Iran Agricultural Research 16:17-38 (1997)

EVALUATING A SEMI-AUTOMATIC SUGAR-BEET STECKLING TRANSPLANTER PERFORMANCE

A. HEMMAT AND K. KAZEMEINKHAH[1]

Department of Farm Machinery, College of Agriculture, Isfahan University of Technology, Isfahan, Iran and Agricultural Research Center, Tabriz, Iran.

(Received: October 29, 1996)

ABSTRACT

Hand planting sugar-beet stecklings for seed production is a labor and time intensive operation. Timeliness of steckling transplanting is important in achieving higher seed yields. This necessitated the study into mechanization of this process. A two-row semi-automatic transplanter prototype was designed, constructed and tested. Forward speed and fuel consumption of the pulling tractor and wheel slip, field efficiency, machine capacity and planting accuracy of the transplanter were measured. The field performance parameters of the prototype and its transplanting accuracy based on the Regional Network for Agricultural Machinery (RNAM) test codes and the International Organization for Standardization (*ISO*) standards were determined. The costs of mechanical transplanting were also evaluated and compared with the hand planting. A paired comparison t-test with five replications was used. Analysis of the field test results showed that at a forward speed of 0.47 km h^{-1} and a field efficiency of 80%, the machine capacity of the transplanter was 0.5 ha day^{-1} The fuel consumption for the transplanting was 5.3 L ha^{-1} The transplanter wheel slip was 5.0%. The prototype performed well and placed the stecklings in the ridges straight and firmly at the within-the-row spacing and a

1. Assistant Professor and Agricultural Researcher, respectively.

planting depth close to the agronomically recommended values of 53 and 15 cm, respectively. The transplanting capacity of the machine was 14.2 stecklings per operator per min. The labor requirements for hand planting and mechanical transplanting were 246 and 63 man-hr ha^{-1}, respectively. In mechanical transplanting, the steckling density was increased by 36.6%. The time and cost required to transplant 1000 stecklings with the transplanter were significantly less than hand planting.

تحقیقات کشاورزی ایران

۱۶: ۱۷-۳۸ (۱۳۷۶)

ارزیابی عملکرد مزرعه ای ماشین ریشچه کار نیمه اتوماتیک چغندر قند

عباس همت و کریم کاظمین خواه

به ترتیب استادیار گروه ماشین های کشاورزی، دانشکده کشاورزی، دانشگاه صنعتی اصفهان، اصفهان، ایران و پژوهشگر مرکز تحقیقات کشاورزی تبریز، تبریز، ایران.

چکیده

کاشت دستی ریشچه از جمله عملیات کارگربر و زمان بر در تولید بذر چغندر قند محسوب می شود. کاشت به موقع نیز در دست یابی به عملکرد بذر بیشتر مهم است. این مسائل ، بررسی امکان ماشینی کردن این مرحله از تولید بذر چغندر قند را ضروری ساخت. یک نمونه ماشین ریشچه کار نیمه اتو ماتیک چغندر قند طراحی، ساخته و ارزیابی شد. سرعت پیشروی و مصرف سوخت تراکتور کشنده و لغزش چرخ های محرک ماشین، بازده مزرعه ای، ظرفیت مؤثر ماشین و دقت نشاء کاری ماشین اندازه گیری شد. پارامتر های عملکردی و دقت کار ماشین به ترتیب بر اساس روش های آزمون RNAM و استاندارد های بین المللی ISO ارزیابی گردید. هزینه های

کاشت ماشینی ارزیابی شد و با هزینه های کاشت دستی مقایسه گردید. در این پژوهش از آزمون t با مشاهدات جفت شده با ۵ تکرار استفاده گردید. آنالیز نتایج آزمون های مزرعه ای نشـان داد کـه در سرعت پیشروی ۰/۴۷ کیلومتر در ساعت و بازده ای برابر با ۸۰٪ ظرفیـت ماشـین ۰/۵ هکتـار در روز بود. مصرف سوخت تراکتور برای عملیات ریشـچه کـاری ۵/۳ لیـتر در هکتـار بـود. لغـزش چرخ های محرک ماشین ۵٪ بود. ماشین ریشچه کار به خوبی عمل نمود و ریشچه هـا را بـه طـور مستقیم در فاصله بین بوته ای و عمق کاشت، نزدیک بـه نیـاز هـای زارعـی ، بـه ترتیـب ۵۳ و ۱۵ سانتیمتر در پشته های ایجاد شده قرار داد و خاک اطراف آنها را فشرده نمود. سرعت کار هر کارگر روی ماشین ریشچه کار، ۱۴/۲ ریشچه در دقیقه بود. کـارگر مـورد نیـاز در روش هـای دسـتی و ماشینی به ترتیب ۲۴۶ و ۶۳ روز- نفر در هکتار اندازه گیری شده است. زمان و هزینه کاشت هزار ریشچه با ماشین ریشچه کار به طور معنی داری کمتر از روش دستی بود.

