

# DEVELOPMENT AND EVALUATION OF A VEGETABLE TRANSPLANTER

**Davood Mohammad Zamani**

Department of Farm Machinery, College of Agriculture,  
Takestan Branch, Islamic Azad University, Takestan, Iran.  
dr.dmozamani@gmail.com

**Abstract-** Design, construction and evaluation of fully automatic tomato transplanter were the main aim of this study. The designed machine include a main chassis, transfer mechanism of seedling trays to pick up armposition, the seedling pick up arm mechanism of the tray, crash tube, furrower and control system. The actuators include pneumatic cylinders and PLC controller was used to control system. A step mechanism gradually guides the tray to the left, right and down sides so that pick up arm will be able to penetrate the needles inside soil into the cell and lift a seedling. The pickup arm then moves to the position of the crash tube and release seedling with soil pot. Then seedling falls into the furrow created by furrower. In order to evaluate performance of transplanter, a field test was conducted. Mechanical damage to seedlings, seedling establishment angle from the vertical line and seedlings distance on the row was investigated. Tests were conducted using a factorial experiment based on Randomized Complete Block design with three repeats. The treatments consisted of three levels of forward speed, including of 1, 1.5 and 2 km.h<sup>-1</sup> and two levels of cultivation depth, including of 5 and 10 cm. Results showed that forward speed and cultivation depth on distance between planted seedlings, seedling establishment angle and damage to seedlings at thelevel 5% has been effective. With a forward speed of 1 km.h<sup>-1</sup>, the theoretical capacity of the single-row machine, 0.06 ha.h<sup>-1</sup> was determined.

**Keywords:** Automatic Transplanting Machine, Tomato Seedling, Tray

## I. Introduction

Transplanting and planting vegetables in traditional way, is of hard job and inefficient activity. In addition, harvesting of prior crop and preparation of the substrate and transplantation should be done in a period of short time in doubled planting which by doing conventional way of transplantation, it would be hard. These factors show the need for mechanization of transplantation even more than before. Labor costs, solicitude in transplanting and the difference in depth of planting seedlings are of other factors that make the mechanical transplanting of vegetables seeding, necessary. Mechanization of transplanting means the reduction demand for labor in cultivating operation in which the minimum damage to seedlingand the maximum efficiency of cultivating is being provided. However, this requirement happens when the labor income is less than the revenue provided by machines replacement. Today there are many instruments which are designed and built for automate cultivating of vegetablesseedlings, But in spite of large estates which are being cultivated by vegetables in Iran, especially tomato, but there hasn't been a widespread and consistent practice in this area, And imported equipment are being used very rare and limited. This need increases by rising cultivating of crops that can be cultivated in transplanted form, and in contrast, it should design and build new equipment and devices for mechanization of this kind of cultures (Javidan, et al., 2012).

