Design and control of metering system and furrow openers for garlic planter

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Abstract: Presently, the garlic planter is an eight-row type. This research has focused on increasing the planter capacity by reducing the draft of the planter, increasing the field efficiency by increasing the optimum number of rows and increasing the uniformity of the seed. For the10-row garlic planter, the test results obtained from the farmer's field were based on the following criteria: working speed 1.68 km/h, height of the seed delivery tube above ground level 30 cm, which was the lowest variation. The field capacity was 0.13ha/man-h and plant spacing was 11.73 cm. The percentage of slip was 10.36%. The furrow opener is a shoe type, placed in two lines with spacing of 250 mm between the lines. It gave a constant draft force of about 1.05 kg f/row. The percentage of germination was 74.57%. The average yield was 26,919 kg/ha, whilst the average yield of planting by the farmer was 30,419 kg/ha. The precision value for human planting was 20.93% while the 10-row garlic planter was 21.0%, on average.

Keywords: garlic, planter, height, angle, seed delivery tube, draft force

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1 Introduction

Garlic (*Allium sativum Linn*) is an important commercial crop, of which bulbs are used not only in cooking in nearly every kitchen, but also as a medical herb. At the present time there is a great demand for this crop in both local and international markets; it is also/potential export commodity for Thailand. In 2002, total world production was at its highest level and valued at 62.5 million USD. Production and total planting areas have been maintained constantly while the export value has been increasing every year. Manual planting of garlic is both labor intensive and costly, resulting in various problems for farmers and, in some years, has necessitated imports as the domestic demand exceeded local production capability.

Researches were undertaken to resolve these problems by developing a mechanical device to replace manpower began from 1999. In 2004, an appropriate prototype of garlic planter was designed and constructed with the concept of a drilling planter attached to a five horsepower power tiller. The main objective was to design and develop a machine that had a simple mechanism; easy to repair and maintain and, equally important, could be manufactured locally at a cost affordable to domestic farmers.

The garlic clove will be placed in wet soil, where

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about three quarters of its height is in the soil, with a planting grid distance of 10 cm×10 cm or 15 cm×15 cm. Hay is used for mulching in order to keep the soil moist and to control weeds. Manual planting was labor intensive and the cost of hired labor for this activity was about 188-267 USD/ha in 1999. The manpower available in the farmer’s field ranged between 13 and 125 man-days/ha. These factors have imposed a limitation on the size of farms: they should not be larger than 0.96 hectare per household. This limitation subsequently curtails the possible production output. Furthermore, farmers have a limited time frame in which to prepare the soil so that it has sufficient moisture for planting. This activity requires substantial manpower for planting the garlic cloves before the soil dries up. The shortage of labor is again a factor to limiting the farm size to be not larger than 0.96 hectare.

This research, therefore, concerns the need to improve, firstly, the precision of the garlic planter, which directly affects 1) the yield, and 2) the farmer’s acceptance, and secondly, the performance of an 8-row garlic planter by 1) increasing planter capacity through reduction of the draft of the planter, and 2) increasing the field efficiency by increasing the optimum number of rows. All of these requirements were of dramatic importance in convincing farmers to accept mechanization which would, in practice, be able to replace their manpower requirement without increasing production cost.

2 Analysis of the problem

A suitable type of furrow opener with highlighted factors was considered during the design process, which took into consideration the release and placement errors in terms of the characteristic dimensions of the release mechanism, i.e., 1) height of release, 2) diameter and type of seed tube, 3) scoop and release angles, and 4) shape of the furrow. The optimum values of these characteristic dimensions were calculated and evaluated in order to minimize the placement errors in the chosen design. Through careful design, we were able to reduce these errors, but not eliminate them completely.

2.1 Analysis of clove velocity

The analysis was divided into six steps as below:

2.1.1 Cloves velocity occurring in the metering system

Cloves velocity occurs in the metering system while cloves were thrown by the buckets (Klenin et al., 1986). The speed of revolution of the buckets was calculated at the forward speed of the machine, 1.5-3.5 km/h, as presented by:

$$n = 60v / a_s pz (\text{r/min}) \tag{1}$$

When slip was

$$v = v_s \left[1 + \frac{s}{100} \right] \tag{2}$$

Where: n = speed of the disk rotation, r/min; v = speed of the machine, m/s; v_s = peripheral speed of the wheel; S = wheel slippage (10-12 percent); a_s = the spacing between cloves in a row, m; z = number of buckets on a disk; p = number of cloves for each bucket.

