DESIGN OF A DISPENSING SYSTEM FOR A GEL TRANSPLANTER

by

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Abstract

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Design of dispensing system for a gel transplanter.

A dispensing system was designed using a diaphragm pump to sow vegetable seeds. The pump was driven by a micro-switch to obtain the output of the pump in a discrete fashion.

The test conducted with 0.75 % gel and a calibrated dispensing rate of 4 ml/stroke, showed that the number of seeds distributed per gel deposit ranged between 0 to 9. The distribution of seeds per deposit was statistically the same for tomato, carrot and radish and was not influenced by their shape and texture and obeyed Poisson's distribution. The spatial distribution of seeds within the gel deposit showed uniform distribution. The length of gel deposit ranged from 6.5 cm to 13.5 cm and showed the uniform distribution. The observed in-row spacing was normally distributed on the calculated in-row spacing.

Seedlings of tomato and carrot did not show mechanical damage but radish seedlings having radicle length of greater than 3 mm were found susceptible to mechanical damage.

Resume

M.Sc Jakhro G. Sarwar Génie Rural

Design d'un système de distribution pour les transplantations en gel.

Un système de distribution utilisant une pompe à diaphragme a été conçu pour semer les graines végétales. Pour obtenir un débit de la pompe de façon intermittente, le commutateur s'actionnait à l'aide d'une roue horloge.

Les tests obtenus avec 0.75% de gel et une distribution calibrée à 4 ml/coup, ont montré que le nombre de graines délivrées par dépôt de gel s'échelonnait entre 0 et 9. Le comportement de la distribution des graines par dépôt de gel est le même statistiquement pour les tomates, carrotes et radis et n'est influencé ni par la forme, ni par la texture des graines et obéit aussi à la distribution de Poisson. La distribution des graines avec le gel était éparse. La longueur du dépôt de gel variait entre 6.5 cm et 13.5 cm donnant une distribution rectangulaire à la fréquence. La fréquence observait de l'espacement en rang entre les dépôts de gel avait une distribution normale sur l'espacement calculé.

les graines de tomates et carrotes n'ont pas subit de brisures dues à la machine, alors que les graines de radis ayant une radicule de plus de 3 mm ont été endommageés.

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Finally this work is dedicated to my parents who are anxious to see me graduate and to Millet my 2 1/2 years baby who misses paternal affection.

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CHAPTER I

INTRODUCTION

Size, weight and surface characteristics are the physiological properties of the seeds which determine their selective sowing methods. Seeds of cereal crops such as wheat, maize or sorghum, by virtue of their weight and size, have become compatible with the metering system of mechanical seed drills. But low density, irregularly shaped and coarse textured vegetable seeds on the other hand, are difficult to meter with conventional mechanical drills. Transplanting as an alternative has been tried to propagate vegetable crops but heavy reliance on manual labour puts a financial burden on commercial production.

Various techniques such as soluble seed-tapes (Chancellor 1969), pelletised seeds (Zink 1955, Pauli and Harriot 1968, Robinson and Mayberry 1976), Vermiculite tablets and agar blocks (Gray 1977a) and plug-mix seeds (Ure and Loughton 1978) have been developed to plant vegetable crops precisely but because of non-selectivity of viable seeds prior to sowing and cost of preparing the seeds in the specific form, little success is achieved in these techniques (Currah 1978 and Gray 1978).

It was during the 1960's, that a new concept for injecting the pregerminated grass seedlings into the pasture field was introduced (Elliot 1966). The applicability of this new sowing system referred to as "Fluid drilling" was later extended for growing small seeded vegetable crops.

Fluid drilling is a method of drilling the pregerminated seedlings suspended in a viscous-gel. In principle, fluid drilling should be regarded as an integrated system comprising the seed germination techniques, seedling storage facilities, preparation of a viscous carrier-fluid and finally a special seedling dispensing system.

Because of technical reasons fluid drilling has proven to be advantageous over conventional dry-drilling. Since the seeds are germinated in the incubator and then drilled into the soil, the variable effects of soil as well as weather on the seed germination are eliminated. In addition, rapid and uniform seedling emergence in the field and predictable plant growth are obtained (Gray 1978, Gray et al 1979 and Lawson 1981).

The fluid drilling system, by virtue of a liquid dispensing system, has become compatible with dispensing the suspension of small, irregular shaped and low density vegetable seedlings such as celery, onion, lettuce, pepper and tomato (Biddington et al 1975, Salter and Darby 1976, 1977, Gray 1978, Entwistle 1978, Currah 1978, Lipe and Skinner 1979, Gray and Steckel 1979, Bussel 1980, Ghate and Phatak 1981 and Gray 1981). Moreover since the seeds are grown under controlled optimal conditions prior to sowing therefore the effect of photo-sensitivity and temperature dormancy are eliminated. Drilling the pregerminated seedlings, besides reducing the variablity of the germination in the field, has practically shortened the germination time. Also, higher and more uniform emergence of seedlings (Currah et al 1974, Currah 1975, 1978 and Gray 1978), early maturity (Gray et al 1979) and higher yields (Currah 1975) are reported for crops sown by fluid drilling than those sown by conventional drilling methods.

An economical and complete seed treatment are favorable characteristics of the fluid drilling system. The addition of insecticide, fungicide or growth promoting nutrients (Entwinstle and Munasinghe 1981) or symbiotic organism (Hardaker and Hardwick 1978) in the carrier-gel has become compatible with the biological system of germinating seeds and has provided a beneficial environment for the seedling emergence in the soil. As a corollary, elimination of seed treatment equipment is an additional advantage of fluid drilling which otherwise is a characteristic requirement of conventional sowing methods.

A pressurised extrusion system is another operational characteristic of the fluid drilling system, since the seed-gel suspension is extruded with enough pressure to eliminate blockage of the drilling tubes. Because of this additional feature, the potential use of fluid drilling could be extended to muddy soils especially for growing rice, which possibly could replace the present and costly manual transplanting method.

Among all the stages involved in fluid drilling, metering the seedling is considered the most delicate design factor of the system. Precise and damage free metering is a critical parameter of the fluid drilling system which has received the attention of many workers.

Many seedling dispensing systems have been designed based on different principles. Mechanical pumps (Currah 1975, Currah et al 1976, Salter and Darby 1977, 1978 and Ghate et al 1981) and air pressure supply coordinated with a valve system (Hiron and Balls 1978, Taylor et al 1981, Ghate et al 1982) have been designed. In later developments electronic sensors (Ghate et al 1978) or logic circuits (Rihrbach and Kun 1972, Lepori et al 1974) have been devised for precise metering but their application for fluid drilling has not been reported.

However fluid drilling is a new technology with its problems and prospects. Still there are some potential advantages which need to be exploited. The study conducted in this project describes an approach to design a simple dispensing system. The main features is to extrude the precise amount of the seedling suspension in a discrete fashion.

CHAPTER II

OBJECTIVES

The main objectives of this project were to design and test the dispensing system for seeds using a suitable pumping device. The following parameters were considered:

1. To study the compatibility of the dispensing system for a gel solution.
2. To determine the reasonable level of gel concentration to keep the seeds suspended by subjecting the seeds to the submerging test.
3. To study the number of seeds distributed per deposit of gel solution.
4. To study the effect of different seed shapes and textures on the number of seeds distributed per deposit of gel solution.
5. To study the spatial distribution of seeds within the deposit.
6. To study the linear spreadability of the gel deposit at a calibrated dispensing rate.
7. To compare an observed in-row spacing between successive gel deposits with the theoretical (calculated) spacing.
8. To quantify the physical damage to the seedlings.

CHAPTER III

REVIEW OF LITERATURE

The technical definition of fluid drilling is not confined to dispensing the seedlings; but germinating the seeds, seedling sorting and storage facilities are integral phases of the over-all drilling system. Since damage free dispensing of delicate seedlings is an operational requirement, the dispensing system is considered comparatively important among all other phases. Since inception of the idea, each phase of fluid drilling has been studied individually to improve the technical potential of the drilling system.

Germinating the seeds under laboratory conditions is the first phase. For better field results and a good crop stand, synchronised germination and high percentage of germinated seeds is the most desirable. To induce synchronised germination, the seed need to be provided with balanced conditions of moisture, temperature, light and aeration suitable for their germination. Various laboratory methods have been developed to accomodate various amounts of seeds ranging from a few grams (Currah et al 1974, Biddington et al 1975, Bleasdale 1976, Bussel 1980 and Gray et al 1981) to large scale production methods (Currah et al 1976, Darby and Salter 1976, Taylor 1976, Salter 1978a, Anon 1978, Finch-

Savage 1981 and Fluid Drilling Limited 1982).

Though optimal conditions are provided in the laboratory even then the seeds of certain vegetable species germinate very slowly and the growth of radicles are not uniform. The seeds of carrots and onions for example, show slow germination response whereas lettuce takes a short time to germinate (Currah 1978, Salter 1978 and Gray 1981). In such situations chemically or osmotic priming of the seeds (Heydecker 1974, Salter and Darby 1976, Longden et al 1979 and Lawson 1980); the germination time shrinks and high germination rate and more uniform radicle length are obtained.

Though various techniques are adopted (described earlier) to induce the germination, with the over-all germination percentage of seeds depends on the viability of seeds. The viability index depends on the vegetable species. Lettuce, for example, gives a higher germination percentage than other vegetables (Salter 1978). Since maintenance of regular spacing along the row is the primary objective, dead seeds need to be sorted out. The ungerminated seeds can be identified during germination and various methods have been established for sorting them. Currah (1974, 1976 and 1977) applied the hydraulic fractionation technique to separate seedlings from ungerminated seeds. A similar technique is described by Salter (1978). Taylor et al (1978 and 1981) have described a successful approach to separate the seedlings from ungerminated seeds by floating the material in glass jars containing maltrin solution of different densities.

In fluid drilling radicle length is a critical factor for damage free dispensing. For different vegetable species different ranges of radicle lengths are suggested (Gray 1979). The radicle keeps on growing if seedlings are kept at room temperature. Therefore, if weather conditions do not permit immediate sowing, then seedlings need to be stored at a lower temperature to check further growing of radicle besides maintaining the viability of seedlings.

Either cold air or chilled water are reported as equally effective mediums to store the seedlings (Salter 1978, Brocklehurst 1978, Brocklehurst et al 1980, Finch Savage 1981 and Gray et al 1981 and Wurr et al 1981) with the only difference that a continuous flow of air in water needs to be maintained to keep the seedlings viable; otherwise the viability is reduced by 40 to 100 percent (Brocklehurst et al 1980 and Gray 1981). For seedlings of carrot, onions, parsnips, cabbage and lettuce, a temperature of 1^0 C is found to be a good threshold to check further growth of the radicle but viability response is dependent on the storage time. The viability response of carrots and parsnips was found good for storage time of 15 days whereas for onions, lettuce and cabbage the viability was reduced (Finch Savage 1981).

The gel serves as a transporting medium for the seedlings from hopper to the furrow through the dispensing system and tubing. Good suspension qualities for seedling of any size, smooth flow characteristics through pump and tubing, non-phytotoxicity, miscibility with ordinary water and relatively cheap cost are the notable properties of a good gel material. Many plant by-products such as starch paste (Gray 1974), guar gum (Darby 1980), potato starch paste (Bleasdale 1976) have been used in experimental work. Also a number of synthetic chemicals are being marketed but some are found to possses peculiar qualities. Sodium alginate and H-Span for example have desirable rheological properties but are sensitive to hardness of water (Darby 1980); high shear force required to mix with water is an additional feature of sodium alginate (Darby 1980 and 1981). However among various types of chemicals available, the mixture of sodium alginate and calcium citrate has been widely used in many research applications (Currah et al 1974, Gray 1978, 1979, Biddington et al 1975 and Bleasdale 1980).

Darby (1980) has assessed the consistency and post drilling emergence effect of many plant by-products as well as synthetic chemicals and reported that synthetic clay (Polyacrylate) gave higher seedling emergence for red beet, lettuce onions and parsley as compared to sodium alginate or dry seeding.

Besides serving as a buffering medium against the mechanical shocks of the pumping system, the gel is also useful for mixing chemicals and inocula to promote seedling growth (Gray et al 1977, Darby et al 1977, Hardwick and Heydaker 1976 and Taylor and Dudley 1977) and control of diseases at early stages of seedling emergence (Entwistle 1978 and Entwistle and Munasinghe 1978).

Squeezing the seed-gel suspension using the peristaltic pump was the first design (Elliot 1966, 1967), of a dispensing system. In later developments, the same principle of the peristaltic pump has been incorporated into hand-operated single coulter to multi-coulter tractor driven machines (Lawson 1980 and Fluid drilling limited). However multi-coulter design has limitation that the distribution of gel dispensed by single pumping unit can not be equalised through the manifold; therefore an individual peristaltic pump for each coulter is the characteristic requirement of this dispensing system. For experimental work Lickorish and Darby (1976) designed a small hand-pushed model using a piston pump powered by ground driven pinion and rack mechanism. This design is characterised by extruding the gel continuously by forward travel of piston and refilling is obtained sucking the gel while the piston is retracted back by hand-operated lever mechanism. Each filling is described good for 15 m of row length. The extrusion system of this machine is described as satisfactory, however the refilling is complicated and requires a couple of components to be manipulated for each refilling. Moreover because of manual refilling, the field work can not be carried continuously.

In an other approach Ward (1981) designed a prototype using a flexible rubber vane pump and obtained satisfactory results up to 600 rpm of the rotor. Spinks et al (1979) designed a small light weight machine incorporating both systems to plant dry seeds as well as seed-gel dispensing with the same furrow opener. A cone operated by sprockets and chain drive mechanism has been used for dry seeding whereas a piston pump operated on the same principle as described by Lickorish and Darby (1978) has been used for dispensing the seedlings. Because both the sowing systems are incorporated into a single unit therefore the drive mechanism has become complicated and switching over from one system to another requires much understanding and adjustments of the drive mechanism. Since refilling is manual, the sowing in the field can not be achieved without interruption.

All the volumetric displacement systems using either peristaltic, piston or vane pumps are characterised by continuous extrusion (Currah 1974, Lickorish and Darby 1976, Lawson 1980 and 1981, and Fluid drill Limited). Seedling rate or spacing is controlled by maintaining the ratio of seedling to volume of gel in the tank which consequently determines the seedling distribution along the row. However Richardson and O'Dougherty (1972) have given theoretical consideration that the number of seedlings extruded through the dispensing system are randomnly distributed along the row. Varying gel extrusion rates of 7 ml/meter of furrow length (Currah et al 1974), 20 ml/m (Gray 1978, 1979 Lawson 1980) and 30 ml/m (Lickorish and Darby 1976) have been used to evaluate the performance of fluid drilling systems but the quantity of gel extruded is not reported in terms of size and varietal characteristics of vegetable seedlings.