Chow, et al., (1980) have designed a semi-automatic lettuce transplanter. The speed of transplanting machine was 2,000 seedlings per hour in in the farm and the error in planting at 30 cm, was 3%. Haffar(2009) has designed a trans planter in the United Arab Emirates that the mechanism of transferring seedlingwas in a waistband type and was set for transplanting seeds into pots and postprandial bare. Ladeindeet al., (2010) in Nigeria, designed a single row transplanter for planting cassava scion that is similar to sugarcane scion. This machine operated with the average forward speed of 4.39 miles per hour, field capacity of 0.39 ha and field efficiency of 60%. Nandede, et al., (2013) has done the evaluations of a multi-stage automatic transplanter of vegetables cultivation for tomato cultivation in potted grown. This assessment had done based on a three-row transplanterwhich is able to plant the seedlings with the space of 45 and 60 cm, and the average forward speed of 2 mil.h<sup>-1</sup>, respectively. The Percentage of inability to seed cultivation, percentage of slant transplanting, distance of cultivation on the rows, cultivation depth and extent of seedling damage was 4 to 5%, 8% to 9%, 45 ±1 cm, 7±1.5 cm and 3 to 4%. Field capacity of machine was 0.114ha.h<sup>-1</sup> and field efficiency was measured 30.6%. In this study the overall performance of the system were ideal. Prasanna, et al., (2012) have suggested a mechanism for feeding vegetables seedlingin an automatic transplanter. Laboratory assessment of the system showed that this mechanism can be fed at the rate of 33 to 50 seedlings per minutes. In the real farm conditions, the proposed mechanism had the output of 98 to 99% with the forward speed 0.9km.h<sup>-1</sup>. Kazmeinkhah, et al, (2007) has designed a semi automatic transplanter machine, in order to cultivate sugar beet seedling .this machine was able to cultivate seedling with the row distance of 65 cm, seedlingdistance of 50.3 cm and 13cm depth. Standard deviation in comparison to the desired position was 4.5% along the cultivation row line and 3.6% perpendicular to the cultivation row line. Javidan, et al., (2012) have designed a semi-automatic tomato transplanter. Planting with this device had a significant different in terms of accuracy, speed and cost compared to manual and traditional way with the possibility of 5% and it is preferred to the manual method.

Byconsidering the materials presented, it can find out the importance of developing methods to reduce the production cost, especially in the planting and harvesting of tomato. Development of these methods will lead to increased interest of farmers in addition to reduce the production costs. Development and application of tomato seedlingtransplanting machines is one of these solutions. There is no report of application of a fully automatic tomato transplanting, on studies conducted by the researcher, at the time of the study. It

seems that one of the main reasons is the lack of proper and appropriate machine for this job. In this research, according to the previous section, and based on the needs of the domestic tomato growers to mechanized planting and harvesting of the crop, this study was discussed designing, constructing and assessment a fully automated tomato transplanter machine based on indigenous technology.

## II. Materials and Methods

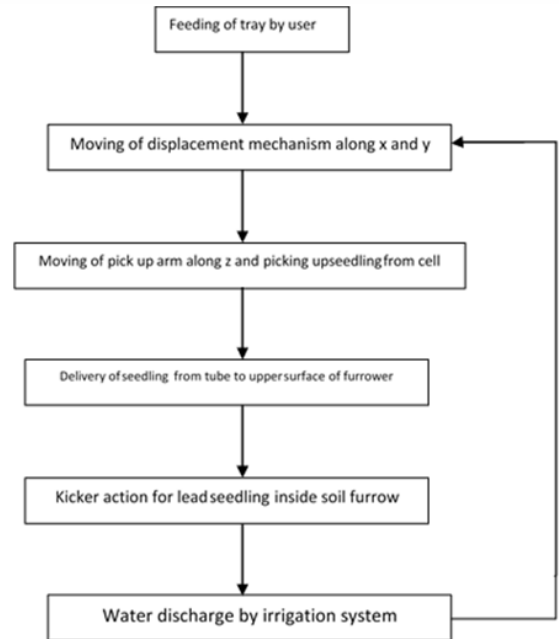
Before beginning the conceptual design of the device, conditions of tomato seedlingstransplanting were investigated in Qazvin province (study area). Then different and several models in foreign models was studied in order to choose, to design the machine mechanisms and to present a new design (there is no domestic sample). Finally, the best design was chosen with regard to local conditions and cultivation patterns of tomato product. After the initial modeling of machine and its mechanisms with software SolidWorks, the construction of the prototype was started and at last, the evaluation of the machine was performed in the farm conditions. Figure 1 shows a picture of constructed transplanter and its components.

In order to select the most appropriate mechanism for the design of desired transplanter components, the block diagram were plotted for the implementation of transplanting from seedling tray(Figure 2). The model presented in this study is composed of three main and independent mechanisms. Tray displacement mechanism in the x-y plane, arm mechanism that involves picking up the seedlingfrom tray, and extrusion mechanisms of seedling from the upper surface of furrow into the furrow. The following describes the operation of these mechanisms.

