

## Development and Evaluation of an Innovative Garlic Clove Precision Planter

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### ABSTRACT

In this study an innovatively designed tractor-mounted, ground-wheel driven, triple unit, row crop precision planter capable of planting three rows of garlic (*Allium sativum* L.) cloves on each raised bed was designed, fabricated and tested. The major components of this planter include; chassis and transport wheels, lister-bedder unit, seed hopper, seed metering drum, sweeper, knocker, seed tube, furrow openers and seed coverers. The metering drums and sweepers are driven by two ground wheels through a chain drive system. Laboratory evaluation of the planter components, especially the seed metering mechanism revealed a satisfactory performance of the planter components, except a few modifications which were needed before conducting field tests. The performance parameters measured/calculated during the field tests included: seeding mass rate, seeding depth, seed spacing, miss index, multiple index and seed damage. The results showed that the new machine is capable of planting 220,000 plants ha<sup>-1</sup> at the seeding depth and spacing of 12.3 and 22.7 cm, respectively. Also, miss index, multiple index and seed damage were measured as 12.23, 2.43 and 1.41 percent, respectively.

**Keywords:** Garlic, Metering drum, Planter, Seed hopper.

### INTRODUCTION

Garlic (*Allium sativum* L.) is a crop with a long history of plantation in Iran. Due to the lack of appropriate planting, cultivation and harvesting machinery for mechanizing its production, it is still grown in relatively small fields using traditional methods. Also, owing to its nutritional and pharmaceutical values, it has received economic interest worldwide. In recent years, many farmers have shown great interest in garlic plantations in Iran, especially in Hamedan Province. Iranian Ministry of Agriculture statistics indicate that, in the year 2000, the total area under garlic plantation in Iran was about 8,000 hectares of which about 2,000 hectares belonged to Hamedan Province [2]. Because of the high costs of the traditional methods of garlic planting, cultivation and

harvesting which is very time consuming and labor intensive, its large scale production is not economical and is therefore very limited. On the other hand, government policy for enhancing non-petroleum based products exports alongside the suitability of garlic as an exportable commodity calls for the development of a machine for its large scale mechanized planting.

Rahman and Das (1985) planted a local variety of garlic clove at three weight levels of 0.54, 0.76 and 1.08 gr in rows 10, 15, 20 and 25 cm apart. The highest yield, 9.03 tons ha<sup>-1</sup>, was obtained by planting 1.08 gr cloves in rows 10 cm apart. Bartos and Holik (1985) compared planting garlic cloves, cv. Japo, using the pneumatic-mechanical unit Fahse-Accord type Monoair 80 with the most widely used tulip bulb planter (control). The pneumatic planter resulted in a markedly better spatial (aerial and in depth)

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plant distribution and emergence, and, eventually, a greater number of harvested bulbs. Yield, market value and quality were all greatly improved and the weight and number of grade I bulbs significantly increased. Orłowski and Rekowska (1989) investigated the effects of garlic clove weight and planting density on garlic yield. They planted 2.5, 3.5 and 5 g garlic cloves at four different spacings (30×6, 30×8, 30×10 and 30×12 cm). The results showed that the highest yield, highest quality and highest income was obtained by planting 5 gr cloves at 30×6cm, 30×12cm and 30×8cm spacing, respectively. Rocha *et al.* (1991) designed and developed a manually operated planter for garlic bulbs mounted on two bicycle wheels and equipped with a toothed belt distribution mechanism. The toothed rubber belt was equipped using the sponge teeth 25 ×47 mm and 25 mm high. In field tests using the prototype equipment, bulbs were spaced at 5 bulbs per m. Orłowski and Rekowska (1992) conducted a three year experiment to investigate the effects of different clove sowing methods on garlic yield. Their treatments included: (1) bud pointed upward (conventional); (2) bud pointed downward; (3) bud pointed either side; and (4) bud at any random position (similar to machine sowing). The dependent variables measured were the number of plants emerged, plant height, garlic yield and quality. The results showed that (1) treatments 1 and 2 had the highest and lowest yield, respectively, (2) treatments 3 and 4 didn't show any significant difference in yield, and (3) treatment 4 had about 13.7-19.4% lower production cost than that of treatment 1 with no significant difference in quality. Lallan *et al.* (1992) investigated the effects of clove size and sowing methods on garlic yield and quality. In this study, three different garlic clove sizes (4-6, 6-8 and 8-10 mm) were planted either on flat bed (15×7.5 cm spacing) or on the ridges spaced at 35 cm and spaced 7.5 cm on the row. The results indicated that: (1) ridge planting resulted in significantly higher yield than flat bed planting; (2) the quality (also, net income) of ridge