For single coulter hand-operated machines or multi-coulter tractor driven designs using either dispensing system (i.e peristaltic, piston or vane) the power to operate the dispening system is taken from ground wheels (Lickorish and Darby 1976, Spinks et al 1979, Currah et al 1974, Currah 1975, Biddington et al 1975 and Salter 1978) which maintains the direct ratio between forward travel of machine and gel extrusion being deposited in the furrow.

An air pressurised system has been used for continuous extrusion of the seedling suspension independent of forward travel (Hiron and Balls 1978). Because the extrusion rate used was independent of ground speed, no constant ratio could be maintained between extrusion rate and linear displacement of the machine. The same pneumatic principle has been used by Ghate et al (1981 and 1982) for continuous extrusion and pulsating extrusion using a poppet valve operated by ground driven photo-electric sensor. Satisfactory performance is reported for the valve operated extrusion system but for continuous extrusion a specific level of air pressure needs to be maintained; otherwise, at high pressure the gel is squirted out before it is covered by the furrow. Pneumatic suction in conjunction with a water jet has been used for seedling singulation and planting but the application of such machine is limited to stationary units for planting the seedlings in the green houses (Fluid Drilling Limited 1982).

No damage to the pre-germinated seedlings has been reported for the peristaltic pump (Fluid drill limited) and air pressurised systems (Hiron and Balls 1978, Ghate et al 1981) but seedlings with radicle lengths greater than 10 mm blocked the tubing (Ghate et al 1982). The centrifugal pump gave satisfactory results at lower speeds but at higher speeds pregerminated seedlings suffered considerable damage (Darby and Gray 1976).

Researchers have investigated new techniques to refine the seed metering. Rohrbach and Kim (1972) developed a fluidic seed meter using plastic beads to simulate the seeds. This technique, although suited to raw seeds, cannot be adapted to sow pregerminated seeds because the pregerminated seeds should be planted wet. In another investigation, for logic control of seed metering, a fluid logic synthesis was developed (Lepori et al 1974). Huang and Toyaputch (1973) have developed the use of a high pressure water jet to open a soil furrow but no planting in the field is reported using a water-jet.

CHAPTER IV

DESIGN CONSIDERATIONS

4.1. Chassis

The main frame of the chassis, measuring 48" (1.22 m) long and 22 1/2" (571.5 mm) wide, was fabricated from 3" x 1 1/2" (76.2 mm x 12.7 mm) and 3/16" (47.6 mm) thick rectangular steel box section. To attach the machine to the tractor, the chassis was fabricated with a three point hitch. To facilitate the machine to trail behind the tractor under undulating field conditions, the hitching point of the top link was made floating. To maintain a fixed ratio between the forward travel of the machine and drilling spacing, the power to operate the micro-switch of the dispensing system was taken from ground wheels through sprockets and a chain drive (Fig 1).

To mount the wheels on the axle, adapter hubs were fabricated by welding a cross plate with 1" (2.54 cm) diameter and 4" (10.16 cm) long galvanised iron pipe. The hubs were bolted onto wheels. One of the hubs was mounted on the axle with a cross-pin, while the other wheel was free to rotate, thus a differential action was obtained while travelling behind the tractor at corners. The floor area of

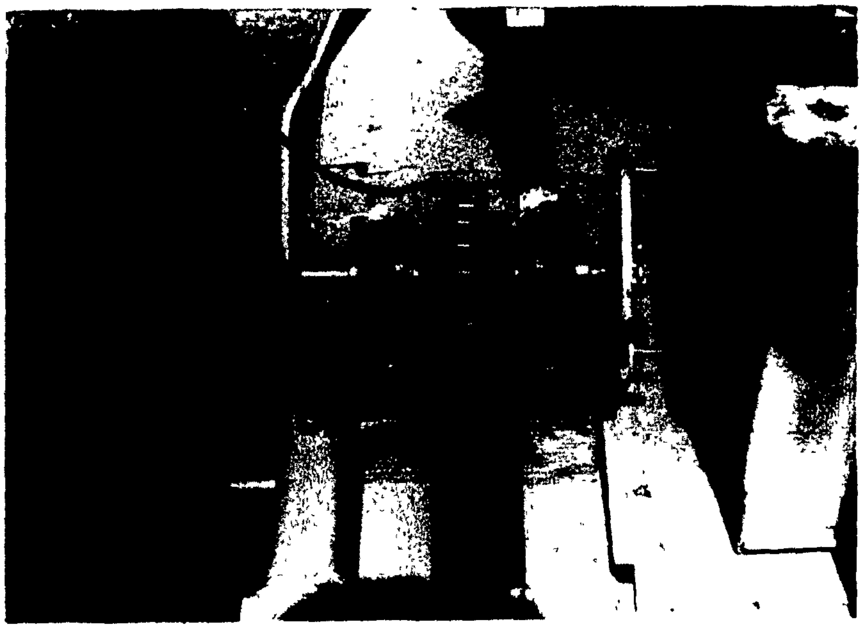

Figure 1. Sprockets and chain drive mechanism used to operate the micro-switch of dispensing system.

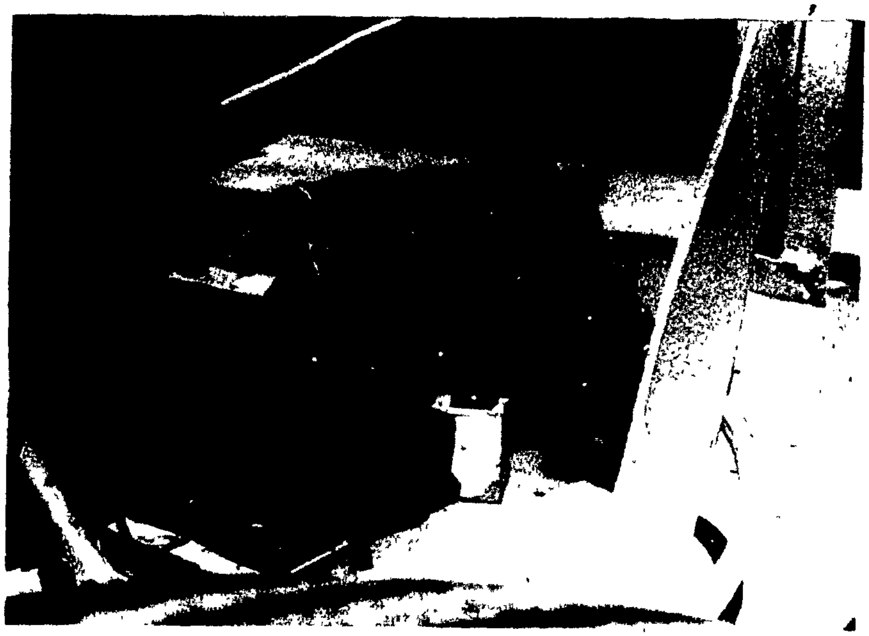

Figure 2. Set-up of diaphragm pump and its attachement with solenoid.

the chassis was covered with # 14 galvanised steel sheet to serve as the base plate for fitting the dispensing and electrical components.

4.2. Dispensing System.

In the first approach, a double acting cylinder harnessed parallel with a driving screw was tried as the dispensing system. The screw on either side was coupled with a magnetic clutch, overrunning (mechanical) clutch and the driving solenoid. The solenoid drove the screw by the ratchet action of an overrunning clutch. To get the clockwise and anti-clockwise rotations of the screw, the solenoids were fitted on either side of the screw hence clockwise and anticlockwise rotations were obtained by energizing the left or right magnetic clutches alternately through the electrical micro-switches. To obtain the uni-directional flow of the gel suspension for the dispensing system, a two-way valve was used. Two solenoids placed in opposition were attached to the axle of the rotor of the two-way valve and rotation of rotor was obtained by energizing the solenoids alternately.

The involvement of many mechanical as well as electrical components complicated the driving mechanism of the screw, with the result that alignment of the functional components became very difficult to maintain. This resulted in high resistance in the driving system. Therefore because of the mis-alignment and high friction in the moving components, the system became over-loaded and failed to give the desired displacement of the screw and cylinder.

In the second approach to meter the seed gel suspension, a diaphragm pump was used (Fig 2). Since the pump was of a relatively high capacity, the stroke of the pump was decreased to meet the requirements of the dispensing system. The pump handle was attached to a 12 VDC solenoid and thus was reciprocated by the solenoid. Since the power stroke of the solenoid was one-way (pushing the axle of solenoid towards the out-side), a spring was provided for the return stroke.

A plastic bucket covered with clamped lid was mounted on the aluminum brackets fitted on the floor of the chassis above the pump (Fig 3) and served as a reservoir for the seed-gel suspension. At the bottom of the bucket a 1/4" (6.35 mm) diameter nipple was fitted for connection with the plastic tubing.

A plastic tubing of 5/16" (7.93 mm) diameter was used as the gel carrier from the tank to the pump and from the pump to the coulter (Figs 2, 3 and 4). In order to observe the physical flow or blockage of the gel, transparent tubing was selected. At end of the plastic tube a 1/4" (6.35 mm) diameter nipple was used. To eject the deposits of the gel directly into the furrow, the nipple was bolted into an adjust-

Figure 3. Mountings of plastic bucket used for seed-gel suspension.

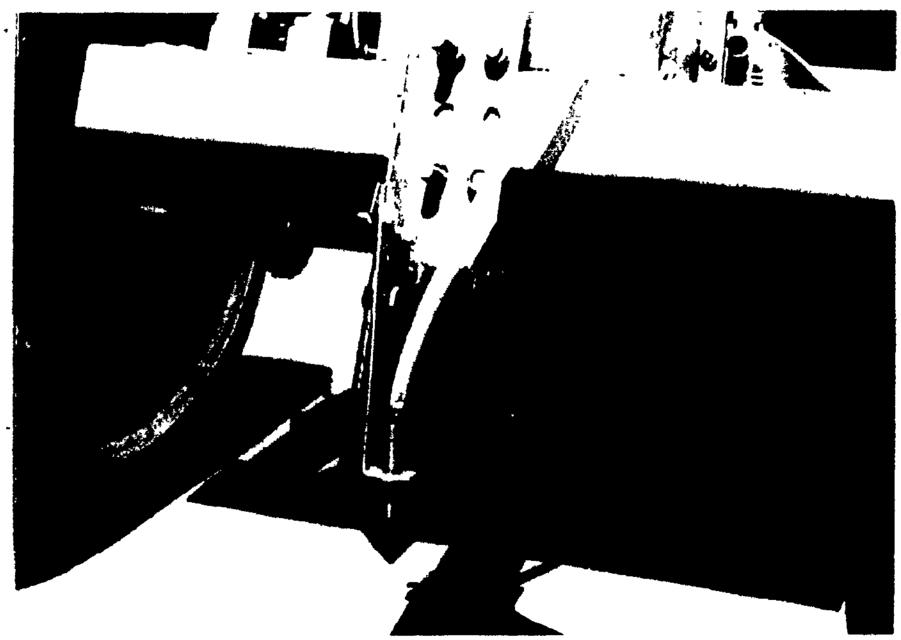

Figure 4. Coulter and bracket for attaching the outlet nipple.

able bracket fitted at the back side of the coulter (Fig 4).

4.3 Electrical components.

To operate the switching mechanism, a 6" (15.24 cm) diameter circular plate and 3/16" (4.76 mm) thick was mounted on the axle of the upper sprocket (Fig 1). In order to meet the variable spacing between successive deposits of the seed-gel suspension, the holes in the circular plate were drilled at 45 degree intervals. Screws 1 1/2" (3.81 cm) long and 1/8" (3.18 mm) diameter bolted in the circular plate served as the switch triggering pins. A single pole micro-switch was mounted beside the circular plate, thus the lever of the micro-switch was actuated by triggering pins when the circular plate was rotated by the ground wheels via the chain drive (Fig 1). The switching mechanism could be operated at various frequencies by changing the number of triggering pins in the circular plate, thus various spacings between successive deposits of seed-gel suspension could be obtained.

To actuate the lever arm of the diaphragm pump, a 12 VDC solenoid was used (Fig 1 and 3). To operate the solenoid (Fig 5), the power was taken from 12V DC tractor battery.

4.4. Coulter

A 3/16" (4.76 mm) thick rhombus shaped plate was curved into

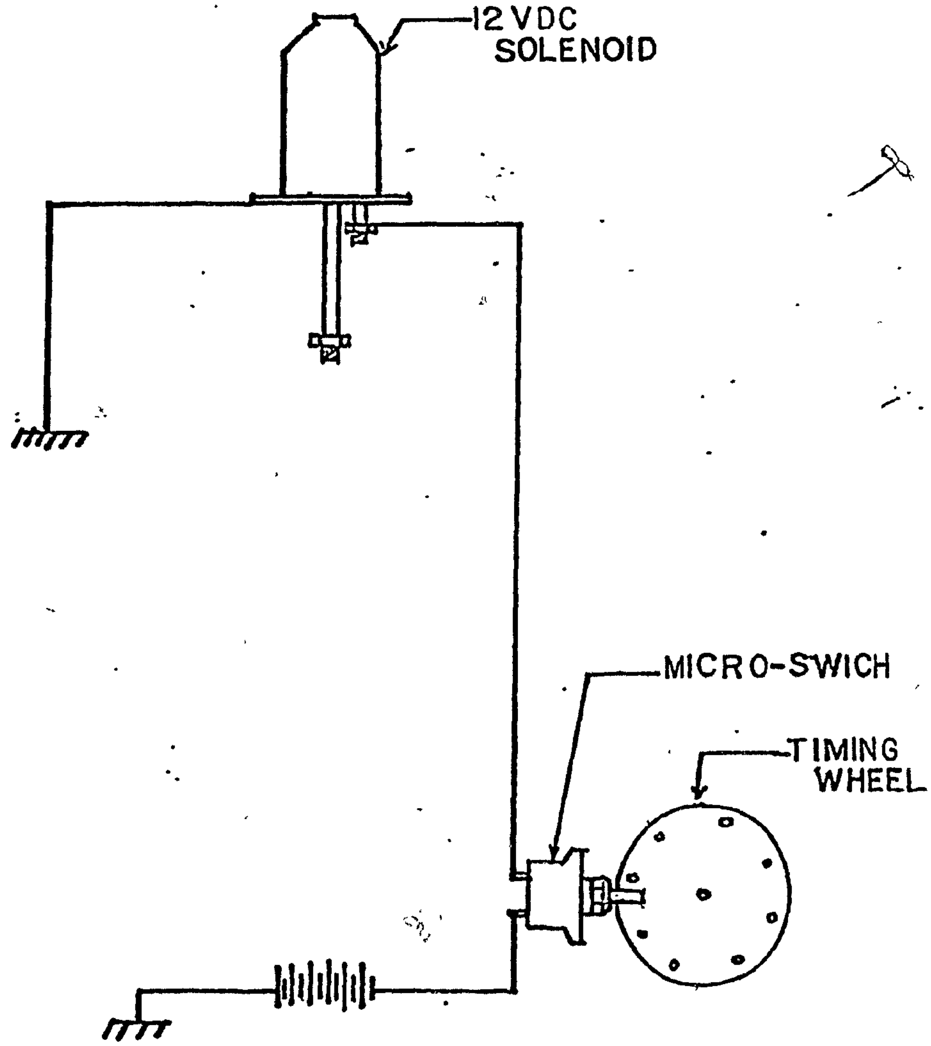

Figure 5. Electric circuit for micro-switch and solenoid.

a parabolic shape and finally made as a coulter. A 10" (25.4 cms) long shank made from 2"x2"x3/16" (5 cm x 5 cm x 4.76 mm) steel angle was welded at the upper end of coulter to be bolted with chassis. The shank was bolted to the chassis beam by two U-bolts (Fig 4). The holes were drilled in the shank at the spacing of 1" (2.54 cm) to adjust the desired depth of penetration of the coulter.