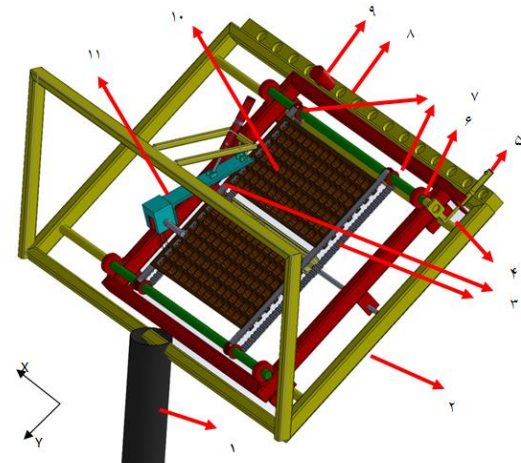
Figure (3) shows the geometric model of the mechanism and tray displacement of component in the x-y plane and pick up arm. As it is clear, this mechanism is consist of a pair of toothed belt and two pairs of toothed pulley. Tray of seedling which is mounted on the belts from edge, moves downward (along y axis) with the move of belts downwards. The belts movements are considered as a step form, so that at each step of the waistband to the bottom, a new row of tray cells placed in front of the arm. In order to provide the step form moves of belt, a ratchet a mechanism is used in conjunction with a pneumatic cylinder (Figure 3).



**Fig.1. Constructed transpalnter and components(1: ratchet mechanism 2: furrower 3: air reservoir and compressor 4: PLC and control box 5: pick up arm 6: x-direction displacement mechanism)**



**Fig.2. Block diagram of the steps required for automatic transplanting by machine**



**Fig.3. Geometric model of the mechanism of tray displacement along the y and x-axis and pick up arm (1: crash tube 2: frame with angle of 60 degree from horizontal 3: belts 4: Ratchet tool 5: cylander 6: bearing 7: pulley 8: Limiting tool 9: limiter 10: tray 11: pick up arm)**

### A. Mechanism of displacement of seedling tray on the x-y plane

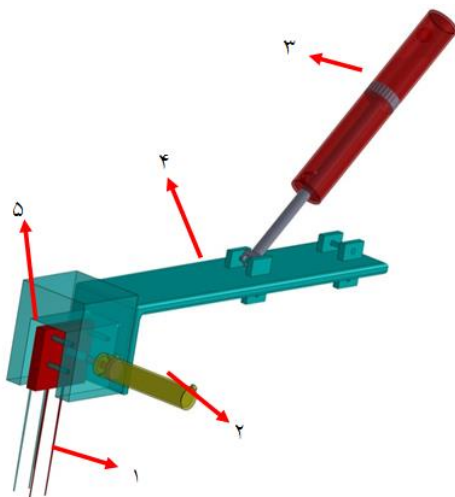
After the pick-up arm, picked the first seedling in a cell, it's the second seedling turns. Lifting the seedling from the second cell on the first row needs of the second cell opposite of pick-up arm. For this purpose, it is necessary that tray have a displacement along line(x axis) too. To achieve this, it is used a pneumatic cylinder with a high stroke length (50 cm). Note that in the pneumatic systems cannot accurately control the movement of the cylinder rod (due to air compressibility), so a special limiter was used for this purpose. This limiter has 15 holes in it, (Figure 3).

**B. Pick up arm of seedling**

As shown in Figures (3) and (4), pick up arm is consisted of two pairs of needle, length of 20 cm. These needles are installed at the tip of arm in such a way that is penetrated into cell soil with the motion of the arm toward tray cell, vertically, with minimal damage to cells, then the span of needles are being closer together to embrace the soil with roots and at last the seedling. The amount of the needles penetrate was 3cm about the trays used in the evaluation of the device. Trays included 105-cell with a depth of 5 cm, and are made of soft polyethylene. It is noted that the used seedling trays have peat moss soil with moisture of 18% at the time of cultivation. After taking soil and seedling, by the needle, pick up arm has fallen toward pipe. Then by wind jack, needles apart from each other, and thus seedling together the soil of roots falls because of the weight.

