then control transfers back to the polling loop. This meant that no disk rotation occurred and the resulting skip was immediately output.

The timing diagram for the revised program is shown in Figure 24. In the revised configuration the microcomputer itself had only two inputs, the optical encoder and the first photoelectric detector. It still had two outputs but the time requirements for these were significantly diminished. The encoder and interrupt system operated as previously described. In response to photoelectric cell 1, the computer counted down the DP1 time delay and sent a three msec maximum width pulse to the first motor circuit. Upon servicing the travel interrupt, the computer enabled the circuit controlling seed transfer and output disk rotation by setting that signal high. Another pulse was then sent to the circuit for motor 1. With the enable signal high, the completion of motor 1 rotation started the seed transfer circuitry. Upon completion of the seed transfer, the second motor rotated to trap the seed in the output disk. This enable signal remained high until the next seed was detected by photoelectric cell 1.

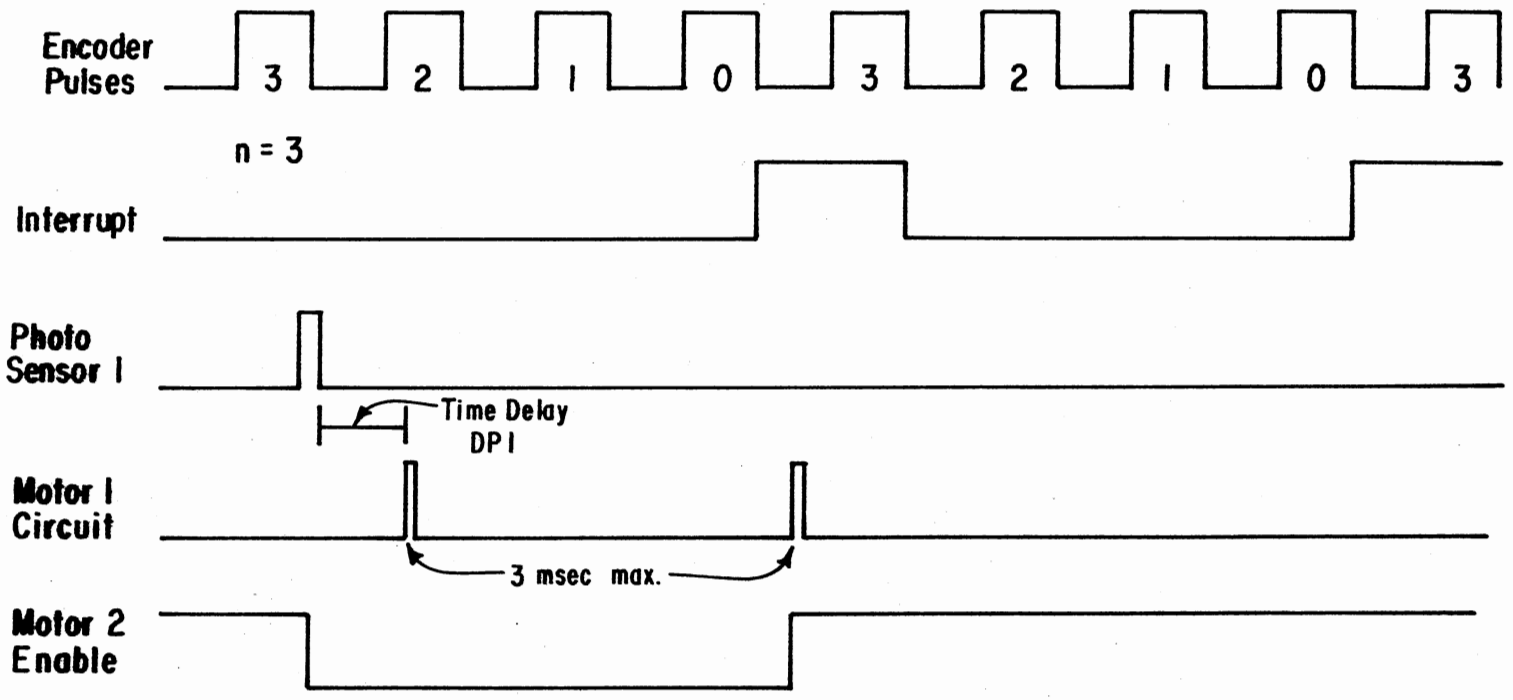


Figure 24. Timing Diagram for the Revised Metering System Control Program

CHAPTER V

PRESENTATION AND DISCUSSION OF RESULTS

Gel Measurements

Early in the development of the concepts of a metering device for pregerminated seed, it was determined that a means of transporting and protecting the fragile seed was necessary. Past experimental work had shown that high viscosity gels worked satisfactorily in this respect. However, little work had been published on the rheology of these gels. For this reason a study was undertaken to determine the rheological properties for two gels: Viterra II Soil Amendment Gel, manufactured by the Nepra Chemical Co. and CLD, manufactured by the Buckeye Cellulose Corp.

Viterra II and CLD were chosen from a group of gels identified as having a possibility for use as a seed carrier. These two gels were identified as best meeting a list of desirable quality for use in a seed metering device. The gels were tested with three different viscometers. Initial tests were conducted on Viterra II with a Fann viscometer. After obtaining a Brookfield viscometer, tests were conducted on both gels. In addition, a capillary viscometer was constructed and also used for taking viscometric data.

Viscosity Relationships

Data from tests with all three viscometers is listed in Appendix C. The test results indicate that shear stress versus shear rate and apparent viscosity versus shear rate relationships were best modeled by the power law equations (Equation 3 and 9). In all cases, the exponent was less than one indicating that the gels were of a pseudoplastic nature.

$$\tau = k\ \gamma^{n} \tag{3}$$

$$\mu = k\ \gamma^{(n-1)} \tag{9}$$

Data taken with each viscometer was modeled with a regression routine to calculate the coefficients and exponents of best fit. This was done indepedently for each viscometer and then for the combined data. Tables III and IV show the calculated values for each viscometer and the combined data along with an estimate of the fit of the equations.

For Viterra II the regression equations yielded similar results. The discrepancies which did occur could be attributed to the variations in the range of shear rates at which the viscometer operated. The Brookfield viscometer was limited to a range of 0.5 to 22 sec^{-1} when used with a 600 ml beaker. The capillary viscometer ranged from 30 to 235 sec^{-1} and the Fann device from 5 to 1025 sec^{-1}. When

TABLE III

COEFFICIENTS AND EXPONENTS OF THE POWER LAW EQUATION FOR VITERRA II

Conc. (%)	Brookfield			Capillary			Fann			Combined		
	k	n	R^2	k	n	R^2	k	n	R^2	k	n	R^2
0.5	3.07	.523	.975	4.86	.509	.999	1.57	.542	.944	2.99	.497	.840
0.7*	4.47	.539	.987	8.11	.482	.978	4.17	.485	.975	4.68	.520	.947
1.0	7.11	.521	.981	10.09	.477	.987	3.92	.551	.973	6.79	.508	.932

*for capillary data, concentration was 0.75

TABLE IV

COEFFICIENTS AND EXPONENTS OF THE POWER LAW EQUATION FOR CLD

Conc. (%)	Brookfield			Capillary			Combined		
	k	n	R^2	k	n	R^2	k	n	R^2
1.8	0.91	.589	.879	0.61	.875	.990	0.62	.827	.946
2.0	3.30	.536	.960	2.35	.701	.915	3.06	.631	.983
2.2	5.52	.602	.958	4.13	.638	.994	5.53	.577	.995

combined, the data gives an estimate of the viscosity over a wide range of shear rates.

The CLD gel did not have the agreement between the two viscometers that was shown with the Viterra II. Although the different ranges of shear rate may have accounted for part of the variation, the method of applying shear may also have accounted for a large portion of the difference. The exponent showed the greatest difference between the two measuring methods. The shear stress increased more slowly for increasing shear rate when measured with the Brookfield viscometer. It was observed while taking measurements, that the rotating bob of the Brookfield machine often seemed to be rotating in a thin film of water rather than the gel. This phenomenon may have been due to the molecular structure of the gel. CLD consisted of large cellulose molecules which would attract a certain number of water molecules. If more water was present than could be bound to the cellulose molecules, free water resulted. This free water in the gel may have behaved differently under different shearing situations, resulting in the exponent variation observed.

Figures 25 and 26 illustrate the shape of the combined apparent viscosity versus shear rate curves for Viterra II and CLD, respectively. In both cases the curves were shear thinning or pseudoplastic in nature. This type of rheology was particularly useful in a seed carrier application. When under low shear, as would be experienced in a tank, the viscosity remained high and the seed could be held in suspen-

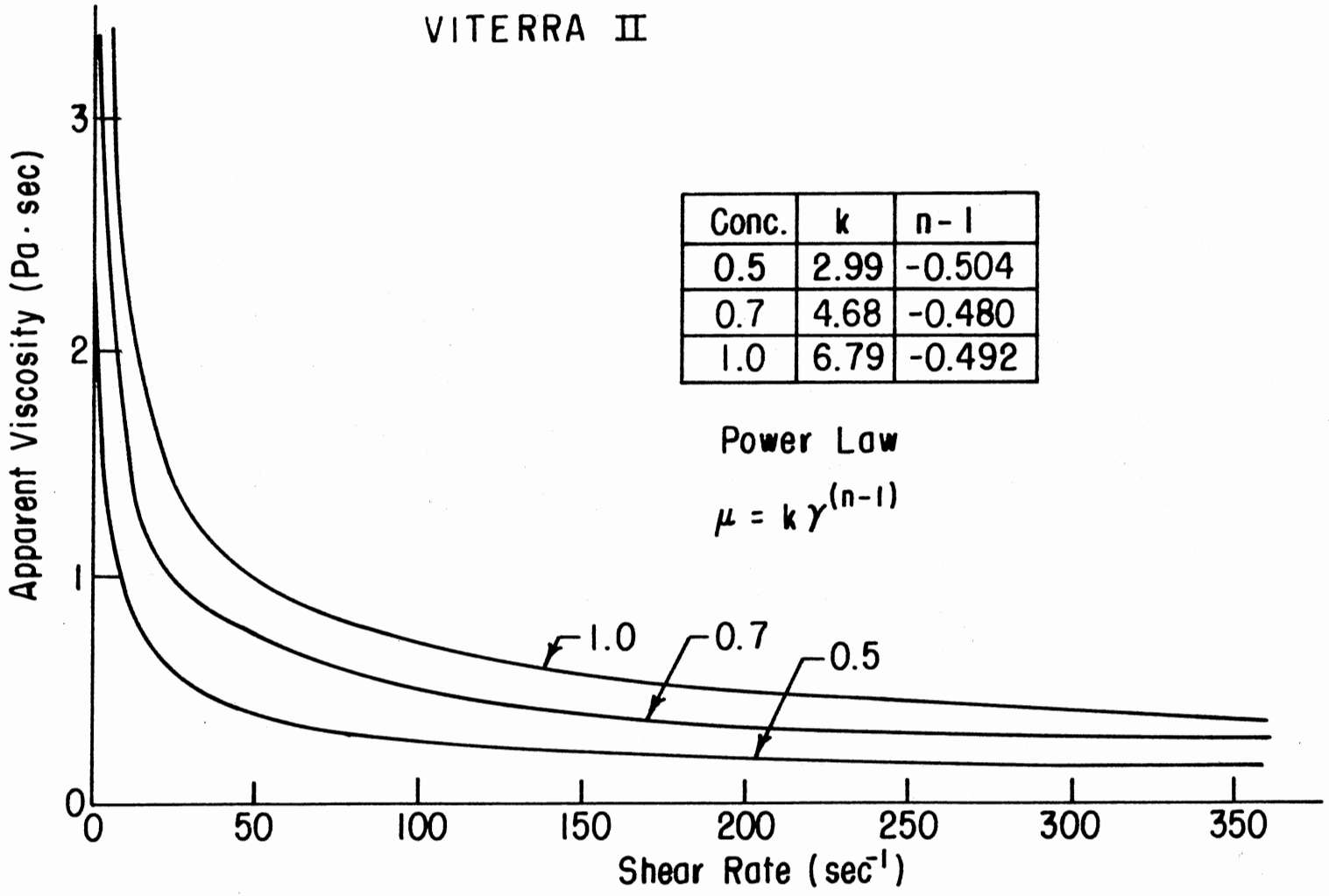


Figure 25. Apparent Viscosity of Viterra II as a Function of Shear Rate for the Combined Data of all Viscometers

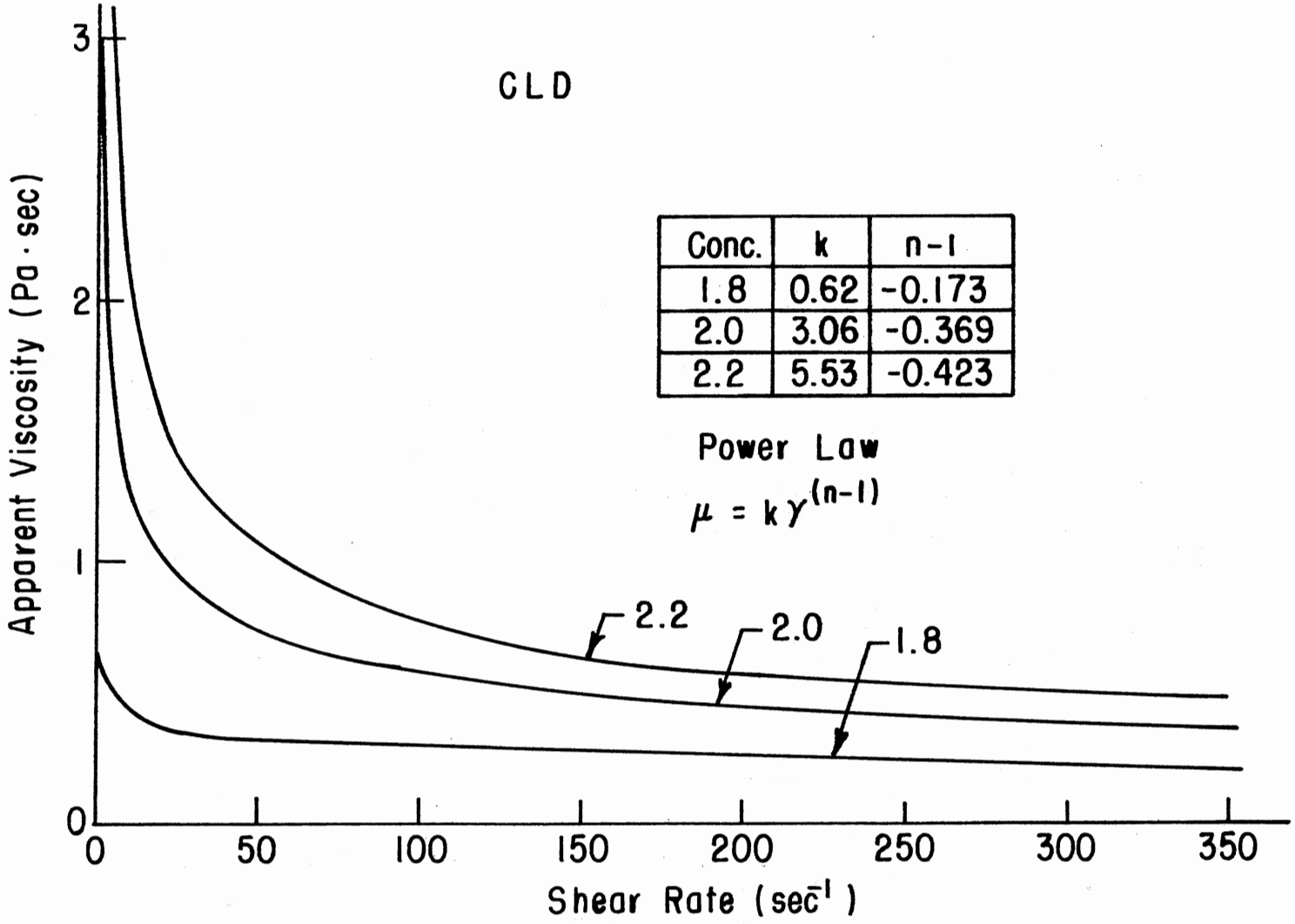


Figure 26. Apparent Viscosity of CLD as a Function of Shear Rate for the Combined Data of all Viscometers

sion. When the gel experienced higher shear rates, during pumping or gel movement, the apparent viscosity dropped significantly. This allowed pumping to take place with a smaller power requirement.

Determination of Thixotropic Characteristics

Non-Newtonian gels often exhibit thixotropic (time dependent) qualities in addition to shear rate dependent characteristics. Tests were conducted to determine the thixotropic properties of Viterra II. The Brookfield viscometer was used to determine the change in shear stress over time at a constant shear rate. The tests were not conducted in an ideal manner due to the need to stop the viscometer to take readings. Thixotropic tests would ideally be conducted continuously, with no disruption in the shear rate over a long period of time. However, Viterra II regained its original viscosity very slowly, so short pauses to read the viscometer caused small error in the resulting data.

Thixotropic behavior can generally be modeled as a linear function of the logarithm of time versus apparent viscosity (Green, 1949) as shown in equation 10. The data was fit to this model with the SAS regression procedure.

$$\mu = \mu_0 - b_t \log(\text{time}) \qquad (10)$$

μ_0 - apparent viscosity at time = Ø

b_t - thixotropic constant

Table V lists the calculated values for μ_0 and b_t at each concentration and shear rate. The pseudoplastic nature of the gel was shown by the initial apparent viscosities at each concentration. As the shear rate (RPM) increased the initial viscosity decreased. Also as the initial viscosity decreased, the rate of change with time also decreased. Figures 27, 28 and 29 show the thixotropic curves for each of the three concentrations. Although it was important to be aware of the thixotropic nature of the Viterra II gel, this property of the gel was of less importance than the pseudoplastic qualities. The gel normally passed through the seed meter rapidly, allowing little time for a change in viscosity.

Seed Suspension Qualities

One of the most important properties of a gel in consideration for use with a seed meter is its ability to hold the germinated seed in suspension. In an effort to determine the particle suspension qualities of CLD and Viterra II, gel/seed mixtures were placed on a vibration table and vibrated for one hour. Four concentrations of each gel were tested for seed suspension ability. CLD concentrations were vibrated at two different frequencies, 15 Hz and 50 Hz. Viterra II was vibrated only at the 15 Hz frequency. Each gel concentration was sampled before and after vibration to

determine the amount of seed movement. Samples were taken from three levels of each concentration and the number of seed at each level was determined. This data is listed in Appendix D. For analysis purposes the number of seed in the upper portion was subtracted from the number of seed in the lower portion. This difference was examined to determine the migration of the seed during vibration. A small difference would indicate little movement due to vibration.

TABLE V

VITERRA II THIXOTROPIC EQUATION COEFFICIENTS

CONC	RPM	μ_0	b_t	R^2
0.6	10	3.530	0.654	0.983
0.6	20	2.114	0.284	0.898
0.6	50	1.264	0.128	0.938
0.8	10	4.913	0.921	0.888
0.8	20	3.366	0.613	0.920
0.8	50	2.059	0.343	0.995
1.0	10	5.857	1.033	0.970
1.0	20	3.276	0.384	0.876

An analysis of variance (AOV) was conducted on the level difference for both gels. The AOV for CLD was done in a split plot design with the concentration as the sub-plot factor. The AOV for Viterra II did not involve a frequency