CHAPTER V

EXPERIMENTAL SETUP

5.1. Performance of the pump.

The prefabricated diaphragm pump used for the dispensing system was of a relatively high capacity; therefore to meet the dispensing requirement, the stroke of the pump was set at its minimum by adjusting its lever arm. To investigate the pumping characteristics of the diaphragm pump (self-priming potentials plus overcoming the friction due to viscosity of the gel solution in the plastic tubing), four levels of gel concentration 0.25 percent, 0.50 percent, 0.75 percent and 1.0 percent (weight basis) were used.

The test was conducted in a stationary position using each level of gel solution separately. In each test, one litre of gel solution prepared in an electric blender was put in the bucket and the triggering switch was operated manually.

5.2. Suspension characteristics of the gel.

To test the dispensing system and to study the settling times of vegetable seeds, Laponite 508 (Laporte Industries Limited) gel was used as a medium. In the literature no particular gel concentration was specified for any particular variety of vegetable seed, therefore a preliminary experiment was conducted to investigate a reasonable level of gel concentration to keep the seeds in suspension. The optimum level of the gel concentration was to be determined in terms of settling times of vegetable seeds. For this purpose four levels of gel concentration (i.e 0.25 percent, 0.5 percent, 0.75 percent and 1.0 percent) were compared with that of ordinary tap water.

The seeds of different vegetable varieties have different geometric shapes, weight and textural characteristics. To observe the effect of different geometric configurations, weight and texture of the seeds on the settling time, four vegetable varieties (i.e tomato (plate type), carrot (oblong and coarse testured), beet (irregular or prismatic shape and coarse textured) and radish (spherical shape and smooth textured)) were used for the experiment.

This experiment was conducted at room temperature, using a completely randomised design (CRD). As this test was concerned with submerging the seeds in the gel solution, the seeds of all the vegetable species were subjected to a floating test in standing water prior to the actual test in the gel solution. Those seeds which became submerged in the water qualified for the test; whereas, those seeds which remained floating on the surface of water were discarded. For each level of solution, 10 seeds (samples) of each vegetable variety, were taken at random. In order to eliminate the effect of surface tension of the gel solution, the selected for the settling test were kept in moist blotting paper untill the test was conducted. The gel solutions prepared in the electric blender were poured in test tubes with equal height (14 cms) in every test tube and the tubes were allowed to stand for 30 minutes to allow any entrapped air to escape. In each test tube, a single seed was released gently and the total time taken to reach the bottom of the test tube was recorded using a stop-watch.

The mixing and rheological properties of the gel are important for the design of the dispensing system. Different gels have different chemical formulations and the consistency of each gel is determined by its chemical composition. Therefore to visualise the behaviour of the gel at different levels of concentration, a viscosity test of each level of solution was performed. This test was also used to interpret the results by a precise viscosity index rather than percent solution. The viscosity of gel solutions was determined using a Brookefield synchro-lectric viscometer (LVT model).

5.3. Distribution of seeds per deposit and mode of seed distribution within the gel deposit.

In the fluid drilling process, the number of seeds distributed per gel deposit is considered as a discrete random event and obeys the Poisson's distribution (Richardson and Dougherty 1972). Therefore to investigate the implication of this parameter statistically, the machine was tested in the workshop.

It was hypothesised that different geometric configurations of seeds could have an effect upon the probable distribution per deposit of gel. To study this effect, four types of vegetable seeds with different geometrical shapes (described earlier) were used.

In the calibration test, the extrusion rate of 4 ml/deposit (stroke) was determined. This extrusion rate was used as the basis for seed distribution and the in-row spacing analysis. To study the number of seeds distributed per deposit, a separate test was conducted for each variety of vegetable seed. For each vegetable variety 1500 seeds were counted and mixed with 1500 ml of gel. This number of seeds was proposed to obtain one seed/ml (4 seeds/deposit) based on the calibrated extrusion rate of 4 ml/ stroke. The seed gel suspension was poured in the tank (bucket) fitted on the chassis (Fig 3) and machine was rolled manually along 30 ft (9.2 m) on the wax paper keeping the same setting of dispensing system (i.e 8 pins in the timing wheel) for all the trials. For each variety, a completely randomised design (RCD) with four replications was used considering every deposit as a treatment. In order to eliminate the localised effect of the seeds in the gel container, the seed suspension was stirred well before every trial (replication). In every gel deposit the number of seeds and mode of seed distribution within the deposit (minimum and maximum distance of seed from center of the deposit) was recorded.

5.4. Length of deposit and in-row spacing between deposits.

The switching mechanism was ground driven through the sprocket and chain drive (Fig 1), therefore there was a positive ratio between forward travel of machine and placement of seed-gel deposit in the ground. To investigate the practicability of the extrusion system, the in-row spacing between successive gel deposits was studied and compared with the theoretical (calculated) spacing based on a wheel diameter of 26 inches (66.04 cm). This study was conducted at two different settings of switching pins in the timing wheel (i.e (a) 4 pins and (b) 8 pins in the timing wheel) which corresponded to the calculated in-row spacings of 10.2 inches (25.92 cm) and 20.4 inches (51.82 cm) respectively.

The other related parameter of the gel deposit was to study the linear spreadability of the calibrated volume the gel extruded through the outlet nozzle, while the machine was pulled with constant force. This study was also conducted at both the pin settings (i.e 4 pins as well as 8 pins in the timing wheel).

At each pin setting, the machine was rolled manually on wax paper with constant pull. At each setting, 30 gel deposits were studied per replication and the experiment was replicated four times using a complètely randomised design (CRD). The length of each gel deposit and the spacings between successive gel deposits were measured (center to center) to the precision of 0.5 cm.

5.5. Seed germination.

The laboratory work was spread over a long time and there were no facilities for seedling storage. In an effort to study parameters like the number of seeds per deposit and distribution of seeds with respect to the center of deposit, soaked seeds were used to simulate the seedling. For the study of seedling damage in the despensing system, a small quantity of seeds of each vegetable variety was germinated in petri-dishes and the germinated seedlings were separated from un-germinated seeds manually. The consistency of gel solution used for the study of seedling damage was the same as that used for seed distribution and in-row spacing studies.

5.6. Physical Damage to the Seedlings.

To evaluate the physical damage to the seedlings of different vegetables in the dispensing system, a stationary test was conducted. Each variety of vegetable seedling was tested separately. Since the seeds were germinated without priming and in the laboratory under un-controlled conditions, the radicle length of seedlings in every vegetable variety ranged from 1 to 5 mm. The seedlings were gently mixed with the gel solution and the mixture of gel was poured in a bucket. The timing switch was operated manually and the extruded gel was collected in the flask. Random samples were taken from the flask and in each sample, the seedlings were checked individually for any mechanical damage with the naked eye.

CHAPTER VI

RESULTS AND DISCUSSIONS

6.1. Gel rheology and its suspension characteristics.

The results of viscosity obtained from laboratory tests of all the four gel concentrations are given in the Appendix (Tables A1 through A4). The graphical representation of the data (Figs 6 and 6a) showed that the apparent viscosity irrespective of the gel concentration decreases with increasing spindle speed which verifies the characteristic property of pseudo-plasticity. This rheological property makes the gel material ideal for transporting the seedlings in the tubing because its flow becomes almost uniform with a constant velocity profile (plug flow) (Mohsenin 1968). Because of this pseudoplastic property, the gel material accelerates easily in the tubing when the force (shear) is increased and conversely it decelerates quickly once the driving force is removed. This property creates a good potential for gel materials to be used in the dispensing systems because flow of gel can be started or stopped quickly by applying or removing the driving force.

The settling times presented in Appendix (tables B1 through B4) showed that in comparison to water, the settlement time for all the vegetable seeds increased as the concentration

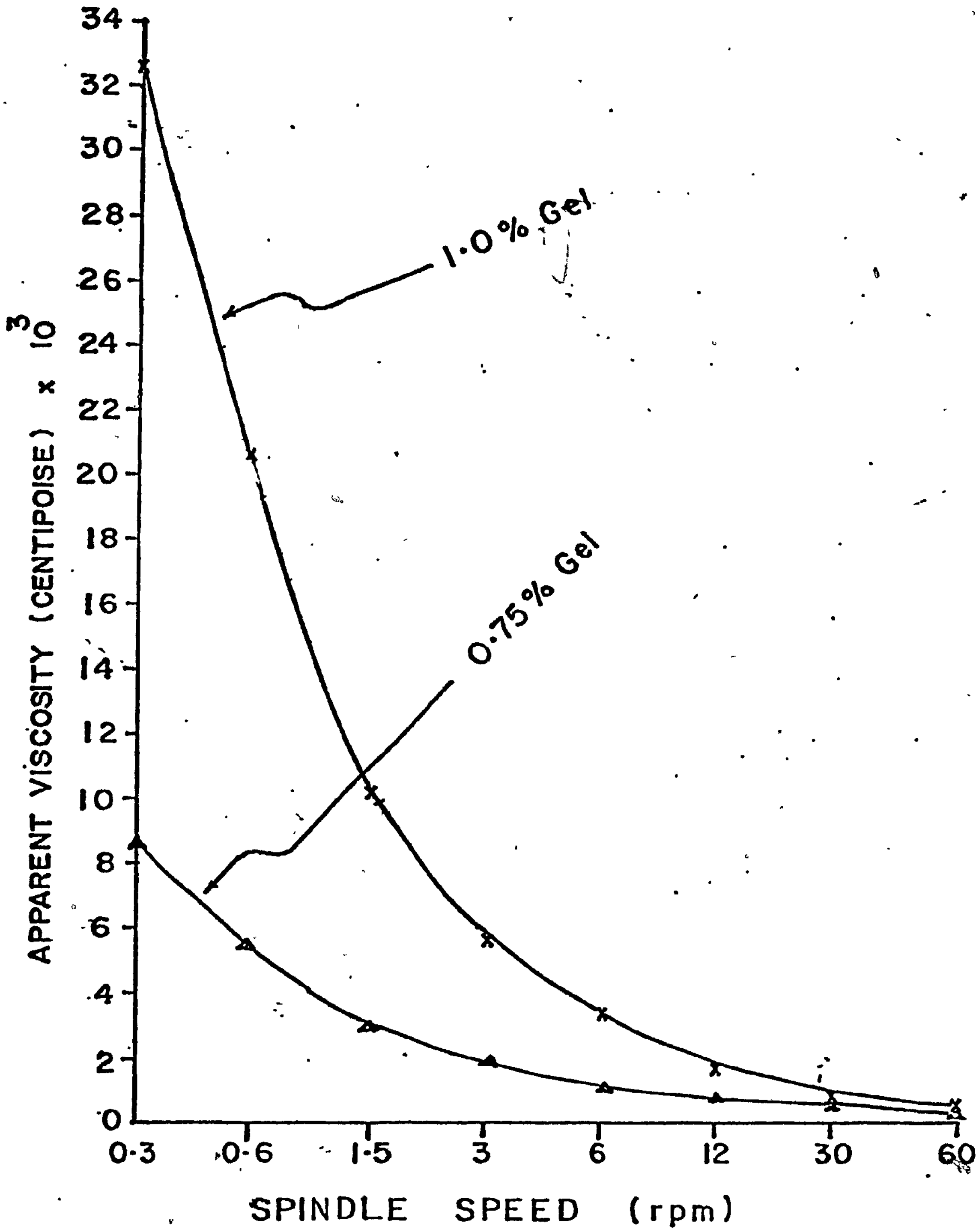

Figure 6. Rheological characteristics of 0.25 and 0.50 percent gel solutioins.

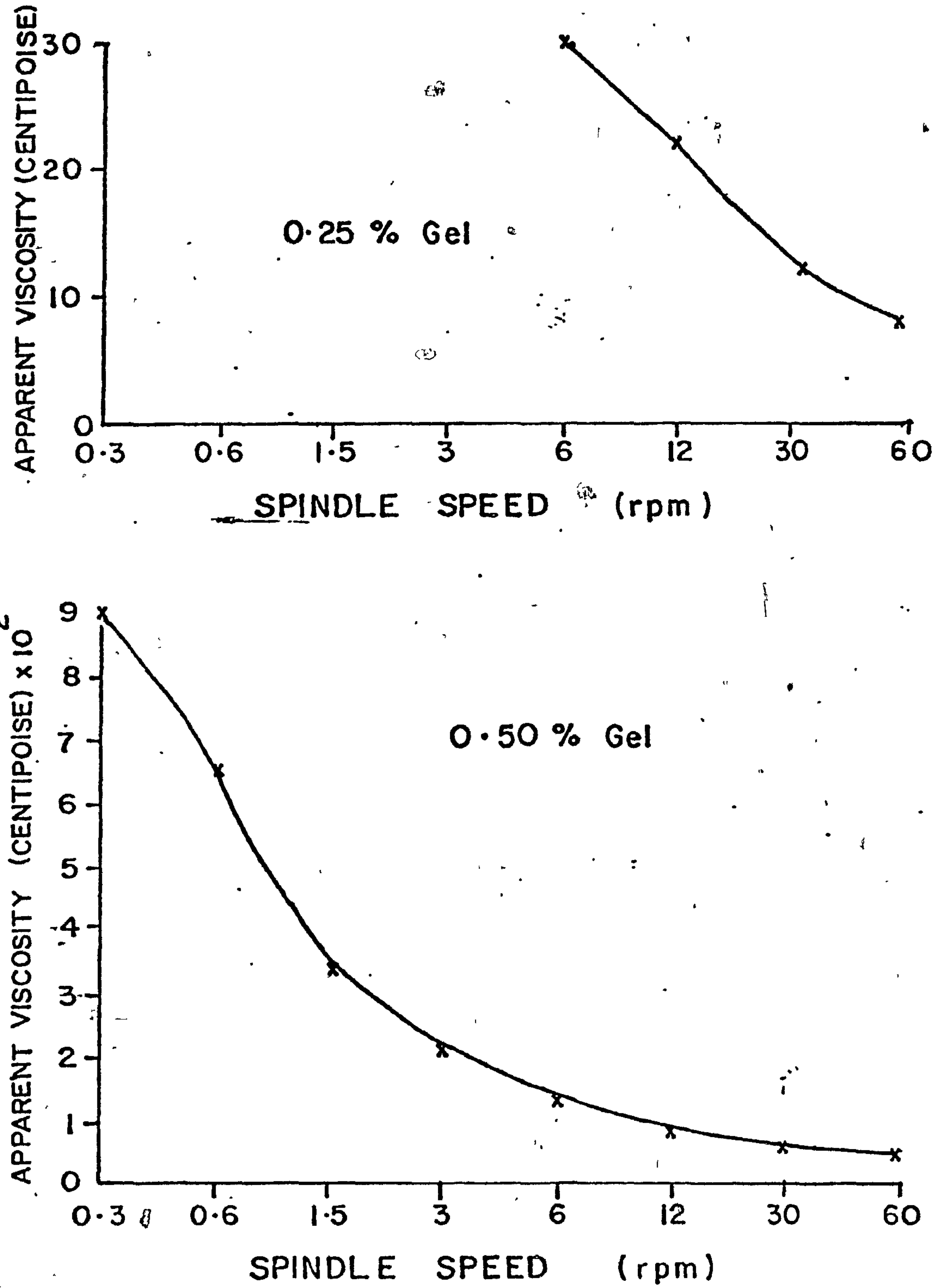

Figure 6a. Rheological characteristics of 0.75 and 1.0 percent gel solution.