**C. Mechanism of seedling drive out from furrower**

After passing through the fall tubes, the first fall site will be part of the top surface of furrower. Because seedling directly into the furrow created by the furrower do not fall this is a direct fall of seedling into soil slot, enabling dislocation and tilt of the vertical position there. A mechanism of seedling drive out from furrower was used for transporting of seedling into the soil furrow. A rod in connection with a pneumatic cylinder was used for providing a kicker motion based on speed of pick up arm. The kicker acted like a golf stick and applies a mild shock to seedling soil, then, it will move into the furrow.



**Fig.4. Pick up arm from tray (1-needles 2-cylinder of needles 3-cylindr of pick up arm 4- pick up arm 5- shifting plate)**

**D. Electronic controller of Components of transplanter**

Electronic control system of transplanter, is selected of a programmable logic controllers (PLC). The controller used is able to determine the stimulating command solenoid of electric valves after receiving data from the sensors and micro switches in conjunction with a laptop and control program developed with WinProladder. PLC which is used in this study (FBs-24MC, FATEK, Taiwan) has the capacity to receive 14 digital inputs with 24-volt DC that current frequency for two inputs was 200 kHz and the frequency of other 12 input is

**E. The machine test and data analysis**

In order to assess of performance of the designed transplanter, and to measure the distance between cultivated seedling, cultivation depth, angle and amount of physical damage to seedlings, field test were done in the research field of Islamic Azad University, Takestan branch. In order to provide drawbar and PTO power, a MF399 tractor was used. PTO power was used to provide needed rotation power in air compressor. Due to the design of machine for transplanting on one row, seedling cultivation was done on a single row. Ashaft encoder attached to the wheel axle of transplanter was used to measure the actual forward speed of machine. Fixing forward speed in quantities of 1, 1.5 and 2 km.h<sup>-1</sup> was done by selecting fixed gear in gearbox of tractor and changing engine speed of the motor, by manual lever.

The physical damage of seedlings was measured arbitrary (damage to each seedling leaves: 10%; seedling stem: 20% (in case of removing of stem from seedling so that removed with leaves, these percentage is calculated for leaves and its amount increases with each new leaf)); seedling root damage: 30% (percent listed, is for full and complete root damage and if they are partially damaged, this amount is reduced). These percentages are measured at the end of planting by objective review for each of planted seedling.

The used seedlings were in four-leaf in the cultivation time. Land used has a sandy loam soil with bulk density 1.25 gr.cm<sup>-3</sup> and the moisture of 12% of dried basis.

Tests were done using a factorial experiment based on complete randomized block design in three times replications. The test treatments consisted of combination three forward speed levels, including the speed of 1, 1.5 and 2 km.h<sup>-1</sup> and cultivation depth in two levels 5 and 10 cm. Statistical analysis of the experimental data was done by Duncan's multiple test at 5% level by SPSS16 software.

**III. RESULTS AND DISCUSSION**

**The effect of forward speed and cultivation depth on the distance between seedlings on the rows**

Table (1) shows results of the analyses of variance distance data between seedlings on the cultivation row. As is clear, different treatments of forward speed and cultivation depth had a significant effect on the cultivation distance at 5% level. With increasing forward speed, the speed of mechanism of tray displacement along the x and y, and pick up arm mechanism, and ultimately Mechanism of seedling drive out increases too. This means that the number of operating cycles of mechanisms increase per time. Increasing the number of cycles per time leads to reduction of accuracy in cultivation operation due to the lack of sufficient time to perform the duties of each mechanism. This result clearly presented in table (2). The mean comparison test of seedlings distance on the cultivation rows in different treatments shows that there is significant difference between treatments at 5% level and also with the increasing of forward speed, the average distance between cultivated seedlings has increased to 44 cm from the first treatment (v<sub>1</sub>d<sub>1</sub>) to 49 cm of the sixth

treatment ( $v_3d_2$ ) (each treatment is marked with  $v_i d_j$  label). The maximum distance between seedlings belongs to  $v_2d_1$  by 51 cm. Among the treatments, one treatment ( $v_1d_1$ ) with appropriate spacing between seedlings 40 cm closer to the desired value.