2.1.2 Cloves velocity at the beginning of the chute

Cloves velocity thrown from the buckets is presented as:

$$v_o = 2\pi rn / 60 \tag{3}$$

Where: v_o = cloves velocity in buckets, m/s; r = turning radius (distance from the center of the cloves in a bucket and the center of rotation), m.

A collision between two bodies occurred within a very small interval of time (Figure 1). The velocities v and v_o of the cloves and chute are presented as:

$$m_B v + m_A v_o \cos\theta = m_B v + m_A v_o^{'} \tag{4}$$

$$v_o \cos\theta = v_o' \tag{5}$$

Where: v_o' = cloves velocity at the beginning of the chute, m/s; θ = release angle (shown in Figures 1 and 2), 40°, degree.

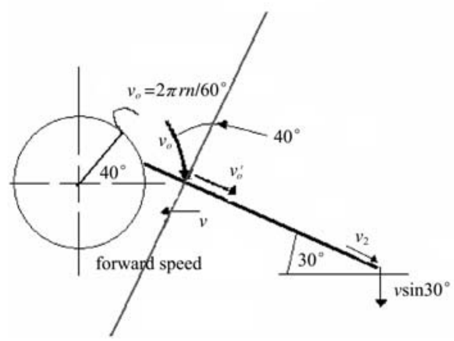


Figure 1 Presenting a collision between two bodies: -cloves and chute

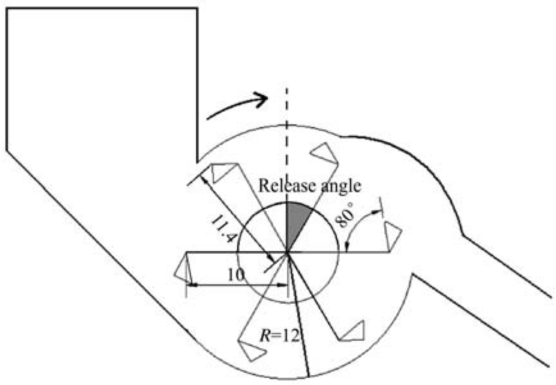


Figure 2 Showing the angle of the cloves release

2.1.3 Clove velocity at the end of the chute

The theory of material flowing on an inclined plate (Spivakovsky et al., 1985) used, was:

$$v_2^2 = 2gh\left(1-\mu\cot\beta\right)+v_0^2 \tag{6}$$

Where: v_2 = cloves velocity at the end of the chute, m/s; h = height of the chute in the vertical direction, (0.15 m), m; μ = coefficient of friction between cloves and the chute, (0.22); β = chute angle, (30°), degrees.

2.1.4 Determination of Kinematics index

In analyzing the precision of placing cloves in rows, the value was considered with its design parameters, kinematics index (Klenin, 1986), that is:

$$\lambda = \frac{u}{v} = \frac{linear}{speed}\frac{velocity}{of}\frac{(buckets)}{machine} \tag{7}$$

For a given spacing of 10 cm, the number of bucket, 6, was selected from the kinematics index, λ. The linear velocity of the bucket equalized the linear velocity of the machine in an opposite direction of the machine. The value may be identical, that is:

$$u = v$$

And

$$u = v_2\cos\beta$$

Then

$$v_2\cos\beta = v \tag{8}$$

The optimal value of λ was selected on the basis of actual field conditions.

2.1.5 Determination of time

Time that cloves travel in the seed tube (RNAM, 1991):

$$t = \frac{-u_v \pm \sqrt{u_v^2 + 2H_d g}}{g} \tag{9}$$

Where: H_d = the distance between the positions of the buckets when cloves are instantly thrown out from the gate above the furrow opener.

Replaced with $u_v = v_2\sin\beta$, if $u_v = 0$, ($\beta = 0$) when the time of the seed falling is taken by the time the cloves travel from the end of the chute into the furrow.