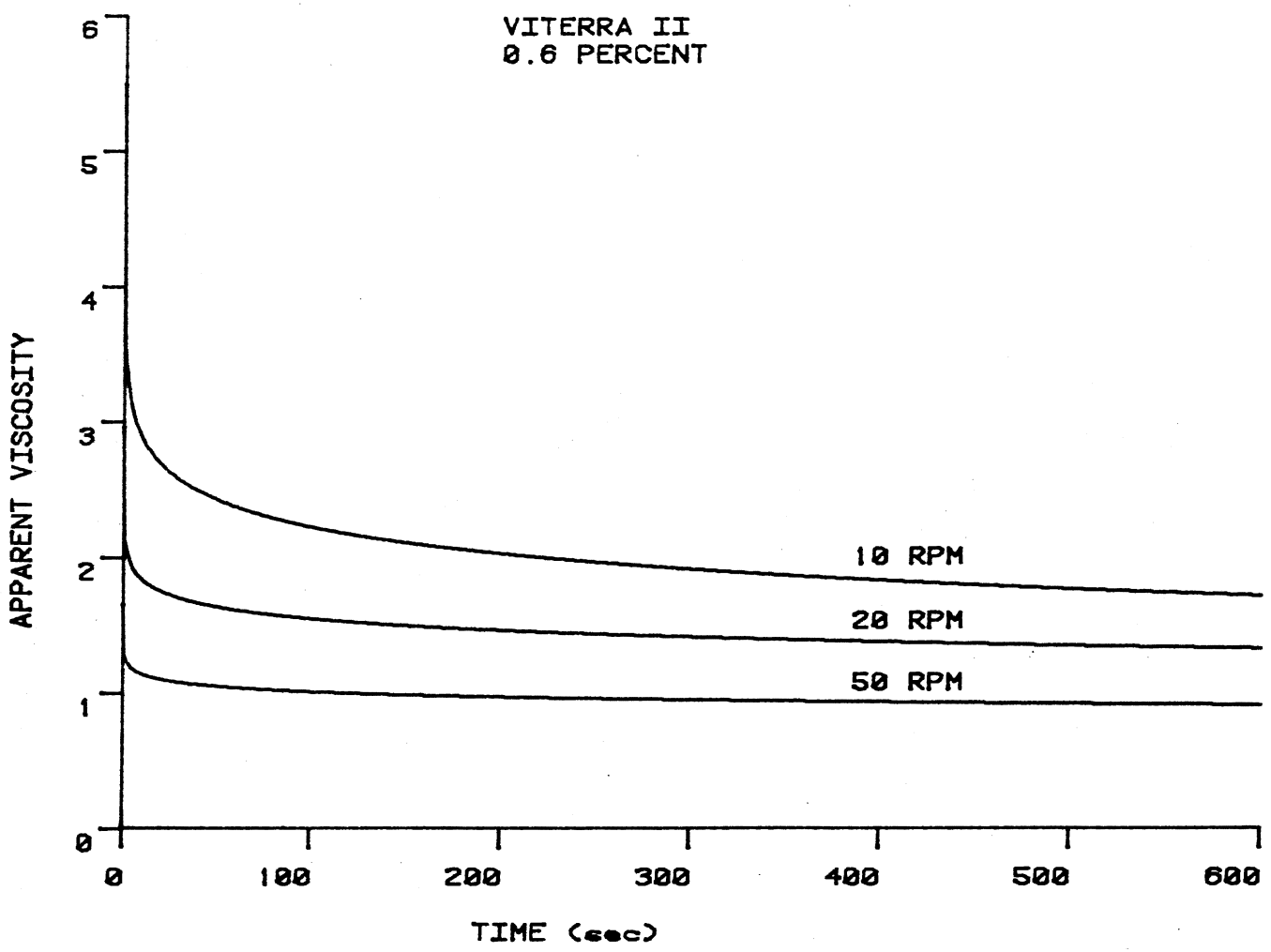


Figure 27. Apparent Viscosity of 0.6 Percent Viterra II as a Function of Time

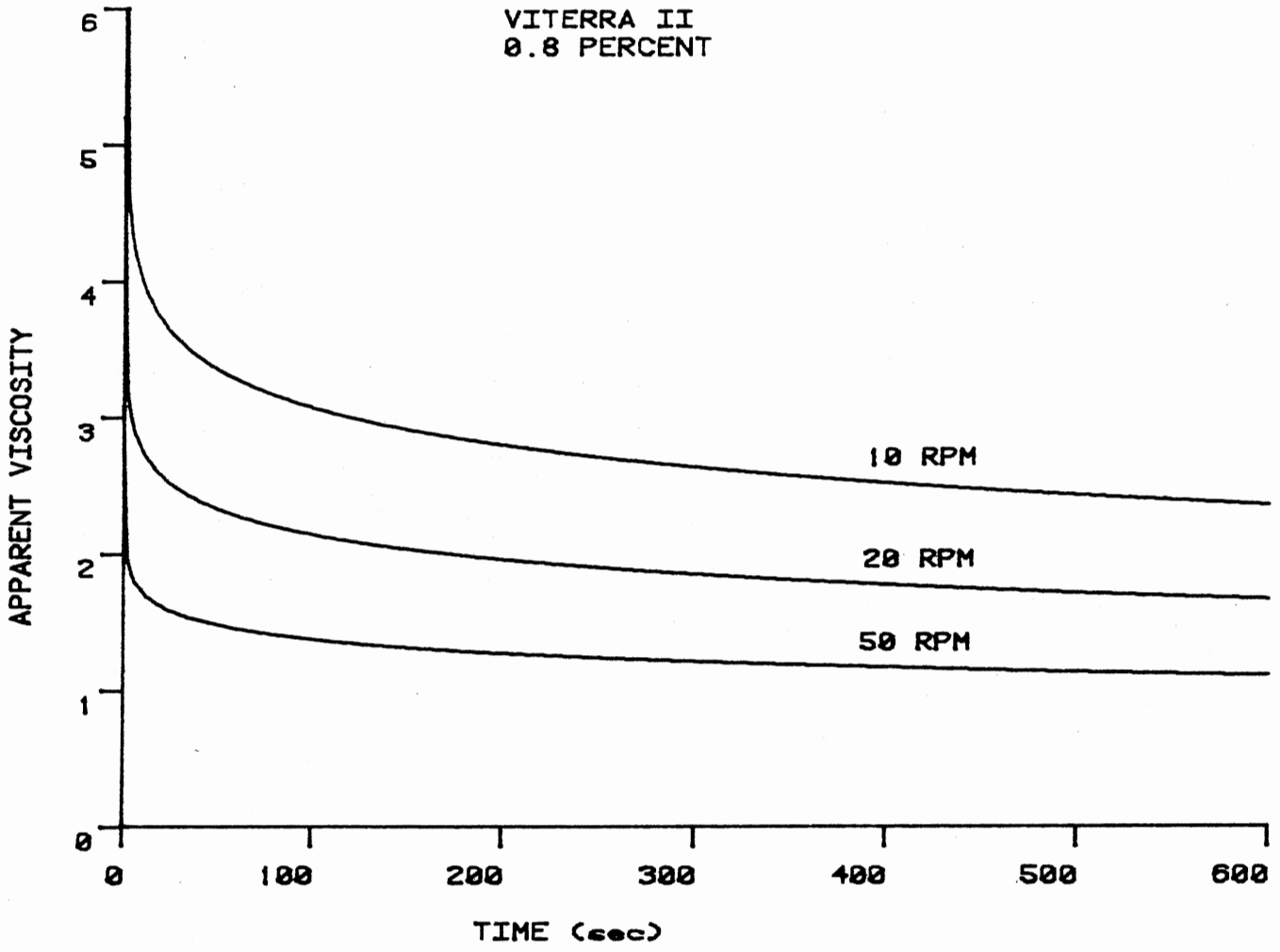


Figure 28. Apparent Viscosity of 0.8 Percent Viterra II as a Function of Time

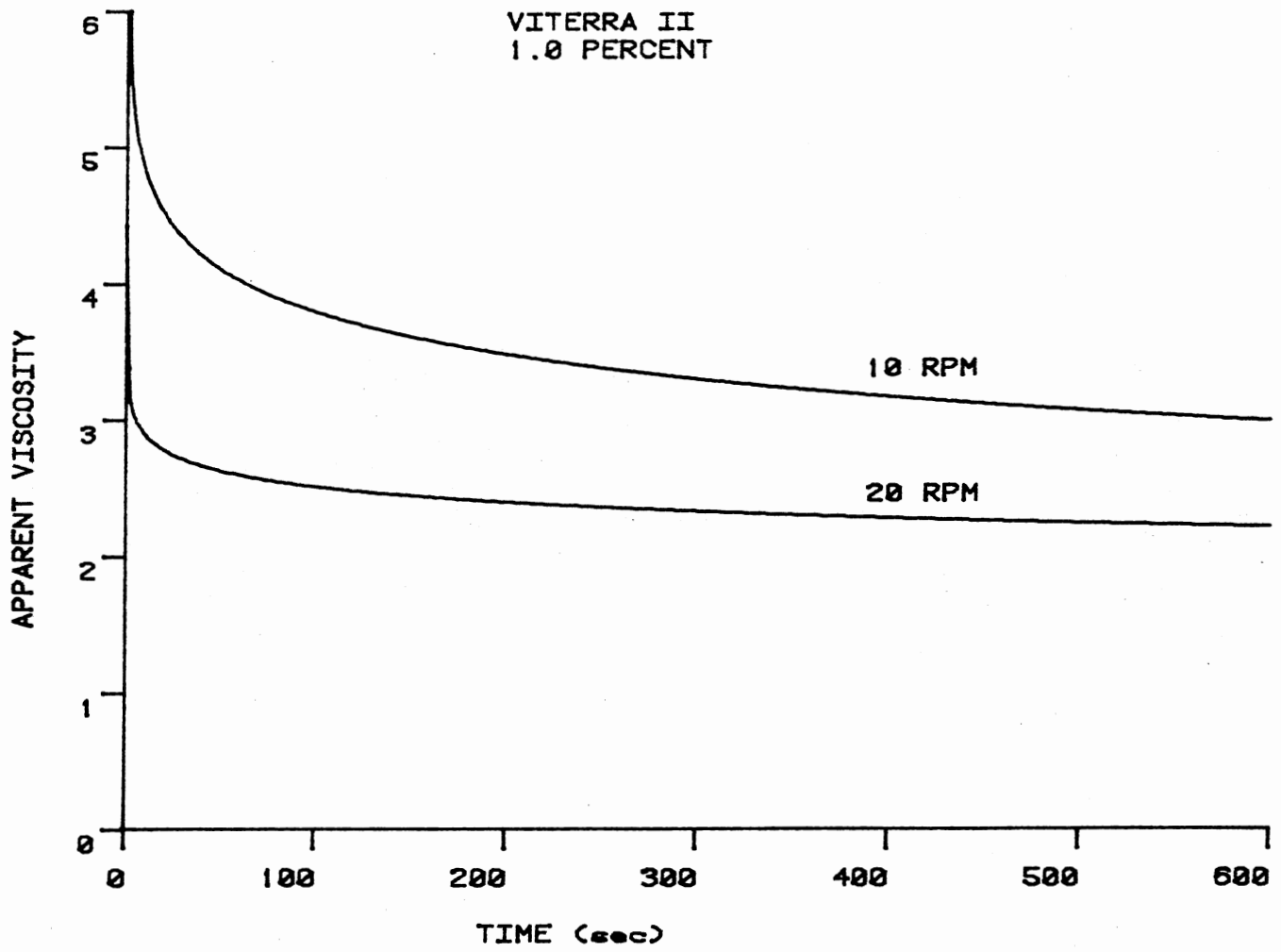


Figure 29. Apparent Viscosity of 1.0 Percent Viterra II as a Function of Time

effect, so it was analyzed as a completely randomized design. Tables VI and VII contain the analysis of variance for the difference between the upper and lower portions for CLD and Viterra II respectively. The analyses shown are for the data taken after vibrating for one hour. Similar analyses were run on data taken before the vibration and as would be expected, no differences were shown between the levels of the variables.

TABLE VI

ANALYSIS OF VARIANCE OF SEED SUSPENSION DATA FOR CLD

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE*
Corrected Total	31	6282.36		
Replication	1	107.64		
Frequency	1	489.45	1.30	0.459
Error A	1	375.73		
Concentration	3	3646.91	14.49	0.005
Freq.xConc.	3	263.67	1.05	0.439
Error B	6	503.40		
Sampling Error	16	895.56		

*Probability of error in rejecting a null hypothesis of no significance of the source of variation.

TABLE VII

ANALYSIS OF VARIANCE OF SEED SUSPENSION DATA FOR VITERRA II

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE*
Corrected total	15	1706.07		
Replication	1	163.20	1.91	0.322
Concentration	3	1034.70	4.04	0.141
Error (Rep.xConc.)	3	256.35		
Sampling Error	8	251.83		

*Probability of error in rejecting a null hypothesis of no significance of the source of variation.

As indicated by the F ratio, the gels did not behave similarly with respect to comcentration. As the gel comcentration increased, the amount of seed movement significantly decreased for CLD. The mean differences between the number of seed in the upper and lower portions were 32.9, 19.1, 11.2 and 4.2 for CLD concentrations 1.65, 1.8, 1.95, and 2.1 percent, respectively. The least significant difference at the five percent level for these means was 11.2. As previously mentioned, CLD consisted of large molecules which bound water molecules to themselves. In visual observation of the gel after vibration, it was noticed that the cellulose settled along with the seed. Each gel container had a layer of free water at the top after the vibration. The height of this layer depended on the gel concentration, ranging from approximately one quarter of the container

depth for the 1.65 percent gel to no visible water for the 2.1 percent mixture. This settling of the gel molecules during vibration was a distinct disadvantage of CLD. The vibration of the CLD mixture at frequencies of 15 and 50 Hz did not have any significant effect on the settling of the seed. Most of the settling was observed to have occurred in the first ten minutes of vibration.

The effect of increasing gel concentration was not significant for Viterra II. The mean differences between the upper and lower portions were 47.0, 44.5, 36.1 and 26.4 for gel mixtures of 0.8, 0.9, 1.0 and 1.1 percent, respectively. The least significant difference between the means at the five percent level was 20.8. Although the Viterra II gel did a poor job of holding seed in suspension, the gel itself did not break down like the CLD.

On the basis of these rheological tests, Viterra II was chosen for use in the rest of the study. Although CLD had several advantages over Viterra II, such as greater optical clarity, easier mixing and cleanup, lower viscosity and better seed suspension qualities, the disadvantage of the free water separation outweighed the advantages. In some preliminary tests with CLD under pressure, the free water was actually squeezed from the gel when it passed through constricted areas. This caused a blockage of the flow, which got worse as more water separated from the gel.

Unmetered Seed Spacing Distribution

Pregerminated seed have been planted with extrusion type devices. The most common method has been the use of a peristalic pump to move a seed/gel mixture from a large holding tank to the furrow in a continuous flow. Several planters of this type have been designed and patented (Fiedler and Summers, 1972; Phillips and Scott, 1967), however, little or no information has been published on the type of spacing distribution achieved by these planters. Richardson and O'Dogherty (1972) completed a theoretical analysis of the spacing distribution that could be expectd from an extrusion type planter but they did not publish any empirical data to substantiate their analysis. Tests were undertaken in this study to determine the spacing distribution which could be expected from an unmetered extrusion of a seed/gel mixture from a tank containing a uniform mixture of seed and gel.

The spacing distribution of cucumber seed was measured at several different travel speeds and gel/seed ratios. The gel/seed ratios were expressed in terms of ml per seed for the entire mixture. Gel flow rates were calculated for the different travel speeds and the proper number of seed was mixed in the gel to give the desired gel/seed ratio. Appendix E lists the spacing distributions for each test.

Richardson and O'Dogherty calculated that the cumulative distribution would have a decaying exponential shape as predicted by the following equation.

$$N_x = N_0 \, e^{-\lambda x} \qquad (11)$$

N_x - number of spacings greater than or equal to x

N_0 - total number of spaces

λ - spacing density constant

x - measured spacing

To evaluate the accuracy with which this equation could predict the measured spacing distribution, the data was modeled with a two parameter nonlinear regression. The two calculated parameters corresponded to N_0 and λ. Table VIII lists the calculated parameters for each recorded test as well as an estimate of the goodness of fit of the resulting equation. The goodness of fit statistic was calculated as the percentage of the total raw sum of squares accounted for by the regression equation. This table illustrates the change in λ as the gel/seed ratio was increased. λ was a measure of rate of decay of the cumulative distribution. As would be expected, as the gel/seed ratio increased the rate of decay decreased. In all cases the calculated equations fit the data very well. Figure 30 shows a representative cumulative distribution with measured values shown along the calculated curve.

Table IX shows the effect of travel speed on the calculated parameters. All tests were run at a gel/seed ratio of 3 ml/seed. A single gel/seed mixture was mixed and all four tests were run from that mixture. The only change between

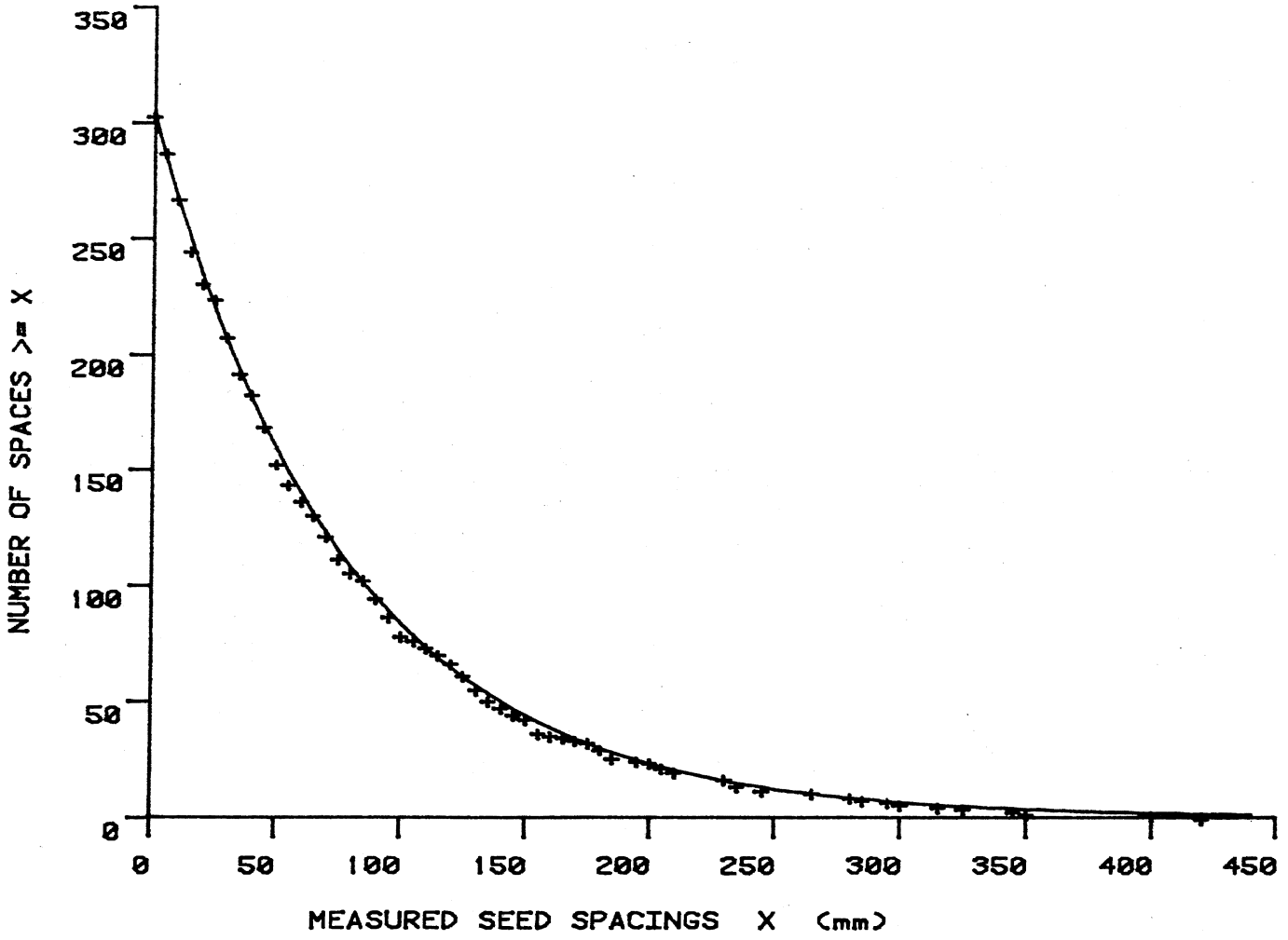


Figure 30. An Example of an Unmetered Cummulative Spacing Distribution, Prediction Equation and Measured Values

TABLE VIII

CALCULATED PARAMETERS FOR CUMULATIVE SPACING DISTRIBUTIONS

GEL/SEED RATIO (ml/seed)	NUMBER OF SPACES N_0	ESTIMATED N_0	λ	REGRESSION PERCENT OF SS
1	358	339.6	0.0463	0.997
1	448	438.4	0.0341	0.999
2	308	303.2	0.0207	0.999
2	363	373.0	0.0226	0.999
3	304	303.7	0.0129	0.999
4	342	341.2	0.0113	0.999
5	260	256.9	0.0088	0.999

TABLE IX

CALCULATED PARAMETERS FOR THE CUMULATIVE DISTRIBUTION AS AFFECTED BY TRAVEL SPEED

TRAVEL SPEED (km/hr)	NUMBER OF SPACES N_0	ESTIMATED N_0	λ	REGRESSION PERCENT OF SS
1	214	217.3	0.0180	0.999
3	254	259.7	0.0134	0.999
5	304	303.7	0.0129	0.999
7	241	246.9	0.0123	0.998

tests was the belt travel speed and a corresponding increase in the tank pressure. With increasing travel speed, the rate decay decreased slightly. The causes of change are uncertain but could be attributed to an inability to hold

the gel outlet velocity equal to the travel speed or an effect of velocity on seed movement through the seed funnel.

The spacing data fits the cumulative distribution as predicted by Richardson and O'Dogherty. The authors did not, however, attempt to predict the mean spacing based on their analysis. The following is a derivation of a predictor of the mean.

Based on the equation for the cummulative frequency distribution, the frequency, f, of any interval width of Δx is:

$$f_{x+\frac{\Delta x}{2}} = \frac{N_x - N_{x+\Delta x}}{\Delta x} \tag{12}$$

If the limit of f is taken as x goes to Ø, then f equals the negative derivative of N .

$$\lim_{\Delta x \to 0} f_{x+\frac{\Delta x}{2}} = \lim_{\Delta x \to 0} \frac{N_x - N_{x+\Delta x}}{\Delta x}$$

$$f_x = -\frac{d}{dx} N_x$$

$$f_x = N_0 \lambda e^{-\lambda x} \tag{13}$$

The mean spacing can be calculated with:

$$\overline{X} = \left(\sum_{x=0}^{\infty} f_x \cdot x\right)/N_0 = (1/N_0) \int_0^{\infty} x \cdot N_0 \lambda e^{-\lambda x}\, dx$$

$$\bar{X} = 1/\lambda \qquad (14)$$

Thus the mean spacing can be predicted by the reciprocal of λ. Table X shows the actual and predicted means for each of measured distribtuions. Although the actual and predicted means do not precisely agree, the actual mean is generally within 10 percent of the predicted value.

TABLE X

ACTUAL AND PREDICTED MEANS FOR UNMETERED SEED DISTRIBUTIONS

TRAVEL SPEED (km/hr)	GEL/SEED RATIO (ml/seed)	ACTUAL MEAN (mm)	PREDICTED MEAN (mm)
5	1	23.0	21.6
5	1	33.2	29.3
5	2	51.6	48.3
5	2	48.6	44.3
5	3	79.9	77.5
5	4	91.5	88.5
5	5	112.4	113.6
1	3	61.9	55.6
3	3	76.0	74.6
7	3	86.5	81.3

In addition to predicting the spacing distribution from a uniformly mixed gel/seed mixture, Richardson and O'Dogherty also state "the seed spacing distribution is generally unsuitable for precision seeding of row crops". The

use of pregerminated seed makes precision spacing even more desirable because a very high emergence percentage can be achieved. This poses the possiblity of planting a crop directly to stand if precision spacing can be achieved. Unmetered sowing is inadequate for this purpose and points out the need for an accurate metering device capable of planting germinated seed.

Metered Seed Spacing Distribution

A precision metering device was developed as previously described and tested with four different vegetable crops. The effects of metering rate and gel/seed ratio on the spacing distribution were determined for cabbage seed. After determining optimum operating conditions, the metering system was tested with three other vegetable seed, lettuce, tomato and cucumber, to determine its ability to handle different seed sizes and shapes. Cabbage was chosen for the initial testing of the seed meter because of its shape, size and uniformity of germination. The cabbage seed was round with a diameter of approximately 3.5 mm and would uniformly germinate in 24 hours. This uniform germination supplied seed with equal radicle lengths, and eliminated the need to sort the seed prior to testing. Because the germination percentages were high for all the vegetables involved, sorting after germination was not utilized. Prior to germination, all four species had been dry sorted in an air column to remove the light, less vigorous seed.

Two major variables affected the operation of the metering system, the gel/seed ratio and the metering rate. The gel/seed ratio was expressed in units of ml per seed and controlled the frequency with which the seed came available for metering. The metering rate was determined by the spacing value loaded into the microcomputer program and the travel speed. With a constant spacing value, the metering rate increased in direct proportion to the travel speed. For testing of the metering system, gel/seed ratios of 4, 3, 2 and 1 ml/seed were used. At each gel/seed ratio four metering rates, 0.5, 1.0, 2.0 and 3.0 seed/sec, were investigated. In addition, rates of 4.0 and 5.0 were tested at the 2.0 ml/seed ratio.

The spacing distributions were measured for each test and evaluated for spacing uniformity and metering error. Metering error consisted of the percentage of skips and doubles for a given distribution. All spacings less than 50 percent of the desired spacing were considered to be doubles. Spacings greater than 150 percent of the desired spacing were considered as single skips, spacings greater than 250 percent of desired were considered two consecutive skips, spacings greater than 350 percent were considered three consecutive skips, etc. For the calculation of percentages, a theoretical number of spacings was determined. The theoretical number of spaces was calculated by adding the actual number of spacings to the number of skips and subtracting the number of doubles. This method approximated

the number of spaces that would have been measured if the seed meter had worked perfectly.