INTRODUCTION

Sugar-beet is a biennial plant, and although the root crop which provides the raw material for sugar production is grown in a single season, seed production requires a second year for reproductive growth. In the indirect method of seed production, small plants known as stecklings are produced in the first season of the vegetative growth and these are grown to produce seeds in the second season (5).

Stecklings should be planted as early as conditions in the transplant field permit. Observations by researchers show that early planting gives higher seed yields. In the mechanized method, strip planting with the female and male components both planted separately is the most common method of producing hybrid seed. Stecklings must be planted straight and in the soil at the correct depth, with the top of the crown covered with soil. For optimal seed yields, it is required to achieve 30000 plants ha^{-1} with row and plant spacings of 65 and 50 cm, respectively (5).

Hand planting the sugar-beet stecklings in the second year is one of the major operations carried out by growers in the sugar-beet seed production region of Iran, namely the Ardebeel province. It is therefore very important to minimize the time and labor involved in this process. Planting stecklings by a transplanter could be a promising solution. For the machine to be attractive to the grower it has to be simple in use, reliable, possess an acceptable transplanting capacity with good quality of the transplanting work and it must do all these at a reasonable cost.

To find a solution to the above problem, efforts were made to mechanize the sugar-beet steckling planting operation. A two-row semi-automatic transplanter prototype was designed and constructed. Its field performance was evaluated and the cost of mechanical transplanting was compared with the hand planting.

MATERIALS AND METHODS

Field tests were carried out with the prototype transplanter in the spring of 1995. The field was plowed twice by moldboard plow, harrowed twice by disc harrow and leveled (by leveler) in the fall of 1994. The field and steckling conditions at the time of the field tests are given in Table 1. A brief description of the machine and methodology adopted are discussed below:

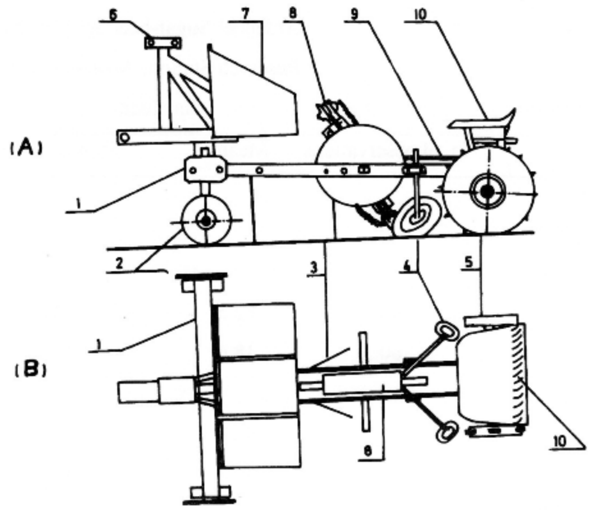
Constructional Features and Operation of Semi-automatic Steckling Transplanter

The sugar-beet steckling transplanter is a mounted-type two-row machine. The transplanter comprises transport wheels, a hopper, furrow openers, metering disk with two grippers, covering device consisting of two disk-type ridgers, driving/press wheels and operator seat. These components are mounted on the frame of the transplanter (Figs. 1 and 2). Its metering mechanism is ground driven by the press wheel so that the within-the-row spacing of the stecklings are independent of the tractor forward speed. The machine specifications are given in Table 2.

Table 1. Test conditions.

Date of test:	3-4-95 to 8-4-95		
Location:	Ardebeel Sugar-beet Seed Production Research Station, Ardebeel, Iran		
Soil texture at 0-30 cm:	Clay loam		
	No. of observations	Mean	Standard error
Field conditions:			
Average soil moisture at (dry weight basis%)			
0-7.5 cm	60	12.5	0.112
7.5-15 cm	60	18.6	0.168
Cone index (MPa) at			
0-10 cm	9	0.62	0.022
10-20 cm	9	1.3	0.025
Conditions of stecklings:			
Length (cm)	30	12.2	0.42
Maximum diameter (cm)	30	4.8	0.21
Weight (g)	300	141.7	5.14
Moisture content (dry weight basis%)	300	85.4	0.077

The operators sit on the transplanter and pick the stecklings from the hopper and feed them into the open jaws of the grippers. The steckling is fed with the crown turned downward. The grippers move in an arcuate motion actuated by the profile of a stationary cam. The steckling is held firmly between the jaws of the gripper until it approaches its lowest position. When the steckling is in the furrow, the jaws of the gripper are opened, the gripping pressure ceases and the steckling is covered with soil by the covering device and a ridge is formed. A pair of press wheels moving in oblique position follow and compress the soil around the stecklings. To reduce wheel slip, the left-hand press wheel (viewed from the rear) has a number of equally spaced lugs on its perimeter.