The problem of increasing the release angle was unable to be solved because the material for the buckets and the size of the garlic cloves were the main parameters. The velocity of the cloves at the release point in the horizontal direction (as presented in Table 10 (1)*) was not nearing zero. In practice, increase of the release angle was unable to achieve this. Cloves fell down by centrifugal force and the force of gravity. As a result of this, the cloves delivery system was re-designed as shown in Figure 7.

Through the careful redesign of the release mechanisms, the effects of imprecise release upon subsequent clove spacing were minimized. The overall improvement in spacing distribution was designed and studied as:

1) As can be seen in the calculations in Table 7, the cloves velocity was reduced almost to zero by increasing the release angle from 40° to 51.2°. Hence, the chute was eliminated because it caused a placement error as the cloves traveled along the chute. Thus, cloves thrown from the buckets traveled directly to the seed tube and fell into the furrow.

2) An installed absorber material, as presented in Figure 7, reduced the clove velocity almost to zero, facilitating the cloves to fall free as required.

3) The furrow openers were set in two lines. The distance between the two lines was studied at 17, 22, 27 and 32 cm, respectively. Selection of a suitable furrow opener was directly relevant to the draft, uniformity of depth and clove spacing, forward speed and germination.

4) The angle of the tube, forward and backward inclined angle with 5°, 10°, 15° and 20° and material to be used for the seed tube, plastic drill tube and corrugated drill tube, were selected for solving the problem of cloves clogging in the seed tube.

The time variation of the seed dropping was in the range of 5%-15% and increased when height of the seed dropping increased (Wilson, 1980) as presented below:

$$t = \sqrt{\frac{2H_d}{g}} \tag{10}$$

2.1.6 Analysis of cloves falling into the bucket

Results from an experiment showed that the analysis of cloves falling into the bucket determined the scoop angle (ϕ), 50° and 80° and the release angle ($90-\theta$), θ = 40° and 23.8° off the vertical, respectively.

Figure 3 shows that cloves did not fall off the bucket if:

$Wa \rangle p_J b$

$$a = \frac{GMD}{2}\sin(\phi - \gamma) \tag{11}$$

$$b = R\sin\alpha \tag{12}$$

Where: *GMD* = geometric mean diameter of garlic cloves, m; *R* = distance from the center of rotation to the edge A of the bucket, m.

Since $W = m_s g = 9.8\ m_s$

$$p_j = m_s R\omega^2$$

Where: m_s = the mass of garlic cloves, g (2.77 g/clove); ω = the angle of rotation of the disk, degree.

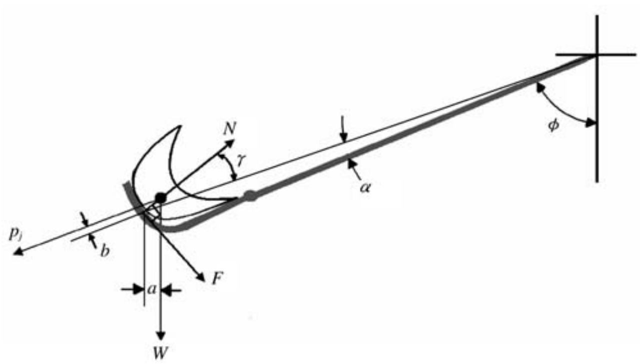


Figure 3 Schematic diagram for determining the stability of the clove from the bucket

According to calculation, at a speed of rotation lower than 40 r/min, the results showed that Ga is higher than p_j and b is higher than Ga. Cloves will not fall into the buckets. Also cloves which are firmly attached dried and of a small size will not be able to fall into the buckets.

2.2 Design of the furrow opener

The performance of three different furrow openers was measured in terms of depth of the seed placement, seed space disturbance, draft requirements and, extension of soil disturbance occurring during their operation and which were suitable to different soil conditions.