Table XI lists the percentage skips, doubles and total error for each of metering tests. The data shows that both gel/seed ratio and metering rate caused changes in the metering error. A high gel/seed ratio meant that seed were less available for filling of cells on the input disk. This caused few doubles and a higher number of skips. As the gel/seed ratio was decreased, the number of doubles increased and the number of skips dcreased slightly. The number of skips did not change as much as the number of doubles because of errors in transferring seed from the input to output disk. Doubles generally resulted from two seed being adjacent as they moved into the input cells. Skips resulted from a seed not being available at the input disk and from failure to transfer correctly from the input to the output disk. As the gel/seed ratio was decreased, the portion of skips due to seed location decreased while those errors due to seed transfer remained approximately the same.

The metering rate also caused a major effect at all gel/seed ratios. As would be expected the number of errors increased as the metering rate increased. A particularly critical point seemed to be a metering rate of 2.Ø seed/sec. Figure 31 illustrates the total error as a function of metering rate. At all four gel/seed ratios, the percentage of total metering errors sharply increased at 2.Ø seed/sec. Tomato was evaluated at only two metering rates in order to

TABLE XI

SEED METERING ERROR FOR ALL METER TESTS

Gel/Seed Ratio (ml/seed)	Metering Rate (seed/sec)	Actual Number of Spaces	Theoretical Number of Spaces	Percent Skips	Percent Doubles	Total Percent Error
4.0	0.5	144	157	10.2	1.9	12.1
4.0	1.0	370	382	8.1	5.0	13.1
4.0	2.0	316	343	12.8	5.0	17.8
4.0	3.0	311	343	21.3	12.0	33.3
3.0	0.5	162	186	15.1	2.2	17.3
3.0	1.0	346	373	14.7	7.5	22.2
3.0	2.0	323	356	15.4	6.2	21.6
3.0	3.0	331	432	36.6	13.2	49.8
2.0	0.5	181	178	6.7	8.4	15.1
2.0	1.0	364	354	4.5	7.3	11.8
2.0	2.0	383	386	5.7	4.9	10.6
2.0	3.0	469	489	12.7	8.6	21.3
2.0	4.0	501	556	18.5	8.6	27.1
2.0	5.0	522	635	29.8	12.0	41.8
1.0	0.5	196	180	5.0	13.9	18.9
1.0	1.0	355	363	12.9	10.7	23.6
1.0	2.0	388	380	7.9	9.2	16.3
1.0	3.0	488	484	12.8	13.6	26.4
2.0*	0.5	126	156	26.9	7.7	34.6
2.0*	3.0	154	375	64.5	5.6	70.1
2.0**	0.5	106	170	47.6	10.0	57.6

*Tomato **Lettuce

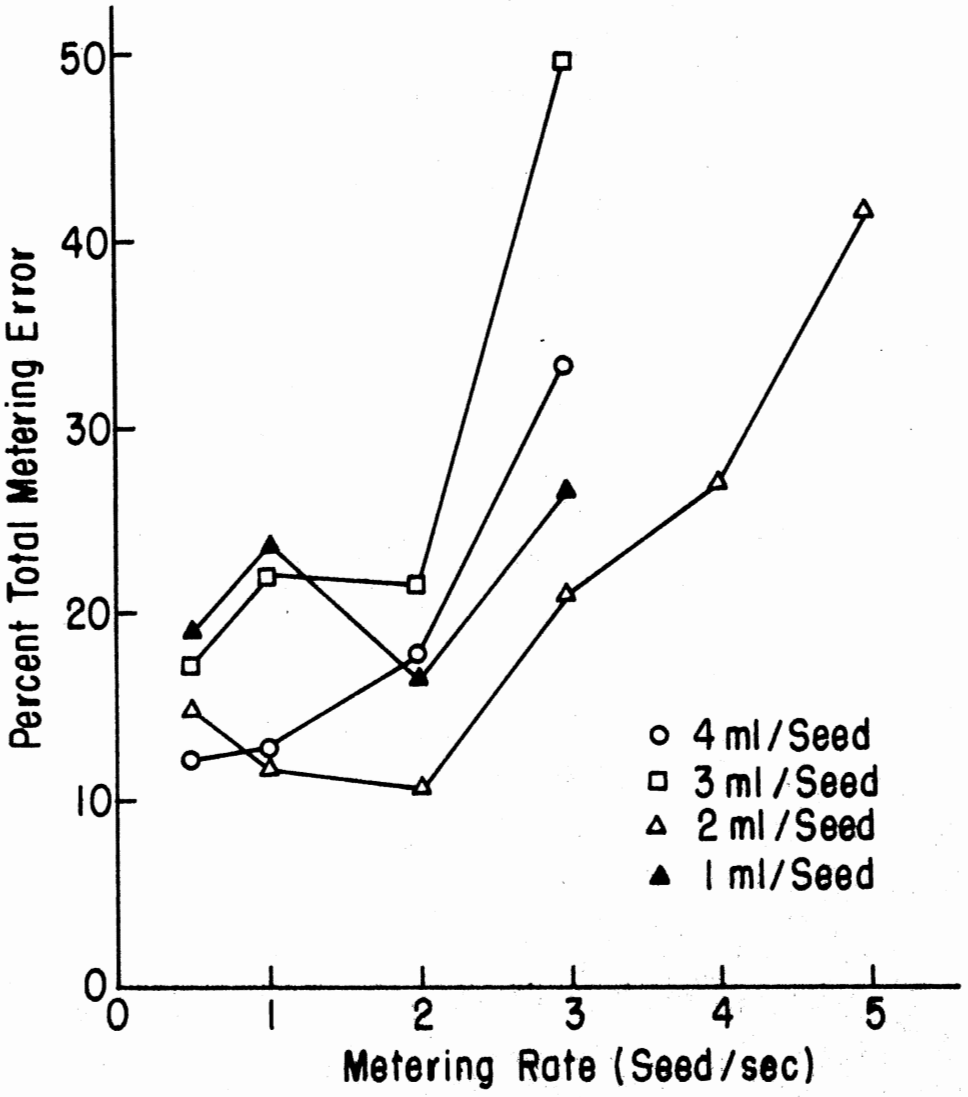


Figure 31. The Effect of Metering Rate on Total Metering Error

get a best and worse case distribution. In both cases the total error was very high. The same procedure was planned for lettuce but the slow metering rate had so many errors that the higher speed was dropped.

For the purposes of measuring the spacing uniformity, the skips and doubles were considered to be machine error and were eliminated in order to evaluate the variation in spacing when the metering system was operating properly. The mean and variance of the remaining distribution were calculated as descriptions of that distribtuion. Table XII shows the mean spacing and variance for each of the tests. The desired spacing was 120 mm in all cases. For most tests the measured mean of the distribution from 60 to 180 mm was within 10 mm of the desired spacing. This amount of variation from the desired spacing would be considered acceptable for most crops. The difference can be attributed to spacing measurement, which was taken to the nearest 5 mm, and to error in regulating the belt travel speed on the test stand. Neither gel/seed ratio or metering rate had enough effect on the mean spacing to be considered significant.

The metering rate had a very dramatic effect on the variance of the spacing distributions. As the metering rate increased, the variance increased. Figures 32, 33, 34 and 35 illustrate the change in the distribution with varying metering rates. In general, the distributions are similar for a given metering rate regardless of gel/seed ratio. Figure 36 shows the effect of gel/seed ratios at the 0.5

seed/sec metering rate. All ratios were similar except the 3 ml/seed ratio. This was due to the use of seed with longer than normal radicles in those tests.

TABLE XII

SPACING DISTRIBUTION UNIFORMITY PARAMETERS

GEL/SEED CONC. (ml/seed)	METERING RATE (seed/sec)	MEAN SPACING (mm)	STANDARD DEVIATION (mm)
4.0	0.5	112.0	8.0
4.0	1.0	103.6	17.7
4.0	2.0	113.6	26.6
4.0	3.0	117.8	31.1
3.0	0.5	110.2	11.3
3.0	1.0	112.9	15.8
3.0	2.0	113.5	21.4
3.0	3.0	123.4	32.9
2.0	0.5	111.3	7.3
2.0	1.0	111.7	12.4
2.0	2.0	112.6	19.1
2.0	3.0	114.8	28.3
2.0	4.0	116.5	30.2
2.0	5.0	120.5	33.5
1.0	0.5	111.4	7.8
1.0	1.0	113.0	13.2
1.0	2.0	111.9	21.2
1.0	3.0	114.4	29.2
2.0*	0.5	113.4	18.8
2.0	3.0	125.8	34.1
2.0**	0.5	115.0	19.3

*Tomato **Lettuce

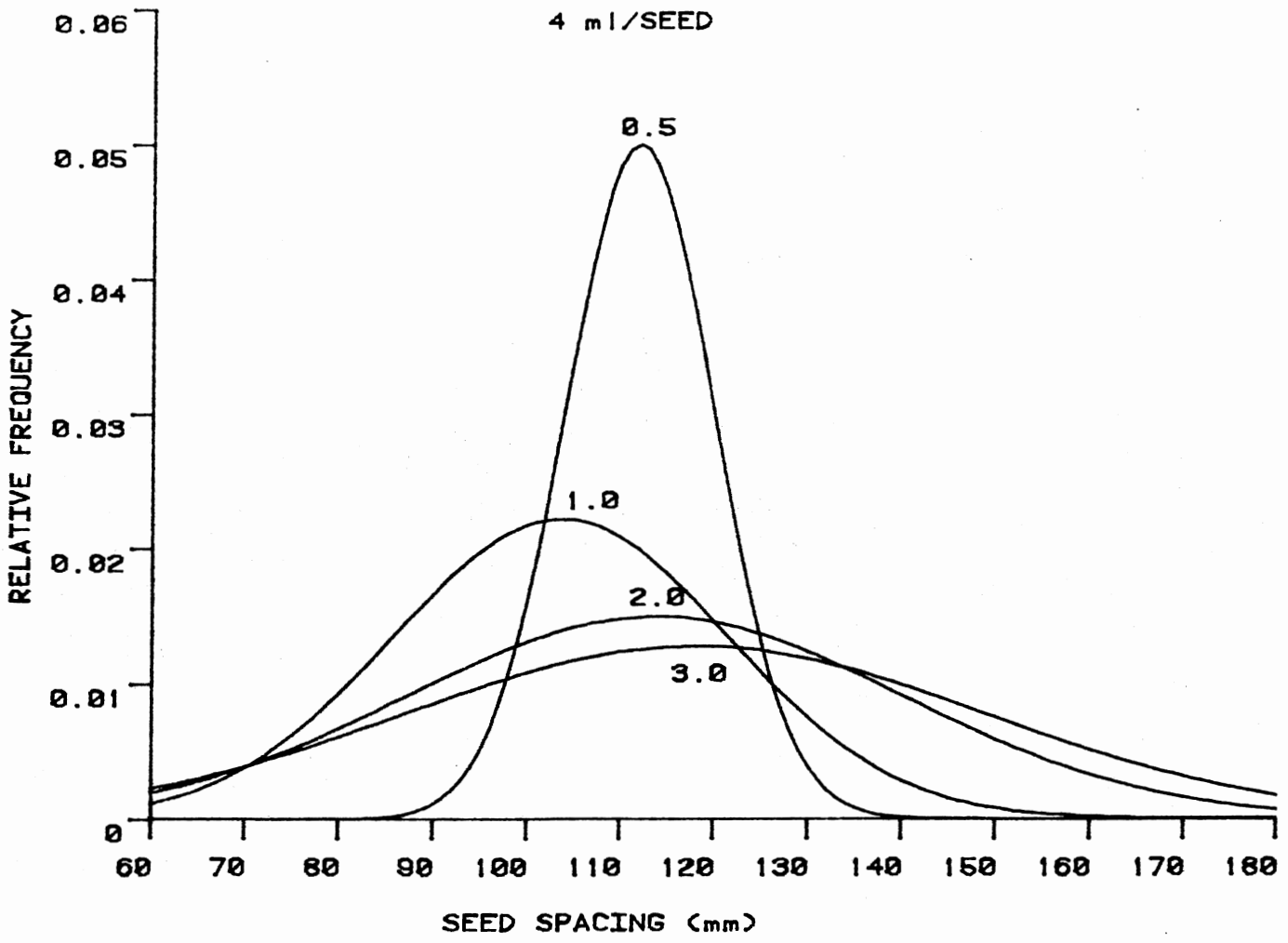


Figure 32. Distribution of 60-180 mm Spacings for Various Metering Rates (seed/sec) at a 4.0 ml/seed Ratio

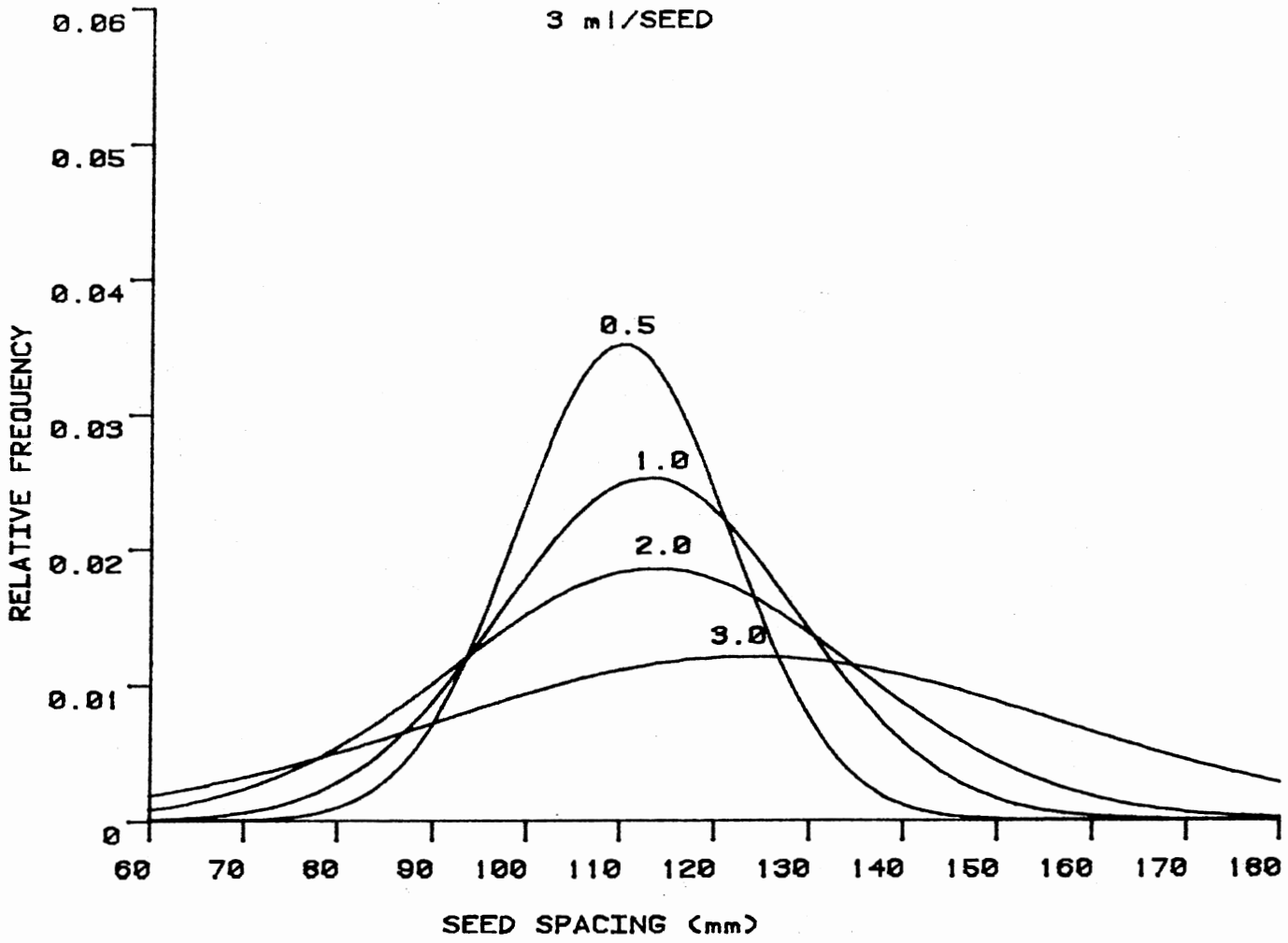


Figure 33. Distribution of 60-180 mm Spacings for Various Metering Rates (seed/sec) at a 3.0 ml/seed Ratio

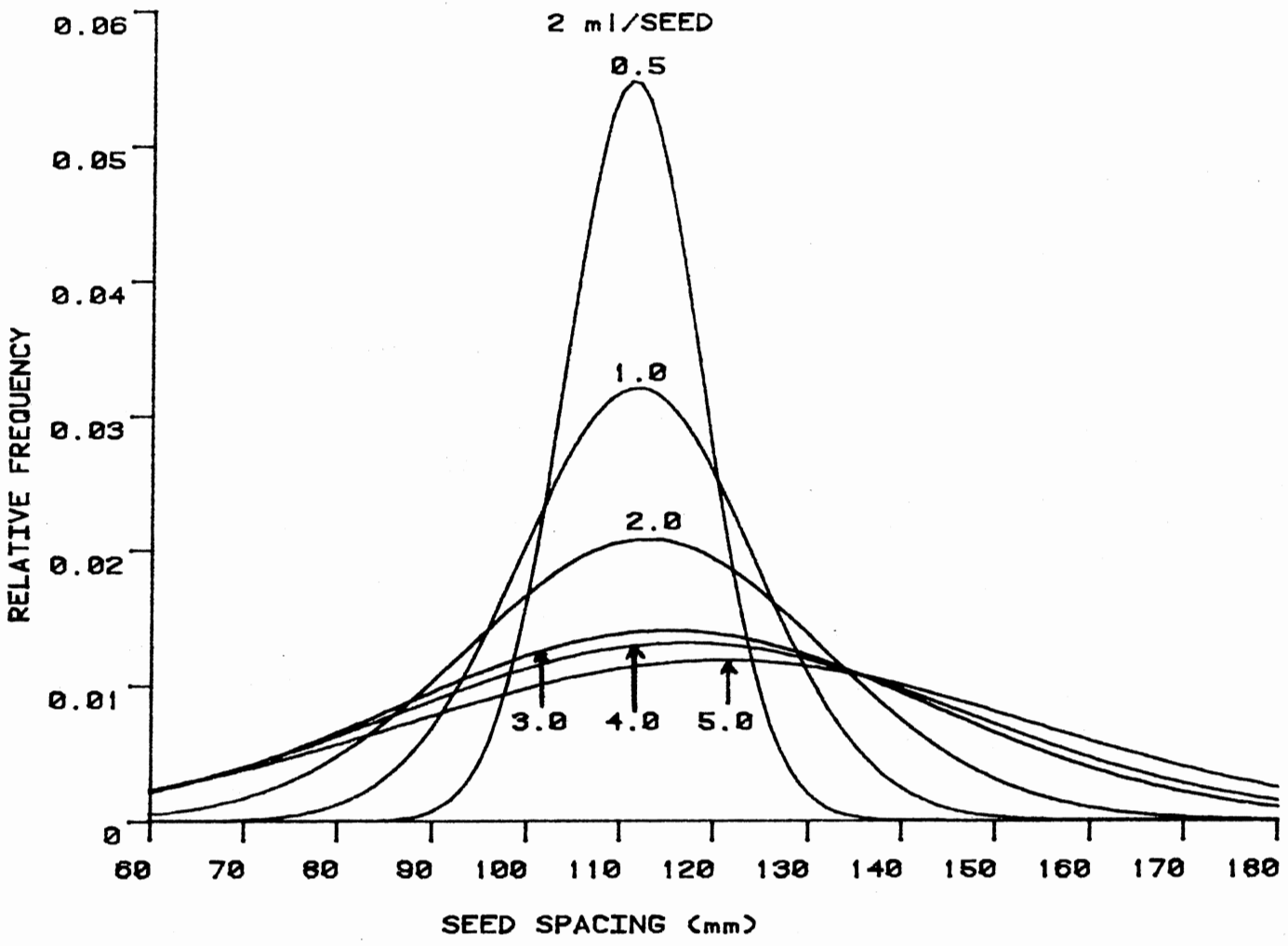


Figure 34. Distribution of 60-180 mm Spacings for Various Metering Rates (seed/sec) at a 2.0 ml/seed Ratio

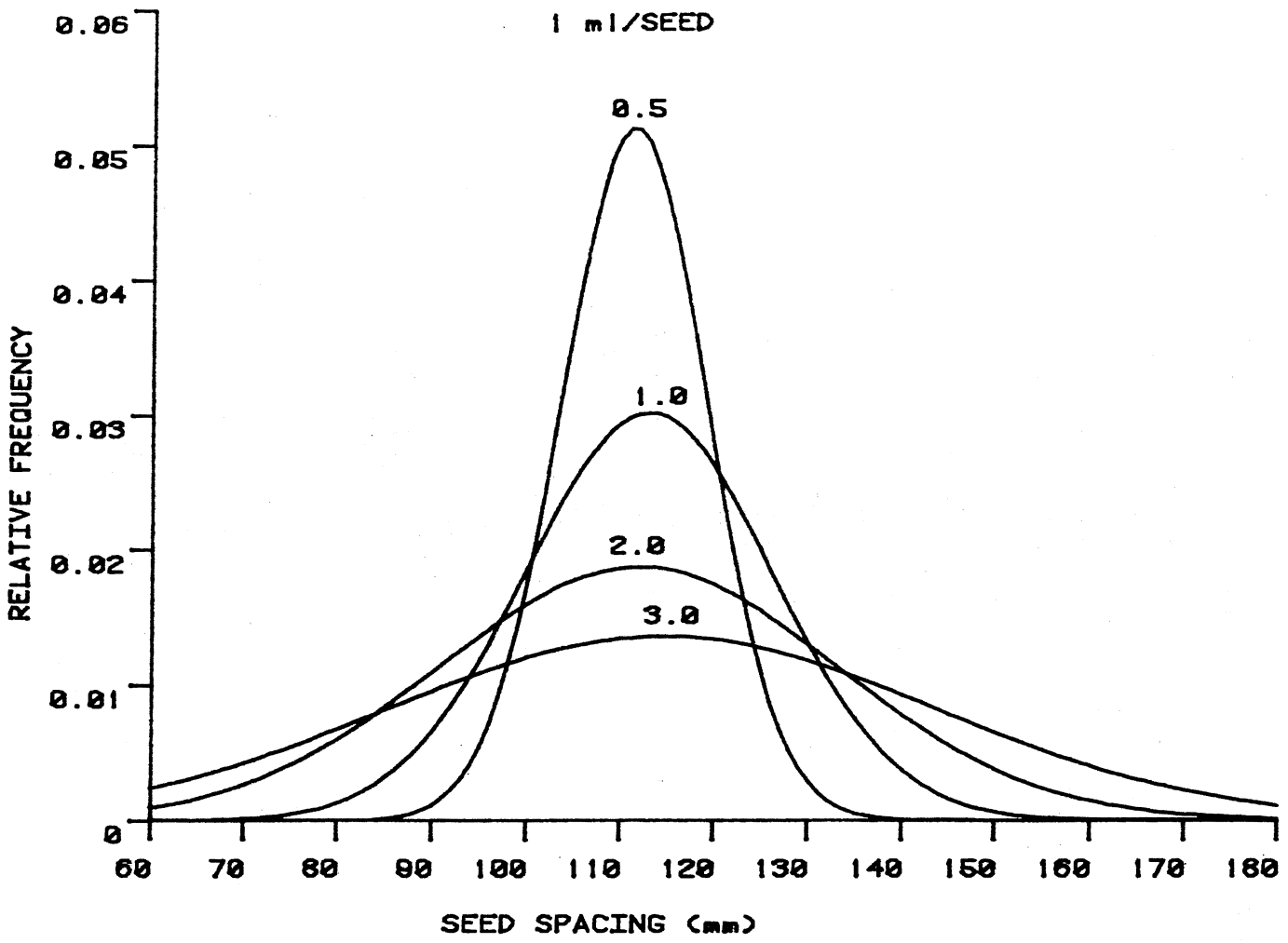


Figure 35. Distribution of 60-180 mm Spacings for Various Metering Rates (seed/sec) at a 1.0 ml/seed Ratio