**The effect of forward speed and cultivation depth on establishment angle of seedlings**

The difference of treatments in establishment angle of seedlings is significant at level 5% based on the results presented in table 3. It means that changing in forward speed of machine and cultivation depth has been effective on the establishment angle of seedlings. This means that the speed of mechanisms increase by increasing forward speed from 1  $km.h^{-1}$  to 1.5 and 2  $k.h^{-1}$ . This leads to shaking of the body, especially in the furrower. Increasing the forward speed increases the rate of getting back of soil into the furrow created by the furrower and this has led to further changes the angle of the seedlings from the vertical. Although it seems that the kicking speed to the seedling by kicker in furrower can also influence it.

According to the comparison test for seedlings establishment angles in table 4, it can be deduced that seedlings establishment angles in different treatments is also significant. According to this table, it can be noted that with increasing forward speed and depth of planting, the angles are increased. Although the third treatment ( $v_2d_1$ ) and fourth ( $v_2d_2$ ) not logically follow that. The lowest angle is for the first treatment ( $v_1d_1$ ).

Table 1.1. AONVA results for seedlings distance on rows

F	MS	SS	Dof	Source of variances
**26.85	21.38	106.89	5	<b>Treatment</b>
1.85 <sup>ns</sup>	1.5	3	2	<b>Repeat</b>
-	0.79	7.96	10	<b>Error</b>
-	0.05	-	-	<b>Coefficient of variances</b>

Significant at the 5% level\*\*                      <sup>ns</sup>non significant difference