1. Frame. 2. Transportation wheel. 3. Furrow opener. 4. Covering disc. 5. Press wheel. 6. Three-point hitch. 7. Hopper. 8. Metering mechanism. 9. Transmission unit. 10. Seat (A) Side view , (B) Plan view.

Fig.1. Semi-automatic sugar-beet steckling transplanter assembly.

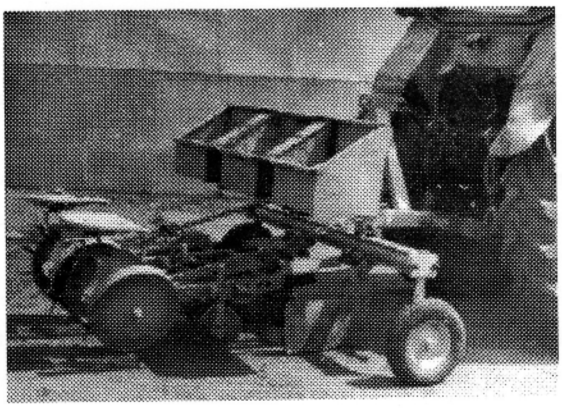


Fig. 2. Side view of the tractor-mounted semi-automatic sugar-beet steckling transplanter.

Table 2. Machine specifications.

Characteristics	
Overall length (m)	1.89
Overall width (m)	2.12
Overall height (m)	1.21
Mass (kg)	347
Hopper capacity (No. of stecklings)	538±20†
Number of rows	2
Row spacing (cm)	65
Plant spacing (cm)	50
Depth of planting (cm)	15

† Mean ± standard error of 5 observations.

Performance Evaluation

The experiment was conducted in a two-ha field using a paired comparison *t*-test with five replications. Manual and mechanical steckling transplanting for sugar-beet seed production were evaluated and compared. Tests were conducted on plots of 60 m long by 3.9 m wide (three passes of the transplanter).

Hand planting. The stecklings were planted by a crew of four persons in each of five plots. Labor used for all operations including steckling shortening, digging, planting, covering and pressing the soil around the stecklings by foot were recorded in man-hr. Other parameters such as the number of stecklings planted in each plot were noted. The degree of soil firmness around the planted stecklings was measured in the trampled areas on both sides of the stecklings. The method is explained under the heading of "degree of soil firmness"

Mechanical transplanting. The parameters studied were forward speed, transplanter wheel slip, field efficiency, machine capacity and fuel consumption. All transplanting performance data were measured and recorded according to the recommendations of the Regional Network for Agricultural Machinery (RNAM) test codes and procedures for farm machinery (9). The criteria of transplanting accuracy measured were row spacing, within-the-row spacing, uniformity of planting depth, steckling vertical position and the soil firmness around it. All transplanting quality data were measured and recorded according to the International Organization for Standardization (ISO) standards and British recommendations (7, 12).

Forward speed. Uniformity of root placement was dependent on the capability of the operator to feed stecklings properly as well as selecting the correct forward speed of the machine. The transplanter was tested for planting opportunity (the opportunity and convenience available to the operator to take the stecklings out of the hopper and put them into the gripper of the transplanting mechanism) with four commonly used tractors in Iran in three different gears. The tractors were a Universal 445 and 650, a Massey Ferguson 285 and a John Deere 3140 with 33.6, 48.5, 56 and 71 kW rated engine powers, respectively. However, the field performance tests were conducted using a Universal 445 tractor in the 1st low gear. The engine speed was set at 1250 rev min^{-1}

Wheel slip. The distance traveled by the transplanter in 10 revolutions of the drive (press) wheel with no-load (L_o.) and with load (L) was measured. The negative wheel slip (wheel skid) was computed by using the following formula (12):

$$S = \frac{L - L_o}{L} *100 \qquad [1]$$

where:

S = wheel slip,%,

L = machine advance with load in the field, m,

L_o = machine advance with no load on concrete, m.

Two measurements were made in each plot.

Field efficiency and effective machine capacity. Field efficiency of the transplanter was calculated by using the following formula (9):

$$\eta_f = \frac{t_e}{t_e+t_a+t_h} *100 \qquad [2]$$

where:

η_f = field efficiency, %,

t_e = effective operating time, h,

t_a =time losses that are proportional to area, h,

(filling the hopper)

r_h = time losses proportional to effective operating time, h,

(rest stops, adjusting transplanter and idle travel at field ends).