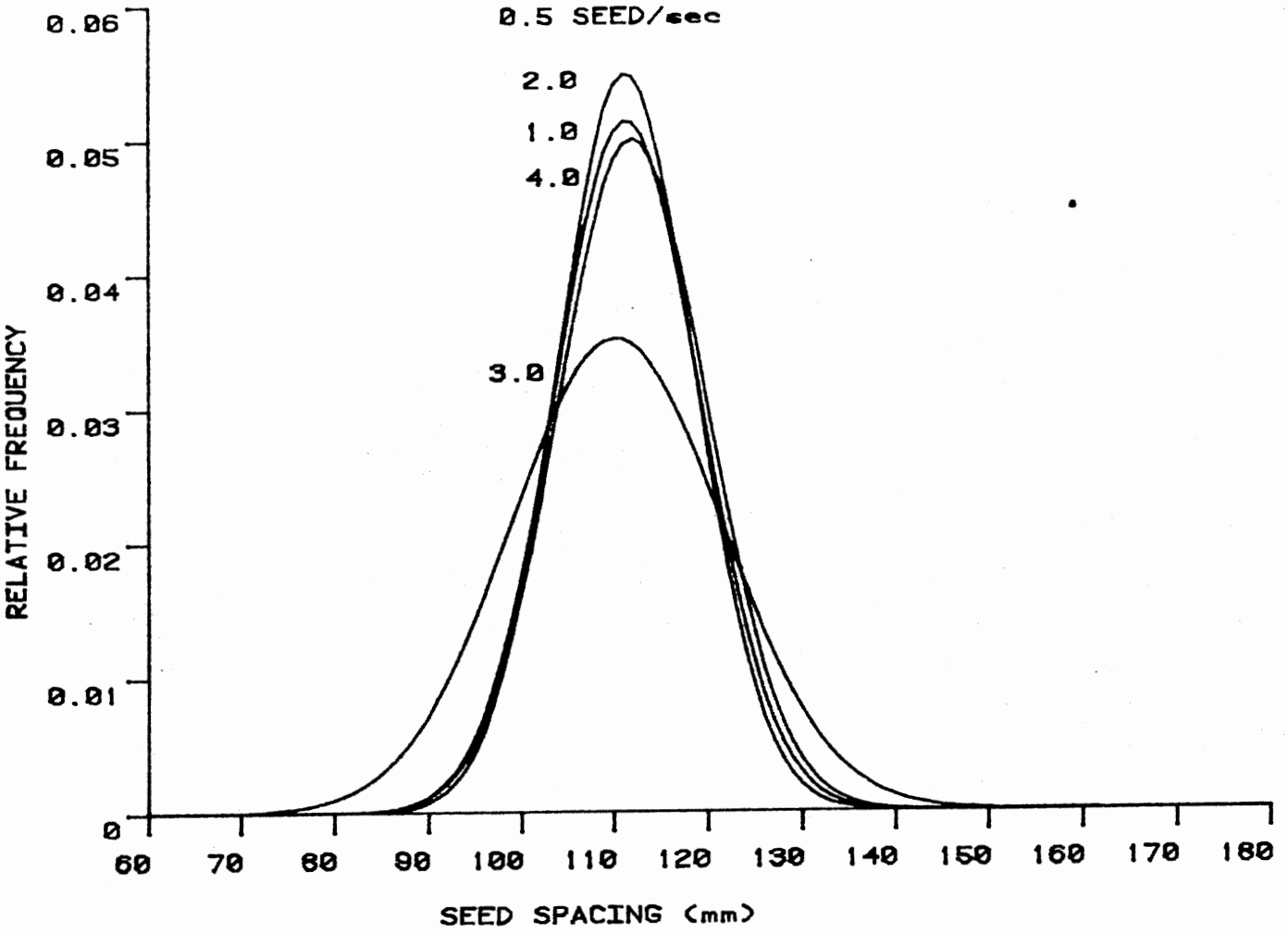


Figure 36. Distribution of 60-180 mm Spacings for Various Gel/Seed Ratios (ml/seed) at a 0.5 seed/sec Metering Rate

A study was made of the damage to pregerminated seed which occurred during the preparation and the metering of the seed. Cabbage seed were germinated, mixed with gel at a 2 ml/seed concentration and metered. Four samples of twenty five germinated seed each were taken after removal from the germinating column, after the seed had been mixed in the gel and poured into the holding tank, and after the seed had been metered at two different rates, Ø.5 and 5 seed/sec. After sampling, the seed were removed from the gel and placed in moist petri dishes. All samples were allowed to grow for two days and at the end of the growth period the number of healthy growing seed were counted. In all cases the entire twenty five seed were growing, indicating no damage was caused at any point in the preparation and metering of the cabbage seed.

After testing with cabbage seed to determine optimum metering conditions, additional tests were conducted with tomato, lettuce and cucumber. In each case the gel/seed ratio was mixed at an optimum rate and the seed were to be metered at a low rate of Ø.5 seed/sec and a high rate of 3.Ø seed/sec. This was to give best and worse case distributions. For tomatoes, the seed most like cabbage, tests were completed at both metering rates. The percentage error and spacing uniformity were poorer than the corresponding tests for cabbage. The number of doubles was similar to cabbage but the percentage of skips was much higher. Most of these skips were due to losing seed at the transfer

point. Lettuce was run at only the lowest metering rate because the spacing was extremely poor at that setting. Again the high number of skips can be attributed to poor seed transfer from the input to the output disk. No tests were recorded for cucumber seed because the seed could not be metered without damage. The timing of the seed transfer was unable to handle the larger cucumber seed and as a result each seed was cut in half as it entered a cell on the output disk. In all cases the seed could be accurately caught without damage in the input disk. The transfer from the input disk to the output disk was the major source of metering error for all seed tested.

In no test was the metering accuracy greater than 90 percent. For precision planting of crops directly to stand, metering accuracy should be greater than 95 percent. The seed metering device as currently designed would be unacceptable for precision planting due to the high percentage of error. The uniformity of the spacing would be acceptable at lower metering speeds. The maximum metering rate would depend on the tolerance of a particular crop to spacing variation.

Metering System Operation

Overall the metering system was not able to precision meter the seed at the desired metering rates. Parts of the system performed their individual functions well and other parts performed poorly. Improvements on the metering mecha-

nism design could increase the metering accuracy to an acceptable point.

Gel, Tank and Seed Funnel

The Viterra II gel performed well during metering tests. The seed settling shown in the vibration tests was not seen even though it was subject to vibration from the planter test stand. A 1.Ø percent concentration of gel held the seed in suspension well.

The gel tanks caused no problems with the metering system. The funnel shaped bottoms of the tanks allowed the complete emptying of the gel. The tank interiors were sprayed with acrylic to retard rusting but this coating was inadequate. During tank clean up the coating was scarred and chipped, leaving areas of bare metal which rapidly developed rust. The pressure regulators used with the tanks were very sensitive and required constant observation to insure proper settings. More stable regulators are needed for future use.

The seed funnel is a particularly weak part of the metering system. No attempt was made to design a funnel that would clear blockages without operator assistance. For the metering system to be acceptable for use as a field planter, a funnel, or other similar mechanism, must be designed to be self cleaning. Blockages can generally be avoided in the current system by using a higher gel/seed ratio. However blocks cannot be completely eliminated in

this manner.

The seed blockages were generally due to two causes, a) seed with long radicles that could not flow through the funnel outlet and b) seed that move into the funnel adjacently and wedge at the opening. The first cause can generally be eliminated by metering seed with short radicles. The second cause of blockage is particularly a problem with long seed with oval crossections such as cucumber. With a round outlet, two seed points could try to enter at the same time, causing them to wedge. In an attempt to eliminate this problem, an oval shaped funnel was constructed. This however, was less successful than the round funnel. The seed did not lodge at the outlet, but wedged together above the outlet.

Seed Detection and Trapping

The initial detection of seed as they entered the metering mechanism was very successful. The photoelectric detector worked well in sensing seed presence. The only difficulties arose when the gel contained air bubbles. The detector would occasionally trigger on an air bubble, resulting in an empty cell. This problem was minimized with careful mixing of the gel to avoid the air bubbles. The seed could be detected and trapped consistently at the same location in the cells. This location was very dependent on the relationship between the programmed time delay and the pressure in the holding tank. An improved design would

include a detection system which could automatically compensate for changes in tank pressure.

Before each test the input and output disks had to be visually aligned with input and output ports to assure correct cell alignment. While this method of alignment was satisfactory for this study, an improved method of alignment is needed. This is particularly true if the mechanism parts are made from a material other than plexiglass.

Seed Transfer

The transfer of the trapped seed from the input to the output disk was the greatest cause of error in the resulting seed distribution. The transfer circuit was not flexible enough to handle seed of various sizes. Seed which were too large were cut in half and small seed were often not detected by the photoelectric detector. A means of separating the timing of the seed input and output functions is still necessary. However, the means used in this design was unsuccessful.

Seed Outlet Tubing

A tube of diameter slightly larger than the seed being metered was used to move the seed from the metering mechanism to the test belt. It was determined that the tubing needed to be as short as possible and only slightly larger than the seed in diameter. If a larger diameter tube was used, the spacing between the seed was lost due to some seed

traveling in the high velocity area at the center of the tube and others moving along the walls of the tube in the slower velocity region. With smaller diameter tubing this action was still present but not as serious as with the larger tubing. Using the shortest length of tubing possible helped to minimize the seed movement relative to each other.

Microcomputer and Controlling Circuits

The microcomputer and the associated controlling circuits worked very well. After the program changes were made and the timing functions were removed from the microcomputer's responsibilities, the controlling system performed its job well. Some problems were experienced with achieving the correct sensitivity setting for the photoelectric detectors, but once the sensitivity levels were set there was no need for further adjustment. The reliability of the entire electronic system appeared to be quite high.

CHAPTER VI

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

Summary

A study was undertaken to improve the means with which pregerminated seed are planted and to develop a precision metering system which would allow the planting of pregerminated seed directly to stand. The specific objectives of this research were:

1. Determine an acceptable means of transporting the pregerminated seed with respect to seed protection, facilitation of planting operation and ease of handling.
2. Design, construct and evaluate a mechanism capable of precision planting pregerminated seed of various sizes, shapes and intra-row spacings at acceptable field planting rates.

Research was conducted in three phases. The first phase was to identify and describe the rheology of a carrier for the pregerminated seed. Two water swellable gels, Viterra II and CLD, were selected from a number of sample gels for rheological evaluation. These evaluations included viscosity measurement, determination of thixotropic properties and seed suspension abilities.

The second phase of the study involved the

determination of the seed spacing distribution which resulted from the unmetered extrusion of a uniform gel/seed mixture. Descriptive parameters of the distributions were determined and the experimental results were compared to the results predicted by theoretical analysis. A theoretical predictor of the spacing mean was derived and compared to the measured means.

The third phase consisted of design, construction and evaluation of a metering system for pregerminated seed. The following design objectives were used in development of the metering system.

1. Damage to the pregerminated seed must be practically non-existant.
2. Metered seed must follow a continuous identical path from the meter to the furrow.
3. The metering system must be portable and achieve reasonable field planting rates.

To achieve these objectives, a metering system was designed which incorporated photoelectric detectors to sense seed presence, a continuous outlet flow of gel to carry seed to the furrow, an electronic detection of travel speed and a microcomputer with associated circuitry to control the entire system. The metering system was tested at different gel/seed concentrations, at various metering rates and with four different seed types.

Conclusions

1. Both Viterra II and CLD water swellable gels were pseudoplastic in nature and their viscosities can be described by the power law equation:

$$\mu = k\ \gamma^{(n-1)}$$

2. Viterra II had thixotropic properties and its apparent viscosity as a function of time could be modeled by the equation:

$$\mu = \mu_0 - b_t \log(\text{time})$$

3. CLD at 2.1 percent concentration was capable of holding seed in suspension under vibration. For concentrations, ranging from 0.8 to 1.1 percent, Viterra II was not able to hold seed in suspension during one hour of vibration.

4. CLD was unsuitable for use in a seed metering device due to the separation of free water from the gel molecules during vibration or pumping.

5. The cumulative seed spacing distribution from an unmetered uniform gel/seed mixture can be accurately predicted by the following equation:

$$N_x = N_0\ e^{-\lambda x}$$

6. The spacing distribution resulting from an unmetered uniform gel/seed mixture was unsuitable for precision

planting of pregerminated seed.

7. The pregerminated seed metering system had unacceptable amounts of metering error at all test conditions. The percentage of total metering errors generally ranged from 10 to 20 with the percentage increasing rapidly with metering rates of greater than 2.0 seed/sec.
8. The metering system was capable of uniformly spacing those seed that were accurately metered. The most uniform spacings were achieved at the 0.5 seed/sec metering rate. Spacing uniormity decreased with increasing metering rate. Gel/seed concentration had little effect on the spacing uniformity.
9. The metering system was only able to accurately meter cabbage seed. Other seed sizes and shapes were metered much less accurately.
10. The system was capable of metering cabbage seed at rates of 0.5 and 5.0 seed/sec without damage to any of the pregerminated seed.

Suggestions for Further Study

Although the performance of the metering system was poor, certain parts of the design performed their functions very well. With appropriate refinements of the design of the metering mechanism, the possibility of high speed precision planting of pregerminated seed is great. Further work in this area is recommended to improve the metering system.

Specific areas of the metering mechanism that need fur-

ther study include the seed funnel, cell alignment and the seed transfer. The seed funnel should be improved so that any seed blockage would be self cleaning. In addition, a seed detection method should be developed that could accurately catch seed in the input cells independent of tank pressure. A method of automatically aligning the disk cells with input and output ports is needed. The seed transfer from the input disk to the output disk was the major cause of metering error. The transfer operation should be greatly improved or eliminated in future work.

Further work should be conducted to identify improved seed carrying gels. Alternative gels should have better seed suspension characteristics, better optical clarity and be easier to handle.

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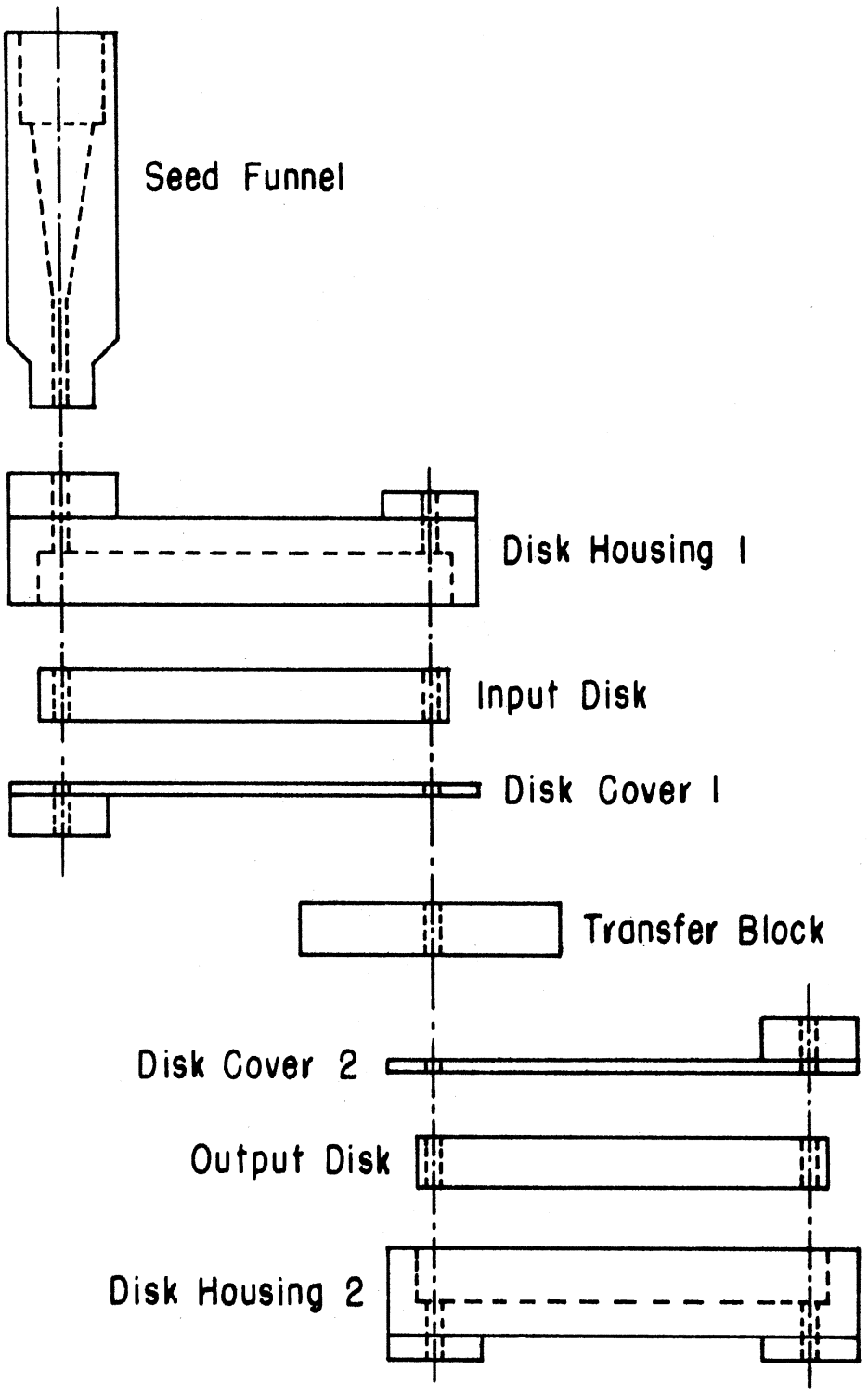
APPENDIXES

APPENDIX A

PLANS FOR METERING MECHANISM PARTS

APPENDIX A-1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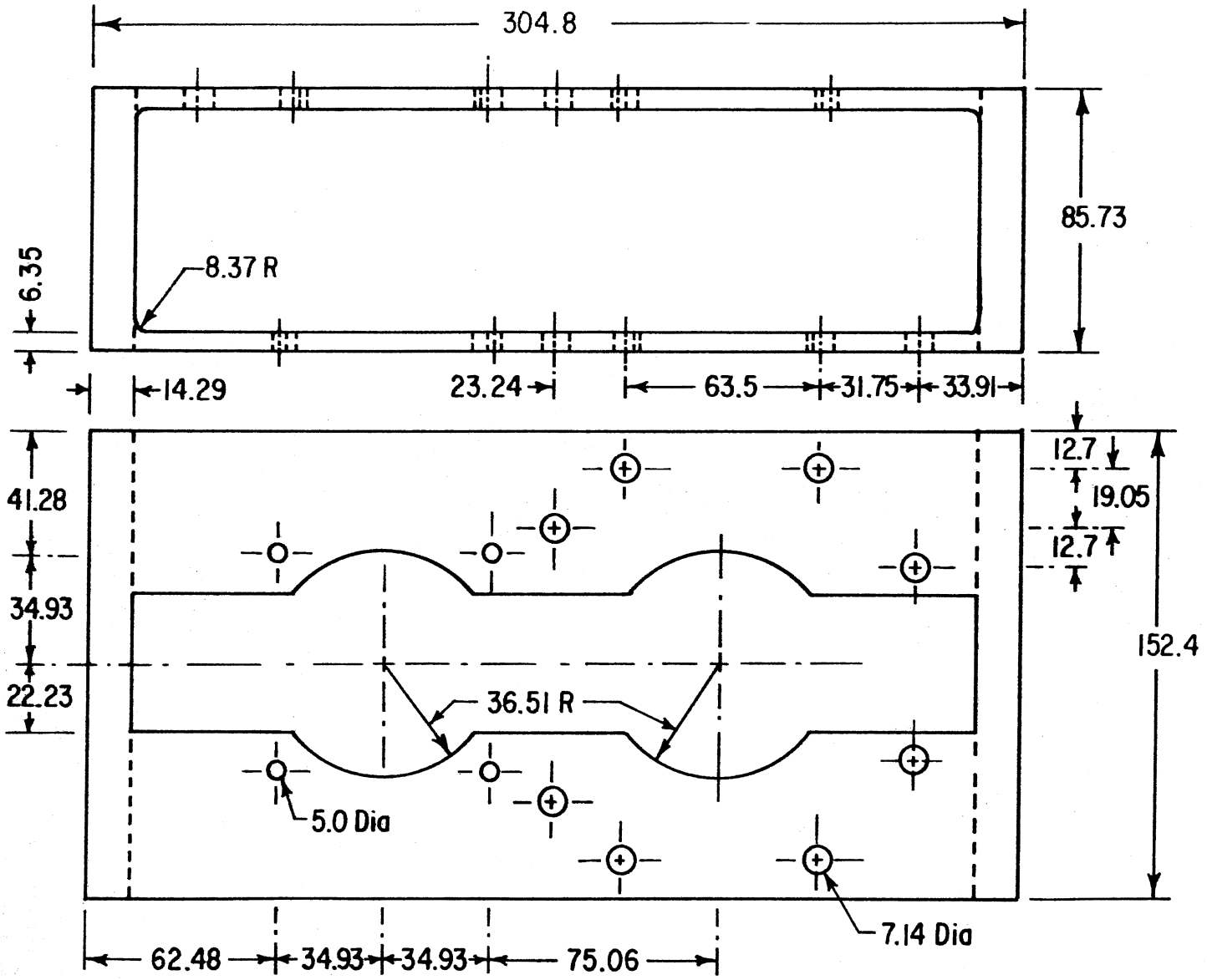
Disk Housing 1
Input Disk
Disk Cover 1
Transfer Block
Disk Cover 2
Output Disk
Disk Housing 2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6.35
8.37 R
14.29
23.24
63.5
31.75
33.91
12.7
19.05
12.7
41.28
34.93
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36.51 R
5.0 Dia
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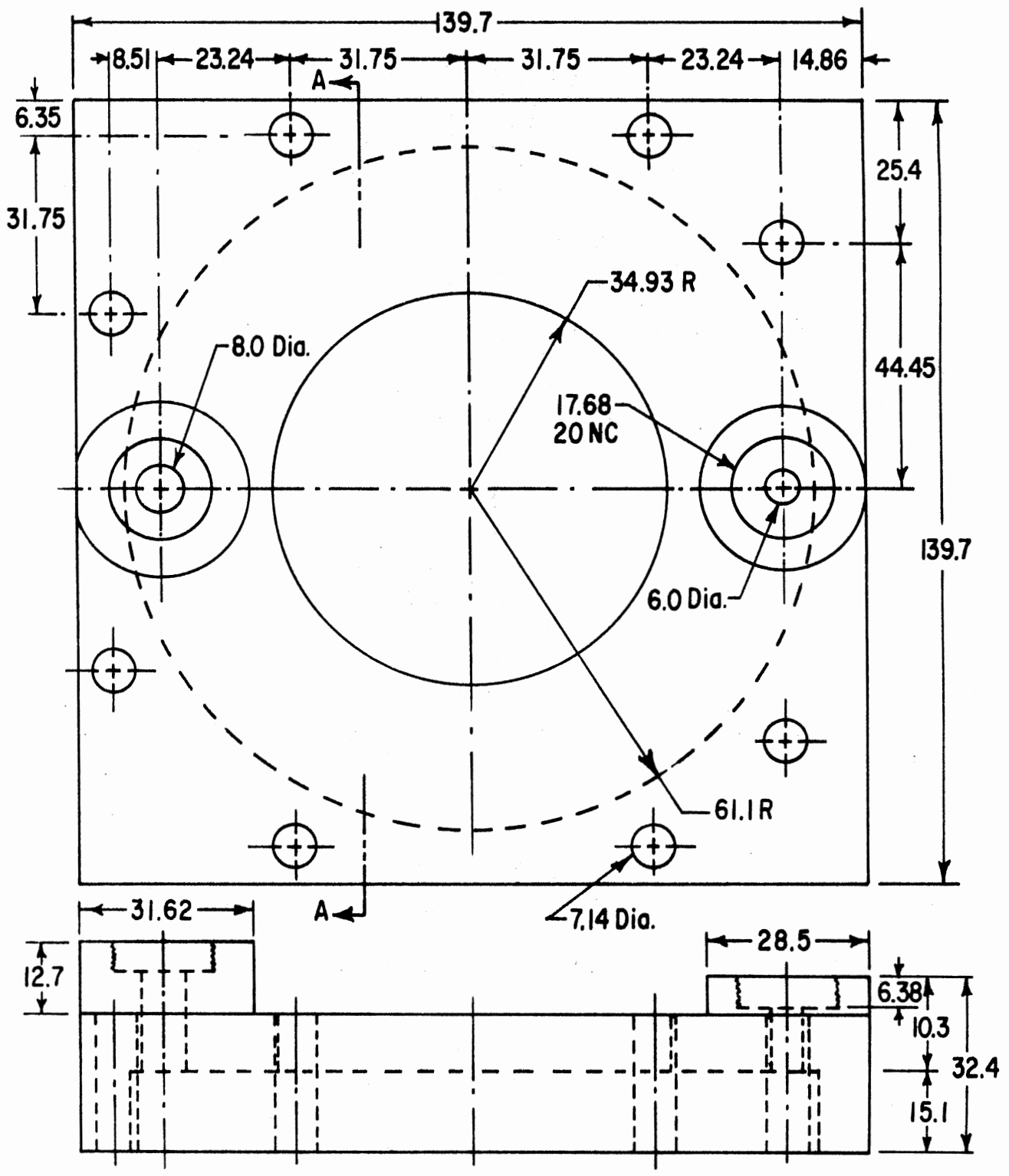
34.93
34.93
75.06