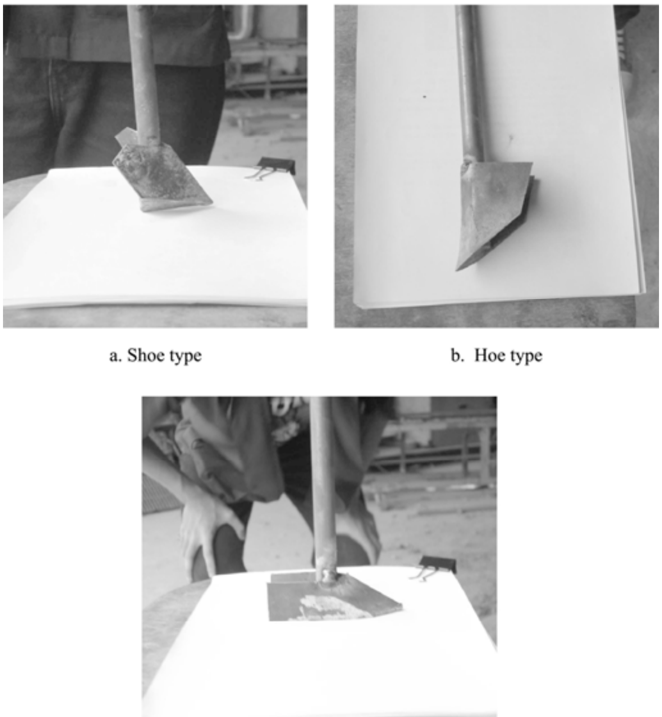
The performance of the openers was determined by size, shape and construction materials of the openers. Soil disturbance caused by the furrow opener affected seed distribution. As the depth of operation increased, soil disturbance and back flow increased.

All of these points were recognized as important factors, and the design of the openers system proceeded by technically testing and evaluating three types of openers: shoe type, hoe type and shovel type (as presented in Figure 4). The methods of testing to select one type of opener were as follows:

1) The design for furrow openers which required a low variation of depth and had to be suitable for garlic germination;

2) Testing for draft in soil bin conditions and in the Institute's field area;

3) Accuracy of cloves placement was tested on a sticky belt rig.



a. Shoe type b. Hoe type

c. Shovel type

Figure 4 Three types of furrow openers

3 Factors for consideration

Three variables used for evaluating the design of the opener for the garlic planter were as follows:

3.1 Germination test

Seedling emergence for garlic: three types of openers were tested at forward speeds of 1.00, 1.68 and 3.00 km/h, at a planting depth of 2 cm. The number of seedlings was counted every week for a period of five weeks. Three replications were used.

3.2 Placement accuracy

One of the objectives of this study was to compare alternatives of measures of accuracy in seed placement for garlic planters using single seed metering mechanisms (ISO, 1984). The International Organization for Standardization defined a number of measures based on theoretical spacing for the planter. The measures include multiples, miss index, quality of feed index and precision.

The garlic planter was equipped with a sticky belt test station which was adapted to have a conveyor belt 11 m in length.

3.3 Drafts

To determine the draft force of the openers, a load cell transducer, attached between the planter and a power source, which was connected to a signal converter. Drafts were measured at a constant speed.

4 Results

4.1 Testing for draft force and germination in soil bin conditions and in the Institute's field area

In a soil bin with soil moisture (db) of 7.92%, the test was conducted with a forward speed of 1.68 km/h, 2 cm in depth, the distance between the front and the rear opener, 32 cm. The soil furrows opened were narrow, about 3 centimeters, and caused less soil disturbance. The depth of planting was adjustable. In the comparison tests for the three types of openers to study the effect of the draft, the spacing between the two lines of openers was 17, 22, 27 and 32 cm, at a working depth of 2 cm.

The test results presented in Figure 6 show that the draft force of the hoe type opener gave the minimum outcome, about 0.27 kgf/row at a line spacing of 22 cm.

Analysis of the draft force (presented in Table 1) was considered under test conditions. Results of the draft force from the Institute's field test for all openers were twice higher than the draft force from the laboratory. The hoe type opener gave the lowest draft, about 1.2 kgf/opener, under 3 times that by a rotary tiller. For the shovel type, the best germination result percentage was 83.3%, and at a line spacing of 27 cm.