bed treatments was significantly higher than that of the flat bed treatments; and (3) the larger cloves resulted in higher garlic yield and quality than the smaller ones on both ridged bed and flat bed treatments. Iwasaki *et al.* (1992) conducted fundamental experiments on the mechanization of Baker's garlic bulb planting on sand dune fields of Japan's coastal area. They developed a prototype garlic planter which was attached to a 4WD tractor to reduce labor requirements and to reduce the hard planting work. It planted six rows at a working speed of 0.13 m s<sup>-1</sup> with a theoretical planting capacity of 1.5 hours per 10 acres. Later, they investigated the relationship between the furrow shape formed by furrow openers and the soil moisture content (Iwasaki *et al.*, 1993). The planting position of bulbs dropped onto the furrow was also examined to investigate the possibility of mechanizing planting by dropping the bulbs into the seed tubes during tillage operations. The draught force of the furrow openers was also measured at different soil moisture contents. The draught force of the furrow opener increased in direct proportion with the increase of soil m.c. from 1 to 6% d.b. having a correlation coefficient of approx 0.9. The furrow shape formed by the furrow opener was the same as the cross sectional shape of the opener when the soil moisture content was >3% d.b. However, the furrow shape formed by a cylindrical seed tube collapsed during the opening operation at a soil moisture content of 1-6% d.b. The probability of achieving a suitable planting position for the seed bulb increased when the seedbed was soft enough to allow the bulb to sink easily into the soil. Nosrati (2001) investigated the effects of planting density, planting method and clove size on garlic yield quantity and quality. Three clove sizes (1.5-3, 3-5.5 and 5.5-7cm) were planted by three methods (flat bed, 2-row and 3-row) at three densities (330,000, 440,000 and 740,000 plants ha<sup>-1</sup>). The results showed that the effects of plant density and clove size on garlic yield were both significant, while the planting method had no significant effect on yield. In the end, plant-

ing density of 740,000 (plant ha<sup>-1</sup>), clove size of 5.5-7 gr and row planting with two rows on ridge were recommended.

Jarudchai *et al.* (2002) designed and developed a garlic planter in Thailand. They constructed and tested two models with different metering devices which included (1) a vertical metering plate with triangular grooves and (2) a bucket type device. The bucket type metering device presented the most impressive results regarding uniformity of the metering system and low garlic clove damage (0.23%). The planter was attached to a 5 hp power tiller and was tested under actual field conditions. The maximum forward speed was 2.63 km h<sup>-1</sup> and planter wheel skid was high at about 23%. The planter field capacity was 0.31 ha h<sup>-1</sup> and, with three operators, the planter capacity was 0.83 ha man<sup>-1</sup> day<sup>-1</sup>. Masoumi (2004) developed a roller-type metering device for a laboratory prototype single row garlic planter consisting of a seed hopper, a vertical roller-type seed plate driven by an electric motor and a seed counter. He conducted some laboratory tests to investigate the effects of roller speed and size of seed cavities (cells) on the percentage of seed singulation and cell filling performance.

The specific objectives of this research were as follows:

1. To design and develop a tractor-mounted precision planter capable of singu-

lating and planting garlic cloves at predetermined depth, row and plant spacings.

2. To test and evaluate field performance of a prototype developed for a garlic clove planter.

## MATERIALS AND METHODS

### Planter Development

Technical specifications for the developed garlic clove planter are given in Table 1. The planter is a tractor-mounted, 3-row precision seeder machine that plants garlic cloves on a raised bed (Figure 1). Ridges are made by four furrowers mounted on a toolbar and spaced at 60 cm from each other. The planter automatically singulates, picks up and transfers the garlic cloves from the hopper to the three furrows on top of each ridge. Each furrow is then covered and firmed with a covering steel chain and a press wheel, respectively (Figure 3).