APPENDIX A-3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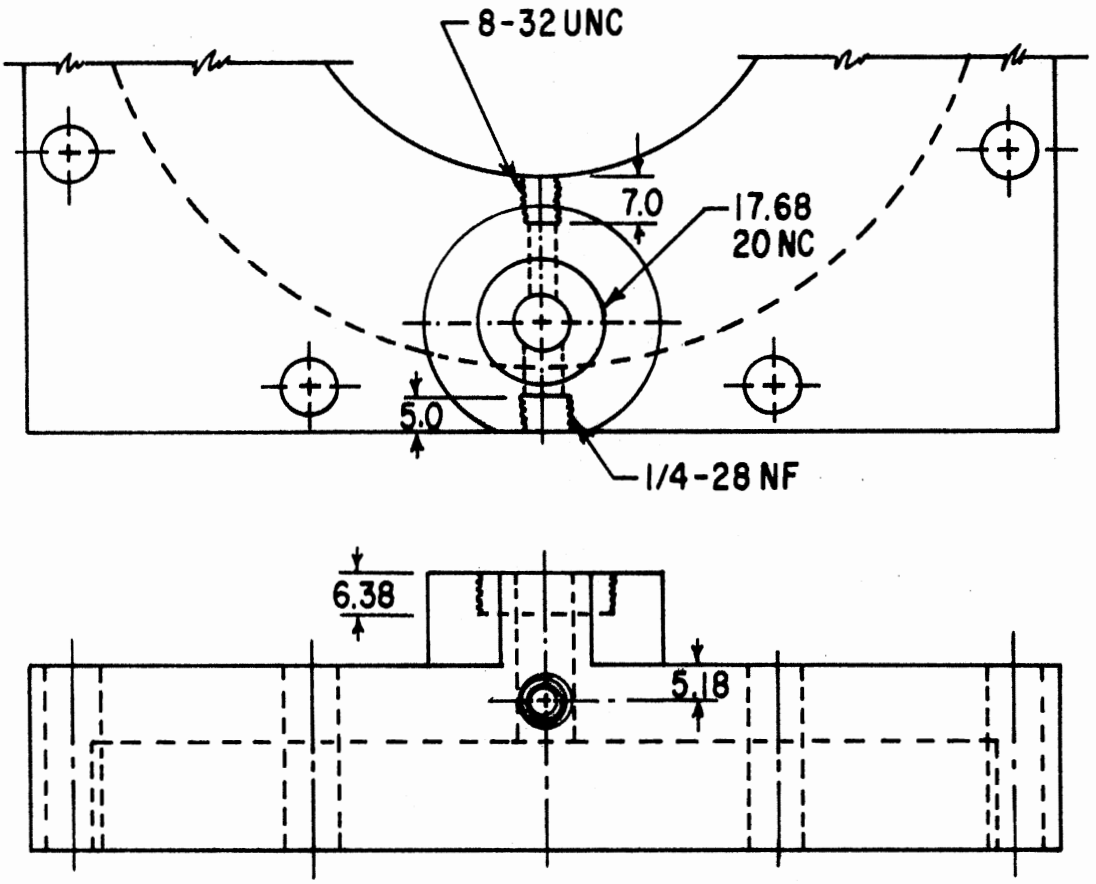
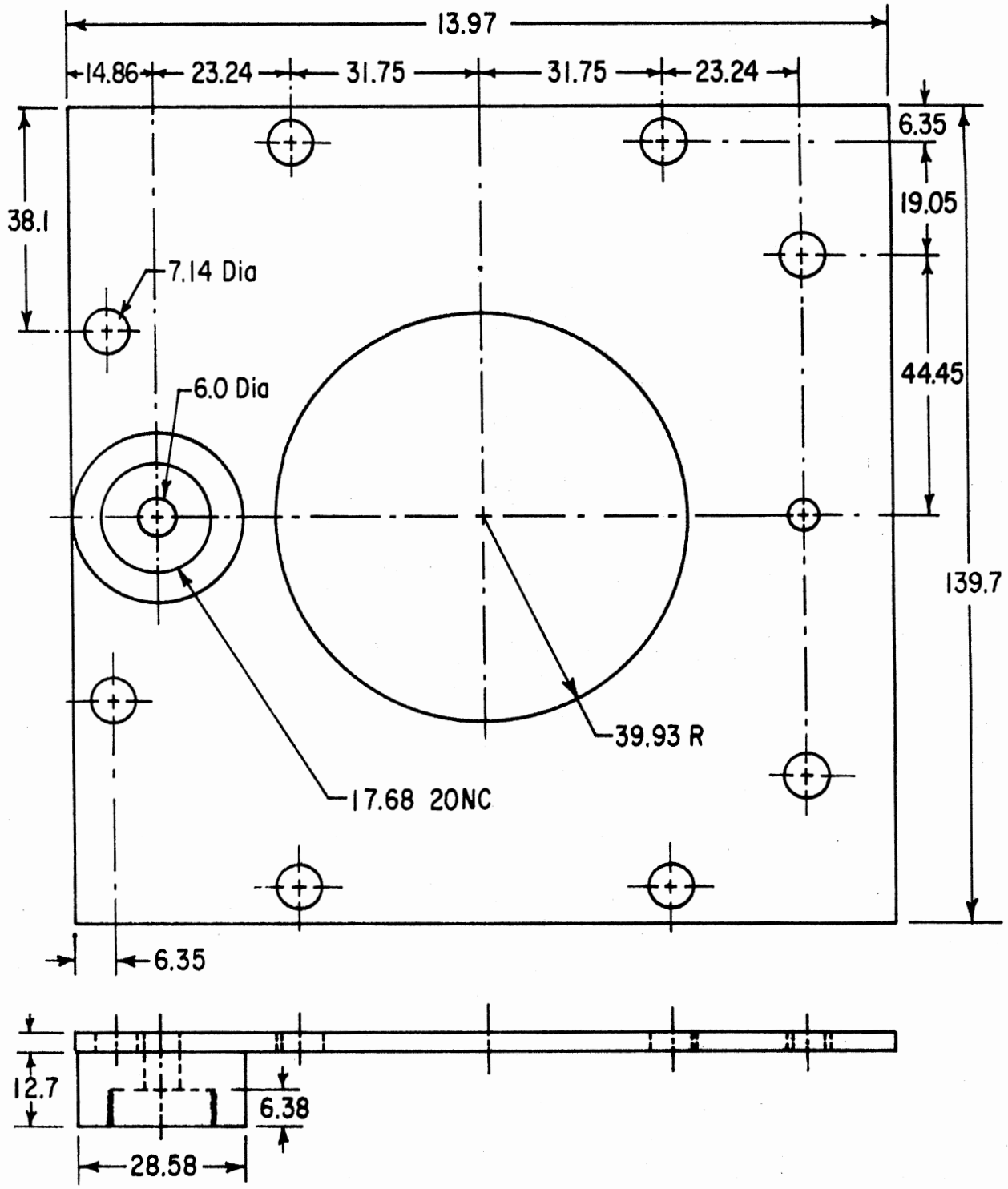
23.24
31.75
31.75
23.24
14.86
A
6.35
31.75
25.4
44.45
139.7
34.93 R
8.0 Dia.
17.68
20 NC
6.0 Dia.
61.1 R
7.14 Dia.
A
31.62
12.7
28.5
6.38
10.3
32.4
15.1

APPENDIX A-4



APPENDIX A-5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23.24
31.75
31.75
23.24
6.35
19.05
38.1
7.14 Dia
6.0 Dia
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139.7
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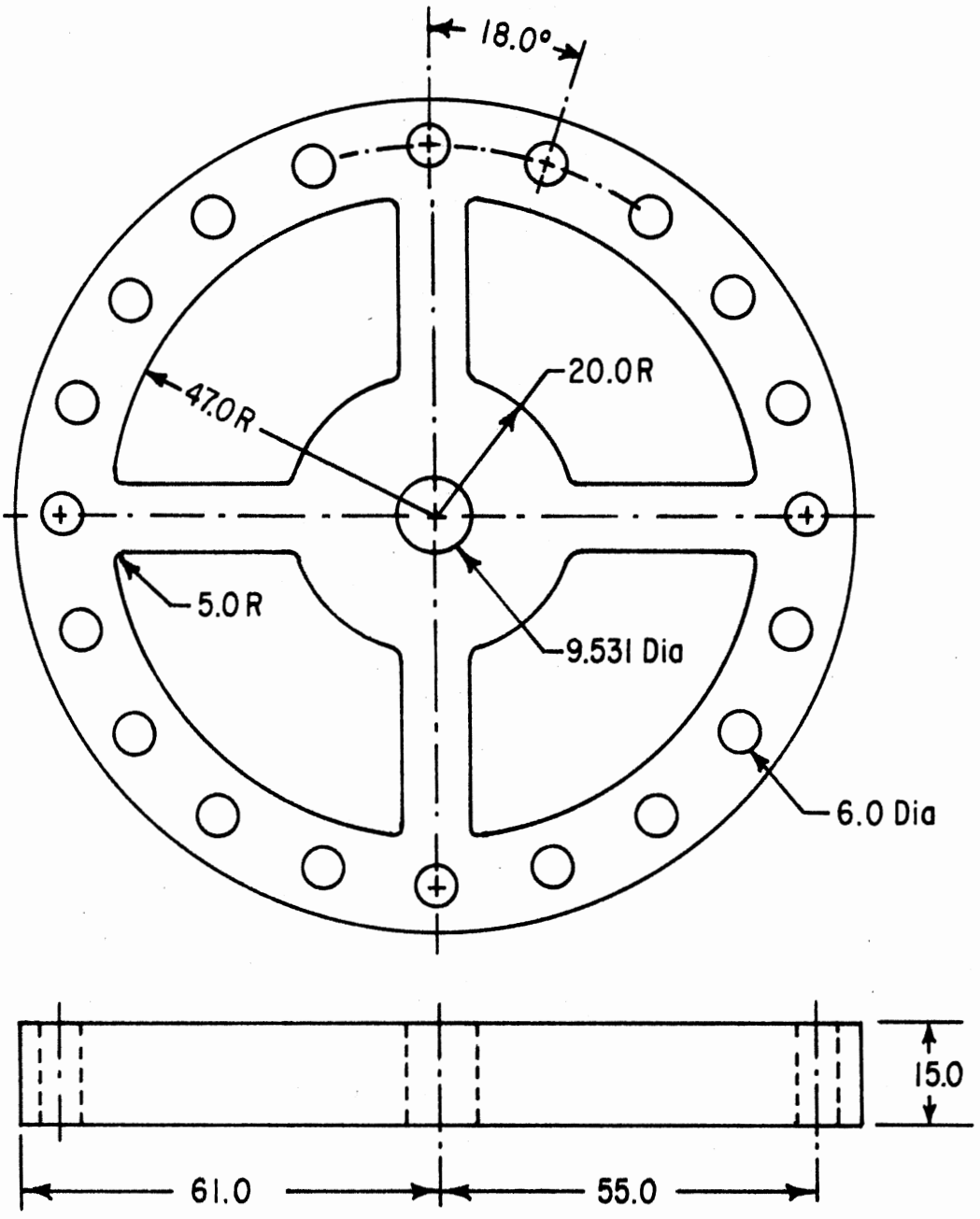
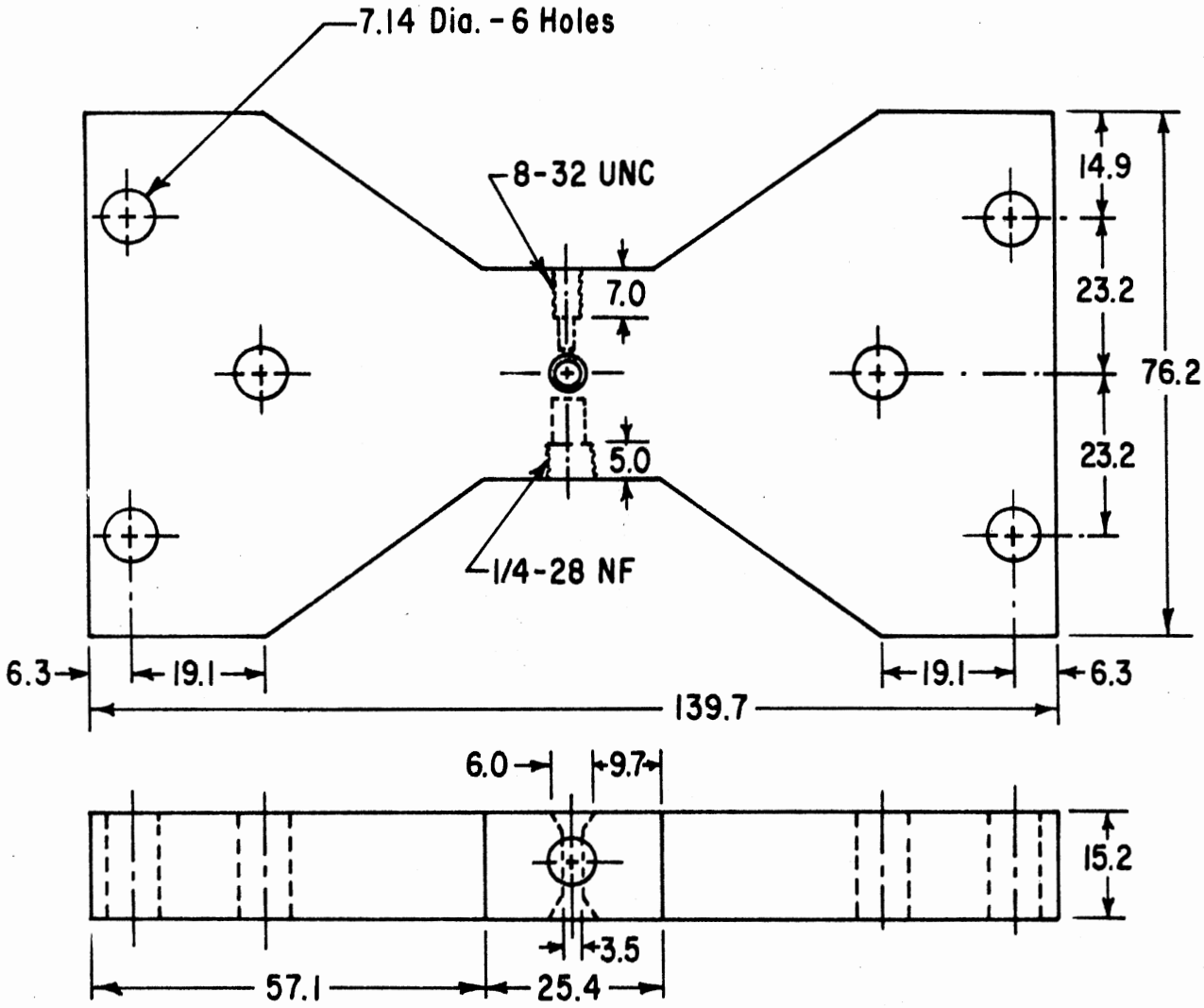
6.35
12.7
6.38
28.58

APPENDIX A-6



APPENDIX A-7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8-32 UNC
7.0
5.0
1/4-28 NF
14.9
23.2
76.2
23.2
6.3
19.1
19.1
6.3
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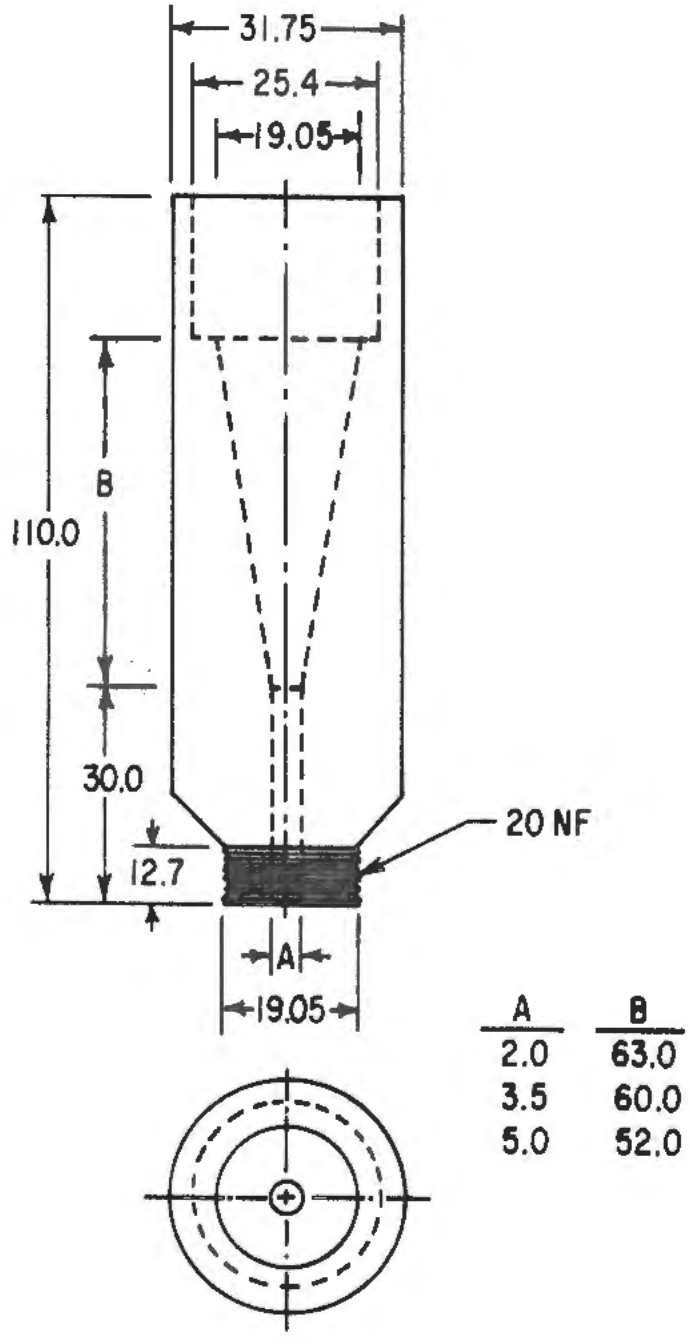
6.0
9.7
15.2
3.5
57.1
25.4

APPENDIX A-8



A	B
2.0	63.0
3.5	60.0
5.0	52.0

APPENDIX B

METERING SYSTEM CONTROL PROGRAMS

APPENDIX B-1

This is a listing of the original program which controled the metering mechanism. This program caused the microcomputer to monitor seed movement and control the disk rotation. It was written in Intel's assembly language and was stored at memory location 3000H. The program had three inputs, two photoelectric devices and the optical encoder, and two outputs, the two stepping motors.

The following is a list of the RAM locations that are referred to by the main program and which must be set before the program is executed.