The actual operating hr, time spent for turning at headlands and time spent for filling the hopper were measured. The time losses for rest stops and adjusting the transplanter were assumed to be 15 % of the effective operating time[1].

The effective machine (field) capacity was calculated as follows from the test data(6):

$$C_{a} = \frac{V\,W\eta_f}{10} \qquad [3]$$

where:

C_a =effective machine capacity, ha hr^{-1},

V =travel speed, km hr^{-1},

W =transplanter working width, m.

Fuel consumption. The fuel consumption was measured by filling the fuel tank to capacity before starting the test and refilling to the same level with a graduated syringe after transplanting the 60 m long test run. The total quantity of fuel needed to refill the tractor fuel tank was recorded (9). The fuel consumption ha^{-1} was computed from the data obtained.

Transplanting accuracy. After transplanting, measurements of row spacing, the distance between the stecklings within-the-row, planting depth and ridge height uniformity were made on six randomly selected positions in each plot (7). The angle of steckling placement relative to a vertical line and the steckling deviation to the sides were evaluated along a randomly selected 10 m run in each plot (10). From these measurements, the mean and the standard error of each parameter were calculated.

The required feed rate. The rate at which stecklings can be fed into the transplanter was calculated by using the following formula (10):

$$R_{fr} = \frac{6000\,V_m\,\lambda_r}{d_p} \qquad [4]$$

where:

1. The results of some studies in Russia (former Soviet Union), orally stated by professor Khalid Gorbanev, Academy of Agricultural Sciences, College of Agricultural Mechanization, Ganjeh, Azarbaijan Republic, May 1995.

R_{fr} = required feed rate of stecklings, min^{-1},

V_m = forward speed of transplanter, m s^{-1},

λ_r = number of rows planted simultaneously by transplanter,

d_p = actual steckling spacing along the row, cm.

Five measurements were made in each plot.

Steckling density. The number of stecklings planted ha^{-1} was calculated according to the following formula (7):

$$R_d = \frac{10^8}{d_p\, R_s} \qquad [5]$$

where:

R_d = steckling density, ha^{-1},

R_s = actual row spacing, cm.

The actual nuumber of stecklings transplanted in each plot was also measured and the actual steckling density was determined.

Transplanting rate. Total mass of sugar-beet stecklings planted ha^{-1} was calculated by using the following formula (7):

$$R_q = \frac{10^5\, m_r}{d_p\, R_s} \qquad [6]$$

where:

R_q = steckling quantity, kg ha^{-1},

m_r = average steckling mass, g.

Degree of soil firmness. The degree of soil firmness around the planted stecklings was measured by two methods. First, the soil firmness shortly after planting was checked by pulling the root by a spring balance and noting the uprooting force needed (14). Second, the soil penetrometer resistance (10 probes plot^{-1}) was measured in 1 cm increments to a depth of 20 cm with a hand held penetrometer having a 30° cone, 12.83 mm in diameter (1). Measurements were made on the left and right sides of each row in the press wheel ruts shortly after planting. Penetrometer measurements on both sides of the row were combined to obtain an average value. Before planting the soil strength (10 probes plot^{-1}) in the experimental plots was also measured.

Cost Analysis

To compare the costs of the mechanical transplanting with the hand planting, the costs in each method were determined as follows:

Hand planting. The costs of hand planting were calculated by considering the man-hr ha^{-1}, the labor wage[1] and the costs of hand tools. The hand tools included a bucket, a spade and a knife. Their prices were 15000, 5000 and 3500 Rials, respectively.

Mechanical transplanter. The annual cost of the transplanter was detemined by using the cost relationship (6) given by Eq. [7]:

$$AC = C_{ao} + \frac{A}{C_a} [RM+L+T] \qquad [7]$$

where:

AC = annual cost of operating transplanter, R yr^{-1} [2],

C_{ao} = total annual ownership costs, R yr^{-1},

A = annual transplanted area, ha,

C_a = machine capacity of transplanter, ha h^{-1},

RM = repair and maintenance cost of transplanter, R hr^{-1},

L = labor cost of transplanter, R hr^{-1},

T = hiring cost of the tractor pulling the transplanter, R hr^{-1}, (8000 R hr^{-1}).