(viscosity) of solution increased. The 0.5 percent gel solution was found as the upper limit for tomato and carrot seeds because both vegetable seeds did not settle and remained permanently suspended in this concentration. In the case of radish and beet seeds, the 0.75 percent gel concentration produced the upper limit and both varieties of seeds remained suspended in this solution.

The weight of 100 randomly selected seeds of each vegetable variety (tables B1 through B4) showed that seeds of radish and beet were comparatively heavier than the seeds of tomato and carrot. Because of the heavier weight, the seeds of beet and radish settled in the 0.5 percent gel solution whereas the seeds of carrot and tomato being lighter in weight did not settle and remained suspended in the solution.

In case of water, although the tomato seeds were heavier than those of carrot, the tomato seeds required more time to settle than the carrot seeds. This factor is attributed to their geometrical configuration. Since the seeds of tomato are flat, more resistance is offered to the downward flow of the seeds. Also the seeds of both vegetable varieties (i.e tomato and carrot) showed a similar pattern in case of 0.25 percent gel solution and remained suspended in the 0.5 percent and 1.0 percent gel solutions. But the settling times of beet and radish seeds in water, 0.25 percent and 0.5 percent gel solution did not show any generalised pattern.

Also, it is observed that in each vegetable variety, the settling times of individual seeds have high variation among themselves and results seem to be non-reproducible. This is because, in every vegetable variety, one seed differs from the other in size and weight. These biological inherited properties of the individual seed have led to high variation in the settling time. This natural inheritance remained as a limiting factor in generalising a specific pattern of settling time. However from this preliminary laboratory experiment it was revealed that in viscous solutions the weight component of the seed was the predominant factor in settling time rather than the geometrical shape or texture.

However, from these studies of settling times it was inferred that in 0.5 percent gel solution carrot and tomato seeds remained suspended whereas beet and radish seeds were suspended in 0.75 percent gel solution. Thus 0.75 percent gel solution being as a upper limit, was selected to be used as a dispensing medium for the seed distribution and in-row spacing studies. In addition, the vibration encountered while moving the machine in the field, was considered an additional favorable factor for keeping the seeds in suspension.

6.2. Pump performance and calibration of dispensing system.

The test of the dispensing system at four levels of gel concentration showed that at lower concentration levels (i.e 0.25 percent, 0.5 percent and 0.75 percent), the pump performed satisfactorily but at 1.0 percent concentration level it became rather difficult to prime the pump. In other words it could be said that at 1.0 percent concentration (i.e viscosity of 32500 centipoise), viscosity became the limiting factor because of the high friction in the plastic tubing.

Since the 0.75 percent gel solution was found to be the optimium concentration level to keep the seeds suspended, it was used to calibrate the dispensing system. The calibration test was conducted in a stationary position using the minimum stroke of diaphragm pump. One litre of gel prepared with the electric blender was poured into the bucket and the switching mechanism of the pump was operated manually for 100 strokes. The output collected in the flask was measured to be 4 ml/stroke as an average. This calibrated extrusion rate of 4 ml/stroke was used as a basis for seed distribution, length of gel deposit and in-row spacing studies.

6.3. Statistical analysis of seed distribution per deposit.

Seed distribution tests for each variety of vegetable seed showed that beet seeds, because of larger size and a coarser textured surface, caused a bridging action at both the nozzles (inlet and oulet) and consequently blocked the passage. Therefore the nipple size became the limiting factor for beet seeds, otherwise the flow of seeds through the pump was observed to be satisfactory. Under the same conditions of nipple sizes, the flow of the remaining three vegetable varieties, i.e carrot, tomato and radish, through the dispensing system was smooth and regular.

As the beet seeds caused blockage in the tubing system, they were not used for seed distribution studies. The seed distribution studies were conducted for the remaining three species (i.e carrot, tomato and radish). For these vegetable species, the number of seeds/deposit and mode of seed distribution with respect to center of gel deposit are presented in appendices (Tables C1 through C3).

Since it was hypothesized that the seed distribution obeys the Poisson's distribution, the data for all the three vegetable varieties were analysed using Poisson's formula of distribution:

$$f(x) = \frac{e^{-u} u^{x}}{x\,!}$$

Where x = number of seeds per gel deposit which in this case is : 0, 1, 2, ... 9.

u= 4 (theoretical number of seeds per deposit i.e proposing one seed/ ml (4 seeds/deposit), basing on the calibrated extrusion rate of 4 ml/stroke).

And expected frequency was calculated as:

$$E = n\ f(x)$$

Where n = total number of observations (i.e 120 in this case).

The results of the frequency distribution were analysed statistically using the chi-square test and were found to be significant for all the vegetable species at both levels of significance (i.e .05 and .01) (Tables D1, E1 and F1) (Steel and Torrie 1960 and Gomez and Gomez 1976). Therefore from these statistical results, it is proved that the number of seeds distributed per deposit is a random process and obeys the Poisson's distribution and supports theoretical consideration of Richardson and O'Dougherty (1972).

Moreover from these results it was observed that the number of seeds distributed per gel deposit behaved statistically the same for all the three vegetable varieties, therefore it could be inferred that seed shapes and textural qualities did not affect the number of seeds distributed per gel deposit.

6.4. The spatial distribution of seed within the deposit.

To study the mode of seed distribution within the gel deposit, the distance of seed placed nearest to the center and distance of seed placed at the farthest to the center of gel deposit were measured to the precision of 5 mm. For all the three vegetable varieties (i.e carrot, tomato and radish), the measurements of seed placement within the gel deposit are shown in the Appendix (Tables C1 through C3). The measurements for both the modes of seed placement (i.e nearest as well as farthest) are classified into frequency distribution based on the class interval of 5 mm (Tables D2, E2 and F2).

The graphical representation of data of the seeds placed nearest to the center of gel deposit showed that in all the three vegetable varieties, the trend of frequency distribution skewed to the right i.e frequency of seeds reduced as the distance increased from the center of the gel deposit (Figs 7a, 8a and 9a); whereas the graphical representation of data of farthest seeds in all the three vegetable varieties showed a uniform (rectangular) distribution (Figs 7b, 8b and 9b). A separate analysis of the seed distribution at either location (nearest or farthest) provides incomplete understanding of seed distribution within the gel deposit. Therefore to observe the overall distribution (within the whole length of gel deposit),

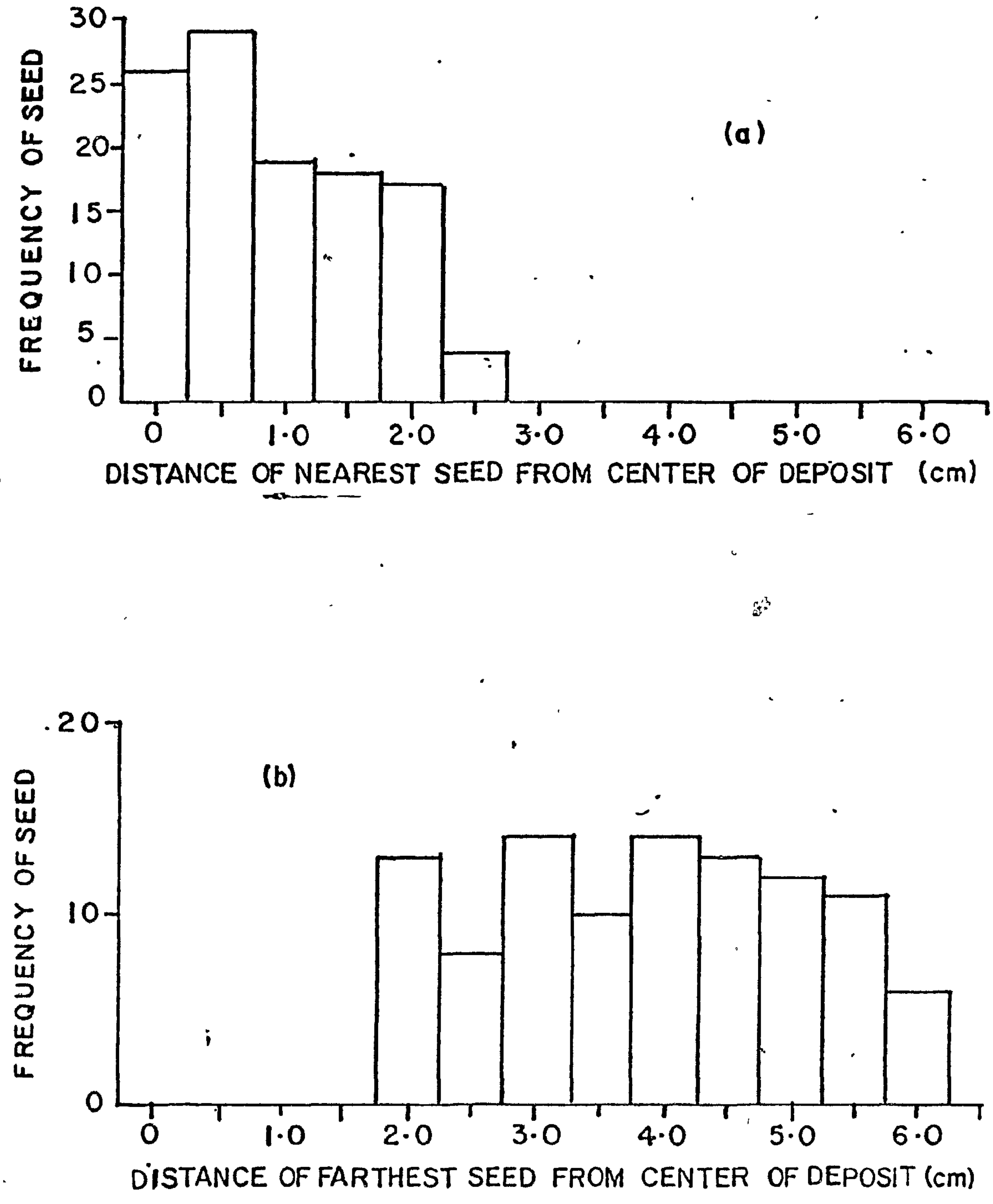

Figure 7. Frequency distribution of nearest and farthest carrot seeds from the center of gel deposit.

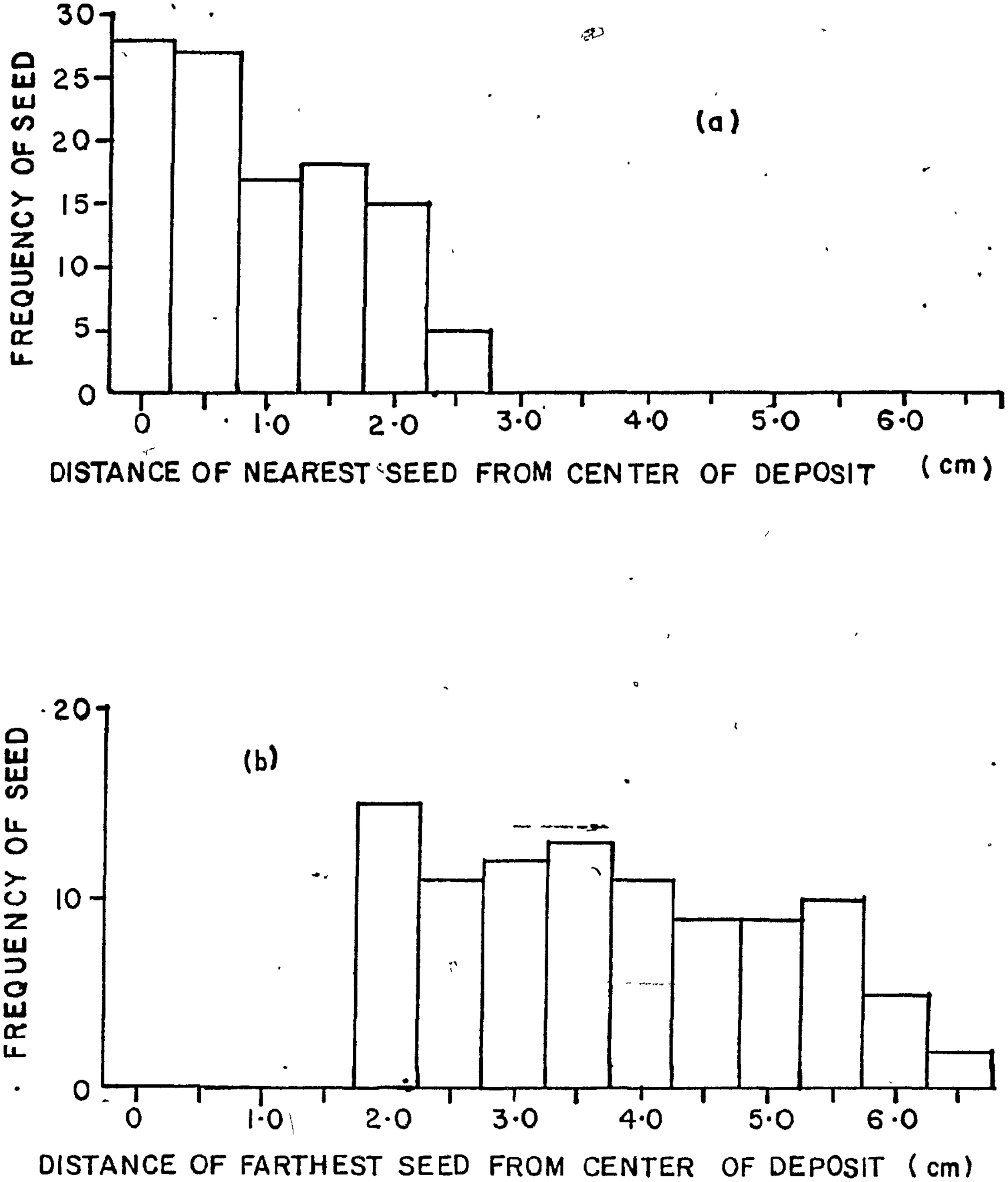

Figure 8. Frequency distribution of nearest and farthest radish seeds from the center of deposit.