Location	Name	Description
2000-2001	DP1	The delay time to allow the seed to move from the photocell in to the disk. Loaded by user (hexidecimal).
2002-2003	D12	The delay time to allow the seed to move from disk 1 to disk 2. Loaded by user (hexidecimal).
2004-2005	PDELAY	The delay time between output pulses. Loaded by user (hexidecimal).
2008	SPACE	Distance in centimeters between seeds. Loaded by user (hexidecimal).
20C8-20CA		Location of the JMP command for RST 6.5 C3H,38H,30H should be loaded by user.
20CE-20D0		Location of the JMP command for RST 7.5 C3H,50H,30H should be loaded by user.

```
LABEL     OPCODE    OPERAND    COMMENTS
EMPTY     EQU       2009H
DETECT    EQU       200AH
IVAL      SET       18H
CVAL      SET       13H
METER     MVI       A,0EH      ;load bit pattern in Acc.
          OUT       20H        ;output Acc. to port 20
          MVI       B,20H      ;load the memory loc. 20FF
          MVI       C,0FFH     ;in Reg. B and C
          STAX      B          ;store Acc. at loc. 20FF
          MVI       A,IVAL     ;load interrupt mask value
          SIM                  ;set interrupt mask
          MVI       A,CVAL     ;load counter value
          OUT       13H        ;output value to counter
          LDA       SPACE      ;load seed spacing
          DCR       A          ;decrement SPACE
          OUT       10H        ;output SPACE to counter
          MVI       A,05H      ;set bits for output signal
          OUT       23H        ;output signal to counter
          MVI       A,01H      ;turn bit 3 off
          OUT       23H        ;outputs a pulse to load
NEXT      EI                   ;enable interrupts
          MVI       A,00H      ;set Acc. equal to zero
          STA       DETECT     ;set DETECT equal 0
          MVI       E,01H      ;set Reg. E equal to one
POLL      IN        21H        ;input from photocell
          CMP       E          ;check for photocell being on
          JZ        PCON       ;if photocell is on, go to PCON
          JMP       POLL       ;if off, check again
PCON      IN        21H        ;input photocell
          CMP       E          ;check for photocell on
          JNZ       SEED       ;if off jump to SEED
          JMP       PCON       ;if on jump to PCON

   THIS SECTION HANDLES THE COUNTER INTERRUPT
INTER     POP       PSW        ;remove data from stack
          MVI       A,00H      ;set gate 0 value low
          OUT       23H        ;output to counter 0 gate
          MVI       A,01H      ;set gate 0 value high
          OUT       23H        ;output to counter 0 gate
          MVI       B,00H      ;set Reg. B equal to 0
          LDA       DETECT     ;load DETECT in Acc.
          CMP       B          ;check for Acc. equal to zero
          JZ        NOSEED     ;if Acc. = 0 go to NOSEED
          JMP       RSTRT      ;if not, go to RSTRT

  THIS SECTION STOPS THE METER IF NO SEEDS ARE ENTERING
HELP      MVI       B,00H      ;set pulse counter = 0
LP        MVI       A,01H      ;turn pulse on
          OUT       22H        ;output pulse to motor 1
          LXI       D,0008H    ;load pulse width delay value
          CALL      DELAY      ;call delay routine in monitor
          MVI       A,00H      ;turn pulse off
          OUT       22H        ;output to stepping motor 1
```

```
        INR     B       ;increment pulse counter
        MOV     A,B     ;move pulse counter into Acc.
        CPI     05H     ;compare pulse counter to 5
        JZ      FLASH   ;if equal, go to FLASH
        LHLD    PDELAY  ;load PDELAY into Reg. H and L
        XCHG            ;exchange Reg. H & L with D & E
        CALL    DELAY   ;call delay routine
        JMP     LP      ;start another pulse
FLASH   MVI     A,01H   ;use data field on keyboard
        MVI     B,00H   ;no decimal indicator
        LXI     H,BLANK ;use characters at BLANK
        CALL    OUTPT   ;output blanks
DPY     MVI     A,00H   ;use address field on keyboard
        MVI     B,00H   ;no decimal indicator
        LXI     H,CHAR  ;use characters at CHAR
        CALL    OUTPT   ;output four characters to the
                        ;keyboard to flash HELP
        LXI     D,0FFFFH ;load time between flashes
        CALL    DELAY   ;call delay routine
        MVI     A,00H
        MVI     B,00H
        LXI     H,BLANK ;use characters at BLANK
        CALL    OUTPT   ;output blank characters
        LXI     D,0FFFFH ;load value for time delay
        CALL    DELAY   ;call delay routine
        JMP     DPY     ;continue until reset

              SEED DETECTED SECTION
SEED    DI              ;disable interrupts so that the
                        ;pulse train can't be disturbed
        MVI     A,00H   ;set Acc. equal to zero
        STA     EMPTY   ;set empty cell counter to zero
        INR     A       ;increment Acc. to one
        STA     DETECT  ;set program control counter =1
        LHLD    DP1     ;load DP1 into Reg. H and L
        XCHG            ;move DP1 into reg. D and E
        CALL    DELAY   ;use DELAY to allow seeds
                        ;time to move from the
                        ;photocell to disk 1
        MVI     C,00H   ;set train counter equal 0
RSTRT   MVI     B,00H   ;set pulse counter equal 0
LOOP    MVI     A,01H   ;turn pulse on
        OUT     22H     ;output pulse to motor 1
        LXI     D,0008H ;load pulse width delay value
        CALL    DELAY   ;call delay routine in monitor
        MVI     A,00H   ;turn pulse off
        OUT     22H     ;output to motor 1
        INR     B       ;increment pulse counter
        MOV     A,B     ;move pulse counter into Acc.
        CPI     05H     ;compare pulse counter to 5
        JZ      CHECK   ;if equal, go to CHECK
        LHLD    PDELAY  ;load PDELAY into Reg. H and L
        XCHG            ;exchange Reg. H & L with D & E
        CALL    DELAY   ;call delay routine
```

```
        JMP     LOOP    ;start another pulse
CHECK   MOV     A,C     ;put train counter in Acc.
        CPI     01H     ;compare counter to 1
        JZ      LOOP2   ;if equal, go to LOOP2
        INR     C       ;increment train counter
        EI              ;enable the interrupts
        HLT             ;wait for interrupt
LOOP2   MVI     B,00H   ;
        MVI     C,00H   ;set registers
        MVI     E,02H   ;
        LHLD    D12     ;load D12 in Reg. H and L
SNDLP   IN      21H     ;*********************************
        CMP     E       ;
        JNC     TRDLP   ;
        INX     B       ;this section counts up while
        DCX     H       ;waiting for the seed to pass
        MOV     A,L     ;the second photocell
        ORA     H       ;
        JZ      STRT    ;
        JMP     SNDLP   ;*********************************
TRDLP    IN      21H    ;
        CMP     E       ;
        JNC     TRDLP   ;this section counts back down to
WAIT    DCX     B       ;zero to trap the moving seed
        IN      21H     ;count down starts after the seed
        IN      21H     ;is past the photocell
        ACI     01H     ;after reaching zero, the output
        ACI     01H     ;disk is rotated
        MOV     A,B     ;
        ORA     C       ;
        JNZ     WAIT    ;*********************************
STRT    MVI     B,00H   ;set pulse counter
LOP2    MVI     A,40H   ;turn pulse on
        OUT     22H     ;output pulse to motor 2
        LXI     D,0008H ;load pulse width delay value
        CALL    DELAY   ;call delay routine in monitor
        MVI     A,00H   ;turn pulse off
        OUT     22H     ;output to motor 2
        INR     B       ;increment pulse counter
        MOV     A,B     ;move pulse counter into Acc.
        CPI     05H     ;compare pulse counter to 5
        JZ      NEXT    ;if equal, go to NEXT
        LHLD    PDELAY  ;load PDELAY into Reg. H and L
        XCHG            ;exchange Reg. H & L with D & E
        CALL    DELAY   ;call delay routine
        JMP     LOP2    ;start another pulse

              NO SEED SECTION
NOSEED  LDA     EMPTY   ;load empty cell counter in Acc
        INR     A       ;increment counter
        STA     EMPTY   ;store empty cell counter
        MVI     B,00H   ;set pulse counter equal 0
LOOP3   MVI     A,01H   ;turn pulse on
        OUT     22H     ;output pulse to motor 1
```

```
        LXI     D,0008H   ;load pulse width delay value
        CALL    DELAY     ;call delay routine
        MVI     A,00H     ;turn pulse off
        OUT     22H       ;output to motor 1
        INR     B         ;increment pulse counter
        MOV     A,B       ;move pulse counter into Acc.
        CPI     0AH       ;compare counter to 10
        JZ      LOP3      ;if equal, go to LOP3
        LHLD    PDELAY    ;load PDELAY into Reg. H and L
        XCHG              ;exchange Reg. H & L with D & E
        CALL    DELAY     ;call DELAY routine from monitor
        JMP     LOOP3     ;start another pulse
LOP3    MVI     B,OOH     ;
        MVI     C,00H     ;set registers
        MVI     E,02H     ;
        LHLD    D12       ;load D12 into Reg. H and L
SCNDLP  IN      21H       ;****************************
        CMP     E         ;
        JNC     THRDLP    ;
        INX     B         ;this section counts up while
        DCX     H         ;waiting for the seed to pass
        MOV     A,L       ;the second photocell
        ORA     H         ;
        JZ      START     ;
        JMP     SCNDLP    ;****************************
THRDLP  IN      21H       ;
        CMP     E         ;
        JNC     THRDLP    ;this section counts back down
WAITT   DCX     B         ;to zero to trap the seed
        IN      21H       ;counting starts after the seed
        IN      21H       ;is past the photocell
        ACI     01H       ;the disk is rotated when the
        ACI     01H       ;count reaches zero
        MOV     A,B       ;
        ORA     C         ;
        INZ     WAITT     ;****************************
START   MVI     B,00H     ;set pulse counter equal 0
LOOP4   MVI     A,40H     ;turn pulse on
        OUT     22H       ;output pulse to motor 2
        LXI     D,0008H   ;load pulse width delay value
        CALL    DELAY     ;call delay routine in monitor
        MVI     A,00H     ;turn pulse off
        OUT     22H       ;output to motor 2
        INR     B         ;increment pulse counter
        MOV     A,B       ;move pulse counter into Acc.
        CPI     05H       ;compare pulse counter to 5
        JZ      CHEK      ;if equal, go to CHEK
        LHLD    PDELAY    ;load PDELAY into Reg. H and L
        XCHG              ;exchange Reg. H & L with D & E
        CALL    DELAY     ;call delay routine
        JMP     LOOP4     ;start another pulse
CHEK    LDA     EMPTY     ;load empty call counter in Acc
        CPI     10H       ;compare counter to 16
        JZ      HELP      ;if equal, go to HELP
```

```
        JMP     NEXT        ;return to main section
CHAR    DB      10H,0EH,11H,12H
BLANK   DB      15H,15H,15H,15H
        END     METER
```

APPENDIX B-2

This is a listing of the microcomputer program as revised to incorporate the independent citcuits. It's primary function was monitoring seed movement. The program started the motor rotation with short pulses and rapidly returned to seed monitoring. The program had two inputs, the photoelectric device and the optical encoder, and two outputs, one for each stepping motor.

The following is a list of the RAM locations that are refered to by the main program and which must be set before the program is executed.

Location	Name	Description
2000-2001	DP1	The delay time to allow the seed to move from the photocell in to the disk. Loaded by user (hexidecimal).
2003	SPACE	Distance in centimeters between seeds. Loaded by user (hexidecimal).
20C8-20CA		Location of the JMP command for RST 6.5 C3H,52H,30H should be loaded by user.
20CE-20D0		Location of the JMP command for RST 7.5 C3H,72H,30H should be loaded by user.

```
LABEL     OPCODE     OPERAND    COMMENTS
EMPTY     EQU        2003H
DETECT    EQU        2004H
POFF      EQU        2005H
PON       EQU        2006H
IVAL      SET        18H
CVAL      SET        12H
PVAL1     SET        52H
PVAL2     SET        92H
NUMPUL    SET        05H
METER     MVI        A,0EH      ;load bit pattern in Acc.
          OUT        20H        ;output Acc. to port 20
          MVI        B,20H      ;load the memory loc. 20FF
          MVI        C,FFH      ;in Reg. B and C
          STAX       B          ;store Acc. at loc. 20FF
          MVI        A,IVAL     ;load interrupt mask value
          SIM                   ;set interrupt mask
          MVI        A,CVAL     ;****************************
          OUT        13H        ;
          LDA        SPACE      ;
          DCR        A          ;
          OUT        10H        ;
          MVI        A,PVAL1    ;this section sets the
          OUT        13H        ;counting modes and values
          MVI        A,PVAL2    ;for each of the three
          OUT        13H        ;counters
          MVI        A,NUMPUL   ;
          OUT        11H        ;
          OUT        12H        ;
          MVI        A,05H      ;
          OUT        23H        ;
          MVI        A,01H      ;
          OUT        23H        ;
          MVI        A,00H      ;
          STA        EMPTY      ;****************************
NEXT      EI                    ;enable interrupts
          MVI        A,00H      ;
          STA        DETECT     ;reset DETECT
          MVI        E,01H      ;
POLL      IN         21H        ;input photocell
          ANI        00000001B  ;mask out all but bit 1
          CMP        E          ;check for photocell on
          JZ         PCON       ;if on jump to PCON
          JMP        POLL       ;if off continue to poll
PCON      IN         21H        ;input photocell
          ANI        00000001B  ;mask out all but bit 1
          CMP        E          ;check for photocell on
          JNZ        SEED       ;if off jump to SEED
          JMP        PCON       ;if on continue to poll

   THIS SECTION HANDLES THE THE TRAVEL INTERRUPT
INTER     POP        PSW        ;pop data off stack
          MVI        A,00H      ;****************************
          OUT        23H        ;
```

```
        MVI     A,01H       ;
        OUT     23H         ;
        MVI     B,00H       ;this section checks to see if
        MVI     A,OOH       ;a seed has been detected
        OUT     22H         ;if no seed has entered the
        STA     POFF        ;meter, then control moves to
        INR     A           ;CHEK
        STA     PON         ;if a seed was detected, then
        LDA     DETECT      ;control transfers to RSTRT
        CMP     B           ;
        JZ      CHEK        ;
        JMP     RSTRT       ;*****************************

   THIS SECTION STOPS THE METER IF NO SEEDS ARE ENTERING
HELP    MVI     B,00H       ;set pulse counter = 0
LP      MVI     A,01H       ;turn pulse on
        OUT     22H         ;output pulse to motor 1
        LXI     D,0008H     ;load pulse width delay value
        CALL    DELAY       ;call delay routine in monitor
        MVI     A,OOH       ;turn pulse off
        OUT     22H         ;output to stepping motor 1
        INR     B           ;increment pulse counter
        MOV     A,B         ;move pulse counter into Acc.
        CPI     05H         ;compare pulse counter to 5
        JZ      FLASH       ;if equal, go to FLASH
        LHLD    PDELAY      ;load PDELAY into Reg. H and L
        XCHG                ;exchange Reg. H & L with D & E
        CALL    DELAY       ;call delay routine
        JMP     LP          ;start another pulse
FLASH   MVI     A,01H       ;use data field on keyboard
        MVI     B,00H       ;no decimal indicator
        LXI     H,BLANK     ;use characters at BLANK
        CALL    OUTPT       ;output blanks
DPY     MVI     A,00H       ;use address field on keyboard
        MVI     B,00H       ;no decimal indicator
        LXI     H,CHAR      ;use characters at CHAR
        CALL    OUTPT       ;output four characters to the
                            ;keyboard to flash HELP
        LXI     D,0FFFFH    ;load time between flashes
        CALL    DELAY       ;call delay routine
        MVI     A,00H
        MVI     B,00H
        LXI     H,BLANK     ;use characters at BLANK
        CALL    OUTPT       ;output blank characters
        LXI     D,0FFFFH    ;load value for time delay
        CALL    DELAY       ;call delay routine
        JMP     DPY         ;continue until reset

   THIS SECTION INITIATES DISK ROTATION WHEN A SEED IS PRESENT
SEED    DI                  ;disable the interrupts
        MVI     A,40H       ;*************************
        OUT     22H         ;
        STA     POFF        ;set POFF and PON to catch a seed
        INR     A           ;and start the time delay for
```

```
        STA     PON         ;seed movement
        MVI     A,ØØH       ;
        STA     EMPTY       ;
        INR     A           ;
        STA     DETECT      ;
        LHLD    DP1         ;
        XCHG                ;
        CALL    DELAY       ;
        MVI     C,ØØH       ;**************************
RSTRT   MVI     E,Ø8H       ;
PCHK    IN      21H         ;
        CMP     E           ;
        JC      PCHK        ;this section outputs a pulse
LOOP    LDA     PON         ;to start the motor circuits
        OUT     22H         ;
CK      IN      21H         ;the transfer circuit is enabled
        CMP     E           ;or disabled, depending on the
        JNC     CK          ;current operation
        LDA     POFF        ;
        OUT     22H         ;it is off to catch a seed in the
CHECK   MOV     A,C         ;input disk and on to transfer a seed
        CPI     01H         ;
        JZ      NEXT        ;
        INR     C           ;
        EI                  ;enable interrupts
        HLT                 ;halt for the interrupt
CHEK    LDA     EMPTY       ;**************************
        CPI     10H         ;this section increments the EMPTY
        JZ      HELP        ;counter and returns to the polling
        INR     A           ;loop if there have been less than
        STA     EMPTY       ;16 consecutive misses
        JMP     NEXT        ;**************************
CHAR    DB      10H,0EH,11H,12H
BLANK   DB      15H,15H,15H,15H
```

APPENDIX C

GEL VISCOSITY DATA

APPENDIX C-1

Concentration (Percent)	Shear Rate (Sec^{-1})	Shear Stress (Pa)
0.5	30.29	27.72
0.5	58.71	38.38
0.5	87.12	46.91
0.5	115.53	55.44
0.5	143.94	61.84
0.5	143.94	59.70
0.5	172.35	68.23
0.5	200.77	72.50
0.5	200.77	72.50
0.5	229.18	76.76
0.5	229.18	76.76
0.75	30.71	40.51
0.75	59.52	59.70
0.75	59.52	61.84
0.75	88.33	74.63
0.75	88.33	63.98
0.75	117.14	83.16
0.75	117.76	76.76
0.75	145.94	91.69
0.75	145.94	87.42
0.75	174.75	100.22
0.75	174.75	95.95
0.75	203.56	106.61
0.75	203.56	104.48
0.75	232.37	110.88
0.75	232.37	110.88
1.0	30.94	53.31
1.0	59.95	72.50
1.0	59.95	66.10
1.0	88.97	89.55

APPENDIX C-1 (Continued)

Concentration (Percent)	Shear Rate (Sec^{-1})	Shear Stress (Pa)
1.0	88.97	81.03
1.0	117.98	102.35
1.0	117.98	98.08
1.0	147.00	110.88
1.0	147.00	108.74
1.0	176.01	121.54
1.0	176.01	117.27
1.0	205.03	130.07
1.0	205.03	127.94
1.0	234.04	134.33
1.0	234.04	134.33

APPENDIX C-2

Concentration (Percent)	Shear Rate (Sec^{-1})	Shear Stress (Pa)
0.5	2.13	4.62
0.5	2.13	4.62
0.5	2.13	4.62
0.5	4.25	6.40
0.5	4.25	6.75
0.5	4.25	6.40
0.5	4.25	6.40
0.5	4.25	7.11
0.5	4.25	6.40
0.5	10.63	10.66
0.5	10.63	11.01
0.5	10.63	11.01
0.5	10.63	9.59
0.5	10.63	11.01
0.5	10.63	9.24
0.5	21.25	16.34
0.5	21.25	16.70
0.5	21.25	16.70
0.5	21.25	12.79
0.5	21.25	15.63
0.5	21.25	14.92
0.7	1.06	5.33
0.7	1.06	4.62
0.7	1.06	4.62
0.7	1.06	4.62
0.7	1.06	4.26
0.7	1.06	4.26
0.7	2.13	7.46
0.7	2.13	7.11
0.7	2.13	6.75
0.7	2.13	6.75
0.7	2.13	6.40
0.7	2.13	6.04
0.7	4.25	10.66
0.7	4.25	9.95

APPENDIX C-2 (Continued)

CONCENTRATION (percent)	SHEAR RATE (sec^{-1})	SHEAR STRESS (Pa)
0.7	4.25	10.30
0.7	4.25	10.30
0.7	4.25	9.23
0.7	4.25	9.23
0.7	10.63	17.77
0.7	10.63	15.99
0.7	10.63	15.28
0.7	10.63	14.92
0.7	10.63	14.92
0.7	10.63	14.92
0.7	21.25	26.29
0.7	21.25	24.16
0.7	21.25	23.45
0.7	21.25	22.74
0.7	21.25	22.38
0.7	21.25	22.38
1.0	1.06	7.11
1.0	1.06	7.46
1.0	1.06	7.46
1.0	2.13	10.30
1.0	2.13	10.30
1.0	2.13	10.30
1.0	2.13	13.50
1.0	2.13	9.94
1.0	2.13	9.94
1.0	4.25	14.57
1.0	4.25	14.57
1.0	4.25	14.57
1.0	4.25	16.70
1.0	4.25	15.63
1.0	4.25	14.21
1.0	10.63	22.74
1.0	10.63	23.45
1.0	10.63	23.45
1.0	10.63	25.94

APPENDIX C-2 (Continued)

CONCENTRATION (percent)	SHEAR RATE (sec^{-1})	SHEAR STRESS (Pa)
1.0	10.63	24.52
1.0	10.63	21.68
1.0	21.25	36.95
1.0	21.25	35.53
1.0	21.25	34.11
1.0	21.25	38.02
1.0	21.25	38.02
1.0	21.25	31.98

APPENDIX C-3

Concentration (Percent)	Shear Rate (Sec^{-1})	Shear Stress (Pa)
0.5	5.11	4.35
0.5	5.11	4.35
0.5	5.11	5.44
0.5	10.22	5.99
0.5	10.22	5.44
0.5	10.22	3.81
0.5	170.34	20.68
0.5	170.34	20.68
0.5	170.34	15.78
0.5	340.68	38.10
0.5	340.68	38.01
0.5	340.68	26.67
0.5	511.02	54.43
0.5	511.02	53.33
0.5	511.02	32.66
0.5	1022.04	99.06
0.5	1022.04	103.41
0.5	1022.04	69.67
0.7	5.11	9.25
0.7	5.11	11.97
0.7	5.11	10.89
0.7	10.22	12.52
0.7	10.22	10.34
0.7	10.22	12.52
0.7	170.34	47.90
0.7	170.34	39.73
0.7	170.34	37.55
0.7	340.68	76.20
0.7	340.68	68.03
0.7	340.68	62.59
0.7	511.02	96.33
0.7	511.02	94.16
0.7	511.02	76.2
0.7	1022.04	137.15
0.7	1022.04	152.39

APPENDIX C-3 (Continued)

Concentration (Percent)	Shear Rate (Sec^{-1})	Shear Stress (Pa)
0.7	1022.04	125.18
1.0	5.11	11.43
1.0	5.11	10.34
1.0	5.11	10.89
1.0	10.22	14.70
1.0	10.22	14.15
1.0	10.22	9.80
1.0	170.34	66.40
1.0	170.34	65.31
1.0	170.34	45.17
1.0	340.68	108.85
1.0	340.68	104.50
1.0	340.68	82.73
1.0	511.02	157.84
1.0	511.02	134.43
1.0	511.02	119.74