The total annual ownership costs, C_{ao}, can be calculated using the following equation (10):

$$C_{ao} = P\{(1-S_v) [\frac{I_r(1+I_r)^{t_L}}{(1+I_r)^{t_L}-1}] + \frac{K_{tis}}{100}\} \qquad [8]$$

where:

P = purchase price of the transplanter, R (4000000 R)[3],

t_L = economic life of the transplanter, yr (5 years)[4],

S_v = salvage value as a fraction of purchase price, decimal (0. 1),

I_r = annual interest rate, decimal, (0.18),

K_{tis} = annual cost of taxes, insurance and shelter as percent of purchase price (2).

The following equation was used to estimate accumulated repair and maintenancecost of the transplanter (3):

1. In 1995, the labor wage day^{-1} (eight hr) was 15000 Rials, 1 US \$ = 3000 Rials (official exchange rate).
2. Rials $year^{-1}$.
3. This was assumed to equal to the price of a two-row semi-automatic potato planter that would cost 4000000 Rials in 1995.

$$G_{rm} = P\{ RF_1 [\frac{t}{1000}]^{RF_2} \} \quad [9]$$

where:

G_{rm} = accumulated repair and maintenance costs, R,

t = accumulated use, hr, (1250 hr),

RF_1, RF_2 = repair factors, [RF_1=0.54, RF_2=2.1, (2)].

In the region, planting can be done from the 15th of March till the 4th of May each year. Therefore, the length of the working season $year^{-1}$ is 51 days. The rate of available working days in the season is considered to be 70% . The rate of available work hr $year^{-1}$ is also assumed to be 70% (9). Thus, the number of operating hr $year^{-1}$ is 250 hr.

The repair and maintenance cost hr^{-1}, RM, of the transplanter was computed by using the following formula (10):

$$RM = \frac{G_{rm}}{t} \quad [10]$$

RESULTS AND DISCUSSION

Forward Speed

Table 3 shows that when the working speed of the transplanter ranged from 0.47 to 1.0 km hr^{-1}, the operator had sufficient time to take the stecklings out of the hopper and put them into the gripper of the transplanting mechanism.

Machine Capacity, Wheel Slip and Fuel Consumption

The field performance results of the transplanter are shown in Table 4. The machine capacity of the machine was about 0.5 ha day^{-1} at the tested speed of 0.47 km hr^{-1}. The machine capacity of the transplanter could be doubled if it worked at the speed of 1 km hr^{-1} The machine capacity of a semi-automatic potato planter for planting chitted seeds with a crew of three workers is 1 ha day^{-1} (8). The wheel slip of the driving wheels of the transplanter was 5%. This would increase the distance between the planted steckling (Table 7). Although the fuel consumption of the tractor pulling this machine for

4. Its economic life was assumed to equal the economic life of a potato planter.

Table 3. Forward speeds of the sugar-beet steckling transplanter with different tractors.

Tractor model	Tractor gear	Working speed (km hr^{-1})			Planting opportunity†
		No. of observations	Mean	Standard error	
U†† 445	1-L§	5	0.47	0.011	very good
	2-L	5	1.03	0.014	good
	1-H¶	5	1.71	0.040	none
U 650	1-L	5	1.03	0.008	good
	2-L	5	1.14	0.016	insufficient
	1-H	5	1.69	0.030	none
MF§§ 285	1-L	5	0.77	0.011	very good
	2-L	5	1.13	0.016	insufficient
	1-H	5	2.63	0.054	none
JD¶¶ 3140	1-L	5	0.94	0.011	good
	2-L	5	1.54	0.020	insufficient
	1-H	5	2.73	0.036	none

† The opportunity and convenience available to the operator to take the stecklings out of the hopper and put them into the gripper of the transplanting mechanism; *very good* refers to when the operator has sufficient time to do the job; in *good* situation, the result is acceptable.

§ Low. ¶ High. †† Universal. §§ Massey Ferguson. ¶¶ John Deere.

Table 4. Summary of field performance results of the semi-automatic steckling transplanter.

Parameters	No. of observations	Mean	Standard error
Forward speed (km hr^{-1})	5	0.47	0.011
Wheel slip (%)	10	5.0	0.51
Field efficiency (%)	5	80	0.063
Effective machine capacity (ha day^{-1})†	5	0.48	0.067
Fuel consumption§ (l ha^{-1})	10	5.34	0.063
Ease of operation		Good	
Breakdowns		Nil	

† Ten working hr d^{-1} was assumed.

§ For transplanting only.

transplanting operation was 5.34 l ha^{-1}, the fuel consumption for turning at the headlands should be added to obtain the total fuel consumption.

Degree of Soil Firmness

The amount of force required to pull the steckling out of soil used as a measure of soil firmness around the planted steckling is given in Fig. 3 and Table 5. It can be seen that uprooting force depends on the mass of the steckling. Thus, this method is not appropriate for determination of the soil firmness for plants which have nonuniform masses.