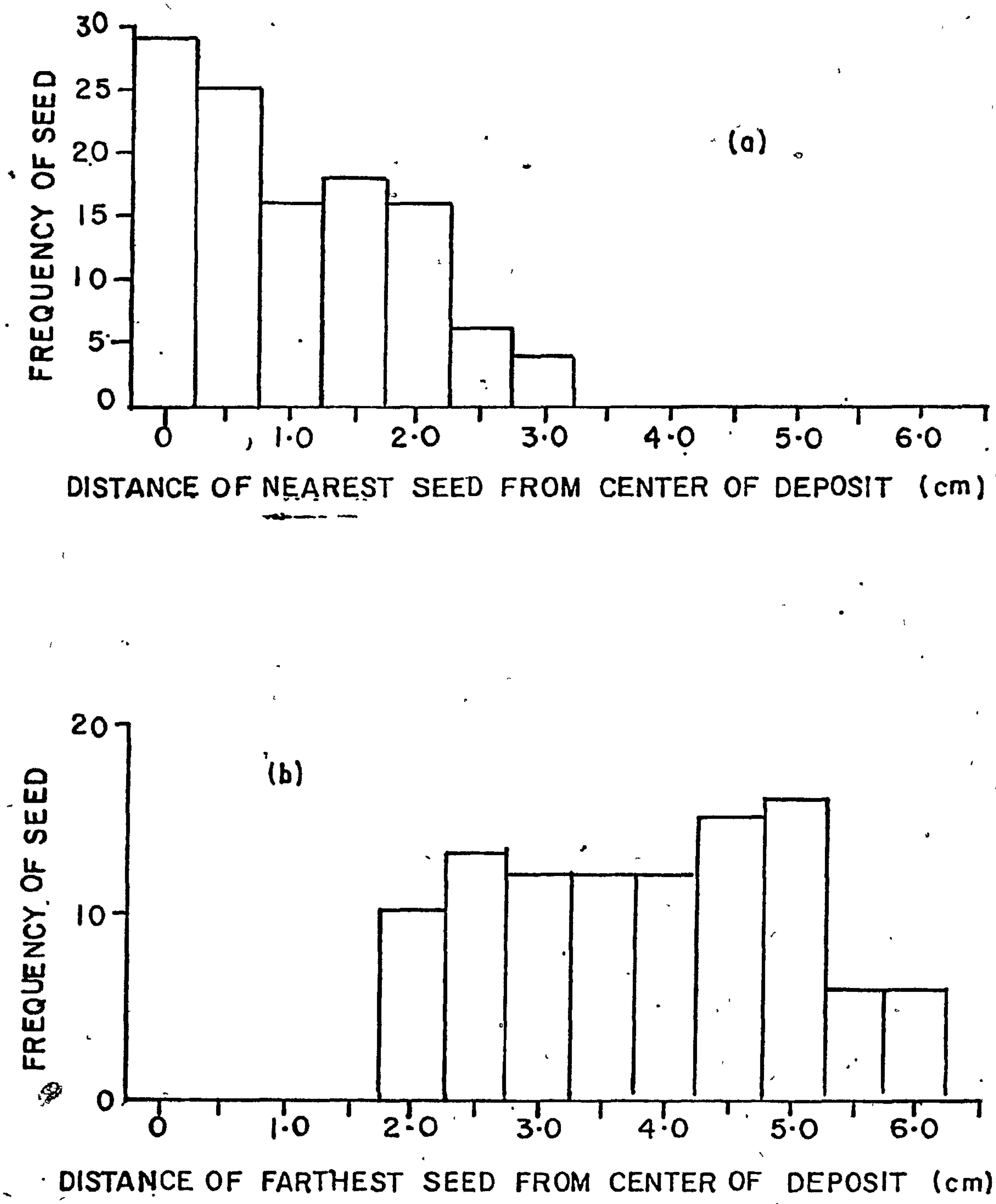

Figure 9. Frequency distribution of nearest and farthest tomato seeds from the center of gel deposit.

both the graphical presentations are superimposed and it is observed that the seeds are evenly distributed within the gel deposit and have no localised or pooling effect.

For all the three vegetable varieties, from the superimposing effect of graphs (7a and 7b), (8a and 8b) and (9a and 9b); it is observed that the pattern of frequency distribution is similar. Therefore it is concluded that the distance of seed placed within the gel deposit with respect to its center, is not influenced by the shape and textural qualities of seed. In other words, when the seeds are properly mixed and dispersed in the gel solution, then irrespective of their textural qualities they do not cling among themselves while passing through the dispensing system.

6.5. Length of gel deposit and in-row spacing between gel deposits.

The data of trials conducted to study the length parameter of gel deposits and in-row spacing between successive gel deposits with (a) 8 pins and (b) 4 pins in the timing wheel are presented in the Appendix (Tables G1 and G2). Also the length of gel deposit at both the pin settings in the timing wheel is classified into frequency distribution based on the class interval of 5 mm (Tables H1 and I1). The graphical representation at both the pin settings (i.e 8 as well as 4 pins in the timing wheel) showed that length of gel deposit ranged from 6.5 to 13.5 cm and has a uniform distribution (Figs 10 and 12). To support the graphical results, the data was statistically analyzed using the chi-square test of goodness of fit to the uniform distribution and the results at both pin settings (8 pins as well as 4 pins in the timing wheel) were found significant at .05 and .01 levels of confidence (Tables H1 and I1). Therefore from these results it is interpreted that as chances of length of gel are equally distributed hence no specific length of gel deposit can be suggested.

Visualising the frequency distribution of the in-row spacing between the gel deposits based on class interval of 2 cms (Tables H2 and I2), the graphs at both the settings (i.e 8 pins and 4 pins in the timing wheel) (Figs 11 and 13) showed that an observed frequency of in-row spacing is normally distributed on the theoretical value i.e 10.2 inch (25.92 cm) in case of 8 pins and 20.4 inch (51.82 cm) in case of 4 pins in the timing wheel. These inferences are supported by the statistical anaylsis using the chi-square test of goodness of fit to the uniform distribution and the results werefound significant at .05 and .01 levels of significance (Tables H2 and I2). Considering the practicality of the theoretical in-row spacing, it was observed that theoretical (calculated) spacing proved to be of the highest frequency among all the observed frequency ranges at both the pins

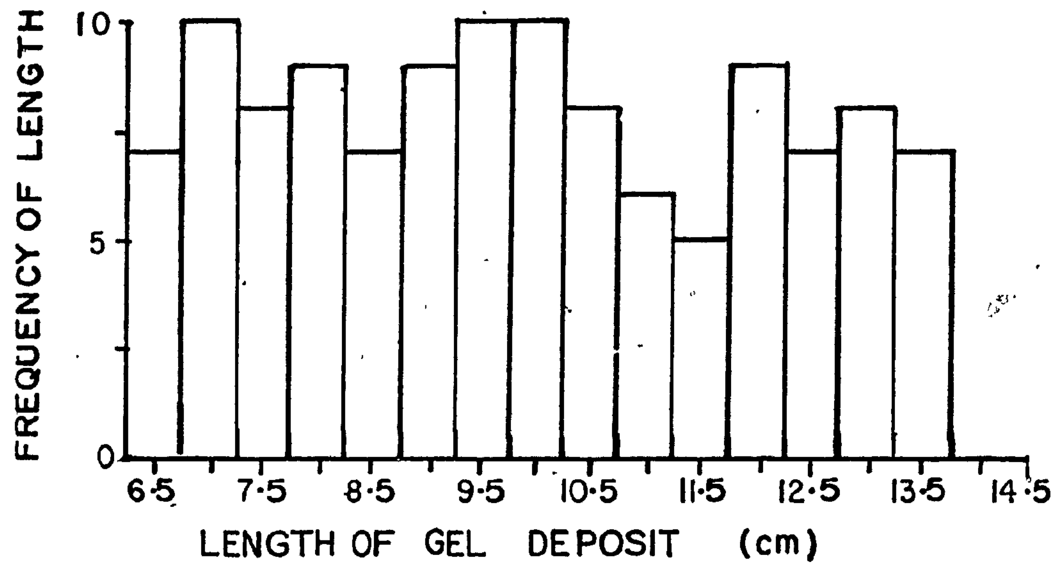

Figure 10. Frequency distribution of length of gel deposit at 8 pins in the timing wheel.

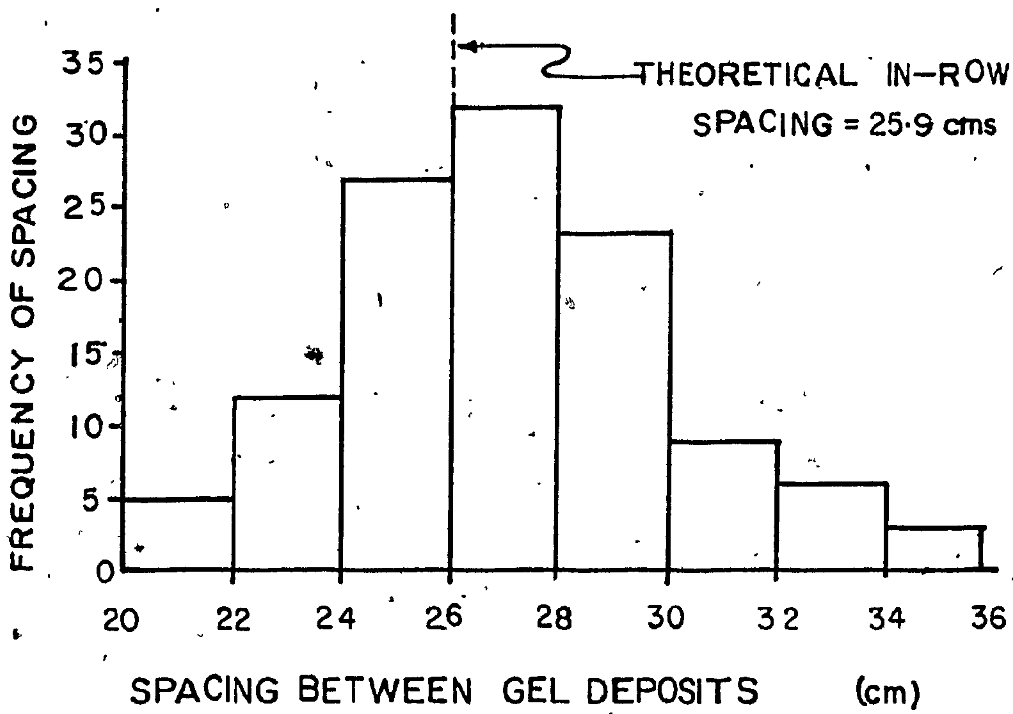

Figure 11. Frequency distribution of in-row spacing between successive gel deposits at 8 pins in the timing wheel.

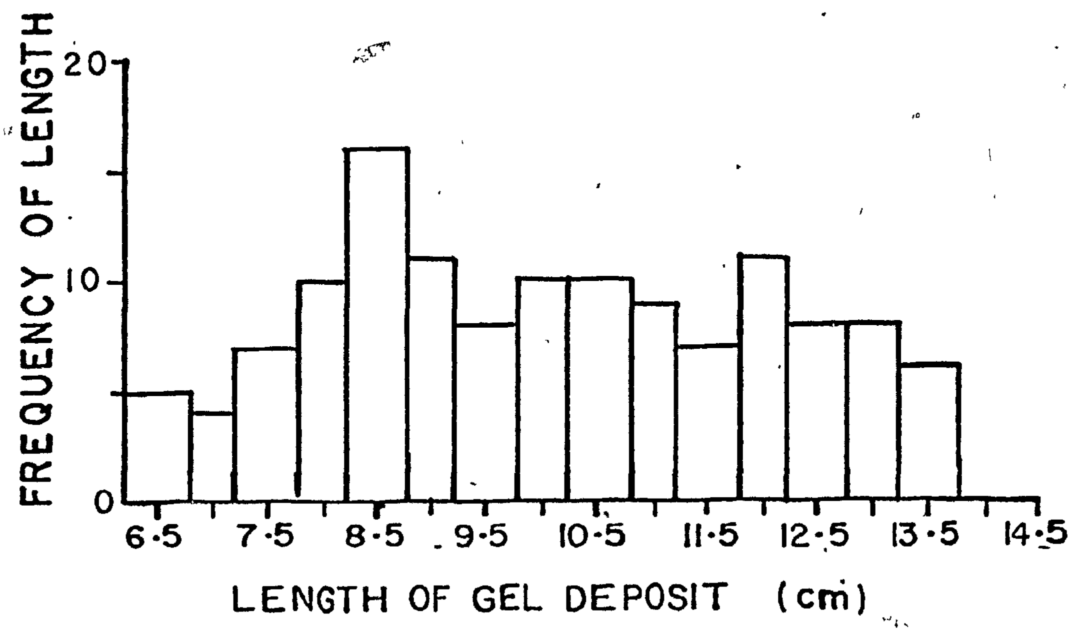

Figure 12. Frequency distribution of length of gel deposit at 4 pins in the timing wheel.

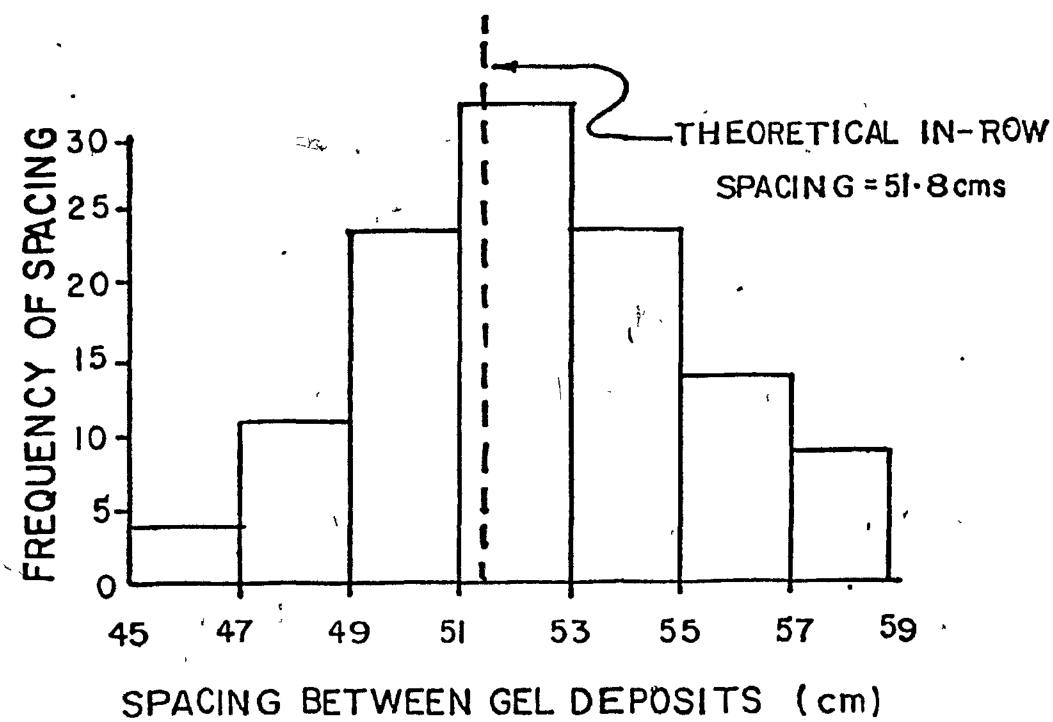

Figure 13 Frequency distr-ibution of in-row spacing between successive gel deposits at 4 pins in the timing wheel.

settings. The relative frequency of theoretical in-row spacing in whole range of an observed frequency was 23.3 percent and 25.8 percent at 8 and 4 pins respectively.