APPENDIX C-4

GEL CONCENTRATION = 0.6 PERCENT

TIME (sec)	SHEAR RATE (sec^{-1})	SHEAR STRESS (Pa)	SHEAR RATE (sec^{-1})	SHEAR STRESS (Pa)	SHEAR RATE (sec^{-1})	SHEAR STRESS (Pa)
5			4.40	7.91	11.01	12.47
30	2.20	5.50	4.40	7.65	11.01	12.04
60	2.20	5.24	4.40	7.40	11.01	11.70
90	2.20	4.99	4.40	7.14	11.01	11.35
120	2.20	4.82	4.40	6.88	11.01	11.18
150	2.20	4.73	4.40	6.79	11.01	11.01
180	2.20	4.56	4.40	6.62	11.01	10.84
210	2.20	4.47	4.40	6.54	11.01	10.66
240	2.20	4.39	4.40	6.36	11.01	10.58
270	2.20	4.30	4.40	6.27	11.01	10.49
300	2.20	4.21	4.40	6.19	11.01	10.41
360	2.20	4.13	4.40	6.02	11.01	10.23
420	2.20	3.96	4.40	5.85	11.01	10.06
480	2.20	3.87	4.40	5.76	11.01	9.98
540	2.20	3.78	4.40	5.68	11.01	9.89
600	2.20	3.70	4.40	5.59	11.01	9.80

APPENDIX C-4 (Continued)

GEL CONCENTRATION = 0.8 PERCENT

TIME (sec)	SHEAR RATE (sec^{-1})	SHEAR STRESS (Pa)	SHEAR RATE (sec^{-1})	SHEAR STRESS (Pa)	SHEAR RATE (sec^{-1})	SHEAR STRESS (Pa)
5	2.20	8.51	4.40	11.95		
30	2.20	8.08	4.40	11.18	11.01	16.86
60	2.20	7.83	4.40	10.66	11.01	16.00
90	2.20	7.31	4.40	9.98	11.01	15.39
120	2.20	6.97	4.40	9.63	11.01	14.96
150	2.20	6.71	4.40	9.29	11.01	14.53
180	2.20	6.45	4.40	9.03	11.01	14.28
210	2.20	6.28	4.40	8.77	11.01	13.93
240	2.20	6.02	4.40	8.51	11.01	13.67
270	2.20	5.93	4.40	8.26	11.01	13.50
300	2.20	5.76	4.40	8.08	11.01	13.33
360	2.20	5.50	4.40	7.83	11.01	12.99
420	2.20	5.25	4.40	7.48	11.01	12.73
480	2.20	5.07	4.40	7.22	11.01	12.47
540	2.20	4.90	4.40	7.05	11.01	12.30
300	2.20	5.76	4.40	8.08	11.01	13.33
360	2.20	5.50	4.40	7.83	11.01	12.99
420	2.20	5.25	4.40	7.48	11.01	12.73
480	2.20	5.07	4.40	7.22	11.01	12.47
540	2.20	4.90	4.40	7.05	11.01	12.30
600	2.20	4.73	4.40	6.79	11.01	12.12

APPENDIX C-4 (Continued)

GEL CONCENTRATION = 1.0 PERCENT

TIME (sec)	SHEAR RATE (sec^{-1})	SHEAR STRESS (Pa)	SHEAR RATE (sec^{-1})	SHEAR STRESS (Pa)
5			4.40	12.47
30	2.20	9.20	4.40	12.21
60	2.20	8.86	4.40	11.87
90	2.20	8.51	4.40	11.52
120	2.20	8.34	4.40	11.27
150	2.20	8.08	4.40	11.01
180	2.20	7.91	4.40	10.84
210	2.20	7.74	4.40	10.66
240	2.20	7.57	4.40	10.49
270	2.20	7.48	4.40	10.41
300	2.20	7.31	4.40	10.23
360	2.20	7.05	4.40	9.98
420	2.20	6.88	4.40	9.80
480	2.20	6.71	4.40	9.63
540	2.20	6.54	4.40	9.46
600	2.20	6.36	4.40	9.29

APPENDIX C-5

Concentration (Percent)	Shear Rate (Sec^{-1})	Shear Stress (Pa)
1.8	25.23	10.66
1.8	48.89	18.76
1.8	72.55	24.73
1.8	96.21	30.70
1.8	119.87	40.94
1.8	143.53	46.91
1.8	167.19	51.17
1.8	190.85	67.38
2.0	26.28	27.29
2.0	38.60	25.59
2.0	50.93	37.53
2.0	75.58	47.76
2.0	75.58	46.91
2.0	75.58	46.91
2.0	100.23	66.10
2.0	112.55	55.44
2.0	124.87	77.61
2.0	124.87	75.06
2.0	137.20	61.41
2.0	137.20	76.76
2.0	137.20	68.23
2.0	137.20	68.23
2.0	149.52	92.11
2.0	149.52	83.16
2.0	161.85	74.63
2.0	174.17	102.35
2.0	174.17	98.08
2.0	198.82	109.17
2.0	198.82	85.29
2.0	198.82	85.29

APPENDIX C-5 (Continued)

Concentration (Percent)	Shear Rate (Sec^{-1})	Shear Stress (Pa)
2.2	27.82	34.12
2.2	27.82	34.12
2.2	53.92	55.44
2.2	80.02	71.64
2.2	80.02	64.82
2.2	106.11	78.04
2.2	132.21	88.70
2.2	132.21	93.82
2.2	158.30	104.91
2.2	158.30	109.17
2.2	184.40	115.99
2.2	210.50	126.23
2.2	210.50	124.52

APPENDIX C-6

Concentration (Percent)	Shear Rate (Sec^{-1})	Shear Stress (Pa)
0.5	30.29	27.72
0.5	58.71	38.38
0.5	87.12	46.91
0.5	115.53	55.44
0.5	143.94	61.84
0.5	143.94	59.70
0.5	172.35	68.23
0.5	200.77	72.50
0.5	200.77	72.50
0.5	229.18	76.76
0.5	229.18	76.76
0.75	30.71	40.51
0.75	59.52	59.70
0.75	59.52	61.84
0.75	88.33	74.63
0.75	88.33	63.98
0.75	117.14	83.16
0.75	117.14	76.76
0.75	145.94	91.69
0.75	145.94	87.42
0.75	174.75	100.22
0.75	174.75	95.95
0.75	203.56	106.61
0.75	203.56	104.48
0.75	232.37	110.88
0.75	232.37	110.88
1.0	30.94	53.31
1.0	59.95	72.50
1.0	59.95	66.10
1.0	88.97	89.55

APPENDIX C-6 (Continued)

Concentration (Percent)	Shear Rate (Sec^{-1})	Shear Stress (Pa)
1.0	88.97	81.03
1.0	117.98	102.35
1.0	117.98	98.08
1.0	147.00	110.88
1.0	147.00	108.74
1.0	176.01	121.54
1.0	176.01	117.27
1.0	205.03	130.07
1.0	205.03	127.94
1.0	234.04	134.33
1.0	234.04	134.33

APPENDIX D

SEED SUSPENSION DATA

APPENDIX D-1

Freq. = 15 Hz, Amp. = 0.38 mm, Vibration Time = 1 hr

TIME	CONC.	LOCATION	REPLIC.	SAMPLE	NO. SEED
before	0.8	lower	1	1	35.0
before	0.8	lower	1	2	27.0
before	0.8	lower	2	1	23.0
before	0.8	lower	2	2	23.0
before	0.8	middle	1	1	12.0
before	0.8	middle	1	2	22.0
before	0.8	middle	2	1	21.0
before	0.8	middle	2	2	26.0
before	0.8	upper	1	1	9.0
before	0.8	upper	1	2	17.0
before	0.8	upper	2	1	9.0
before	0.8	upper	2	2	8.0
before	0.9	lower	1	1	23.0
before	0.9	lower	1	2	24.0
before	0.9	lower	2	1	14.0
before	0.9	lower	2	2	19.0
before	0.9	middle	1	1	19.0
before	0.9	middle	1	2	19.0
before	0.9	middle	2	1	38.0
before	0.9	middle	2	2	23.0
before	0.9	upper	1	1	9.0
before	0.9	upper	1	2	24.0
before	0.9	upper	2	1	19.0
before	0.9	upper	2	2	29.0
before	1.0	lower	1	1	18.0
before	1.0	lower	1	2	21.0
before	1.0	lower	2	1	29.0
before	1.0	lower	2	2	16.0
before	1.0	middle	1	1	29.0
before	1.0	middle	1	2	29.0
before	1.0	middle	2	1	20.0
before	1.0	middle	2	2	17.0

APPENDIX D-1 (Continued)

TIME	CONC.	LOCATION	REPLIC.	SAMPLE	NO. SEED
before	1.0	upper	1	1	24.0
before	1.0	upper	1	2	23.0
before	1.0	upper	2	1	9.0
before	1.0	upper	2	2	19.0
before	1.1	lower	1	1	20.0
before	1.1	lower	1	2	20.0
before	1.1	lower	2	1	12.0
before	1.1	lower	2	2	37.0
before	1.1	middle	1	1	23.0
before	1.1	middle	1	2	18.0
before	1.1	middle	2	1	15.0
before	1.1	middle	2	2	22.0
before	1.1	upper	1	1	16.0
before	1.1	upper	1	2	17.0
before	1.1	upper	2	1	10.0
before	1.1	upper	2	2	26.0
after	0.8	lower	1	1	55.6
after	0.8	lower	1	2	37.8
after	0.8	lower	2	1	51.1
after	0.8	lower	2	2	46.7
after	0.8	middle	1	1	10.0
after	0.8	middle	1	2	7.8
after	0.8	middle	2	1	0.0
after	0.8	middle	2	2	0.0
after	0.8	upper	1	1	2.2
after	0.8	upper	1	2	1.1
after	0.8	upper	2	1	0.0
after	0.8	upper	2	2	0.0
after	0.9	lower	1	1	47.8
after	0.9	lower	1	2	41.1
after	0.9	lower	2	1	41.1
after	0.9	lower	2	2	47.8

APPENDIX D-1 (Continued)

TIME	CONC.	LOCATION	REPLIC.	SAMPLE	NO. SEED
after	0.9	middle	1	1	0.0
after	0.9	middle	1	2	0.0
after	0.9	middle	2	1	2.2
after	0.9	middle	2	2	4.4
after	0.9	upper	1	1	0.0
after	0.9	upper	1	2	0.0
after	0.9	upper	2	1	0.0
after	0.9	upper	2	2	0.0
after	1.0	lower	1	1	35.6
after	1.0	lower	1	2	31.1
after	1.0	lower	2	1	45.6
after	1.0	lower	2	2	46.7
after	1.0	middle	1	1	13.3
after	1.0	middle	1	2	23.3
after	1.0	middle	2	1	0.0
after	1.0	middle	2	2	1.1
after	1.0	upper	1	1	28.9
after	1.0	upper	1	2	6.7
after	1.0	upper	2	1	0.0
after	1.0	upper	2	2	0.0
after	1.1	lower	1	1	28.9
after	1.1	lower	1	2	25.6
after	1.1	lower	2	1	32.2
after	1.1	lower	2	2	25.6
after	1.1	middle	1	1	6.7
after	1.1	middle	1	2	5.6
after	1.1	middle	2	1	7.8
after	1.1	middle	2	2	11.1
after	1.1	upper	1	1	0.0
after	1.1	upper	1	2	3.3
after	1.1	upper	2	1	1.1
after	1.1	upper	2	2	2.2

APPENDIX D-2

Freq. = 50 Hz, Amp. = 0.38 mm, Vibration Time = 1 hr

TIME	CONC.	LOCATION	REPLIC.	SAMPLE	NO. SEED
before	1.65	lower	1	1	15.0
before	1.65	lower	1	2	10.0
before	1.65	lower	2	1	23.0
before	1.65	lower	2	2	24.0
before	1.65	middle	1	1	5.0
before	1.65	middle	1	2	27.0
before	1.65	middle	2	1	18.0
before	1.65	middle	2	2	18.0
before	1.65	upper	1	1	1.0
before	1.65	upper	1	2	0.0
before	1.65	upper	2	1	10.0
before	1.65	upper	2	2	15.0
before	1.80	lower	1	1	8.0
before	1.80	lower	1	2	22.0
before	1.80	lower	2	1	23.0
before	1.80	lower	2	2	20.0
before	1.80	middle	1	1	5.0
before	1.80	middle	1	2	4.0
before	1.80	middle	2	1	22.0
before	1.80	middle	2	2	17.0
before	1.80	upper	1	1	7.0
before	1.80	upper	1	2	1.0
before	1.80	upper	2	1	11.0
before	1.80	upper	2	2	13.0
before	1.95	lower	1	1	7.0
before	1.95	lower	1	2	9.0
before	1.95	lower	2	1	19.0
before	1.95	lower	2	2	20.0
before	1.95	middle	1	1	5.0
before	1.95	middle	1	2	11.0
before	1.95	middle	2	1	19.0
before	1.95	middle	2	2	22.0

APPENDIX D-2 (Continued)

TIME	CONC.	LOCATION	REPLIC.	SAMPLE	NO. SEED
before	1.95	upper	1	1	7.0
before	1.95	upper	1	2	2.0
before	1.95	upper	2	1	16.0
before	1.95	upper	2	2	15.0
before	2.10	lower	1	1	8.0
before	2.10	lower	1	2	10.0
before	2.10	lower	2	1	24.0
before	2.10	lower	2	2	20.0
before	2.10	middle	1	1	11.0
before	2.10	middle	1	2	2.0
before	2.10	middle	2	1	18.0
before	2.10	middle	2	2	23.0
before	2.10	upper	1	1	11.0
before	2.10	upper	1	2	6.0
before	2.10	upper	2	1	17.0
before	2.10	upper	2	2	13.0
after	1.65	lower	1	1	17.8
after	1.65	lower	1	2	16.7
after	1.65	lower	2	1	32.2
after	1.65	lower	2	2	54.4
after	1.65	middle	1	1	18.9
after	1.65	middle	1	2	2.2
after	1.65	middle	2	1	3.3
after	1.65	middle	2	2	0.0
after	1.65	upper	1	1	0.0
after	1.65	upper	1	2	0.0
after	1.65	upper	2	1	0.0
after	1.65	upper	2	2	0.0
after	1.80	lower	1	1	12.5
after	1.80	lower	1	2	7.5
after	1.80	lower	2	1	15.6
after	1.80	lower	2	2	15.6

APPENDIX D-2 (Continued)

TIME	CONC.	LOCATION	REPLIC.	SAMPLE	NO. SEED
after	1.80	middle	1	1	8.8
after	1.80	middle	1	2	10.0
after	1.80	middle	2	1	25.6
after	1.80	middle	2	2	36.7
after	1.80	upper	1	1	0.0
after	1.80	upper	1	2	7.5
after	1.80	upper	2	1	0.0
after	1.80	upper	2	2	2.2
after	1.95	lower	1	1	11.1
after	1.95	lower	1	2	7.8
after	1.95	lower	2	1	24.4
after	1.95	lower	2	2	23.3
after	1.95	middle	1	1	2.2
after	1.95	middle	1	2	17.8
after	1.95	middle	2	1	22.2
after	1.95	middle	2	2	18.9
after	1.95	upper	1	1	6.7
after	1.95	upper	1	2	2.2
after	1.95	upper	2	1	10.0
after	1.95	upper	2	2	7.8
after	2.10	lower	1	1	4.4
after	2.10	lower	1	2	12.2
after	2.10	lower	2	1	21.1
after	2.10	lower	2	2	17.8
after	2.10	middle	1	1	10.0
after	2.10	middle	1	2	8.9
after	2.10	middle	2	1	22.2
after	2.10	middle	2	2	26.7
after	2.10	upper	1	1	4.4
after	2.10	upper	1	2	7.8
after	2.10	upper	2	1	24.4
after	2.10	upper	2	2	14.4

APPENDIX D-3

Freq. = 15 Hz, Amp. = 0.38 mm, Vibration Time = 1 hr

TIME	CONC.	LOCATION	REPLIC.	SAMPLE	NO. SEED
before	1.65	lower	1	1	16.2
before	1.65	lower	1	2	37.9
before	1.65	lower	2	1	14.0
before	1.65	lower	2	2	15.0
before	1.65	middle	1	1	11.7
before	1.65	middle	1	2	21.7
before	1.65	middle	2	1	25.0
before	1.65	middle	2	2	20.0
before	1.65	upper	1	1	9.9
before	1.65	upper	1	2	25.3
before	1.65	upper	2	1	8.0
before	1.65	upper	2	2	7.0
before	1.80	lower	1	1	15.4
before	1.80	lower	1	2	22.6
before	1.80	lower	2	1	24.0
before	1.80	lower	2	2	16.0
before	1.80	middle	1	1	19.9
before	1.80	middle	1	2	21.7
before	1.80	middle	2	1	17.0
before	1.80	middle	2	2	17.0
before	1.80	upper	1	1	19.0
before	1.80	upper	1	2	13.6
before	1.80	upper	2	1	10.0
before	1.80	upper	2	2	9.0
before	1.95	lower	1	1	19.9
before	1.95	lower	1	2	23.5
before	1.95	lower	2	1	23.0
before	1.95	lower	2	2	27.0
before	1.95	middle	1	1	19.0
before	1.95	middle	1	2	12.6
before	1.95	middle	2	1	17.0
before	1.95	middle	2	2	21.0

APPENDIX D-3 (Continued)

TIME	CONC.	LOCATION	REPLIC.	SAMPLE	NO. SEED
before	1.95	upper	1	1	20.8
before	1.95	upper	1	2	25.3
before	1.95	upper	2	1	12.0
before	1.95	upper	2	2	13.0
before	2.10	lower	1	1	9.9
before	2.10	lower	1	2	21.7
before	2.10	lower	2	1	29.0
before	2.10	lower	2	2	17.0
before	2.10	middle	1	1	15.4
before	2.10	middle	1	2	24.4
before	2.10	middle	2	1	17.0
before	2.10	middle	2	2	27.0
before	2.10	upper	1	1	16.2
before	2.10	upper	1	2	13.6
before	2.10	upper	2	1	17.0
before	2.10	upper	2	2	14.0
after	1.65	lower	1	1	28.9
after	1.65	lower	1	2	37.9
after	1.65	lower	2	1	33.3
after	1.65	lower	2	2	42.2
after	1.65	middle	1	1	5.4
after	1.65	middle	1	2	1.8
after	1.65	middle	2	1	11.1
after	1.65	middle	2	2	3.3
after	1.65	upper	1	1	0.0
after	1.65	upper	1	2	0.0
after	1.65	upper	2	1	0.0
after	1.65	upper	2	2	0.0
after	1.80	lower	1	1	20.8
after	1.80	lower	1	2	41.5
after	1.80	lower	2	1	26.7
after	1.80	lower	2	2	24.4

APPENDIX D-3 (Continued)

TIME	CONC.	LOCATION	REPLIC.	SAMPLE	NO. SEED
after	1.80	middle	1	1	15.4
after	1.80	middle	1	2	16.2
after	1.80	middle	2	1	46.7
after	1.80	middle	2	2	28.9
after	1.80	upper	1	1	0.0
after	1.80	upper	1	2	0.0
after	1.80	upper	2	1	0.0
after	1.80	upper	2	2	2.2
after	1.95	lower	1	1	16.2
after	1.95	lower	1	2	25.3
after	1.95	lower	2	1	22.2
after	1.95	lower	2	2	34.4
after	1.95	middle	1	1	12.6
after	1.95	middle	1	2	27.1
after	1.95	middle	2	1	28.9
after	1.95	middle	2	2	24.4
after	1.95	upper	1	1	5.4
after	1.95	upper	1	2	9.0
after	1.95	upper	2	1	17.8
after	1.95	upper	2	2	16.7
after	2.10	lower	1	1	24.4
after	2.10	lower	1	2	20.8
after	2.10	lower	2	1	13.3
after	2.10	lower	2	2	18.9
after	2.10	middle	1	1	19.0
after	2.10	middle	1	2	10.8
after	2.10	middle	2	1	17.8
after	2.10	middle	2	2	13.3
after	2.10	upper	1	1	11.7
after	2.10	upper	1	2	10.8
after	2.10	upper	2	1	17.8
after	2.10	upper	2	2	7.8

APPENDIX E

UNMETERED SEED SPACING DATA

TEST CODE DEFINITIONS

Example Code: VWXYZ

V - seed type

A-lettuce

B-cucumber

C-tomato

D-cabbage

W - travel speed (km/hr)

1, 3, 5, or 7

X - seed funnel used

A-2.0 mm outlet

C-3.5 mm outlet

E-5.0 mm outlet

Y - Gel/Seed Ratio

5-1 ml/seed

10-2 ml/seed

15-3 ml/seed

20-4 ml/seed

25-5 ml/seed

Z - Test Identification

A-first test

B-second test

APPENDIX E-1

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	11	113
10	8	102
15	6	94
20	5	88
25	11	83
30	8	72
35	5	64
40	6	59
45	4	53
50	4	49
55	3	45
60	2	42
65	2	40
70	2	38
75	5	36
80	7	31
85	1	24
90	3	23
95	2	20
100	1	19
105	1	18
110	2	16
115	1	14
120	2	13
125	1	11
130	2	10
140	1	8
150	2	7
170	1	5
175	1	4
180	1	3
235	1	2

APPENDIX E-2

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	8	101
10	6	93
15	5	87
20	7	82
25	4	75
30	7	71
35	6	64
40	8	58
45	4	50
50	3	46
55	5	43
60	4	38
65	5	34
70	4	29
75	1	25
80	1	24
90	4	23
100	1	19
105	1	18
110	2	17
115	1	15
130	3	14
165	3	11
175	1	8
180	1	7
210	1	6
220	1	5
230	1	4
310	1	3

APPENDIX E-3

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	18	254
10	17	236
15	7	219
20	20	212
25	12	202
30	15	190
35	6	175
40	15	169
45	8	154
50	9	146
55	7	137
60	10	130
65	8	120
70	8	112
75	7	104
80	7	97
85	6	90
90	6	84
95	7	78
100	3	71
105	6	68
110	5	62
115	4	57
120	4	53
125	4	49
130	3	45
140	4	42
150	2	38
155	2	36
160	4	34
165	2	30
170	9	28
175	2	19
180	1	17
185	3	16

APPENDIX E-3 (Continued)

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
190	1	13
210	2	12
220	1	10
225	1	9
230	1	8
235	1	7
245	1	6
310	1	5
325	1	4
330	2	3
370	1	1

APPENDIX E-4

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	16	304
10	20	288
15	22	268
20	14	246
25	7	232
30	16	225
35	16	209
40	9	193
45	14	184
50	16	170
55	9	154
60	7	145
65	6	138
70	9	132
75	10	123
80	6	113
85	3	107
90	8	104
95	8	96
100	8	88
105	2	80
110	3	78
115	3	75
120	4	72
125	5	68
130	6	63
135	5	57
140	3	52
145	3	49
150	2	46
155	6	44
160	1	38
165	1	37
170	1	36
175	1	35

APPENDIX E-4 (Continued)

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
180	3	34
185	4	31
190	1	27
200	1	26
205	2	25
210	2	23
215	3	21
235	3	18
240	2	15
250	1	13
270	2	12
285	1	10
290	1	9
300	1	8
305	1	7
320	1	6
330	1	5
350	1	4
355	1	3

APPENDIX E-5

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	16	241
10	11	225
25	5	214
20	12	209
25	7	197
30	13	190
35	7	177
40	15	170
45	7	155
50	14	148
55	8	134
60	12	126
65	6	114
70	6	108
75	8	102
80	5	94
85	4	89
90	6	85
95	3	79
100	5	76
105	5	71
110	8	66
115	5	58
120	3	53
125	4	50
130	3	46
140	2	43
145	2	41
150	3	39
155	1	36
170	1	35
175	1	34
180	1	33
185	3	32
190	1	29