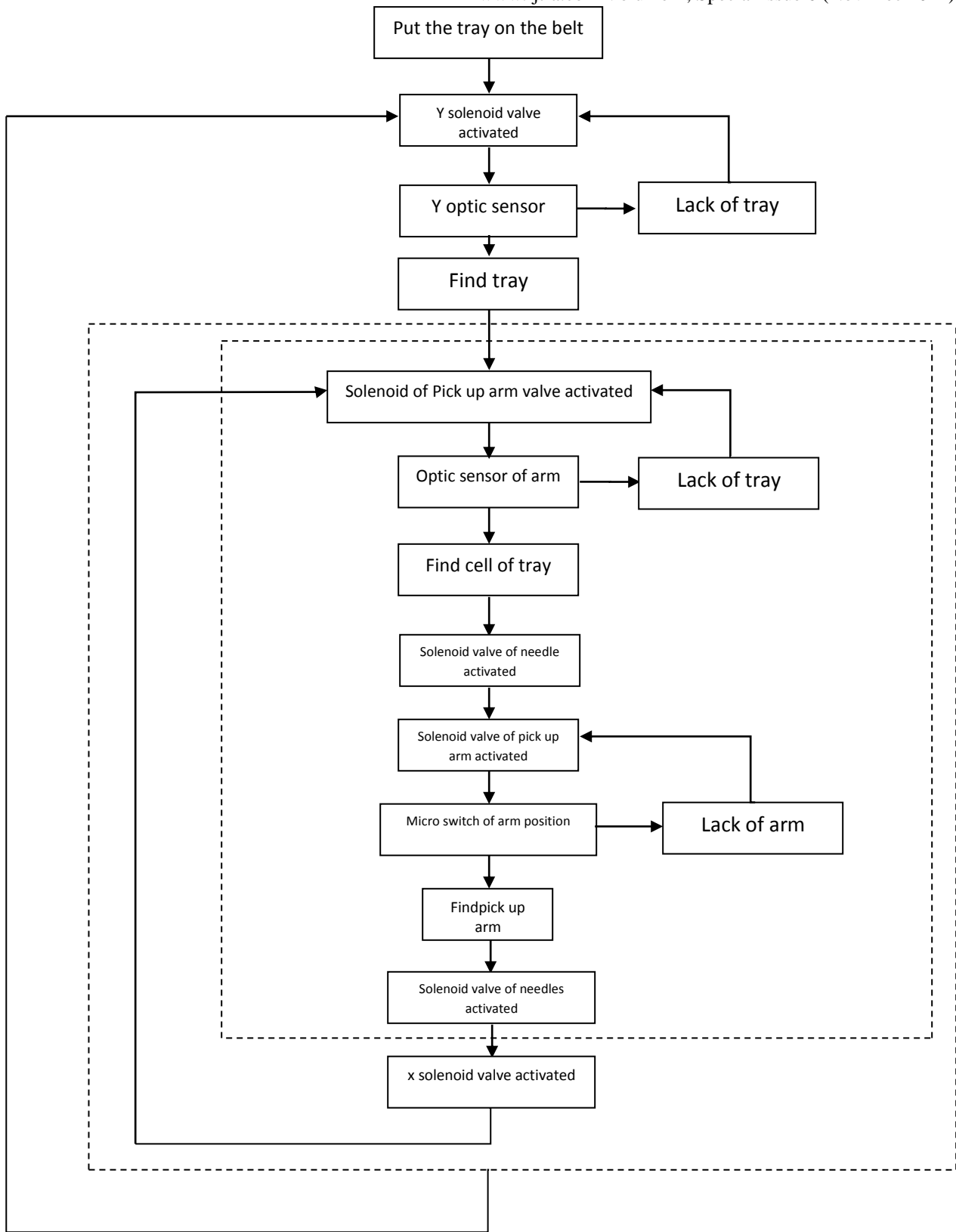


Fig.5. Designed block diagram for control program of PLC

**Table.2. Mean comparison test of seedlings distance on row in different treatments**

Average seedlings distance (cm)	Treatment
44 <sup>a</sup>	v <sub>1</sub> d <sub>1</sub>
47 <sup>bc</sup>	v <sub>1</sub> d <sub>2</sub>
51 <sup>d</sup>	v <sub>2</sub> d <sub>1</sub>
44 <sup>a</sup>	v <sub>2</sub> d <sub>2</sub>
46 <sup>b</sup>	v <sub>3</sub> d <sub>1</sub>
49 <sup>c</sup>	v <sub>3</sub> d <sub>2</sub>

Similar letters in each column indicate no significant difference at 5% level

**Table.3. ANOVA results of angle of transplanting**

F	MS	SS	Dof	Source of variances
**7.86	19.93	99.68	5	Treatment
0.28 <sup>ns</sup>	0.72	1.44	2	Repeat
-	2.53	25.33	18	Error
-	0.17	-	-	Coefficient of variances

Significant at the 5% level\*\*      <sup>ns</sup>non significant difference

**Table.4. Mean comparison test of angle of transplanting on row in different treatments**

Average transplanting angle (degree)	Treatment
11 <sup>a</sup>	v <sub>1</sub> d <sub>1</sub>
15 <sup>b</sup>	v <sub>1</sub> d <sub>2</sub>
19 <sup>c</sup>	v <sub>2</sub> d <sub>1</sub>
14 <sup>b</sup>	v <sub>2</sub> d <sub>2</sub>
14 <sup>ab</sup>	v <sub>3</sub> d <sub>1</sub>
17 <sup>bc</sup>	v <sub>3</sub> d <sub>2</sub>

Similar letters in each column indicate no significant difference at 5% level

#### The effect of forward speed and cultivation depth on physical damage of seedlings

It seems that the amount of physical damage to the pedicles, leaves and roots of seedling increases by increasing of forward speed of machine. Because, as noted earlier, with increasing forward speed, the speed of different mechanisms increases too. This causes at the time of grooving pick up needles into the soil of seedling root, there is the possible of seedling crash and damage to seedling components caused by needles. The fast-moving of mechanisms of tray displacement, causes dislocation of tray from appropriate coordinates and even cause damage to the tray, by the needles.