The main machine components are:

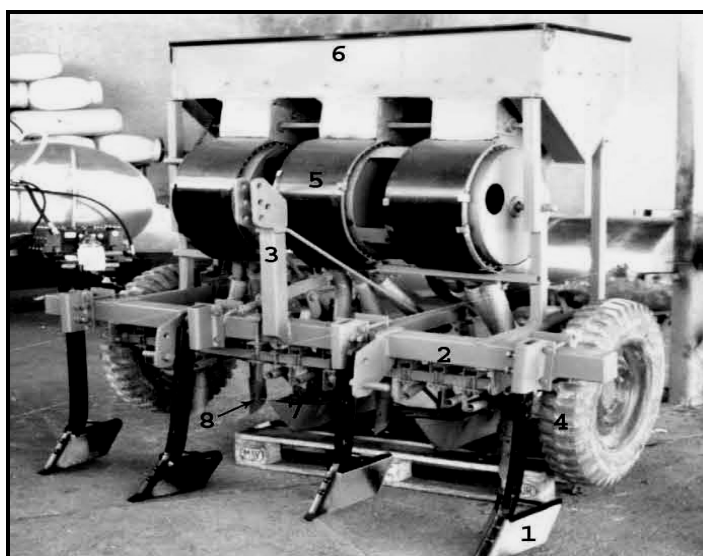
### Lister-bedder Unit

This unit which opens furrows and makes raised beds has two components:

**Furrowers:** Four 18 cm wide furrowers are mounted on a toolbar at 60 cm spacing in

**Table 1.** Technical specifications of the garlic clove planter developed in this study.

Parameter	Units	Specification
Planting width	cm	180
Raised beds	number	3
Plant rows on each bed	number	3
Furrows	number	4
Bed shapers	number	2
Row spacing on each bed	cm	10
Nominal plant spacing on the row	cm	22
Furrow spacing	cm	60
Furrow width	cm	18
Sowing depth	cm	5-15 (adjustable)
Type of furrow opener		Shoe-type
Seed hopper capacity	kg	200
Planter weight (empty)	kg	530
Hitching type		3-point hitch



**Figure 1.** Actual picture of the garlic planter (front view): 1) Furrower; 2) Chassis; 3) Three-point hitch mast; 4) Ground-driven wheel; 5) Metering drum, 6) Seed hopper.

front of the planter (Figures 1 and 2).

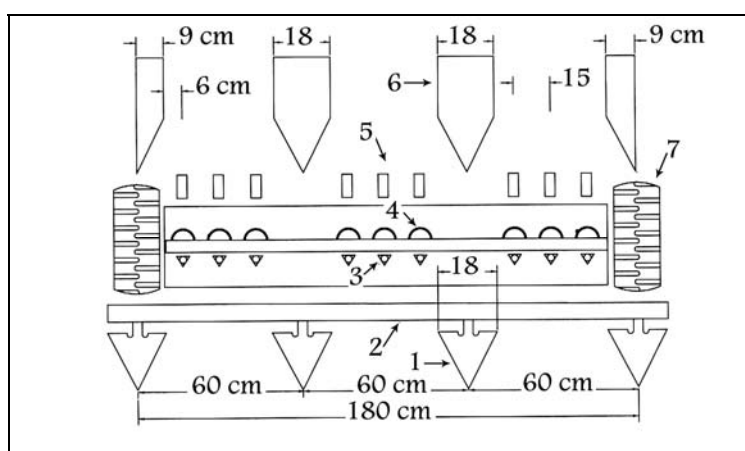
*Bed shapers:* Two bed shapers are mounted on the rear toolbar of the planter to reshape and firm the beds after the garlic cloves have been planted on the beds (Figure 2).

### Planter Unit

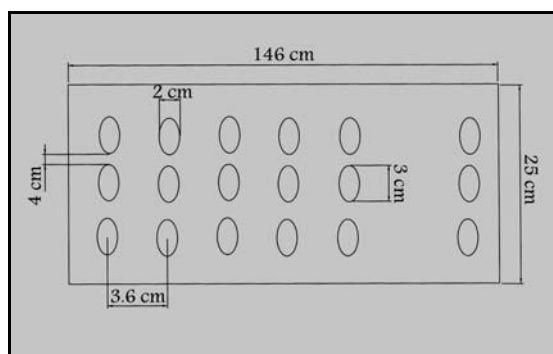
The machine is composed of three planting units. Each unit is composed of the following components:

*Seed hopper:* The garlic hopper is made of 2 mm thick steel sheet with a capacity of 200 kg. A tight fitting lid is provided to keep out rain and dust. The shape of the hopper is a  $180 \times 50 \times 60$  cm rectangular box. The lower part of the hopper is divided into three compartments with sloped bottoms to facilitate the flow of garlic cloves toward the metering drums and sweepers (Figure 1).