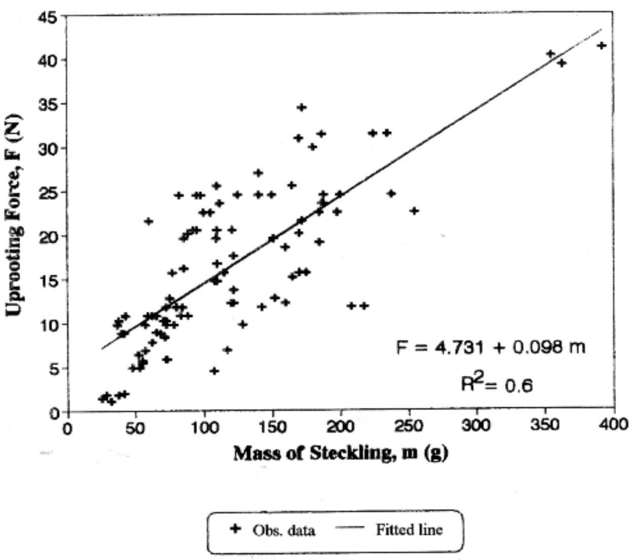


Fig. 3. Variation of uprooting force vs steckling mass.

There was no statistically significant difference in before-planting soil strength between the hand planting and the mechanical transplanting plots. Therefore, the field soil condition was quite uniform. The cone penetration resistance around the planted steckling in the surface 20 cm soil layer for the hand planting and the mechanical transplanting are shown in Fig. 4. There was no statistically significant difference between the hand-planting- and the mechanical-transplanting-soil strength in the 0- to 14-cm depths. The difference was significant for the 15- to 17-cm depths in which the hand planting strength was significantly higher than the mechanical transplanting. It seems that the spade in the hand planting did not penetrate so deeply whereas the furrow opener of the transplanter loosened the soil to a deeper level.

Table 5. The amount of force (N) required to pull the steckling out of the soil.

Steckling mass, m (g)	No. of observations	Mean	Standard error
m<100	46	10.8a†	0.92
100≤ m<200	45	19.5b	0.98
m≥200	9	29.6c	3.3
All mass groups	100	16.4	0.89

† Means followed by different letters are significantly different at the 0.01 level of probability.

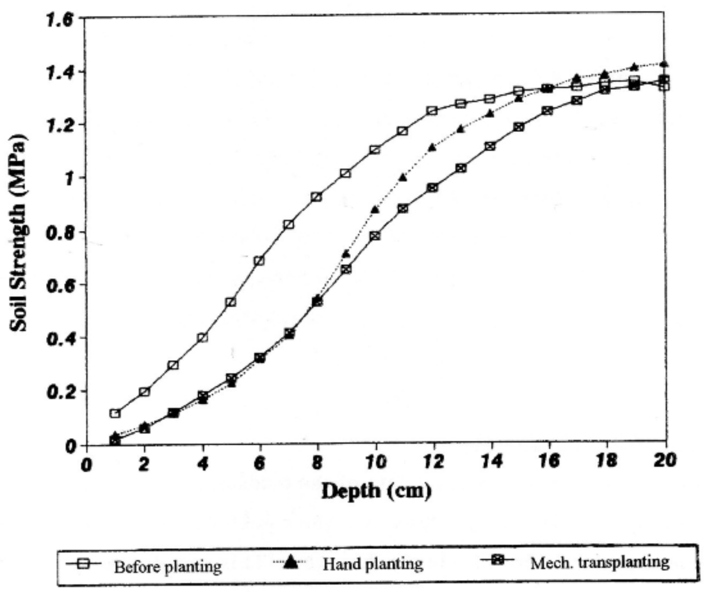


Fig. 4. Before-planting soil strength values and soil strength in the trampled areas and the press wheel ruts for hand planting and mechanical transplanting, respectively.

The ratio of after-planting to before-planting soil strength is used to determine how an opener changes soil strength. A value less than 1 indicates that planting device has loosened the soil (11). In hand and mechanical transplanting, the after-planting soil strength was significantly less than the before-planting up to about 11 and 16 cm depth, respectively (Table 6 and Fig. 4). Therefore, the average depth of spade penetration in the hand planting was 9 cm and considering the average length of the steckling (12.2 cm), the angle of steckling's placement was about 26° relative to the vertical position. In mechanical transplanting , the average height of the soil which covered the steckling was 9 cm and the press wheels were moving on both sides of the ridge 5 cm below the top of the ridge. Therefore, the furrow opener loosened the soil to a depth of 13 cm. This depth is similar to the adjusted depth of the furrow opener. Stephens and Johnson (11) showed that all openers reduced soil strength, but the closing systems provided selectable levels of soil reconsolidation.