6.6. Seedling damage.

Seedling damage is a qualitative term and is defined as the separation of the radicle from the mother embryo or the mechanical breakage of the radicle itself. For an evaluation of the damage to the seedlings, 0.75% gel concentraion level was used. Every vegetable variety was tested separately.

The radicle lengths of every vegetable variety used for evaluating the seedling damage ranged from 1 mm to 5 mm. For each vegetable variety the quantitative observations of individual seedl[illegible] the random sample taken from the extruded (dispensed) gel, are shown in Appendix (Table J1). From these results it is observed that the seedlings of tomato and carrot did not show any mechanical damage. Seedlings of radish having the radicle lengths of 3 mm or below were mostly broken or separated from mother embryo. From the physical appearance it was observed that the radicles of tomato and carrots were soft and flexible whereas the radicles of radish were comparatively stiff and brittle and this physical characteristic made them more susceptible to mechanical damage.

Therefore from this study it is inferred that different seed varieties responded different seedling damage index depending on the physiological characteristics.

CAHPTER VII

SUMMARY AND CONCLUSIONS.

A prototype dispensing system was fabricated using a diaphragm pump. The pump was operated by a 12 VDC solenoid. To investigate the effect of size, shape and texture of the seeds on the their flow through the dispensing system and their distribution per gel deposit, four vegetable varieties were used.

To determine the optimum level of gel concentration to keep the seeds in suspension, the seed settling studies were conducted by immersing the seeds in the gel solution of different concentrations. The machine was tested in the laboratory using Laponite 508 gel as the seed carrier medium. The following conclusions were made from the study.

1. The density of the seeds rather than the geometrical shape or surface texture is the predominant factor in the settling of seeds in a viscous solution.

2. The seed distribution per gel deposit is the same for different vegetable seeds and is not influenced by shape, size and textural characteristics of seed. Also, irrespective of shape, size and textural qualities of seed the seed distribution follows

Poisson's distribution.

3. The spatial distribution of seed in the gel deposit is not influenced by seed shape, size and textural qualities. Overall the seeds are evenly distributed within the gel deposit and have no localised or pooling effect.

4. The observed in-row spacings between successive gel depositsare normally distributed on the theoretical (calculated) value of spacing. The theoretical in-row spacing has the highest relative frequency among all frequency ranges of an observed in-row lengths.

5. The observed length of gel deposit ranged from 6.5 to 13.5 cm and had a uniform (rectangular) distribution. Hence no specific length can be suggested.

6. Seedlings of tomato and carrot did not show mechanical damage, but radish seedlings having radicle length of 3 mm and larger were found susceptible to mechanical damage.Physical properties of radicles (stiffness or softness) rather than seed varietal differences or textural qualities are the determining factors for mechanical damage.

Chapter VIII

Recommendations for further studies.

1. The solenoid, when operated continuously for extended periods became hot, hence if this machine is adapted to field operation of greater areas, a heavy duty solenoid is required or some alternate mechanical arrangement is to be devised.

2. By miniaturising the size of the diaphragm, less floor area can be occupied. Therefore 2 to 3 diaphragm pumps (possibly driven by one actuating mechanism) can be used in a parallel way to make this a multi-coulter dispensing machine.

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Appendices

Table A1. Viscosity of 0.25 percent gel solution.

Spindle #	Spindle speed (rpm)	Scale Reading*	Factor	viscosity (centipoise) poise)
	3	-	-	-
	.6	-	-	-
	1.5	-	-	-
	3.0	-	-	-
LV 1	6.0	3.0	10	30.0
	12.0	4.5	5	22.5
	30.0	6.3	2	12.6
	60.0	8.2	1	8.2

* mean of three scale readings

Table A2. Viscosity of 0.5 percent gel solution

Spindle #	Spindle Speed (rpm)	Scale Reading*	Factor	Viscosity (centi-poise)
	.3	4.5	200	900
	.6	6.5	100	650
	1.5	8.5	40	340
	3.0	10.5	20	210
LV 1	6.0	14.0	10	140
	12.0	18.5	5	92.5
	30.0	31.0	2	62
	60.0	41.5	1	41.5

* mean of three scale readings

Table A3. Viscosity of 0.75 percent gel solution

Spindle #	Spindle Speed (rpm)	Scale Reading*	Factor	Viscosity (centi-poise)
LV 2	.3	8.5	1000	8500
	.6	11.0	500	5500
	1.5	14.5	200	2900
	3.0	18.0	100	1800
	6.0	23.0	50	1150
	12.0	30.0	25	750
	30.0	42.0	10	420
	60.0	49.0	5	245

* mean of three scale readings

Table A4. Viscosity of 1.0 percent gel solution

Spindle #	Spindle speed (rpm)	Scale Reading*	Factor	Viscosity (Centi-poise)
LV 2	.3	32.5	1000	32500
	.6	41.5	500	20750
	1.5	50.5	200	10100
	3.0	57.5	100	5750
	6.0	70.0	50	3500
	12.0	75.0	25	1875
	30.0	95.0	10	950
	60.0	96.0	5	480

* mean of three scale readings.

Table B1. Settling time (seconds) of tomato seeds. Weight of 100 seeds = 0.2715 gms. Settling distance = 14 cms.

Seed #	Settlement Time (seconds)				
	Water	Gel Solutions (percent)			
		0.25	0.5	0.75	1.0
1	6.5	9.9	Seeds did not settle, remaianed suspended.		
2	5.0	15.1			
3	4.4	18.6			
4	4.7	10.2			
5	4.7	12.0			
6	5.0	9.9			
7	6.0	12.6			
8	4.5	14.0			
9	5.5	10.6			
10	5.5	10.4			
Average time	5.2	12.3			

Table B2. Settling time (seconds) of carrot seeds. Weight of 100 seeds = 0.125 gms. Settling distance = 14 cms.

Seed #	Settlement Time (seconds)				
	water	Gel solution percent			
		0.25	0.5	0.75	1.0
1	4.0	8.2	Seeds did not settle, remained suspended		
2	5.0	10.2			
3	4.6	9.2			
4	4.0	12.8			
5	3.8	9.4			
6	5.0	8.6			
7	4.1	11.8			
8	5.9	9.3			
9	5.2	7.7			
10	4.8	8.2			
Average time	4.6	9.5			

Table B3. Settling time (seconds) of beet seeds. Weight of 100 seeds = 1.020 gms. Settling distance = 14 cms.

Seed #	Settlement time (seconds)				
	Water	Gel solution percent			
		0.25	0.5	0.75	1.0
1	3.1	3.4	31.1		
2	2.7	3.6	29.6		
3	3.3	3.9	34.0		
4	2.8	4.6	32.5		
5	2.5	3.4	28.3	Seeds did not settle,	
6	2.5	4.0	27.8	remained suspended	
7	3.6	3.7	30.3		
8	3.3	4.6	33.0		
9	3.0	3.3	34.8		
10	2.9	4.1	30.6		
Average time	2.9	3.8	31.2		

Table B4. Settling time (seconds) of radish seeds. Weight of 100 seeds = 0.729 gms. Settling time = 14 cms.

Seed #	Settlement time (seconds)				
	Water	Gel solution percent			
		0.25	0.5	0.75	1.0
1	3.3	5.7	23.0		
2	2.7	4.4	20.5		
3	3.5	4.5	18.3		
4	2.0	4.8	21.7		
5	3.8	5.6	24.5	Seeds did not settle,	
6	3.7	4.4	19.8	remained suspended.	
7	3.0	6.0	22.0		
8	2.5	5.0	20.0		
9	2.3	6.8	24.0		
10	3.9	5.9	21.0		
Average time	3.0	5.3	21.6		

Table C1. Number of tomato seeds distributed per deposit, length of deposit and distance of seeds from the center of deposit.

Deposit #	Number of seeds per depoist	Length of deposit (cms)	Distance of nearest seed from centre of deposit (cms)	Distance of farthest seed from centre of deposit (cms)
		Replication I		
1	5	9.0	.5	4.5
2	4	8.0	2.0	3.5
3	2	6.5	0.0	2.5
4	1	7.0	.5	-
5	7	10.0	1.5	5.0
6	1	10.0	1.5	-
7	5	8.5	1.0	3.0
8	2	9.5	.5	4.5
9	4	12.5	0.0	5.0
10	9	11.0	1.5	4.0
11	8	13.5	1.0	5.5
12	5	13.0	.5	6.0
13	3	12.0	1.5	5.0
14	4	9.0	0.0	2.0
15	8	10.5	2.0	5.0
16	4	8.0	1.0	3.0
17	9	13.5	0.0	6.0
18	4	7.0	1.5	3.5
19	6	9.5	0.0	4.5
20	7	12.5	1.0	5.5
21	5	8.5	0.0	4.0
22	6	9.5	.5	3.5
23	6	10.5	1.5	5.0
24	7	11.5	0.0	4.5
25	3	12.0	.5	6.0
26	4	8.25	1.0	3.0
27	2	7.0	2.0	2.5
28	0	7.5	-	-
29	1	6.5	2.5	-
30	3	9.5	2.0	4.0

Replication II

1	5	7.5	.5	3.0
2	4	10.5	0.0	5.0
3	2	6.5	.5	2.5
4	8	13.0	1.0	6.0
5	1	6.5	1.5	–
6	2	13.5	1.0	5.0
7	5	12.0	0.0	5.5
8	4	9.5	1.5	3.5
9	1	7.0	2.0	–
10	3	9.0	.5	2.5
11	0	8.0	–	–
12	4	12.0	0.0	4.0
13	7	11.0	0.0	4.0
14	3	7.5	1.5	2.0
15	2	8.5	.5	2.5
16	5	13.5	2.0	4.5
17	3	10.0	1.5	3.0
18	4	8.0	0.0	3.5
19	1	6.5	2.0	–
20	4	10.0	1.0	4.5
21	4	9.0	1.0	4.5
22	6	11.5	0.0	4.0
23	2	10.0	.5	3.5
24	3	7.5	2.0	3.0
25	1	8.0	.5	–
26	3	12.5	2.0	5.0
27	4	11.0	0.0	4.5
28	2	7.0	.5	2.5
29	5	8.5	0.0	2.0
30	3	10.5	–	–

Replication III

1	3	11.5	2.5	5.5
2	1	8.0	3.0	-
3	7	12.0	0.0	5.5
4	4	11.0	.5	2.5
5	6	13.5	0.0	5.0
6	2	9.0	1.0	3.0
7	7	10.5	0.0	5.0
8	4	12.5	.5	6.0
9	8	10.0	0.0	4.5
10	1	7.0	2.5	-
11	6	9.5	.5	3.5
12	4	13.0	2.0	4.0
13	0	10.0	-	-
14	5	8.0	1.0	3.5
15	3	7.0	1.5	2.0
16	4	11.5	1.0	4.0
17	2	9.5	2.0	4.5
18	5	7.0	.5	2.0
19	4	8.5	1.5	2.5
20	3	10.0	.5	3.5
21	4	13.5	2.0	5.0
22	3	12.0	0.0	4.5
23	4	6.5	1.5	2.5
24	6	7.5	2.0	3.0
25	7	12.5	3.0	5.5
26	5	13.0	1.5	5.0
27	3	12.0	0.0	2.0
28	0	7.5	-	-
29	6	13.0	0.0	2.5
30	7	9.5	.5	3.50

Replication IV

1	3	12.0	1.0	5.0
2	4	9.5	2.5	3.0
3	5	9.0	0.0	3.5
4	4	13.0	1.5	4.5
5	0	10.0	–	–
6	4	8.0	.5	3.0
7	2	12.5	2.0	4.0
8	1	11.0	3.0	–
9	4	9.5	0.0	2.0
10	5	8.5	1.0	2.5
11	4	13.5	1.5	5.0
12	4	10.5	2.0	3.5
13	7	8.5	0.0	3.0
14	2	7.5	.5	2.0
15	8	11.5	0.0	5.0
16	3	10.5	.5	4.5
17	1	9.0	2.5	–
18	4	7.0	1.0	2.5
19	4	13.0	1.5	4.0
20	5	10.0	1.0	4.5
21	6	9.5	.5	2.0
22	4	11.0	1.5	5.0
23	1	7.5	3.0	–
24	4	10.5	2.0	4.0
25	7	12.5	0.0	4.5
26	2	9.0	.5	2.0
27	4	7.0	2.5	3.0
28	5	12.0	0.0	4.0
29	4	6.5	.5	2.5
30	6	13.0	0.0	6.0

Table C2. Number of carrot seeds distributed per deposit, length of deposit and distance of seeds from the center of deposit.