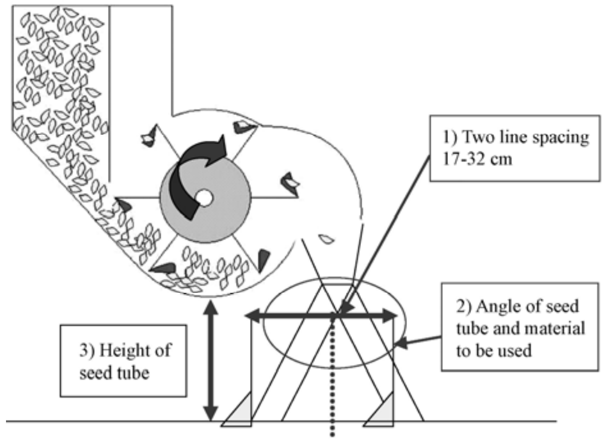


Figure 5 Showing the line spacing of openers

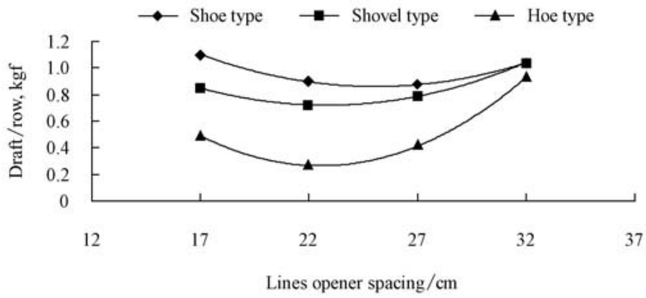


Figure 6 Relationship between lines opener spacing and draft for three types of openers

Table 1 Draft force for three types of openers

Opener	Draft (kgf/opener)				Germination (in soil bin) /%
	Soil bin	Institute's field*			
		1	2	3	
Shovel type	1.067	2.28	2.18	1.92	83.3
Hoe type	0.840	1.70	1.53	1.20	60.0
Shoe type	1.047	1.96	1.99	2.01	76.6

Note: The method of land preparation, Institute's field area, was tilled by rotary tiller 1, 2 and 3 times, respectively.

4.2 Accuracy of cloves placement

The effects of the seed delivery tube in relation to size, material and angle were studied and the findings are as follows:

1) Each of three height levels of the seed delivery tube above ground level, 20, 30 and 40 cm, was tested at a metering revolution, of 40-50 r/min. The variation of motion in the vertical direction was recorded by video

camera for three minutes. The number of scooped cloves was recorded and the results are presented in Table 4.

The seed delivery tube above ground level was set at three heights: 20, 30 and 40 cm. The variation of motion in the vertical direction was 3.5, 2.5 and 3.0 cm, respectively. The optimum height of the seed delivery tube was found to be 30 cm. The diameter of the seed delivery tube which reduced cloves bouncing in the tube was 28.4 mm. Under the same test conditions, about 90% of the scoop efficiency for one clove was evaluated and is presented in Table 2.

Table 2 Influence of the tube angle for the precision value of garlic cloves

Tube angle* / (°) from vertical)	parameter /%							
	Corrugated drill tube*							
	forward				backward			
	P	Mi	Qu	Va	P	Mi	Qu	Va
10*	23.80	19.45	50.10	5.66	24.90	19.45	51.00	6.24
15*	24.70	19.63	52.30	6.10	23.68	17.63	51.02	5.61
20*	25.70	18.15	50.01	6.44	25.82	18.15	50.55	6.67
	Plastic drill tube*							
10	21.00	19.45	52.58	4.37	22.49	19.45	58.22	5.07
15	24.01	17.63	53.17	5.76	24.96	17.63	55.00	6.25
20	25.34	18.15	56.55	6.42	28.26	18.15	57.50	7.99

Note: P—Precision, %; Mi- Miss index, %; Qu—Quality of feed index, %; Va-Variance; * significant at the 1% level by RCBD.

2) Backward and forward angles of the seed delivery tube were tested and evaluated at 10°, 15°, 20°, 25° and 30°. Two types of material for the seed delivery tube were used; corrugated drill tube and plastic drill tube. The height of the seed delivery tube above ground level was 30 cm. The results are presented in Table 3.

Table 3 Scoop efficiency at a disk revolution of 40 r/min

Rep	Number of cloves (cloves)		
	Scoop 1 clove	No. of scoops	Scoops more than 1
1	826	89	7
2	840	72	11
3	834	78	8
Average/%	90.42	8.64	0.94

Evaluation of the previous experiment: The study was concerned with the values of four criteria: precision, miss index, quality of feed index, and variance of cloves spacing for 2-types of drill tube. Tests were conducted for 2 types of seed delivery tubes and the angle of the seed delivery tube, backward and forward, 10°, 15° and 20°, as shown in Table 4.