APPENDIX E-5 (Continued)

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
195	3	28
205	2	25
210	1	23
215	1	22
220	3	21
230	1	18
235	2	17
250	1	15
255	1	14
265	1	13
285	2	12
295	3	10
315	1	7
330	1	6
370	1	5
375	1	4
390	1	3
420	1	2
555	1	1

APPENDIX E-6

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	105	358
10	57	253
15	26	196
20	32	170
25	26	138
30	28	112
35	16	84
40	9	68
45	13	59
50	7	46
55	9	39
60	8	30
65	5	22
70	5	17
75	1	12
80	4	11
85	2	7
95	1	5
100	3	4
150	1	1

APPENDIX E-7

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	84	448
10	51	364
15	50	313
20	45	263
25	37	218
30	27	181
35	21	154
40	30	133
45	12	103
50	11	91
55	10	80
60	13	70
65	8	57
70	6	49
75	4	43
80	6	39
85	2	33
90	5	31
95	1	26
100	4	25
105	3	21
110	1	18
115	2	17
120	3	15
125	1	12
150	2	11
165	1	9
190	1	8
195	2	7
205	1	5
225	2	4
245	1	2
300	1	1

APPENDIX E-8

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	37	308
10	27	271
15	20	244
20	23	224
25	18	201
30	18	183
35	15	165
40	21	150
45	16	129
50	10	113
55	14	103
60	5	89
65	8	84
70	6	76
75	6	70
80	6	64
85	2	58
90	5	56
95	5	51
100	1	46
105	6	45
110	6	39
115	3	33
120	2	30
125	3	28
130	2	25
135	3	23
140	4	20
145	2	16
150	1	14

APPENDIX E-8 (Continued)

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
155	2	13
160	1	11
170	2	10
180	1	8
190	1	7
220	1	6
230	2	5
325	1	3
430	1	2
440	1	1

APPENDIX E-9

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	28	363
10	40	335
15	25	295
20	24	270
25	27	246
30	30	219
35	35	189
40	14	169
45	14	155
50	16	141
55	19	125
60	17	106
65	10	89
70	7	79
75	7	72
80	10	65
85	3	55
90	4	52
95	4	48
100	5	44
105	4	39
110	6	35
120	3	29
125	2	26
130	4	24
135	3	20
140	4	17
150	3	13
160	1	10
165	1	9
170	1	8
185	1	7
190	1	6
200	1	5
205	1	4
240	1	3
260	1	2
545	1	1

APPENDIX E-10

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	25	342
10	18	317
15	7	299
20	21	292
25	16	271
30	16	255
35	10	239
40	5	229
45	6	224
50	15	218
55	17	203
60	19	186
65	3	167
70	11	164
75	6	153
80	7	147
85	4	140
90	5	136
95	11	131
100	12	120
105	6	108
110	8	102
115	3	94
120	5	91
125	3	86
130	4	83
135	2	79
140	4	77
145	5	73
150	4	68
155	1	64
160	2	63
165	2	61
170	7	59
175	1	52

APPENDIX E-10 (Continued)

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
180	8	51
185	2	43
190	8	41
195	1	33
200	2	32
205	1	30
210	1	29
215	1	28
220	1	27
225	1	26
230	3	25
235	1	22
240	1	21
250	1	20
255	2	19
260	1	17
265	1	16
270	1	15
275	1	14
305	1	13
345	2	12
350	1	10
380	1	9
385	1	8
395	1	7
435	1	6
445	1	5
460	3	4
480	1	1

APPENDIX E-11

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
5	16	260
10	10	244
15	10	234
20	6	224
25	11	218
30	9	207
35	5	198
40	9	193
45	10	184
50	12	174
55	9	162
60	10	153
65	10	143
70	3	139
75	3	136
80	7	133
85	3	126
90	6	123
95	6	117
100	2	111
105	5	109
110	7	104
115	4	97
120	3	93
125	6	90
130	4	84
135	1	80
140	4	79
145	2	75
150	3	73
155	4	70
160	3	66
170	3	63
175	1	60
180	4	59

APPENDIX E-11 (Continued)

Seed Spacing X (mm)	Number of Spaces Equal to X	Number of Spaces Greater than X
190	4	55
195	2	51
200	1	49
205	2	48
210	2	46
215	3	44
220	3	41
225	4	38
230	1	34
235	2	33
240	2	31
245	1	29
250	1	28
255	1	27
260	2	26
265	1	24
270	2	23
280	2	21
300	2	19
305	2	17
310	2	15
315	1	13
325	1	12
330	1	11
340	1	10
370	1	9
380	1	8
400	1	7
410	2	6
435	1	4
450	1	3
545	1	2
665	1	1

APPENDIX F

METERED SEED SPACING DATA

TEST CODE DEFINITIONS

Example Code: WX-Y-Z

W - Seed Type

A-lettuce

B-cucumber

C-tomato

D-cabbage

X - Desired Seed Spacing (mm)

Y - Gel/Seed Ratio (ml/seed)

1, 2, 3 or 4

Z - Metering Rate (seed/sec)

0.5, 1, 2, 3, 4 or 5

APPENDIX F-1

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	2	144
15	1	143
85	1	142
100	4	141
105	8	137
110	16	129
115	31	113
120	51	82
125	10	31
130	5	21
135	1	16
140	1	15
150	1	14
215	1	13
220	1	12
225	1	11
230	3	10
235	3	7
240	1	4
345	1	3
355	1	2
360	1	1

APPENDIX F-2

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	7	370
10	2	363
20	2	361
25	1	359
30	1	358
35	1	357
50	2	356
55	1	354
60	2	353
65	2	351
70	3	349
75	7	346
80	16	339
85	8	323
90	24	315
95	22	291
100	34	269
105	41	235
110	40	194
115	29	154
120	46	125
125	15	79
130	14	64
135	11	50
140	6	39
145	1	33
150	2	32
155	1	30
180	1	29
185	2	28

APPENDIX F-2 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
200	1	26
205	2	25
215	2	23
220	1	21
225	5	20
230	3	15
235	1	12
240	1	11
245	1	10
255	2	9
260	1	7
270	1	6
275	1	5
290	1	4
310	1	3
355	1	2
360	1	1

APPENDIX F-3

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	1	316
10	1	315
15	1	314
20	1	313
25	3	312
30	1	309
35	2	308
40	1	306
50	1	305
55	3	304
60	2	301
65	2	299
70	7	297
75	8	290
80	11	282
85	11	271
90	14	260
95	14	246
100	12	232
105	15	220
110	18	205
115	11	187
120	19	176
125	19	157
130	19	138
135	19	119
140	23	100
145	6	77
150	8	71
155	7	63
160	4	56
165	4	52
170	4	48
175	1	44
180	2	43

APPENDIX F-3 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
185	4	41
190	1	37
195	2	36
205	2	34
210	2	32
215	1	30
220	3	29
225	2	26
230	2	24
235	2	22
240	2	20
245	2	18
250	2	16
255	1	14
260	1	13
265	2	12
275	4	10
280	1	6
290	1	5
300	1	4
320	2	3
385	1	1

APPENDIX F-4

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	3	311
10	1	308
15	1	307
20	3	306
25	1	303
30	5	302
35	2	297
40	5	295
45	2	290
50	4	288
55	4	284
60	10	280
65	4	270
70	6	266
75	4	260
80	13	256
85	9	243
90	13	234
100	8	208
105	9	200
110	11	191
115	11	180
120	19	168
125	9	149
130	15	140
135	10	125
140	5	115
145	5	110
150	7	105
155	5	98
160	6	93
165	3	87
170	9	84
175	8	75
180	6	67

APPENDIX F-4 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
185	2	61
190	4	59
195	4	55
205	1	51
210	5	50
215	4	45
220	6	41
225	3	35
230	4	32
235	2	28
240	5	26
245	1	21
255	1	20
260	1	19
270	2	18
280	1	16
285	2	15
300	3	13
330	1	10
385	1	9
400	3	8
405	1	5
410	1	4
420	1	3
430	1	2
515	1	1

APPENDIX F-5

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	4	162
80	1	158
85	1	157
90	1	156
95	9	155
100	4	146
105	15	142
110	22	127
115	24	107
120	22	83
125	19	61
130	15	42
135	2	27
140	1	25
145	1	24
195	1	23
205	1	22
220	1	21
230	3	20
235	1	17
240	4	16
245	4	12
250	3	8
255	1	5
260	1	4
360	1	3
465	1	2
490	1	1

APPENDIX F-6

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	8	346
10	9	338
15	3	329
20	3	326
30	1	323
35	1	322
45	1	321
55	1	320
60	1	319
75	2	318
80	6	316
85	2	310
90	7	308
95	9	301
100	14	292
105	20	278
110	28	258
115	40	230
120	43	190
125	33	147
130	34	114
135	16	80
140	5	64
145	9	59
150	2	50
160	1	48
165	1	47
170	1	46
180	1	45
190	1	44
195	2	43
205	1	41
210	2	40
215	2	38
220	1	36

APPENDIX F-6 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
225	1	35
230	5	34
235	4	29
240	4	25
245	6	21
250	1	15
265	1	14
275	1	13
295	2	12
305	1	10
315	1	9
345	1	8
350	1	7
370	1	6
380	1	5
385	1	4
435	1	3
485	1	2
555	1	1

APPENDIX F-7

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	6	323
10	4	317
15	2	313
20	3	311
25	3	308
30	1	305
35	1	304
50	2	303
65	1	301
75	3	300
80	5	297
85	9	292
90	12	283
95	8	271
100	20	263
105	17	243
110	27	226
115	19	199
120	29	180
125	30	151
130	20	121
135	13	101
140	7	88
145	7	81
150	9	74
155	7	65
160	5	58
165	1	53
170	2	52
175	4	50
190	1	46
195	3	45
200	2	42
205	1	40
210	1	39

APPENDIX F-7 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
215	1	38
220	4	37
225	5	33
230	4	28
235	4	24
240	4	20
255	1	16
260	1	15
265	2	14
285	2	12
295	1	10
300	1	9
330	1	8
345	1	7
355	2	6
370	1	4
380	1	3
405	1	2
520	1	1

APPENDIX F-8

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	9	331
10	4	322
15	4	318
20	4	314
25	3	310
30	6	307
35	3	301
40	5	298
45	7	293
50	4	286
55	4	282
60	4	278
65	6	274
70	5	268
75	4	263
80	8	259
85	4	251
90	7	247
95	8	240
100	5	232
105	4	228
110	7	224
115	9	217
120	8	208
125	4	200
130	10	196
135	4	186
140	10	182
145	6	172
150	11	166
155	7	155
160	8	148
165	4	140
170	8	136
180	7	122

APPENDIX F-8 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
185	7	115
190	8	108
195	4	100
200	4	96
205	6	92
210	5	86
215	5	81
220	5	76
225	2	71
230	5	69
235	2	63
240	2	61
245	3	59
250	9	56
255	3	47
260	1	44
265	1	43
270	1	42
275	2	41
280	2	39
285	3	37
295	2	34
300	6	32
305	1	26
310	3	25
315	1	22
320	1	21
330	1	20
335	1	19
340	2	18
350	1	16
355	1	15
360	2	14
380	1	12
390	1	11

APPENDIX F-8 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
420	1	10
430	1	9
435	1	8
445	1	7
460	1	6
465	1	5
520	1	4
610	1	3
650	1	2
1245	1	1

APPENDIX F-9

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	10	181
10	5	171
85	1	166
95	1	165
100	2	164
105	11	162
110	29	151
115	44	122
120	41	78
125	22	37
130	6	15
135	1	9
220	1	8
230	1	7
235	1	6
240	1	5
245	1	4
350	2	3
440	1	1

APPENDIX F-10

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	10	364
10	9	354
15	5	345
20	1	340
25	1	339
70	1	338
80	1	337
85	3	336
90	3	333
95	7	330
100	21	323
105	35	302
110	44	267
115	51	223
120	68	172
125	42	104
130	19	62
135	11	43
140	7	32
145	2	25
150	6	23
155	1	17
165	1	16
200	1	15
210	1	14
225	2	13
230	2	11
235	2	9
240	4	7
245	1	3
255	1	2
340	1	1

APPENDIX F-11

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	2	383
10	5	381
15	3	376
20	4	373
35	1	369
40	2	368
55	1	366
60	1	365
65	2	364
70	1	362
75	3	361
80	4	358
85	6	354
90	21	348
95	20	327
100	15	307
105	30	292
110	37	262
115	32	225
120	44	193
125	30	149
130	36	119
135	12	83
140	18	71
145	12	53
150	6	41
155	4	35
160	3	31
165	2	28
170	3	26
175	1	23
180	1	22
210	1	21
215	4	20
230	3	16

APPENDIX F-11 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
235	1	13
240	4	12
245	2	8
250	2	6
255	1	4
260	1	3
265	1	2
320	1	1

APPENDIX F-12

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	1	469
10	1	468
15	1	467
20	3	466
25	3	463
30	3	460
35	1	457
40	4	456
45	6	452
50	7	446
55	3	439
60	9	436
65	2	427
70	12	425
75	12	413
80	17	401
85	12	384
90	20	372
95	17	352
100	21	335
105	23	314
110	28	291
115	14	263
120	32	249
125	18	217
130	25	199
135	20	174
140	22	154
145	9	132
150	21	123
155	13	102
160	11	89
165	5	78
170	6	73
175	5	67

APPENDIX F-12 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
180	7	62
185	4	55
190	1	51
195	5	50
200	3	45
205	1	42
210	4	41
215	4	37
220	1	33
225	2	32
230	4	30
235	1	26
240	3	25
245	1	22
250	1	21
255	1	20
260	1	19
265	1	18
270	1	17
275	2	16
280	3	14
285	1	11
290	1	10
295	2	9
300	2	7
305	1	5
320	1	4
365	1	3
390	1	2
550	1	1

APPENDIX F-13

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
10	2	501
15	4	499
20	3	495
25	5	492
30	2	487
35	3	485
40	5	482
45	1	477
50	9	476
55	7	467
60	7	460
65	5	453
70	10	448
75	14	438
80	19	424
85	18	405
90	12	387
95	20	375
100	18	355
105	20	337
110	20	317
115	21	297
120	31	276
125	16	245
130	29	229
135	17	200
140	12	183
145	10	171
150	21	161
155	9	140
160	11	131
165	8	120
170	16	112
175	7	96
180	8	99

APPENDIX F-13 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
185	6	91
190	7	85
195	4	78
200	10	74
205	7	64
210	1	57
220	5	56
230	6	51
235	5	45
240	4	40
245	1	36
250	4	35
255	5	31
260	3	26
265	2	23
270	1	21
275	1	20
280	1	19
285	2	18
290	2	16
295	2	14
300	2	12
310	1	10
320	2	9
325	1	7
335	1	6
350	1	5
430	1	4
460	1	3
485	1	2
585	1	1

APPENDIX F-14

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	3	522
10	1	519
15	2	518
20	8	516
25	8	508
30	6	500
35	3	494
40	3	491
45	7	488
50	11	481
55	10	470
60	14	460
65	9	446
70	15	457
75	10	432
80	13	422
85	10	409
90	16	399
95	11	383
100	22	372
105	10	350
110	14	340
115	12	326
120	21	314
125	14	293
130	21	279
135	12	258
140	15	246
145	6	231
150	17	225
155	5	208
160	15	203
165	9	188
170	13	179
175	9	166

APPENDIX F-14 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
180	17	157
185	9	140
190	13	131
195	3	118
200	5	115
205	4	110
210	10	106
215	1	96
210	7	95
225	6	88
230	2	82
235	2	80
240	6	78
245	5	72
250	7	67
255	2	60
260	6	58
265	2	52
270	5	50
275	5	50
280	2	45
285	1	43
290	1	42
300	2	41
305	4	39
310	5	35
320	3	30
325	2	27
340	2	25
350	1	23
355	1	22
360	3	21
365	1	18
370	2	17

APPENDIX F-14 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
380	1	15
385	2	14
390	2	12
395	1	10
440	1	9
465	1	8
470	1	7
480	1	6
490	2	5
505	1	3
515	1	2
545	1	1

APPENDIX F-15

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	17	196
10	8	179
95	1	171
100	8	170
105	10	162
110	29	152
115	38	123
120	46	85
125	19	39
130	11	20
140	1	9
225	1	8
235	2	7
240	3	5
245	1	2
345	1	1

APPENDIX F-16

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	12	355
10	10	343
15	6	333
20	3	327
25	4	322
30	1	318
60	1	317
70	1	316
75	2	315
80	2	313
90	3	311
100	13	308
105	21	295
110	50	274
115	50	224
120	61	174
125	26	113
130	27	87
135	8	60
140	10	52
145	4	42
150	2	38
155	1	36
160	1	35
170	1	34
175	1	33
200	2	32
205	1	30
210	3	29
220	1	26
225	3	25
230	2	22
235	1	20
240	2	19
245	2	17

APPENDIX F-16 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
255	1	15
260	1	14
265	1	13
270	1	12
280	1	11
330	2	10
360	2	7
365	2	5
450	2	3
690	1	1

APPENDIX F-17

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	3	388
10	3	385
15	4	382
20	3	378
25	4	375
30	4	371
35	3	367
40	1	364
45	1	363
50	3	362
55	2	359
60	4	357
65	2	353
75	4	351
80	10	347
85	14	337
90	17	323
95	15	306
100	23	291
105	22	268
110	41	246
115	25	205
120	37	180
125	24	143
130	29	119
135	18	90
140	15	72
145	8	57
150	8	49
155	4	41
160	4	37
165	4	33
170	2	29
180	2	27
185	2	25

APPENDIX F-17 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
190	1	23
200	3	22
205	2	19
210	1	17
220	2	16
225	1	14
230	2	13
235	1	11
240	3	10
245	1	7
250	1	6
255	1	5
280	1	4
290	1	3
305	1	2
310	1	1

APPENDIX F-18

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	5	488
10	2	483
15	1	481
20	5	480
25	5	475
30	9	470
35	4	461
40	5	457
45	5	452
50	12	447
55	5	435
60	8	430
65	11	422
70	12	411
75	17	399
80	14	382
85	9	368
90	17	359
95	21	342
100	24	321
105	13	297
110	18	284
115	18	266
120	35	248
125	22	213
130	23	191
135	23	168
140	19	145
145	6	126
150	8	120
160	17	102
165	11	85
170	7	74
175	4	67
180	6	63

APPENDIX F-18 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
185	7	57
190	4	50
195	1	46
200	4	45
205	5	41
210	2	36
215	4	34
220	5	30
225	3	25
230	1	22
235	2	21
240	3	19
245	1	16
250	2	15
255	3	13
260	2	10
280	2	8
295	1	6
310	1	5
340	1	4
345	1	3
350	1	2
410	1	1

APPENDIX F-19

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	5	126
10	1	121
15	2	120
25	1	118
55	1	117
60	2	116
65	1	114
80	3	113
85	2	110
90	3	108
95	2	105
100	5	103
105	5	98
110	8	93
115	12	85
120	9	73
125	8	64
130	9	56
135	2	47
140	2	45
145	4	43
150	2	39
155	2	37
160	1	35
165	1	34
210	3	33
215	1	30
220	1	29
225	3	28
230	3	25
235	2	22
240	4	20
245	1	16
250	2	15
255	1	13

APPENDIX F-19 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
260	1	12
265	1	11
270	1	10
275	1	9
295	1	8
310	1	7
355	2	6
360	1	4
365	1	3
380	1	2
585	1	1

APPENDIX F-20

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	3	154
10	4	151
15	2	147
20	4	145
25	1	141
30	2	140
35	1	138
40	2	137
50	1	135
55	1	134
65	1	133
70	2	132
75	2	130
85	3	128
90	3	125
105	1	122
110	3	121
115	3	118
120	4	115
125	1	111
130	1	110
135	3	109
145	2	106
150	1	104
155	2	103
160	3	101
165	6	98
170	1	92
175	3	91
180	1	88
185	1	87
190	1	86
200	2	85
205	1	83
210	2	82

APPENDIX F-20 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
215	4	80
220	1	76
225	1	75
235	1	74
240	3	73
250	1	70
255	2	69
260	2	67
265	1	65
270	2	64
275	1	62
285	2	61
290	1	59
295	1	58
300	2	57
305	1	55
310	1	54
315	1	53
320	2	52
325	1	50
335	3	49
340	1	46
350	2	45
355	1	43
360	2	42
365	1	40
370	1	39
375	1	38
380	1	37
385	3	36
395	1	33
405	1	32
425	1	31
435	1	30
445	1	29

APPENDIX F-20 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
450	1	28
465	2	27
475	1	25
480	1	24
495	1	23
520	1	22
535	1	21
540	1	20
550	2	19
615	1	17
630	1	16
680	1	15
700	1	14
705	1	13
750	2	12
875	1	10
915	1	9
960	1	8
970	1	7
975	1	6
1050	1	5
1060	1	4
1070	1	3
1225	1	2
1630	1	1

APPENDIX F-21

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
5	10	106
10	2	96
15	1	94
25	1	93
55	2	92
60	1	90
75	1	89
90	1	88
95	2	87
100	5	85
105	5	80
110	6	75
115	5	69
120	6	64
125	3	58
130	5	55
135	3	50
140	3	47
145	1	44
150	2	43
160	1	41
165	2	40
200	2	38
205	1	36
220	1	35
225	2	34
230	1	32
235	1	31
240	1	30
245	1	29
250	2	28
260	2	26
265	1	24
275	1	23
280	1	22

APPENDIX F-21 (Continued)

SEED SPACING X (mm)	NUMBER OF SPACES EQUAL TO X	NUMBER OF SPACES GREATER THAN X
285	1	21
295	1	20
305	1	19
310	1	18
320	1	17
325	1	16
350	1	15
370	1	14
405	1	13
420	1	12
440	2	11
445	1	9
450	1	8
475	1	7
495	1	6
535	1	5
540	1	4
710	1	3
1240	1	2
1280	1	1

VITA

Stephen W. Searcy

Candidate for the Degree of

Doctor of Philosophy

Thesis: DEVELOPMENT OF A PRECISION METERING SYSTEM FOR PREGERMINATED SEED

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Kansas City, Missouri, October 15, 1952, son of Lloyd W. and Wilma A. Searcy.

Education: Graduated from Liberty High School, Liberty, Missouri, May, 1970; received the Bachelor of Science in Agriculture degree from the University of Missouri, Columbia, in May, 1974; received the Bachelor of Science in Agricultural Engineering degree from the University of Missouri, Columbia, in December, 1976; received the Master of Science degree from the University of Missouri, Columbia, in December, 1976; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in July, 1980.

Professional Experience: Graduate Research Assistant, University of Missouri, Columbia, 1974-76; Graduate Teaching Assistant, University of Missouri, Columbia, 1975; Registered as Engineer-in-Training, Missouri, 1976; Graduate Teaching Assistant, Oklahoma State University, 1977; Graduate Research Assistant, Oklahoma State University, 1977-1980.