*Seed metering drum:* For every three planting rows on each raised bed there is one seed metering drum. Each drum consists of a 45



**Figure 2.** Schematic diagram of the garlic planter (top view).



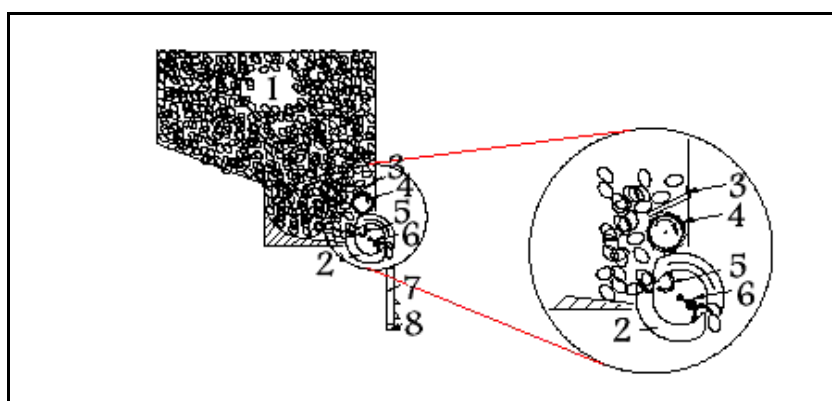
**Figure 3.** Arrangement and dimensions of the elliptical holes punched on the rubber belt cover of the metering drums.

cm diameter, 34 cm height closed ends cylinder made of 2 mm thick steel plate. Three rows of 40 equally spaced (7 cm), 6 mm diameter holes ( $3 \times 40 = 120$ ) have been punched around the cylindrical shell of the metering drum. The three seed metering drums are horizontally mounted on a common central shaft, each by a pair of self-aligning antifriction bearings. The outer surface of these cylindrical shells is covered with a layer of 250 mm wide, 15 mm thick rubber belt having three rows of 40 elliptical seed holes ( $30 \times 20$  mm) for accommodating garlic cloves (Figure 3). The thickness of the rubber sheet and the size of the elliptical seed holes were selected according to the size distribution of garlic cloves usually used for garlic planting in Hamedan Province. Table 2 shows the size distribution of

local garlic clove samples at 41.3% moisture content (w.b.). Number, spacing and arrangement of the elliptical holes are chosen in such a way to be aligned with the circular holes of the seed metering drum.

**Sweeper:** Inside the hopper and on the top of the seed metering drum, a steel drum covered with a layer of finned rubber rotating at the same direction but four times greater than the metering drum, acts as a sweep to brush off the extra garlic cloves from the metering drum and to prevent the seeds from being thrown out of the hopper (Figure 4).

**Knocker (knockout pawl):** Inside the seed metering drum, there is a knocker for each seed hole. Therefore the knockers are arranged in 40 rows, equally spaced around the inside periphery of the seed metering drum. Each three knockers are fixed to a



**Figure 4.** Schematic diagram of the garlic clove metering system (viewed from driver's right side): 1) Seed hopper; 2) Metering drum; 3) Deflector plate; 4) Sweeper; 5) Knocker; 6) Knocker roller; 7) Seed tube, 8) Seed furrow opener.



pivoted, spring loaded angle bar which is actuated once per revolution of the seed metering drum. This arrangement will knock out the garlic cloves simultaneously at the right time and position.

**Seed tube:** There are three seed tubes for each seed metering drum. The role of these tubes is to guide and transfer the garlic cloves released from the seed holes under the action of gravity and/or impact of the knockers to the furrows opened on the top of the ridges by the furrow openers.

**Furrow openers:** There are three shovel-type furrow openers for each seed metering drum (a total of 9 furrow openers for the whole planter). They open three seed furrows spaced 10 cm apart on the top of each raised bed. Depth of planting was made adjustable by implementing a 4-bar linkage and a screw type lifting mechanism which could raise or lower the furrow openers with respect to the planter chassis.

**Seed covering:** A cover chain was connected behind each furrow opener to refill the seed furrows and to cover the garlic cloves with soil.

## Power Transmission

A chain drive system is used to transmit the drive power from the transport (ground)

wheels of the planter to the driven shafts of the metering drums and sweepers as shown in Figures 5 and 6. Three strands of roller chain No. 40 and six sprockets were used to transmit the rotation of the planter ground wheel to the metering drum and sweeper. The numbers of teeth on the driver to the last driven sprockets (denoted as  $N_2$  to  $N_6$ ) were chosen as 15, 30, 12, 24, 56 and 14, respectively. If we denote the rotational speed of these sprockets as  $n_1, n_2 \dots n_6$ , their speed ratios with respect to the rotational speed of the ground wheel,  $n_1$  are:

$$n_2/n_1 = N_1/N_2 = 15/30 = 0.5$$

$$n_4/n_1 = (N_1/N_2) \times (N_3/N_4) = (15/30) \times (12/24) = 0.25$$

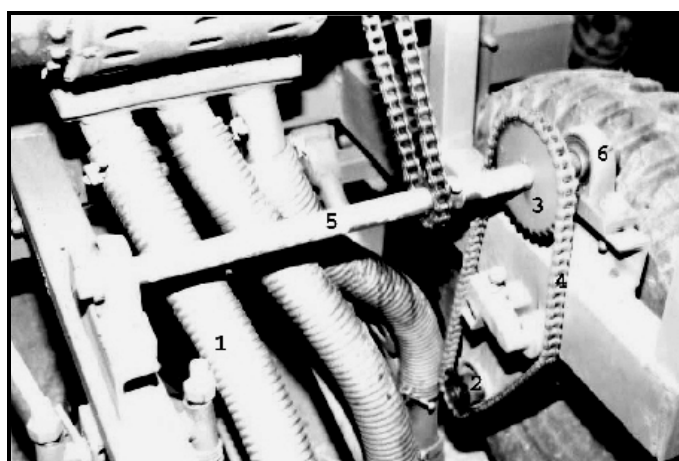
$$n_6/n_1 = (N_1/N_2) \times (N_3/N_4) \times (N_5/N_6) = (15/30) \times (12/24) \times (56/14) = 1$$

The above calculations show that the rotational speed of the metering drum and sweeper are one fourth of and equal to the rotational speed of the ground wheel, respectively.

During preliminary tests, the appropriate forward speed of the planter was determined to be about  $2 \text{ km h}^{-1}$ . Based on this assumption and with a ground wheel diameter of 70 cm, the rotational speed of the metering drum  $n_5$  was calculated as:

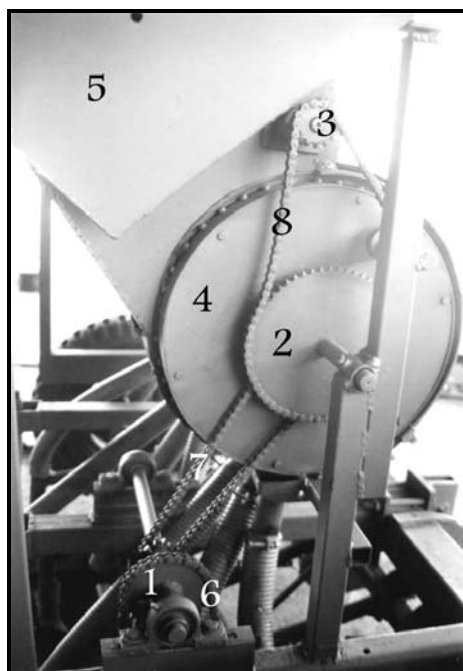
$$V_w = 2 \text{ km h}^{-1} = 33.3 \text{ m min}^{-1}$$

$$V_w = n_w \Pi D \rightarrow n_w = n_1 = V_w / \Pi D = 33.3 /$$



**Figure 5.** Power transmission system from ground wheel to counter shaft:

- 1) Seed tube; 2) First driving sprocket; 3) Counter shaft driven sprocket;
- 4) First driving chain; 5) Counter shaft, 6) Self-aligning ball bearing.



**Figure 6.** Power transmission system from counter shaft to metering drums and sweepers: 1) Counter shaft driven sprocket; 2) Sweeper drive sprocket; 3) Sweeper driven sprocket; 4) Metering drum; 5) Seed hopper; 6) First driving chain; 7) Second driving chain, 8) Third driving chain.

$$(3.14 \times 70) = 15.1 \text{ rpm}$$

$$n_1/n_5 = 0.25 \rightarrow n_5 = 15.1(0.25) = 3.8 \text{ rpm}$$

### Chassis

The components of the garlic planter are mounted on the main frame (chassis) which is supported by two pneumatic ground wheels. The machine is also connected to the tractor 3-point hitches. During road transportation and displacement from one field to another, the whole frame is fully mounted on the tractor while, during planting, the arms are in floating position and the planter frame is supported by the ground wheels.

### Test and Evaluation

The preliminary laboratory evaluation of the planter components, especially the seed metering mechanism revealed a satisfactory

performance regarding uniformity of seed metering and negligible garlic clove damage. Field tests were conducted in spring 2004 at the Ekbatan Research Station located 5 km to the East of Hamedan, Iran. The soil of the test field composed of 24.4% clay, 26.6% silt and 49.8% sand, was classified as loam with an average moisture content of 14.3% d.b. at the depth range of 0-25 cm. The plot dimensions were 20 by 1.8 m (3 raised beds spaced at 60 cm and 3 rows spaced at 10cm on each bed). The measurements for each plot were depth of seed placement, nominal seed spacing, actual seed spacing and row spacing. The data measured were used to calculate the indices introduced in the following section.