Table 4 Precision value for the angle of the seed tube-corrugated drill tube

Tube angle (°) from vertical)	parameter, Corrugated drill tube/%							
	forward				backward			
	P	Mu	Mi	Qu	P	Mu	Mi	Qu
10	27.6	27.96	19.45	52.58	24.9	43.42	19.45	52.28
15	29.2	29.48	17.63	53.17	23.9	43.64	17.63	53.17
20	27.4	24.70	18.15	56.55	25.8	44.76	18.15	56.55
25	27.2	31.73	21.53	46.18	29.6	47.73	21.53	46.18
30	28.3	31.49	20.41	47.81	30.51	31.46	20.41	47.81

Note: P—Precision, %; Mu—Multiple index, %; Mi—Miss index, %; Qu—Quality of feed index, %.

The different tube angles and tube materials show a significant difference at the 1% level. The plastic drill tube located at the forward and backward positions at 10° gave a lower precision value and variance than the corrugated drill tube did. Table 5 shows the average spacing. At 10°, the tube angle backward, for both the corrugated and the plastic drill tubes produced an identical seed spacing of 10 cm.

Table 5 Average cloves spacing for the corrugated drill tube and plastic drill tube at tube angles of 10°, 15° and 20°, respectively

Tube angle / (°) from vertical)	Average cloves spacing /cm			
	Corrugated drill tube		Plastic drill tube	
	forward	backward	forward	backward
10	9.33	10.00	9.13	10.00
15	9.36	8.77	9.66	9.77
20	9.56	9.82	9.56	11.48

Based on the analysis of the cloves velocity, the chute was removed and cloves were thrown directly to the delivery tube (the speed of the cloves is shown in Table 7). Absorber materials were installed, as shown in Figure 7, in order to reduce the horizontal speed and the cloves were dropped to the furrow by the force of gravity only. Tests were conducted to compare the three types of absorber materials-sponge sheet, carpet and Scotchbrite. The precision value was used for the evaluation, as shown in Table 6.

It was found that the carpet produced the lowest precision value for both forward and backward angles of the seed drill tube with values in the range of 21%-24%. At the lowest angle of the seed drill tube, 10°, showed the lowest value of precision. (as shown in Table 6).

Table 6 Pecision value of three types of absorber materials at 10°, 15° and 20° forward and backward angles of the plastic seed drill tube

Seed drill tube angle /(°)	Precision /%					
	sponge sheet		Scotchbrite		carpet	
	forward	backward	forward	backward	forward	backward
10	23.30	24.00	25.20	24.2	21.30	21.31
15	24.90	25.10	26.00	23.8	22.00	22.45
20	25.70	25.50	26.60	25.00	24.00	24.37

Table 7 Comparison of cloves velocity of the original model (Figure 1) and the new one.

Forward speed of machine /km • h^{-1}	Linear velocity of the buckets /m • s^{-1}		Buc-kets revolution /r • min^{-1}	Velocity of cloves on chute		The clove velocity at the release point in the horizontal direction /m • s^{-1}		The clove velocity at the release point in the vertical direction	
	(1)	(2)		Beginning /m • s^{-1}	End /m • s^{-1}	(1)*	(2) **	m/s	km/h
1.5	0.76	0.68	15	0.58	0.58	0.33	-0.01	0.68	2.45
2.5	1.27	1.13	25	0.97	0.97	0.54	-0.02	1.13	4.07
3.5	1.77	1.58	35	1.36	1.36	0.76	-0.03	1.58	5.70

Note: * release angle was 40°; ** release angle increased from 40° to 51.2°; (1) the original model (metering-chute-seed tube).(Figure 1); (2) the new model (metering-seed tube).

5 Re-design for cloves delivery by metering system

The existing prototype, a 10-row garlic planter, was fabricated as illustrated in Figures 7 and 8. Results from farmer's field are shown in Table 8. This 10-row garlic planter produced cloves spaced at 9.48 cm. The precision value of the 10-row garlic planter, is 21.0%, which is about 5% lower in comparison with the average precision value of the 8-row garlic planter (Table 1). Planting by farmers produced the precision of about 20.93%. The quality of planting, uniform spacing and depth of cloves, increased about 8.61% from the prototype of the 8-row garlic planter.