In hand planting the soil strength in the surface 20 cm at the left and right of a planted steckling was not statistically different, but in mechanical transplanting the soil strength at the left side (viewed from the rear) of the steckling was significantly less than on the right side. This was caused by the loosening action of the lugs on the left-side press wheel. Therefore, proper collection of the cone penetrometer data and careful examination in appropriate format can allow accurate assessment of the effect of hand and mechanical transplanting tools on soil strength around the planted stecklings.

Transplanting Accuracy

The transplanting accuracy data of the transplanter are shown in Table 7. The row spacing is quite uniform, but the steckling distance was higher than machine specification (Table 2) by 6.2%. This was due to the transplanter drive wheel slip (Table 4). Ninety-one percents of the stecklings were planted vertically. The planting rates of semi-automatic transplanters are in the range of 25-30 plants operator^{-1} min^{-1}(8). However, 15 plants operator^{-1} min^{-1} is reported for tobacco (13). The steckling density of the transplanter was 5% less than the optimum density of 30000 stecklings ha^{-1} (5). This was due to the wheel slip and transplant missing which the latter accounted for 1.6%. This is in agreement with the percent of stecklings fallen from the gripper of the transplanter on the ground.

Table 6. Level of significance for comparison of before- and after-planting soil strength means for each depth in hand and mechanical transplanting.

	Level of significance†	
Depth (cm)	Hand planting	Mechanical transplanting
1	0.0018	0.0036
2	0.0001	0.0048
3	0.0000	0.0006
4	0.0000	0.0030
5	0.0001	0.0027
6	0.0330	0.0029
7	0.0022	0.0011
8	0.0008	0.0003
9	0.0032	0.0031
10	0.0189	0.0245
11	0.0342	0.0596
12	0.0821	0.0216
13	0.1819	0.0172
14	0.3796	0.0093
15	0.6846	0.0196
19	0.9414	0.0533
17	0.4880	0.1645
18	0.5482	0.4044
19	0.3694	0.3759
20	0.1831	0.7025

† For hand planting and mechanical transplanting from depth of 13 and 17 cm, respectively, the differences (between before-and after-planting soil strength means) are not significant even at 10% level.

Table 7. Transplanting accuracy data of the semi-automatic steckling transplanter.

Parameters	No. of observations	Mean	Standard error
Evenness of row spacing (cm)	25	65.0	0.12
Uniformity of steckling spacing along the row (cm)	30	53.1	0.35
Uniformity of steckling's placement in the soil (cm)	30	21.2†	0.17
Deviation from vertical position (%)	100	9	-
Deviation to right or left (cm)	100	0.5	0.073
Steckling fallen from the grippers on the ground (%)	5	1.68	0.18
Transplanting rate of the transplanter (stecklings man^{-1} min^{-1})	25	14.2	0.14
Steckling density (No. of stecklings ha^{-1})	5	28487	51
Rate of transplanting (kg ha^{-1})	5	4089	38.9

† The distance between the tap root of the steckling and the top of the ridge.

Costs and Times for Transplanting

Comparative costs and times for hand planting and mechanical transplanting are given in Table 8. Labor requirements for the mechanical transplanting were 63 man-hr ha^{-1} and were 25.6% of the hand planting. For cabbage mechanical transplanting, it is 75-100 labor-hr ha^{-1} (8). To transplant 1000 stecklings with the transplanter, 2.22 man-hr were required. As this figure includes time to turn the machine at the end of the row and reload it with stecklings, actual feeding rates were appreciably higher than the overall average transplanting rate indicated above. For tobacco, a total of 2.24 hr of labor to transplant 1000 plants are required (13). The cost of transplanting ha^{-1} for two methods were not significantly different. However, the cost required to transplant 1000 stecklings by the mechanical transplanting was significantly less than the hand planting. This was due to different steckling densities in these two methods. The time required to transplant 1000 stecklings was significantly higher for the hand planting than the mechanical transplanting. In mechanical transplanting, the stecklings can be planted in a shorter time. Therefore, the crop flowers and matures more evenly and gives higher seed yields with better quality (5).

Table 8. Cost and time comparisons for hand planting and mechanical transplanting.

Parameters	Hand planting†		Mechanical transplanting†	
	Mean	Standard error	Mean	Standard error
Labor requirement (man-hr ha^{-1})	245.7	13.1	63	0.9
		LSD§ = 66.2		
Cost of transplanting (R ha^{-1})	484233	24623	446126	4796
		LSD¶ = 57846		
Steckling density (No. of stecklings ha^{-1})	20855	189	28487	52
		LSD§ = 988		
Cost required to transplant 1000 stecklings (R)††	23219	1181	15661	167
		LSD§ =6011		
Time required to transplant 1000 stecklings (hr)	2.95§§	0.165	0.74¶¶	0.01
		LSD§ = 0.84		

† No. of observations were five.