### Garlic Clove Geometric Dimensions and Unit Mass

Length, width and thickness of 100 randomly selected garlic cloves were measured



by using a vernier caliper. The geometric mean diameter ( $D_p$ ) of the cloves was calculated by using the following relationship (Mohsenin, 1986).

$$D_p = (LWT)^{1/3} \quad (1)$$

where L, W and T are length, width and thickness in mm, respectively.

To obtain the mass, each clove was weighed using an electronic balance reading to 0.001 g.

### Theoretical Seeding Rate ( $R_{st}$ )

The number of garlic cloves planted per hectare was calculated using the following relationship.

$$R_{st} = \frac{10^7}{w \times x_s} \quad (2)$$

where:

$R_{st}$  = Theoretical seeding rate (seeds  $ha^{-1}$ )

w = Row width (cm)

$x_s$  = Seed spacing along the row (cm).

### Seeding Mass Rate

The total mass of garlic cloves planted per hectare expressed in  $Mg\ ha^{-1}$  was calculated using the following relationship.

$$R_{sm} = \left[ \frac{M}{w \times x_s} \right] \times 100 \quad (3)$$

where:

$R_{sm}$  = Seeding mass rate ( $Mg\ ha^{-1}$ )

M = Average mass of one seed (g)

w = Row spacing (cm).

$x_s$  = seed spacing along the row (cm)

Assuming a planter working width of 180 cm and three planting units each equipped with three seed tubes and furrow openers, the effective average row spacing of  $180 \div 9 = 20$  cm was used for calculation of the performance parameters.

*Skips* or *misses* are created when seed cells fail to pick up and deliver seeds to the drop tubes. Misses are counted along a randomly selected 10 m length of each planted row while the covering chains and press wheels were removed. The missing percentage is presented by an index called the Miss Index

(MI) which is the percentage of spacings greater than 1.5 times the theoretical spacing (Katchman and Smith, 1995). Smaller values of MI indicate better performance than larger values. For example, a miss index of 15% means that 15% of planted cloves were viewed as having at least a single skip between them. With a theoretical spacing of 22 cm in this study, the miss index is the percentage of spacings that are greater than  $22 \times 1.5 = 33$  cm.

*Multiples* are created when more than one seed is delivered by a cell. Multiples were also counted along a randomly selected 10 m segment on each planted row. The multiple percentage is represented by an index called Multiple Index (DI) which is the percentage of spacings that are less than or equal to half of the theoretical spacing (Katchman and Smith, 1995). Smaller values of DI indicate better performance. For example, a multiple index of 5% means that 5% of the seeds are viewed as "dropped at the same time" as the previous one. With a theoretical spacing of 22 cm in this study, the multiple index is the percentage of spacings that are less than or equal to 11 cm.

### Seed Damage

In three randomly selected one kilogram samples taken from a bulk of 20 kg cloves passed through the metering drums and seed tubes, the number of cloves that were damaged mechanically including any significant bruising, skin removal or crushing was counted and their percentage was calculated as the seed damage percentage.

### Coefficient of Variation (CV)

This represents the overall difference between the actual and nominal seed spacing in a percentage along a randomly selected 5m length of each planted row. That is:

$$CV\% = \frac{\sum (|D - L_1| + |D - L_2| + \dots + |D - L_n|)}{n \times D} \times 100$$

where:



D= Nominal seed spacing (cm)

L= Actual seed spacing (cm)

n= Total number of seed spacings measured (20).

## RESULTS AND DISCUSSION

### Size and Unit Mass Distribution of Garlic Cloves

Table 2 shows the size and unit mass distribution of garlic cloves used in the preliminary laboratory test and field evaluation tests of the planter.

#### Preliminary Laboratory Test

In the preliminary design, each of the three seed metering drums was mounted on two antifriction bearings and was independently driven by a separate chain drive. After conducting preliminary tests, it was decided to mount the three metering drums on a common shaft driven by a single chain drive. This modification was made to improve the power transmission efficiency by eliminating two extra sets of chains, sprockets and bearings as well as producing a more compact design.

In the preliminary laboratory tests of the seed metering system, the following problems were noticed;

1. The seed holes around the metering drums were not completely filled by garlic cloves. Actually, about 55% of the seed holes were empty when they left the seed hopper.