Based on the data in table 5 can be noted that the effect of different treatments with different forward speed and cultivation depth on physical damage to seedlings at level 5% is significant. The remarkable thing is that in all tests, the effect of repeat on variables was not significant.

By the survey results presented in table 6, it can be noted that maximum damage was for the third treatment (v<sub>2</sub>d<sub>1</sub>) and the minimum damage was for the first treatment, (v<sub>1</sub>d<sub>1</sub>). Although the most damage is not seen in the sixth treatment (v<sub>3</sub>d<sub>2</sub>) but there is the most damages in the third group (v<sub>2</sub>d<sub>1</sub>). It seems that in this treatment, the device did not respond appropriately

to changes of forward speed. This means that it must have the most damages in the sixth treatment (v<sub>3</sub>d<sub>2</sub>), but the result was observed in the third treatment (v<sub>2</sub>d<sub>1</sub>). So designed machine, was not appropriate for this treatment.

#### Theoretical capacity of the machine

According to the results of the previous sections, we can consider the first treatment (v<sub>1</sub>d<sub>1</sub>) as the most appropriate treatment for the designed machine. So, we can calculate the theoretical capacity of the machine by forward speed of 1 km.h<sup>-1</sup> and considering a distance of 60 cm between cultivation rows, by equation (1):

$$C_t = \frac{nv_d}{10} \quad (1)$$

In which C<sub>t</sub> is theoretical capacity of machine, n is the number of cultivation rows, v is the forward speed of machine and d is the distance of two rows of cultivation. So

$$C_t = \frac{1 \times 0.6}{10} = 0.06 \text{ ha} \cdot \text{h}^{-1}$$

The theoretical capacity of machine with one row of cultivation, is 0.06 ha.h<sup>-1</sup>. Although, with consideration the actual conditions and the time required for service, repair and workarounds, the actual capacity will be less.

Fig.5.ANOVA results of seedlings damage

F	MS	SS	Dof	Source of variances
**10.42	50.68	253.43	5	<b>Treatment</b>
0.05 <sup>ns</sup>	0.25	0.51	2	<b>Repeat</b>
-	4.86	48.62	10	<b>Error</b>
-	0.29	-	-	<b>Coefficient of variances</b>

Significant at the 5% level\*\*      <sup>ns</sup>non significant difference

Fig.6. Mean comparison test of seedlings damage

Seedling damage (%)	Treatment
7.27 <sup>a</sup>	<b>v<sub>1d1</sub></b>
13.21 <sup>bc</sup>	<b>v<sub>1d2</sub></b>
18.78 <sup>d</sup>	<b>v<sub>2d1</sub></b>
15.80 <sup>bcd</sup>	<b>v<sub>2d2</sub></b>
12.35 <sup>b</sup>	<b>v<sub>3d1</sub></b>
17.13 <sup>cd</sup>	<b>v<sub>3d2</sub></b>

Similar letters in each column indicate no significant difference at 5 % level

#### IV. CONCLUSION

Based on the results of analysis of variance in different treatments of forward speed and cultivation depth on the characteristics of distance between seedlings, establishment angle and the percentage of physical damage to seedlings was found that in all treatments, changing in forward speed and cultivation depth was significant on the variables statically. The lowest amount of investigated variable was for the first treatment (v<sub>1d1</sub>) at a rate of 27.7%. While by increasing the forward speed and cultivation depth, these variables increased. The third treatment (v<sub>3d2</sub>) on all variables had higher amount than the other treatments. This is probably due to lack of compliance mechanisms in terms of forward speed and cultivation depth in this treatment. But there has been logical flow in the changing amounts of variables in other treatments.

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