§ Least significant difference at P=0.001.

¶ Least significant difference at P=0.05.

†† Rials, 1US $=3000 R (official exchange rate).

§§ With a crew of four labors.

¶¶ With a crew of three labors.

CONCLUSIONS AND RECOMMENDATIONS

1. At a forward speed of 0.47 km hr^{-1} and a field efficiency of 80% the machine capacity of the transplanter was 0.5 ha day^{-1}. Fuel consumption for the transplanting operation was 5.3 l ha^{-1}. The transplanter wheel slip was 5.0%.
2. In terms of agronomical requirements of the stecklings, the transplanter performs well and plants the stecklings in the ridges upright and firmly at about 53 cm within-the-row spacing and at a selected depth of 15 cm.
3. The transplanting capacity of the transplanter is 28.4 stecklings min^{-1}
4. The time required to transplant 1000 stecklings with the mechanical transplanter is 2.22 hr of labor and is significantly less than the hand planting.
5. The cost required to transplant 1000 stecklings with the mechanical transplanter is 15661 Rials and is significantly less than the hand planting.
6. In mechanical transplanting, mechanized inter-row cultivation, weeding and seed harvesting are possible.
7. Penetration resistance is a good index for measuring the degree of soil firmness around the stecklings.
8. To increase the machine capacity of the transplanter, the number of transplanter units could be increased to four, the speed of the machine could be increased to 1 km hr^{-1} and the capacity of the hopper can be enlarged.

ACKNOWLEDGEMENT

The authors wish to express their thanks to Iranian Agricultural Engineering Research Institute and Sugar-beet Breeding and Seed Production Research Institute for their financial support, and to Mr. S. Abdul-Mohammadyan and A. Bakhtiari for helping us in conducting the field experiments.

LITERATURE CITED

1. Anderson, G., J.D. Pidgeon, H.B. Spencer and R. Parks. 1980. A new hand-held recording penetrometer for soil studies. J. Soil Sci. 31: 279-296.
2. ASAE. 1992. ASAE Standards, 39th ed. D487. Agricultural machinery management data. ASAE, St. Joseph, MI, U.S.A.781 p.
3. ASAE. 1992. ASAE Standards, 39th ed. EP496. Agricultural machinery management. ASAE, St. Joseph, MI, U.S.A. 781 p.
4. Ball, R.C. 1985. Horticultural Engineering Technology: Field Machinery. MacMillan Education Ltd. London, U.K. 216 p.
5. Bornscheuer, E., K. Meyerholz and K.H. Wunderlich. 1993. Seed production and quality. In: D.A. Cooke and R.K. Scott (eds.), The Sugar-beet Crop: Science into Practice Chapman & Hall, London, England 122-155.
6. Hunt, D.H. 1983. Farm Power and Machinery Management, 8th ed., Iowa State Univ. Press. Ames, Iowa, U.S.A. 365 p.
7. International Organization for Standardization. 1981. 1st ed. ISO 5691. Equipment for planting - Potato planters - Method of testing. Paris, France. 3 p.
8. Nix, J. and P. Hill. 1986. Farm Management Pocketbook. 16th ed. Department of Agricultural Economics, Wye College, England. 186 p.
9. Regional Network for Agricultural Machinery. 1983. RNAM Test Codes and Procedures for Farm Machinery. Technical Series No. 12. Bangkok, Thailand. 291 p.
10. Srivastava, A.K., C.E. Goering and R.P. Rochrbach. 1994. Engineering Principles of Agricultural Machines. ASAE Textbook No. 6. American Society of Agricultural Engineers. 601 p.
11. Stephens, L.E. and R.R. Johnson. 1993. Soil strength in the seed zone of several planting systems. Soil Sci. Soc. Amer. J. 57: 481-489.

12. Stevens, G.N., 1982. Equipment Testing and Evaluation. National Institute of Agricultural Engineering. Wrest Park, Silsoe, Bedford, England. 137 p.

13. Suggs, C.W., T.N. Thomas, D.L. Eddington H.B. Peel T.R. Seaboch and J.W. Gore,. . 1987. Self-feeding transplanter for tobacco and vegetable crops. Applied Engineering in Agriculture. 3: 148-152.

14. Werken, J. Van De. 1991. The development of the finger-tray automatic transplanting system. J. Agric. Eng. Res. 50: 51-60.