2. About 43% of the garlic cloves leaving the hopper were broken, crushed or partially damaged. This was mainly due to accumulation and jamming of garlic cloves at the bot-

tom of the hopper where the metering drums were leaving the hopper. This also resulted in an excessive torque requirement of the metering drums and therefore overloading the power transmission system. This problem was thought to be due to utilizing fixed sweeper blades in the preliminary design, and so, the sweeper blades were replaced with rotating 50 mm dia. steel drums covered in a layer of finned rubber to brush off extra cloves from the metering drums. The sweepers were driven in the same direction as the metering drums by the ground wheels through a chain drive with a speed ratio of 1:1 (Figure 6). Further tests showed that although the problem of garlic clove damage and excessive power requirement was resolved by this modification, the problem of excessive misses (empty seed holes) was still present. This problem was thought to be due excessive speed of the metering drums. In the preliminary design, the speed ratio of the ground wheel to the metering drums was 2:1. Testing the metering drums at lower rotational speeds resulted in significantly higher cell filling. So, in the final design, the speed ratio of ground wheel to metering drum was increased to 4:1, cutting its speed in half. The percentage of empty cells at this speed ratio was reduced to about 8%, which was considered satisfactory.

#### Field Evaluation Tests

During the field evaluation tests, the following performance parameters were measured or calculated:

*Planting depth:* The mean value of garlic clove placement depths measured along each row (a total of 90 points) was calculated and found to be 12.3 cm with a CV of 7.5%, indicating that the cloves were placed very close to

**Table 2.** Size and unit mass distribution of garlic cloves at 41.3% moisture content (w. b.).

Physical attributes	Length (mm)	Width (mm)	Thickness (mm)	Geometric mean dia. (mm)	Unit mass (g)
Range	20.64-30.32	9.58-23.76	9.42-22.40	13.78-24.01	2.78-4.07
Mean	26.28	20.39	17.15	20.71	3.43
St. deviation	3.05	4.21	3.05	2.9	0.19



the target depth of 12cm with an acceptable uniformity.

*Actual seed spacing along the row (L):* The mean value of the actual seed spacing measured along a randomly selected 5 m segment on each planted row was 22.7 cm with a CV of 3.18%. Hence the actual seed spacing is only about 3% larger than the theoretical seed spacing of 22 cm, which is attributed to slight ground wheel skid.

*Seeding rate:* The actual number of garlic cloves planted per hectare was calculated by inserting the measured values for row spacing and seed spacing in Equation (1) to be about 220,000 seeds ha<sup>-1</sup>.

*Garlic clove average mass (M):* The average mass of 100 randomly selected garlic cloves was calculated to be 3.43 g with a CV of 5.7%. This indicates that the garlic cloves used were relatively large and fairly uniform in weight. Other researchers have reported the weight of garlic cloves in their studies ranging from 0.54 up to 5.10g [11, 12 and 14].

*Seeding mass rate (R<sub>sm</sub>):* The amount of garlic cloves planted per hectare was calculated by using Equation (2) to be about 0.8 Mg ha<sup>-1</sup> (800 kg ha<sup>-1</sup>). The normal seeding rate practiced by local farmers varies between 1,000 to 1,500 kg ha<sup>-1</sup>. Therefore, the proposed planting technique could offer about a 20-47% saving in garlic clove requirements for planting.

*Miss Index (MI):* The average miss index for the data taken from three randomly selected 10 m segments along the planted rows while the seed covering chains were removed in order to measure clove spacing was 12.23%. This level of miss index could be due to a number of factors including the failure of the metering drum seed holes to be filled with garlic cloves, failure of the knockers to knock out the cloves from seed holes and any possible clogging or staggering motion of cloves along the drop tubes.

*Multiple Index (DI):* The average multiple index for the data taken along the planted rows was 2.43%. This means that only 2.43% of the cloves were viewed as "dropped at the same time" as the previous clove. More specifically, with a theoretical spacing of 22 cm in this study, only 2.43% of clove spacings were less

than or equal to 11 cm. This level of multiple index which is considered to be "fairly low" and acceptable could be due to a failure of the sweepers to brush off extra cloves from the metering drum seed holes or possible self-adhering of cloves in the drop tube.

*Garlic clove damage:* The average percent of garlic cloves damaged after being metered, dropped and planted by the garlic planter was measured as 1.41%, which is considered to be very low and acceptable.

## CONCLUSION

A tractor-mounted, ground wheel-driven, triple unit row crop garlic planter capable of planting three rows of garlic cloves on each of the three raised beds formed by four forward-mounted furrowers was built and tested in the laboratory and the field. The performance parameters measured/calculated during the field tests included planting depth, seeding rate, seed spacing, miss index, multiple index and clove damage. The results of the field evaluation showed that the new machine was capable of planting 220,000 plants ha<sup>-1</sup> at the average clove placement depth and spacing of 12.3 and 22.7 cm, respectively. Other performance parameters included miss and multiple indices of 12.3 and 2.43%, respectively.

The overall performance parameters of this prototype garlic planter are considered to be satisfactory, except for the planting rate of 220,000 plants ha<sup>-1</sup> which is too low. One trivial solution would be to double the speed ratio of ground wheel to metering drum and reduce the forward speed of the planter to half of the existing 2 km h<sup>-1</sup>. This would double the planting rate without damaging other acceptable performance parameters, especially the miss and double indices.

## Recommendations

In order to improve the performance of the prototype garlic planter, the following modifications are recommended.

1. The present planting density of 220,000 plants ha<sup>-1</sup> is significantly lower than the recommended range of 330,000 to 740,000 plants ha<sup>-1</sup>. To reach this goal, the present seed spacing of 22 cm along the row should be reduced to 7-15 cm. Desirable plant spacing and density could be obtained by either increasing the number of seed holes around the metering drum or increasing the rotational speed of the metering drum relative to the ground wheel. Increasing the number of seed holes on the periphery of the metering drum with its existing dimensions is limited and almost impractical. Preliminary tests showed that the miss index increased drastically with increasing the rotational speed of the metering drum. So, without applying any major modification to the present design, the only other choice would be to reduce the travel speed of the planter while keeping the rotational speed of the metering drum constant (changing the speed ratio). For example, if we change the existing speed ratio of the ground wheel to the metering drum (4:1) to 2:1 at a travel speed of 1 km h<sup>-1</sup> (instead of 2 km h<sup>-1</sup>), the seed spacing on the row would be reduced from 22 to 11 cm, which is very close to the optimum seed spacing (10 cm) found by Rahman and Das (1985). With this seed spacing, the recommended planting density of about 450,000 plants ha<sup>-1</sup> could be accessible.

2. The relatively soft texture and sticky surface of the garlic cloves causes some kind of staggering motion and clogging of the garlic cloves along the slopped and curved seed tubes. As suggested solution would be using straight and vertical seed tubes and adding a water tank and installing a water jet at the entrance of each seed tube to prevent stickiness and to facilitate the flow of garlic cloves.

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## ساخت و ارزیابی یک ماشین ابتکاری کارنده حبه سیر

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### چکیده

در این تحقیق یک دستگاه ردیفکار دقیق سه واحدی سوار بر تراکتور مجهز به چرخ های زمین گرد که هر واحد قادر به کاشت سه ردیف حبه سیر (*Allium sativum* L.) بر روی هر پشته بود، طراحی، ساخت و ارزیابی گردید. اجزای اصلی این ماشین شامل شاسی و چرخهای حامل، واحد جوی و پشته ساز، مخزن بذر، موزع بذر، جاروگر، ضربه زن، لوله سقوط بذر، شیار بازکن و پوشاننده بذر است. استوانه های موزع و جاروگرها توسط دو عدد چرخ زمین گرد و از طریق سیستم رانش زنجیری دوران می نمایند. ارزیابی آزمایشگاهی اجزای کارنده، بویژه مکانیزم موزع بذر، حاکی از کارکرد رضایتبخش اجزای کارنده بود، هرچند لزوم چند مورد تغییرات اصلاحی قبل از اجرای آزمونها را ایجاب نمود. سنجنده های کارکردی مورد اندازه گیری یا محاسبه درحین اجرای آزمونهای مزرعه ای شامل، نرخ کاشت، عمق کاشت، فاصله کاشت حبه سیر بر روی ردیف، شاخص نکاشت، شاخص چندتایی و آسیب وارد بر حبه سیر بود. نتایج نشان داد که ماشین جدید قادر به کاشت ۲۲۰۰۰۰ حبه سیر در هکتار بترتیب با میانگین عمق و فاصله کشت ۱۲/۳ و ۲۲/۷ سانتیمتر است. همچنین میانگینهای شاخص نکاشت، شاخص چندتایی و درصد خسارت بترتیب برابر با ۱۲/۲۳، ۲/۴۳ و ۱/۴۱ درصد اندازه گیری شد.