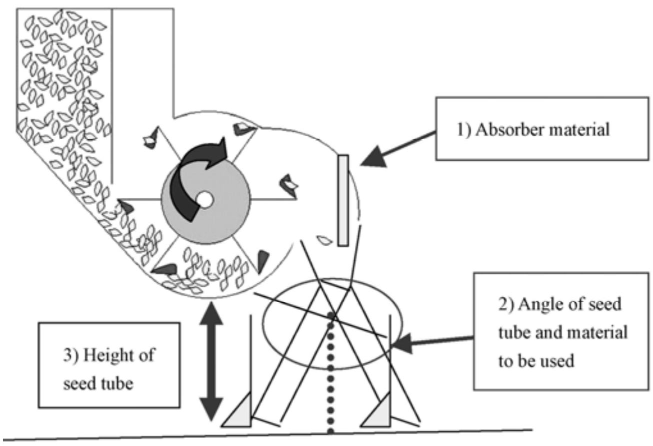


Figure 7 Diagram showing the careful design of the metering system

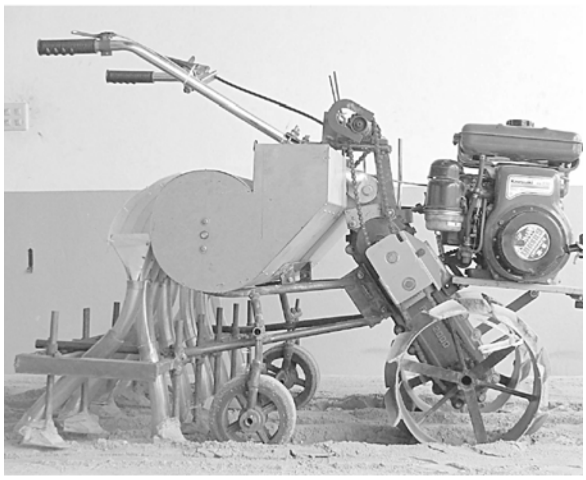


Figure 8 New mechanism at positions (1), (2) and (3). prototype 10-row garlic planter

Table 8 Comparison parameters showing the precision of planting, 2000/2003

Plot areas	Number of data	Average seed spacing	SD	Coefficient of variation	percentage of seed spacing (10 cm)	Multiple index	Miss index	Quality of feed index	Precision
New model Figure 5 (2)	152	9.48	4.56	21.0%	50.01%	12.50%	12.50%	75.00%	21.0%

Remark (1) The original model; (2) The new prototype (Figure 10), tube angle 10 degrees from vertical, plastic tube, carpet as absorber was tested on a sticky belt test unit at a forward speed 1.67 m/s, the metering revolution was 40 r/min.

6 Conclusions

1) With the chute being eliminated, the cloves were thrown directly into the delivery tube. The use of absorber materials reduced the horizontal speed while the cloves were being dropped into the furrow by gravity force only.

2) With the height of the seed delivery tube at 30 cm above ground level provided the lowest variation, 25 mm, from the line of motion, the maximum scoop efficiency for one clove at a disk revolution of 40 r/min and at a forward speed 1.67 km/h was 90.42%.

3) A plastic seed delivery tube with the angle of the seed delivery tube set backward at 10° gave a lower precision value and variance than the corrugated drill delivery tube. The average clove spacing was 90-100 mm, which was close to 100 mm.

4) The installation of absorber materials reduced the horizontal speed. The carpet absorber gave the lowest precision value for both the forward and backward angles of the seed drill tube.

5) The shovel type opener showed the maximum germination percentage of about 83.3 with a draft force of 1.067 kgf/opener, which was 27% higher than the improvement over the hoe type opener. However, the hoe type opener gave the lowest draft force, 0.84 kgf/opener in a soil bin. The performance index for the garlic clove is 0.024, which is 33% higher than the index for the hoe type and shoe type openers.

6) The openers set into two lines spacing, with the distance between the front and the rear openers varying within the limits of a range of 170-320 mm indicated that a change in the value of the draft force and performance was necessary. Consequently, the two lines spacing was adjusted to between 220-270 mm which then gave a constant draft force for the shovel type opener of about 0.76 kgf/row.

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