Deposit #	Number of seeds per deposit	Length of deposit (cms)	Distance of nearest seed from centre of deposit (cms)	Distance of farthest seed from centre of deposit (cms)
		Replication I		
1	5	13.5	0.0	5.5
2	8	12.0	.5	5.0
3	7	7.5	2.0	3.0
4	8	12.5	0.0	4.5
5	4	10.5	1.0	3.5
6	4	9.5	0.0	2.0
7	3	10.0	1.5	2.5
8	5	9.0	1.0	4.0
9	3	8.0	.5	2.0
10	1	12.0	2.0	-
11	1	8.0	1.5	-
12	6	10.0	0.0	3.5
13	4	7.0	2.0	3.0
14	8	13.5	0.0	6.0
15	5	10.5	1.0	5.0
16	2	12.5	0.0	2.0
17	1	9.5	.5	-
18	4	7.5	1.5	3.0
19	6	12.0	2.0	5.0
20	2	12.5	-	-
21	4	9.0	1.5	2.5
22	3	10.0	.5	3.5
23	0	7.0	-	-
24	5	13.5	2.5	4.0
25	1	12.5	.5	-
26	2	10.5	1.5	4.5
27	2	9.0	.5	2.0
28	7	13.5	0.0	5.5
29	1	12.0	1.0	-
30	4	7.5	2.0	3.0

Replication II

1	5	9.5	.5	3.0
2	7	13.5	0.0	6.5
3	4	12.5	1.0	5.0
4	2	9.5	.5	2.0
5	3	10.5	1.5	3.5
6	2	7.5	–	–
7	6	13.5	1.5	4.5
8	4	11.5	.5	4.0
9	3	8.0	1.0	2.0
10	2	9.5	.5	2.5
11	1	7.5	2.0	–
12	4	7.0	0.0	2.0
13	5	10.0	0.0	3.5
14	3	12.0	1.0	5.5
15	4	7.0	1.5	2.0
16	6	13.5	1.0	3.5
17	4	10.0	.5	2.0
18	8	13.0	0.0	5.5
19	4	9.0	2.0	3.0
20	3	12.5	2.5	4.0
21	3	7.5	–	–
22	2	9.5	1.0	3.5
23	5	10.0	0.0	4.5
24	7	9.0	1.5	2.5
25	1	6.5	2.0	–
26	3	13.5	2.5	4.0
27	5	12.5	.5	3.0
28	7	10.5	0.0	5.0
29	2	9.0	1.5	2.5
30	0	7.0	–	–

Replication III

1	5	12.5	0.0	5.5
2	3	9.5	.5	4.5
3	4	7.0	1.5	2.0
4	3	12.5	-	-
5	2	13.0	2.5	5.5
6	6	10.0	.5	3.5
7	4	9.0	1.0	2.0
8	3	13.5	2.0	6.0
9	0	12.0	-	-
10	2	7.0	.5	2.5
11	7	9.5	0.0	3.5
12	4	10.0	.5	2.0
13	6	12.0	2.0	4.0
14	5	13.5	2.5	5.5
15	4	12.0	0.0	4.5
16	3	7.0	1.0	3.0
17	1	7.5	.5	-
18	4	9.5	2.0	4.5
19	5	10.0	0.0	3.5
20	0	9.0	-	-
21	7	13.5	0.0	4.0
22	5	12.0	1.5	5.5
23	1	7.5	1.0	-
24	2	8.0	.5	3.5
25	8	11.5	0.0	5.0
26	6	7.0	2.0	2.5
27	4	9.0	.5	2.0
28	3	7.5	1.5	3.0
29	1	6.5	1.0	-
30	7	9.5	0.0	4.0

Replication IV

1	5	7.0	0.0	3.0
2	3	9.0	.5	3.5
3	2	6.5	1.5	2.5
4	4	9.5	1.0	2.0
5	8	12.5	0.0	6.0
6	2	11.0	-	-
7	6	13.0	0.0	5.0
8	5	9.5	.5	2.5
9	7	13.5	0.0	6.5
10	1	7.5	2.0	-
11	5	12.5	0.5	4.5
12	3	10.5	1.5	4.0
13	6	9.0	0.0	3.0
14	4	7.0	1.0	2.5
15	3	7.5	1.5	2.0
16	6	12.5	.5	5.5
17	4	12.0	0.0	5.0
18	2	7.5	2.0	2.5
19	1	9.0	.5	-
20	5	13.5	0.0	6.0
21	7	11.0	0.0	5.5
22	4	13.5	1.5	6.0
23	0	7.5	-	-
24	4	12.0	.5	5.0
25	3	9.0	1.0	4.0
26	5	7.0	1.5	3.0
27	4	9.5	2.0	3.5
28	1	6.5	.5	-
29	3	13.5	1.0	4.0
30	2	10.5	.5	4.5

Table C3. Number of radish seeds distributed per deposit, length of deposit and distance of seeds from the center of deposit.

Depoist #	number of seeds per deposit	Length of deposit (cms)	Distance of nearest seed from center of deposit (cms)	Distance of farthest seed from center of deposit (cms)
		Replication I		
1	4	11.0	1.5	4.5
2	1	8.0	.5	-
3	4	12.5	1.5	4.0
4	3	7.0	1.0	2.5
5	4	9.0	0.0	4.0
6	2	6.5	1.5	2.0
7	2	10.5	2.0	5.0
8	3	9.0	.5	3.5
9	3	12.0	0.0	5.5
10	5	12.5	2.0	5.0
11	4	13.0	1.0	4.5
12	4	13.5	2.0	5.5
13	3	9.5	.5	3.5
14	1	7.0	1.5	-
15	4	9.0	2.0	3.0
16	7	10.5	0.0	4.0
17	1	11.5	1.0	-
18	0	7.5	-	-
19	2	11.0	2.0	5.0
20	2	12.5	2.5	5.5
21	5	9.5	0.0	3.0
22	4	12.5	1.0	4.0
23	3	8.0	1.5	3.5
24	4	13.0	.5	5.0
25	3	12.5	2.0	4.5
26	4	11.0	.5	5.5
27	2	8.0	1.0	2.0
28	0	7.5	-	-
29	4	6.5	0.0	2.5
30	5	9.5	.5	3.0

Replication II

1	5	12.0	0.0	5.5
2	4	9.0	.5	3.0
3	2	10.5	1.5	4.0
4	5	13.0	.5	5.5
5	1	7.5	2.5	-
6	4	13.5	2.0	4.0
7	7	12.0	0.0	4.5
8	6	9.0	1.0	2.5
9	4	10.0	2.0	4.5
10	5	13.0	0.0	5.0
11	6	12.0	1.5	3.5
12	7	8.0	1.0	2.0
13	3	7.0	.5	3.0
14	2	9.0	2.0	3.5
15	4	12.0	2.5	4.0
16	6	13.5	0.0	5.0
17	3	12.5	.5	4.5
18	0	12.0	-	-
19	4	9.0	1.5	4.0
20	8	12.5	0.0	5.5
21	1	10.5	1.0	-
22	8	9.0	0.0	3.5
23	4	12.0	2.0	5.0
24	3	6.5	.5	2.0
25	6	9.5	0.0	3.0
26	9	11.5	0.0	4.5
27	3	10.0	-	-
28	7	13.0	1.5	6.0
29	5	8.0	.5	3.0
30	3	6.5	1.0	2.0

Replication III

1	6	10.5	1.5	5.0
2	4	9.5	.5	4.5
3	5	11.0	0.0	2.0
4	4	8.0	.5	3.0
5	1	12.0	2.0	-
6	7	10.0	0.0	3.5
7	4	7.0	1.0	2.5
8	4	10.5	.5	4.0
9	1	12.5	2.5	-
10	3	13.5	-	-
11	2	10.5	2.0	3.0
12	6	9.0	1.0	2.0
13	5	6.5	0.0	2.5
14	7	8.0	1.0	3.5
15	3	10.0	1.5	4.5
16	4	12.0	0.0	5.5
17	2	7.5	.5	2.0
18	5	13.5	.5	5.0
19	3	8.0	1.0	3.0
20	7	12.5	1.5	6.0
21	6	12.0	.5	4.5
22	9	9.5	0.0	4.0
23	7	6.5	0.0	2.0
24	4	10.5	.5	5.0
25	1	9.5	1.5	-
26	3	13.5	1.0	6.0
27	5	12.0	1.5	5.5
28	4	9.0	.5	3.5
29	3	10.5	0.0	4.0
30	1	6.5	1.0	-

Replication IV

1	8	12.0	0.5	4.0
2	5	9.0	1.0	3.0
3	4	13.0	2.0	4.5
4	1	10.0	1.5	-
5	2	9.5	.5	2.0
6	7	13.5	1.0	6.0
7	5	12.0	2.0	4.5
8	8	8.0	0.0	3.0
9	3	7.0	.5	2.5
10	4	9.0	2.0	3.0
11	4	12.5	.5	6.0
12	1	9.5	1.5	-
13	3	6.5	0.0	2.0
14	4	9.5	2.0	5.5
15	0	10.5	-	-
16	3	7.5	1.5	2.5
17	4	13.0	.5	6.0
18	7	12.0	0.0	5.5
19	8	9.0	0.5	2.0
20	2	6.5	1.5	2.5
21	6	10.5	2.0	5.0
22	3	12.5	1.0	4.0
23	1	7.5	.5	-
24	4	7.0	0.0	3.0
25	3	10.0	-	-
26	2	8.0	.5	3.5
27	4	13.5	1.0	4.0
28	7	9.5	0.0	4.5
29	5	7.5	0.0	2.0
30	6	10.5	.5	5.0

Table D1. Statistical analysis for number of tomato seeds distributed per deposit.

# of seeds per deposit (X)	Observed frequency (O)	expected frequency (E)	$\frac{(O - E)^2}{E}$
0	5	2.1979	3.572
1	12	8.7920	1.170
2	13	17.5830	1.194
3	16	23.4440	2.363
4	32	23.4440	3.122
5	15	18.7552	.751
6	10	12.5034	.501
7	10	7.1448	1.140
8	5	3.5724	.570
9	2	1.5877	.107
Total	120	119.0244	14.49**

$$X^2_{cal} = \sum \frac{(O - E)^2}{E} = 14.49$$

df = 9

** Significant at .05 and .01 level

Note: Calculation based on the theoretical value of u = 4

Table D2. Frequency distribution of nearest and farthest tomato seeds from the center of gel deposit.

Seed nearest to the center of deposit		Seed farthest from the center of deposit	
Distance (cms)	Frequency of seed	Distance (cms)	Frequency of seed
At center	29	2.0	10
.5	25	2.5	13
1.0	16	3.0	12
1.5	18	3.5	12
2.0	16	4.0	12
2.5	6	4.5	15
3.0	4	5.0	16
		5.5	6
		6.0	6

Table E1. Statistical analysis for number of carrot seeds distributed per deposit

# of seeds per deposit (X)	Observed frequency (O)	Expected frequency (E)	$\frac{(O - E)^2}{E}$
0	5	2.1979	3.572
1	13	8.7920	2.040
2	16	17.5830	.142
3	19	23.4440	.842
4	24	23.4440	.023
5	17	18.7552	.164
6	10	12.5034	.877
7	10	7.1448	1.140
8	6	3.5724	1.649
Total	120	117.42364	10.449**

$$X^2_{cal} = \sum \frac{(O - E)^2}{E} = 10.449$$

df = 8

** Significant at .05 and .01 level

Note: Calculation based on theoretical value of u = 4

Table E2. Frequency distribution of nearest and farthest carrot seeds from the center of gel deposit.

Seed nearest to the center of deposit		Seed farthest from the center of deposit	
Distance (cms)	Frequency of seed	Distance (cms)	Frequency of seed
At center	28	2.0	15
.5	27	2.5	11
1.0	17	3.0	12
1.5	18	3.5	13
2.0	15	4.0	11
2.5	5	4.5	9
		5.0	9
		5.5	10
		6.0	5
		6.5	2

Table F1. Statistical analysis for number radish of seeds distributed per deposit.

# of seeds per deposit (X)	Observed frequency (O)	Expected frequency (E)	$\frac{(O - E)^2}{E}$
0	4	2.1979	1.477
1	12	8.7920	1.170
2	15	17.5830	.379
3	16	23.4440	2.363
4	34	23.4440	4.752
5	14	18.7552	1.20
6	9	12.5034	.981
7	11	7.1448	2.080
8	3	3.5724	.091
9	2	1.5877	.107
Total	120	119.0244	14.605**

$$X^2_{cal} = \sum \frac{(O - E)^2}{E} = 14.605$$

df = 9

** Significant at .05 and .01 level

Note: Calculation based on theoretical value of u = 4

Table F2. Frequency distribution of nearest and farthest radish seeds from the center of gel deposit.

Seed nearest to the center of deposit		Seed farthest from the center of deposit	
Distance (cms)	Frequency of seed	Distance (cms)	Frequency of seed
At center	26	2.0	13
.5	29	2.5	8
1.0	19	3.0	14
1.5	18	3.5	10
2.0	17	4.0	14
2.5	4	4.5	13
		5.0	12
		5.5	11
		6.0	6

Table G1. Length of individual deposit and in-row spacing between successive deposits based on 8 pins in the timing wheel.

Deposit #	Length of deposit (cms)	Spacing between successive depoists (center to center) (cms)	Cumulative distance (cms)
		Replication I	
1	9.0	-	-
2	8.0	22.0	22.0
3	6.5	27.0	47.0
4	7.0	26.5	75.5
5	10.0	25.5	101.0
6	10.0	31.5	132.5
7	8.5	25.0	157.5
8	9.5	26.5	184.0
9	12.5	26.0	210.0
10	11.0	25.5	235.5
11	13.5	30.0	265.5
12	13.0	26.5	292.0
13	12.0	27.5	319.5
14	9.0	20.5	340.0
15	10.5	24.0	364.0
16	8.0	24.0	388.0
17	13.5	27.0	415.0
18	7.0	28.0	443.0
19	9.5	26.0	469.0
20	12.5	29.5	498.5
21	8.5	26.5	525.0
22	9.5	28.5	553.5
23	10.5	25.5	579.0
24	11.5	24.0	609.0
25	12.0	26.5	629.5
26	8.0	29.0	658.5
27	7.0	26.5	685.0
28	7.5	27.0	712.0
29	6.5	25.5	737.5
30	9.5	23.5	716.0

Replication II

1	7.5	—	—
2	10.5	25.5	25.5
3	6.5	29.5	54.5
4	13.0	33.0	87.5
5	6.5	22.5	110.0
6	13.5	23.5	133.5
7	12.0	21.5	155.0
8	9.5	28.0	183.0
9	7.0	24.0	207.0
10	9.0	27.0	234.0
11	8.0	26.5	260.5
12	12.0	25.5	286.0
13	11.0	28.5	314.5
14	7.5	31.5	346.0
15	8.5	34.5	380.5
16	13.5	34.0	414.5
17	10.0	31.0	445.5
18	8.0	25.5	471.0
19	6.5	24.0	495.0
20	10.0	25.5	520.5
21	9.0	29.0	549.5
22	11.5	25.5	575.0
23	10.0	23.0	598.0
24	7.5	26.5	624.5
25	8.0	29.0	653.5
26	12.5	26.0	679.5
27	11.0	24.0	703.5
28	7.0	26.5	730.0
29	8.5	28.0	758.0
30	10.5	33.5	791.5

Replication III

1	11.5	-	-
2	8.0	33.5	33.5
3	12.0	31.5	65.0
4	11.0	28.0	93.0
5	13.5	26.5	119.5
6	9.0	29.0	148.5
7	10.5	25.0	173.5
8	12.5	25.5	199.0
9	10.0	22.5	221.5
10	7.0	29.0	250.5
11	9.5	26.5	277.0
12	13.0	31.0	308.0
13	10.0	23.0	331.0
14	8.0	21.0	352.0
15	7.0	21.5	373.5
16	11.5	25.5	399.0
17	9.0	28.5	727.5
18	7.0	24.0	451.5
19	8.5	25.5	477.0
20	10.0	32.0	509.0
21	13.5	23.0	532.0
22	12.0	28.0	560.0
23	6.5	23.5	583.5
24	7.5	26.5	610.0
25	12.5	28.5	638.5
26	13.0	24.0	662.5
27	12.0	33.0	695.5
28	7.5	23.0	718.5
29	13.0	28.5	747.0
30	9.5	30.0	777.0

Replication IV

1	12.0	–	–
2	9.5	23.0	23.0
3	9.0	26.0	49.0
4	13.0	29.0	78.0
5	10.5	26.5	104.5
6	8.0	29.5	134.0
7	12.5	24.0	158.0
8	11.0	25.5	183.5
9	9.5	26.5	210.0
10	8.5	29.5	239.5
11	13.5	27.0	266.5
12	10.5	26.5	293.0
13	8.5	31.5	324.5
14	7.5	24.0	348.5
15	11.5	26.0	474.5
16	10.5	28.0	402.5
17	9.0	21.5	424.0
18	7.0	27.0	451.0
19	13.0	31.5	482.5
20	10.0	27.0	509.5
21	9.5	24.0	533.5
22	11.0	28.0	561.5
23	7.5	26.5	588.0
24	10.5	26.0	614.0
25	12.5	25.5	639.5
26	9.0	34.0	673.5
27	7.0	26.5	700.0
28	12.0	23.5	723.5
29	6.5	29.0	752.5
30	13.0	26.0	778.5

Table G2. Length of individual deposit and in-row spacing between successive deposits based on 4 pins in the timing wheel.

Deposit #	Length of deposit (cm)	Distance between successive depoists (cneter to cneter) (cm)	Cumulative distance (m)
		Replication I	
1	11.0	-	-
2	12.5	53.0	.53
3	9.0	52.0	1.05
4	11.5	57.5	1.625
5	13.5	50.5	2.130
6	12.0	54.0	2.67
7	6.5	49.5	3.165
8	10.0	56.5	3.73
9	9.0	50.5	4.235
10	13.0	48.0	4.715
11	9.5	50.0	5.215
12	11.0	52.0	5.735
13	7.5	47.0	6.205
14	12.0	51.5	6.72
15	11.5	54.5	6.265
16	8.5	52.0	7.785
17	10.5	57.0	8.355
18	7.0	49.5	8.85
19	9.0	52.5	9.375
20	10.5	45.5	9.83
21	8.0	54.5	10.375
22	10.0	50.5	10.88
23	9.5	48.5	11.365
24	11.0	50.5	11.87
25	13.5	55.5	12.425
26	10.0	52.0	12.945
27	7.0	48.0	13.425
28	12.5	52.0	13.945
29	9.5	58.0	14.525
30	6.5	49.5	15.02

Replication II

1	8.5	-	-
2	9.0	51.5	.515
3	13.0	55.0	1.065
4	11.0	53.0	1.595
5	8.0	51.5	2.11
6	12.5	55.5	2.665
7	9.0	52.0	3.185
8	10.5	48.5	3.665
9	7.5	54.0	4.205
10	8.5	57.0	4.775
11	12.0	45.0	5.225
12	8.0	55.0	5.7[illegible]5
13	7.0	51.5	6.29
14	10.5	57.5	6.865
15	12.5	49.5	7.36
16	10.0	50.5	7.865
17	8.0	54.5	8.41
18	6.5	48.5	8.895
19	9.5	52.5	9.42
20	12.0	53.0	9.95
21	9.0	56.5	10.515
22	10.5	54.0	11.055
23	10.0	52.0	11.575
24	13.0	53.0	12.105
25	9.5	49.5	12.6
26	11.5	50.5	13.105
27	11.0	52.0	13.625
28	9.5	48.5	14.11
29	10.5	53.0	14.61
30	12.0	45.5	15.065

Replication III

1	9.0	-	-
2	13.0	47.5	.475
3	8.0	54.5	1.02
4	11.5	52.0	1.54
5	12.0	56.5	2.105
6	13.5	54.5	2.65
7	8.0	51.5	3.165
8	12.0	50.0	3.665
9	10.0	57.0	4.235
10	6.5	46.0	4.695
11	7.5	55.0	5.245
12	8.5	51.5	5.76
13	10.5	50.5	6.265
14	12.5	49.5	6.76
15	12.0	54.0	7.3
16	7.5	50.5	7.805
17	13.0	55.5	8.36
18	11.0	54.5	8.905
19	9.5	55.5	9.46
20	13.0	49.5	9.955
21	10.0	52.5	10.48
22	11.5	53.0	11.01
23	8.0	51.5	11.525
24	10.5	54.0	12.065
25	13.0	48.0	12.545
26	10.0	52.0	13.065
27	8.5	54.0	13.605
28	9.0	57.0	14.175
29	12.5	54.5	14.72
30	11.0	49.5	15.215

Replication IV

1	13.5	-	-
2	7.5	55.5	.555
3	6.5	57.5	1.13
4	12.5	50.5	1.635
5	12.0	52.0	2.155
6	11.5	56.5	2.72
7	13.5	52.0	3.24
8	10.0	48.5	3.725
9	8.0	54.5	4.27
10	10.5	52.5	4.795
11	9.0	57.0	5.365
12	12.5	51.5	5.88
13	10.5	50.5	6.385
14	7.5	54.0	6.925
15	7.0	52.0	7.445
16	8.0	55.0	7.995
17	10.0	48.0	8.475
18	8.5	49.5	8.97
19	9.0	52.0	9.49
20	11.5	52.5	10.015
21	9.5	49.5	10.51
22	12.0	52.5	11.035
23	13.0	55.5	11.59
24	8.0	54.5	12.135
25	11.0	50.5	12.64
26	9.0	52.0	13.16
27	12.0	53.0	13.69
28	7.5	54.5	14.235
29	11.0	51.5	14.75
30	13.5	49.5	15.245

Table H1. Frequency distribution and computations for expectedfrequencyandchi-square testfor goodness of fit to the uniform distribution of length of gel deposit at 8 pins in the timing wheel.

Length of gel deposit (cm)	Observed frequency of length (O)	Expected frequency of length (E)	$\frac{(O - E)^2}{E}$
6.5	7	8	.125
7.0	10	8	.50
7.5	8	8	0.0
8.0	9	8	.125
8.5	7	8	.125
9.0	9	8	.125
9.5	10	8	.50
10.0	10	8	.50
10.5	8	8	0.0
11.0	6	8	.50
11.5	5	8	1.125
12.0	9	8	.125
12.5	7	8	.125
13.0	8	8	0.0
13.5	7	8	.125
Total	120	120	3.5**

** Significant at .05 and .01 levels of confidence
df = 14

$$\text{Expected (uniform) frequency} = \frac{\text{Total observations}}{\text{Nr. of classes}}$$

$$8 = \frac{120}{15}$$

Table H2. Frequency distribution and computations for mean and variance of in-row spacing between successive gel deposits at calculated in row-spacing of 25.92* cm (10.2 in) keeping 8 pins in the timing wheel.

Class		Observed freq.	Commputations for mean and variance		
Spacing interval	Mid-point (X)	(f)	(f)(X)	X^2	$(f)(X)^2$
20.0 - 21.9	21.0	5	105	441	2205
22.0 - 23.9	23.0	12	276	529	6348
24.0 - 25.9	25.0	27	675	625	16875
26.0 - 27.9	27.0	32	864	729	23328
28.0 - 29.9	29.0	23	667	841	19343
30.0 - 31.9	31.0	9	279	961	8649
32.0 - 33.9	33.0	6	198	1089	6534
34.0 - 35.9	35.0	3	105	1225	3675
Total		117	3169		86957

* Theoretical in-row spacing calculated on wheel diameter of 26 in (66.04 cm).

$$\overline{X} = \frac{3169}{117} = 27.09$$

$$s^2 = \frac{1}{(117 - 1)} (86957 - (3169)^2/117) = 9.68$$

$$s = 3.11$$

Table H2. (Continued) Computations for expected frequency and chi-square test for goodness of fit to the normal distribution.

Observed freq. (O)	Standarised Z values Z_1	Z_h	Probability (P)	Expected freq. (E)	$\frac{(O-E)^2}{E}$
5		-1.65	.5000 -.4505 = .0495	5.79	.108
12	1.65	-1.01	.4505 -.3438 = .1076	12.48	.018
27	1.01	-0.37	.3438 -.1443 = .1995	23.34	.574
32	0.37	0.28	.1443 +.1103 = .2546	29.79	.164
23	0.28	0.92	.1103 -.3212 = .2109	24.68	.114
9	0.92	1.56	.3212 -.4406 = .1194	13.96	1.762
6	1.56	2.21	.4406 -.4864 = .0458	5.36	.076
3	2.21		.4864 -.5000 = .0136	1.59	1.250
117				116.99	4.06**

$$X^2_{cal} = \sum \frac{(O - E)^2}{E} = 4.06$$

** significant at .05 and .01 levels of confidence.

df = 7

$$z_l = \frac{L_l - \overline{X}}{s}$$

$$z_h = \frac{L_h - \overline{X}}{s}$$

Where:

L_l = Lower true class limit

L_h = Upper true limit of second class

s = variance

For example:

$$L_l = \frac{21.9 + 22.0}{2} = 21.95$$

$$L_h = \frac{23.9 + 24.0}{2} = 23.95$$

And

$$z_l = \frac{21.95 - 27.09}{3.11} = -1.65$$

$$z_h = \frac{23.95 - 27.09}{3.11} = -1.01$$

Table 11. Frequency distribution and computations for expected frequency and chi-square test for goodness of fit to the uniform distribution of length of gel deposit at 4 pins in the timing wheel.

Length of gel deposit (cm)	Observed frequency of length (O)	Expected frequency of length (E)	$\frac{(O - E)^2}{E}$
6.5	5	8	1.125
7.0	4	8	2.0
7.5	7	8	.125
8.0	10	8	.50
8.5	6	8	.50
9.0	11	8	1.125
9.5	8	8	0.0
10.0	10	8	.50
10.5	10	8	.50
11.0	9	8	.125
11.5	7	8	.125
12.0	11	8	1.125
12.5	8	8	0.0
13.0	8	8	0.0
13.5	6	8	.50
Total	120	120	8.25**

** Significant at .05 and .01 levels of conficdence
df = 14

$$\text{Expected (uniform) frequency} = \frac{\text{Total observations}}{\text{Nr. of classes}}$$

$$8 = \frac{120}{15}$$

Table I2. Frequency distribution and computations for mean and variance of in-row spacing between successive gel deposits at calculated in-row spacing of 51.82* cm (20.4 in) keeping 4 pins in the timing wheel.

Class		Observed freq.	Computations for mean and variance		
Spacing interval	Mid-point (X)	(f)	(f)(X)	$(X)^2$	$(f)(X)^2$
45.0 - 46.9	46.0	4	184	2116	8464
47.0 - 48.9	48.0	11	528	2304	25344
49.0 - 50.9	50.0	24	1200	2500	60000
51.0 - 52.9	52.0	30	1560	2704	81120
53.0 - 54.0	54.0	24	1296	2916	69984
55.0 - 56.9	56.0	14	784	3136	43904
57.0 - 58.9	58.0	9	522	3364	30276
Total		116	6074		319092

$$\bar{X} = \frac{6074}{116} = 52.36$$

$$s^2 = \frac{1}{(116 - 1)} \left(319092 - (6074)^2/116 \right) = 9.085$$

$$s = 3.014$$

Table I2. (Continued) Computations for expected frequency and chi-square test for goodness of fit to the normal distribution.

Observed freq. (O)	Standarised Z values Z_1	Z_h	Probability (P)	Expected freq. (E)	$\frac{(O-E)^2}{E}$
4		-1.80	.5000 - .4641 = .0359	4.16	.006
11	1.80	-1.13	.4641 - .3708 = .0933	10.82	.003
24	1.13	-0.48	.3708 - .1844 = .1864	21.62	.261
30	0.48	0.19	.1844 + .0753 = .2597	30.13	.0005
24	0.19	0.86	.0753 - .3051 = .2298	26.66	.264
14	0.86	1.52	.3051 - .4357 = .1306	15.15	.087
9	1.52		.4357 - .5000 = .0643	7.46	.318
116				116	.939**

$$X^2_{cal} = \sum \frac{(O - E)^2}{E} = .939$$

** Significant at .05 and .01 levels of confidence

df = 6

$$Z_1 = \frac{L_1 - \overline{X}}{s}$$

$$Z_h = \frac{L_h - \overline{X}}{s}$$

Where

L_1 = Lower true class limit

L_h = Upper true limit of second class

s = variance

For example:

$$L_1 = \frac{46.9 + 47.0}{2} = 46.95$$

$$L_h = \frac{48.9 + 49.0}{2} = 48.95$$

And

$$Z_1 = \frac{46.95 - 52.36}{3.014} = -1.80$$

$$Z_h = \frac{48.95 - 52.36}{3.014} = -1.13$$

Table J1. Quantitative observation showing mechanical damage to the seedlings passed through the dispensing system.

Sample #	Number of seedlings per sample	length of radicle (mm)	Number of seedlings	Remarks
		Radish		
1	21	1 to 2	4	Undamaged
		2 - 3	3	Undamaged
				The remaining quantity of seedlings were found with broken radicles.
2	26	1 to 2	7	Undamaged
		2 - 3	5	Undamaged
				The remaining quantity of seedlings were found with broken radicles.
3	17	1 to 2	2	Undamaged
		2 - 3	6	Undamaged
				The emaining quantity of seedlings were found with broken radicles.
4	12	1 to 2	1	Undamaged
		2 - 3	4	Undamaged
				The remaining quantity of seedlings were found with broken radicles.
		Tomato		
1	35	1 to 2	6	
		2 - 3	8	No damage
		3 - 4	10	
		4 - 5	11	
2	24	1 to 2	3	
		2 - 3	4	No damage
		3 - 4	9	
		4 - 5	8	

3	:	19	: 1 to 2	: 4	:
			: 2 - 3	: 6	: No damage
			: 3 - 4	: 2	:
			: 4 - 5	: 7	:
4	:	14	: 1 to 2	: 2	:
			: 2 - 3	: 5	: No damage
			: 3 - 4	: 3	:
			: 4 - 5	: 4	:

Carrot

1	:	22	: 1 to 2	: 7	:
			: 2 - 3	: 9	: No damage
			: 3 - 4	: 4	:
			: 4 - 6	: 2	:
2	:	20	: 1 to 2	: 5	:
			: 2 - 3	: 3	: No damage
			: 3 - 4	: 7	:
			: 4 - 5	: 5	:
3	:	17	: 1 to 2	: 4	:
			: 2 - 3	: 3	: No damage
			: 3 - 4	: 6	:
			: 4 - 5	: 4	:
4	:	27	: 1 to 2	: 6	:
			: 2 - 3	: 9	: No damage
			: 3 - 4	: 7	:
			: 4 - 5	: 5	: