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DESIGN AND DEVELOPMENT OF PLUG SEEDLING TRANSPLANTER FOR VEGETABLE CROPS

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DESIGN AND DEVELOPMENT OF PLUG SEEDLING TRANSPLANTER FOR VEGETABLE CROPS

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GAIKWAD BHASKAR BHARAT

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CERTIFICATE

This is to certify that the thesis entitled, **"DESIGN AND DEVELOPMENT OF PLUG SEEDLING TRANSPLANTER FOR VEGETABLE CROPS"** submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** in **AGRICULTURAL ENGINEERING** is a record of *bona fide* research work carried out by **Shri. GAIKWAD BHASKAR BHARAT, Roll No. 9270** under my guidance and supervision, and that no part of this thesis has been submitted for any other degree or diploma. It is further certified that all the assistance and help availed during the course of investigation as well as all sources of information have been duly acknowledged by him.

(N. P. S. Sirohi)
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CONTENTS

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LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
ASABE	American Society of Agricultural and Biological Engineers
ASAE	American Society of Agricultural Engineers
BEP	Breakeven point
C.G.	Centre of gravity
C.V.	Coefficient of variation
CAD	Computer Aided Designing
cm	Centimetre
CPCT	Centre for Protected Cultivation Technology
db	Dry basis
Dia.	Diameter
Fig.	Figure
g	Gram
ha	Hectare
HP	Horsepower
h	Hour
i.e.	That is
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
IRR	Internal rate of return
kg	Kilogram
$km.h^{-1}$	Kilometre per hour
kPa	Kilo Pascal
LSD	Least significant difference
M.S.	Mild steel
$m.s^{-1}$	Meter per second
$Mg.m^{-3}$	Mega gram per cubic meter
min	Minute
mm	Millimetre
N	Newton
No.	Number
p.c.p.a.	Per cent per annum
R^2	Coefficient of determination
RMSE	Root mean square error
S.D.	Standard deviation
SAS	Statistical Analysis System
sec	second
viz.	Videlicet (namely)
W	Watt
yr	Year
₹	Rupee

Chapter I

Introduction

India is the second largest producer of vegetables in the world with an estimated annual production of 125.88 million tonne from 7.8 million ha, which accounts for about 13.3% of total world vegetable production (Indian Horticulture Database 2008). Although, annual growth rate of 2.6 per cent in total vegetable production has been recorded during the last 10 years, the average yield of vegetables in India is still lower than that in many Asian countries. The main reason of low productivity and quality is the lack of technology transfer and adoption at the growers' level. With the opening and accessibility of global markets under WTO regime, the agro-products, especially the horticultural produces, have to be competitive in cost as well as in quality both in domestic and in overseas markets. Seeds and management practices are the key factors to enhance the productivity and quality of produce.

A major portion of the area under vegetable cultivation is now sown with F1 hybrid seeds, which are costly but give higher yields and quality. In view of high cost of such seeds, it is necessary to achieve maximum germination with healthy plants. Traditional method of direct sowing of seeds has the disadvantages such as longer growth period of plants, higher water and nutrient consumption, high seed rate, and non-uniform plant density. Also, the seeds are exposed to soil-born diseases, insects, birds, and adverse climate conditions like heat, frost, wind, heavy rainfall etc. As a result, plant germination and establishment are generally poor and it becomes uneconomical to use costly hybrid seeds for direct sowing. Raising of vegetable seedlings in nursery and transplanting them is advantageous as it ensures shorter growth period, efficient utilization of land, early crop maturity, extended crop production, efficient use of irrigation water, and weed management. Transplanting of seedlings also helps in maintaining desired plant density, facilitates inter-cropping, and saves on the cost of seeds. Most important of all, it helps to plan planting time to minimize incidence of diseases, insect-pests, and schedule of crop harvest according to the market demand and price.

Vegetable seedlings have been traditionally grown on soil beds in open field for a long time. While this method involves low costs and skills, it also results in considerable loss of seeds on account of poor germination and subsequent plant establishment in the field. Over the past few years, plug tray seedling technology has gained momentum due to several advantages. This technology ensures maximum germination with healthy plants, which makes it favourable for growing costly hybrid seeds. Plug transplants also establish better in the field due to disease-free and prolific root development. Seedlings of high value vegetable crops such as tomato, capsicum, cucumber, broccoli, chillies, brinjal etc are now being widely grown in plug trays by a large number of farmers in India for obvious advantages. The technology of plug tray nursery is now fast emerging as an agro-enterprise. A large number of such nurseries have been operating in Maharashtra, Karnataka and several other states where seedlings are grown in plug trays and sold on pre-ordered basis to farmers. Vegetable farmers get the required number of healthy seedlings grown under greenhouse or net house at the scheduled time and need not bother to raise their own nursery. After taking the delivery of seedlings from the nursery, the farmer has to transplant them in the field within a day to minimize their mortality.

Transplanting of plug seedlings is a manual and labour-intensive operation. Timely transplanting of vegetable crops is essential for higher yields. Assuming that seedlings are available at the site, the sequence of manual operations normally practiced are as follows:

i) Placing the seedlings at predetermined spacing on the beds
ii) Making small groove with fingers in wet soil at the place of transplanting
iii) Placing the seedling in the groove, covering plug with soil and compacting it with both hands

Plate 1. Sequence of operations performed in manual plug seedling transplanting

On an average, about 197 man-hours are required to transplant seedlings in one hectare area with a plant spacing of 600 mm x 600 mm. In peak season manual labour can hardly meet the transplanting requirements of vegetable seedlings. Besides the quantum of labour, manual transplanting involves considerable drudgery and human discomfort. The labour has to stoop forward while placing the seedling on the bed to avoid shattering of plug media and damage to its root. Stooping posture results in bio-mechanical stresses in the back and has higher energy consumption as compared to other working positions. At the same time, the labour has to hold the plug tray in one hand which results in static stresses in the hand. The labour engaged in actual transplanting has to squat to move to next planting position. Continuous use of bare fingers of hands for making grooves in soil causes inflammatory abrasions on finger tips and nails leading to infections. Manual transplanting operation, performed in stooping and squatting postures, is a strenuous activity and is not recommended for ergonomic considerations. Oxygen consumption during squatting with movement action is 31-35 % of VO_2 max and that during bending posture is 70-80% of VO_2 max (Grandjean, 1988). This results in higher fatigue and reduced work capabilities.

Increased cost of labour in the past decade has made the manual transplanting uneconomical. The transplanting operation of seedling from plug tray to the field needs to be mechanized for precision and higher production capacities and also to reduce transplanting cost.

In view of the above investigation, the present study was undertaken to design and develop a tractor-operated mechanical transplanter to reduce labour costs and enhance timeliness of transplanting in order to minimize mortality of vegetable seedlings. The specific objectives of the study were as follows:

Objectives:

1. To determine design parameters affecting mechanical transplanting of vegetable plug seedlings
2. To design and fabricate tractor-operated transplanter for vegetable plug seedlings
3. To evaluate the performance of prototype vegetable plug seedling transplanter

Chapter II

Background

India has achieved an annual growth rate of 2.6 per cent in total vegetable production during the last 10 years; however the average yield of vegetables in India is still lower than that in many Asian countries. Mechanized cultivation, along with other improved crop production practices, can increase crop productivity and quality. One cultivation practice that would benefit from mechanization in vegetable production is timely transplanting of good-quality vegetable seedlings. Over the past few years, plug tray seedling technology has gained momentum in India due to several advantages, over traditional method of growing seedlings on soil beds in open field. However, only few research studies have been carried out till date in India for mechanizing seedling transplanting operation and have been limited to traditional bare root seedling type. Enough published information is not available on the design of vegetable transplanters for plug seedlings. Also, studies investigating factors affecting plug seedling transplanting operation, particularly the soil parameters are not available. This chapter includes the available published information related to plug seedling raising and its transplanting. The information is presented under the following headings:

2.1 Plug seedling raising technology

2.2 Mechanizing vegetable seedling transplanting operation

2.3 Performance evaluation

2.1 Plug seedling raising technology

With the advent of modern technologies such as hybrid production, integrated management of pest, disease and nutrients, protected cultivation, scenario of vegetable production in India is changing at a fast rate. Most of the vegetable crops are now transplanted due to expensive hybrid seeds and high mortality rate of plants in direct sowing of seed. The seedlings used for transplanting are raised in nurseries. Traditionally, vegetable transplants have been grown on raised beds either in greenhouses or in open field. Recently, growers have made the transition to greenhouse / nursery grown transplants using various types of containers, like plug trays of different sizes depending on the crop or plant species.

2.1.1 History

Plug trays are made of plastic and are partitioned into individual cells for growing seedlings of different horticultural crops. The plug trays have cells in which growing media is filled and one seed is placed in each cell manually. After seeding, the trays are regularly watered to raise the seedlings suitable for transplantation.

Walters (1981) reported that nurserymen can grow better stock using Hawaiian forestation system, in which tree and shrub seedlings are grown in dibbling tubes (about 5 inches (12.7 cm) deep and 11/8 inches (3.5 cm) in diameter at the bottom), which are filled with a mixture of sphagnum peat and vermiculite, and transported in racks each holding 100 seedlings. Guava, passion fruit, and pawpaw seedlings were reported to be grown successfully by this method.

Palmieri and Sonnino (1990) studied the trends and characteristics of nursery production of vegetable transplants and concluded that the rapid growth of this sector was the result of the advent of F1 hybrids and the development of the technology for growing seedlings in peat.

Vavrina and Summerhill (1992) conducted survey of vegetable transplant producers in Florida and found that majority (83%) of vegetable transplants were from three crops namely, tomatoes (45%), peppers (28%), and cabbage (10%).

Saiful Islam *et al.* (2002) compared the plug transplants with conventional cuttings with respect to the growth and development of the plant vegetation and storage roots, and yield of sweet potato under field conditions. It was reported that the overall yield of the plug transplants was greater than that of the conventional cuttings. It was reported that the high survival rate, up to (100%), and more rapid and uniform growth of intact plug transplants in the field were due to their established root system, whereas 15% of conventional cuttings died after planting in the field. It was also reported that plug transplants were likely to adjust to the field environment by minimizing transpiration rate, with reduced wilting, and initiation of absorbing roots and leaves earlier than conventional cuttings.

2.1.2 Growing Media

One of the most important aspects of plug production is the quality of growing media (Biernbaum, 1992; Styer and Koranski, 1997). For proper shoot and root growth, the root media must provide water, supply nutrients, permit gas exchange to, and from the roots, and provide support for the plants (Nelson, 1991). Also the media should not shatter during removal of seedling from the container to avoid shock to roots. Thus, acceptable physical properties are an integral part of growing media quality. However, there is no single growing medium that would work best in all situations because many of the key aspects of a medium's physical property are not constant, but rather can be affected by the grower. The distribution of air, water and solid in a container root media which affects seedling growth is dependent on several factors, like pore space, particle size distribution, container height, and media compaction.

The physical properties of root-medium are influenced by bulk density (Bunt, 1983; Beardsell *et al.*, 1979; Hanan *et al.*, 1981), particle size (Puustjarvi and Robertson, 1975) and container height (Fonteno, 1988; Milks *et al.*, 1989). Physical properties are also influenced by irrigation method, applied water volume, and media moisture content (Argo and Biernbaum, 1994; Beardsell and Nichols, 1982; Bunt, 1988; Airhart *et al.*, 1978).

Aoyama *et al.* (1987) reported 50:50 (by volume) mix of sandy clay loam and stable manure as the optimum soil type and 500 $ml \cdot day^{-1} \cdot tray^{-1}$ as the optimum amount of water for growing plug seedlings in a 72 cell plug tray suitable for use in automatic vegetable transplanter.

Saito *et al.* (1988) studied physical requirements of seedling blocks used in an automatic vegetable transplanter. The strength of soil blocks was greatly affected by the initial compaction level, the irrigation level and root growth. The amount of water added immediately before transplanting also had a great effect on the strength of a soil block .The desirable initial strength of the soil blocks was found between 2-5 $kgf.cm^{-2}$ in unconfined compression tests, which allowed roots of seedling plants grow rapidly until the time of transplanting.

2.1.3 Factors affecting plug seedling production

Suganuma and Iwase (1993) studied effects of plastic tray seedlings on the growth of summer cabbage and found that a 200-plug tray resulted in the same plant growth as a 128-plug tray. Young Hah *et al.* (1996) studied effect of low night time temperature in the nursery on growth of seedlings, field-grown plants and yield of tomatoes in late raising. It was reported that low night temperatures reduced the growth of seedlings and one-month old plants compared with control plants grown in moderate night temperatures, yet promoted flowering by 2 days and harvesting by 7 days compared with controls. The total and marketable yields increased by about 9 and 12%, respectively, compared with the control.

Seung Koo *et al.* (2001) conducted experiments to study the effect of plug cell volume and medium composition on rooting and growth of lateral shoot cuttings of tomato plant and found that rooting and growth were not influenced by a plug tray cell medium of 120 ml or more and rooting was 100% in all the growing media tested in the plug tray 30 ml volume.

Chen *et al.* (2002) studied the effects of cell shape (round, pentagonal, square and triangular cells with the same volume of growing medium) on the growth of plug transplants of lettuce, cucumber, tomato, and sweet corn. It was reported that square or pentagonal cells were more suitable for lettuce and cucumber plug transplants than round and triangular cells. Except triangular cells, the cells with other shapes were found suitable for the production of tomato plug transplant. The cell shape was not an important factor in sweet corn plug transplant production.

HyoHoon Nam *et al.* (2003) conducted experiments to determine the optimum method for seedling growth of bedding plants and found that a 200-cell plug tray was the most appropriate for producing high quality seedlings for a given unit area.

Bennett *et al.* (2004) compared three cell sizes and two cultivars of processing tomatoes to determine the effect of cell size on processing tomato seedling development, maturity, and earliness. Cultivars ‘O7983’ and ‘RG611’ were seeded into 200, 288, and 338 deep cell plug trays. This study showed no differences in yield or early emergence in the three cell sizes for both cultivars.

2.2 Mechanizing vegetable seedling transplanting operation

2.2.1 Need for mechanizing vegetable transplanting operation

Improving productivity or production efficiency is required to meet the growing national demand as well as to keep economically competitive in the global market. In developed countries mechanization in agriculture has released millions of agricultural workers for the industrial sectors, and has helped contribute remarkably to industrial expansion. Demand for food will continue to increase due to a constantly expanding population. Increased production is, therefore, required as cultivable land remains the same. As a result, there is a need to produce more within the shortest possible period of time, using minimum manpower and improved cultural practices.

One of the major constraints in increasing vegetable productivity is the low level of mechanization (Chatterjee *et al.*, 1995). Panwar *et al.* (2001) opined that the state of mechanization in vegetable crops in India is very dismal except potato. Mechanized cultivation, along with other improved crop production practices, can increase crop yield and quality. One cultivation practice that would benefit from mechanization in vegetable production is transplanting of good-quality seedlings of tomato, eggplant, cabbage, cauliflower, and chile peppers, among others (Clarke, 1997). Manual transplanting on a large commercial scale is labor intensive, expensive, and often does not result in uniform distribution of plants compared with mechanical transplanters (Orzolek, 1996). The labour requirement in manual transplanting of vegetable seedlings is as high as 253 man-h·ha^{-1} (Satpathy, 2003). Vegetable transplanting should always be done in the evening time so that plants establish in the cool weather at night and recover from the shock of transplanting before the sun comes up next morning. In addition, the transplanting should be completed as early as possible after removing the plants from the nursery (Chauhan, 2000). Vegetable crops are very sensitive to climatic conditions and require timely operations. However, labour shortage during peak season causes delay in transplanting, leading to drastic reduction in yields (Chaudhuri *et al.*, 2002). The manual transplanting work is very tiring and labour consuming and operation requires bending/sitting and squatting postures. The transplanting in bending posture requires an extra energy expenditure of 8 kJ·min^{-1} and increases the heart rate by 51 per cent (Nag *et al.* 1980). Vos (1973) observed that the bending posture followed in paddy transplanting has a harmful effect on spinal cord of the workers. It also required an extra energy expenditure of about 2 kcal·min^{-1} and increased heart rate by 35 per cent. Similar bending postures are also observed in manual vegetable transplanting operation. The manual transplanting also causes muscular fatigue to the operator due to long duration of squatting posture. Thus, transplanting is a tedious, time consuming and expensive operation and needs mechanization.

The operation of transplanting has not been completely mechanized. The transplanting operation requires a considerable amount of hand labor in pulling of the plants and setting them in the field. The results of transplanting are also not always satisfactory, in that stands may suffer high mortality or non-uniformity of growth. Reliable automation of transplanting operations has become important as labor costs will continue to rise. Huang and Splinter (1968) have studied the transplanting and subsequent growth of tobacco and cabbage and reported the following disadvantages for conventional transplanting: a) High labor requirement in a short period of time b) Weather often causes farmers to miss the best transplanting period, thus resulting in reduced yield c) During the transplanting operation, plant losses are to be expected and the missing plants need to be reset; therefore, extra labor is required d) Unavoidable human error results in non uniformity of stands and missing plants which consequently affects mechanical harvesting.

In India, the gap between potentially achievable and actual yields range from 26% to 72% for various crops (Subramanian *et al.*, 2000). This gap may be reduced by introduction of suitable vegetable transplanters and other improved crop cultivation practices that aid in precise placement of plants with little or no transplanting shock to the seedlings. This potential increase in yield can be significant considering that developing countries contribute 72% of the worldwide vegetable production (Segre, 1998).

2.2.2 Factors affecting vegetable transplanting operation

Various types of furrow opening and closing system for transplanter had been developed but the effect of soil parameters viz. bulk density, moisture content and machine parameters viz. speed of operation and transplanting configuration on success of transplanting has not been fully established. Johnson *et al.* (1964) reported that the effect of furrow closing system with respect to the soil as well as seedling transplanted by transplanting machine and environment are not yet fully established.

Huang and Splinter (1968) used two press wheel, set at an angle of 45° with respect to the ground and slightly inclined to line of travel in forward direction in order to bring press wheels normal closer to the seedlings without excessive compaction of soil. Another press wheel at the rear end of the transplanter covered the peat-potted plants effectively.

Salter *et al.* (1979) found that transplanting caused plant damage especially to the root system. This occurred in moving seedlings from the greenhouse bed or seed tray to the growing field which caused the plant and its root system to lose water by transpiration. It was reported that the damaged roots were unable to absorb enough water from the soil to regain their loss. This resulted in the plant becoming weak and further could not produce its own food material. It was found that the growth of seedlings was temporarily reduced, and maturity was delayed, causing less yield.

Pickett *et al.* (1981) used a soil covering device, in planting containerized tree and shrub seedlings which consisted of a cylinder, compaction blade, solenoid valve and flow control valve. This valve maintained covering and compaction blade in a retracted manner. On energizing solenoid valve, it operated cylinder of soil covering wheel, which moved the covering wheel blade to compress the soil around the transplanted seedlings.

Bosoi *et al.* (1987) designed and evaluated different designs of press wheel and reported optimum diameter of 450 mm and rim width of 80 mm. Suggs *et al.* (1987), used covering wheels set at an angle of 15º to the vertical to compress the soil around the roots and stems of the transplanted seedlings.

Munilla and Shaw (1987) developed high speed transplanter consisting of a pair of packing wheels mounted at an angle from vertical varying from 12º to 22º and a weight rack to provide additional pressure on the soil. They found that the optimal dead weight required to produce sufficient compaction of soil around the seedlings was 45.4 kg at optimal angle 15º of press wheels.

Werken (1991) evaluated press wheels with diameter of 400 mm and rim width of 60 mm with different loads of 100N, 250N and 500N, for finger tray automatic transplanting system. He found that weight of 500N on the press wheels was not desirable and weight of 100 N on the press wheel did not create desirable compaction near the seedling. Therefore, 250 N load was recommended. Data revealed that a parallel position of the compaction systems ensured the best results but it was not able to keep the seedlings in vertical position. The seedlings formed an angle of 20º with the vertical in the direction of the travel. Due to press wheels a kind of rotating effect was given to soil and plant between the compaction systems.

Fujiwara *et al.* (1999) studied the effects of the morphological and physical properties of cabbage plug seedlings on the adaptability to the fully-automatic transplanter for the improvement of labor saving of the transplant work. They found that the transplanting accuracy decreased by the occurrence of the vacant hill, excessive shallow planting and excessive deep planting was observed in the seedlings of breakable root ball, large hill spread, high flatness ratio and soft foliage. The occurrence of the excessive shallow planting and of the excessive deep planting increased by the small parachute effect in the soft seedlings and in the seedlings of a high flatness ratio. It was concluded that the small hill spread, fully formed rootball, low flatness ratio and the firm foliage are suitable properties for fully-automatic transplantation.

Nikhade (2001) evaluated different size of covering wheels (585 x 85 mm, 610 x 85 mm, 610 x 95 mm and 635 x 85 mm) mounted at angles of 5º, 10º and 15º with vertical, at moisture content 8% and 22% for its seedling establishment and soil compaction around seedling. Maximum erect seedling was 100%, and was obtained at 8% soil moisture content with 10º angle and at 20% soil moisture content with 15º angle, respectively with press wheel size of 585 mm x 85 mm and 610 mm x 85 mm, respectively. Minimum soil compaction was obtained for press wheel diameter of 635 mm with width of 85 mm set at an angle of 15º. The values were 0.23 $kg \cdot cm^{-2}$ and 0.54 $kg \cdot cm^{-2}$ at soil moisture content 8% and 20% respectively. Maximum soil compaction was obtained for press wheel diameter of 585 mm with width of 85 mm set at an angle of 5º. The values were 0.60 $kg \cdot cm^{-2}$ and 0.75 $kg \cdot cm^{-2}$ at soil moisture content 8% and 20%, respectively.

Landge *et al.* (2004) evaluated covering wheel of small diameter (300, 350 and 400 mm) with rim width of 50 mm mounted at an angle of 20º, 25º and 30º for use in narrow row transplanter. The minimum average values of lying down seedlings were found to be in moist soil (20.57% on dry basis), at 20º angle of inclination and 350 mm diameter of covering wheel and maximum in dry and loose soil (9.19% soil moisture) at 30º angle of inclination.

Geyer (2006) conducted study on the influence of the press wheels on bedding in quality of vegetable transplanter. Data revealed that various design parameters of press wheels such as weight, angle, distance between the wheels, width and diameter of wheels had significant effect on the pressure exerted by the soil on the seedling root. He found that by increasing the weight and by increasing angle of press wheels and reducing the distance between two press wheels and decreasing width of press wheels increased the pressure on the roots. Altering the diameter of press wheels had only a minor effect on soil pressure.

2.2.3 Transplanters for vegetable seedlings

Transplanters are designed based on seedling type to be transplanted and the mode of feeding seedlings. Vegetable transplanter generally consist of a furrow opener that opens a small furrow to a desired depth; a feeding and metering mechanism that feeds the seedlings and meters them to obtain the correct spacing in rows; place the seedlings vertically in a furrow or hole; and a furrow closing mechanism that covers the seedlings with a sufficient amount of soil, and firm the soil around seedlings.

Boa (1984) developed and evaluated the performance of an automatic transplanter for field vegetables. The transplants were raised in cylindrical blocks which are linked together by a continuous chain. The automatic machine was 3.5 times faster in forward speed than the fastest of the manual machines. Work rates of 1300-1700 plants per operator-hour were recorded with cabbages spaced 360 mm apart. With more-closely spaced crops the work rates were 15% faster, but headland turns and stops to replenish plant trays resulted in the overall work rates being 20-25% lower than the net rates.

Munilla and Shaw (1987) developed a high-speed dibbling transplanter for transplanting seedlings extracted directly from a commercial growing flat. The functions of dibbling the hole, withdrawing, and depositing the plants were all accomplished at zero relative velocity. However transplanter lacked an appropriate feeding device. Also, changing plant spacing needed design of new cams for each desired spacing.

Brewer (1990) developed an experimental single-row automatic transplanter which dropped bare-plug seedlings from shipping modules into static cassettes, then into rotating dibbles. Transplanting rates of 60 to 300 seedlings per minute were observed at 300 mm plant spacing. Short and sturdy seedlings were required for transplanting with automatic transplanter.

Suggs *et al.* (1992) developed an automatic feeding transplanter that automatically fed seedlings from the cell tray into a transplanting mechanism which transferred them to the furrow. Rods entered the bottom of the cells and pushed the plant root balls onto small planting rods which transferred the plant to the furrow. The mechanism operated effectively at speeds up to 3 cycles per second but some root balls disintegrated when pushed onto the planting rod and dropped the plant.

Nambu and Tanimura (1992) developed an automatic transplanter using chain pot for vegetable crops. The chain pot was made from two-ply sheets of paper joined together with water-resistant adhesive to form individual paper pots. Each pot was connected by a paper joint, which formed a “chain” of paper pots. Each joint had a perforated section which facilitated separation during transplanting. The transplanting mechanism had rotary planting fingers that advanced the chain of pots, separated the chain of potted seedlings into individual pots, and planted the individual potted seedlings.

Brewer (1994) conceptually modeled automated seedling transfer from growing trays to shipping modules of automated field transplanters. The design was conceptually modeled on a computer to correct the deficiencies of an experimental machine that ejected plugs from cells, gripped stems of seedlings and lifted them, transferred seedlings from tray to module, and dropped seedlings into a module. Projections from the conceptual model indicated that three 200-cell trays of seedlings can be transferred per minute.

Tsuga (2000) developed three models of riding-type, fully automatic vegetable transplanters. These prototypes were suitable for cell mould seedlings and pulp mould cell pot seedlings, mainly of leaf vegetables such as cabbage, Chinese cabbage, and lettuce. The prototypes enabled continuous transplanting work on two rows simultaneously, at a planting speed of 60 $\text{cells}\cdot\text{row}^{-1}\cdot\text{min}^{-1}$, with vegetable seedlings fed automatically. The working capacity per worker was approximately 10 acre.h^{-1}.

Choi *et al.* (2001) developed a new seedling pick–up device for vegetable transplanters that extracted 30 seedlings·min^{-1} with a success ratio of 97% using 23-day old seedlings from a 200-cell tray, and transferred them to a position from which they can be transplanted into the soil. The device consisted of a path generator, pick–up pins, and a pin driver. Operational parameters such as seedling age, approach direction of the pins, penetration depth of the pins into the cell, seedling holding method, and extracting velocity were examined using a prototype. The best performance was obtained when the pins penetrated into the root soil as deeply as possible. Sudden squeezing of the seedlings by the pins at the maximum depth of penetration worked better than gradual squeezing along the penetration depth.

Chaudhari *et al.* (2002) developed a two row semi-automatic tractor drawn finger type vegetable transplanter for transplanting of bare root nursery vegetable crops like tomato, brinjal, cauliflower, tomato, chilly etc. The field capacity of transplanter ranged from 0.08 to 0.10 ha·h^{-1}. Missing hills ranged from 2.85% to 9.33%, whereas percentage of seedlings in lying down position ranged from 4.0% to 13.43%. The estimated cost of the unit was ₹25,000. The operational cost of mechanical transplanting, when using a plant geometry of 600 mm x 450 mm, was between ₹2033-2594 ha^{-1} as compared to ₹2000-2300 ha^{-1} for manual transplanting.

Craciun and Balan (2005) used the seedling feeding cups with bottoms open and supported on a horizontal stationary plate that has an opening, into which the seedling is discharged. This type of planting device allowed the operator to place several seedlings rapidly and then have a brief time to untangle seedlings or remove seedlings from cells rather than having to maintain exact timing for each seedling (Parish, 2005). It is used for planting pot seedlings in a semiautomatic vegetable transplanter. The transplanter with this type of unit can plant 50-80 seedlings·min^{-1}·row^{-1} depending on the row spacing

Feng *et al.* (2000) used a horizontal belt conveyor driven from a soil ground wheel shaft for metering and feeding seedlings. Margolin *et al.* (1986) used a conveyor belt having series of cross-wire partitions (compartments), on which seedlings are placed. The conveyor delivers a seedling to split cone cups in a mulch planter or transplanting disc in a regular automatic transplanter by setting it in an upright position.

Many foreign companies manufacture vegetable transplanters for different seedling types (Holland Transplanter, Lännen Plant Systems, Mechanical Transplanter Co., Williames Hi-Tech International Pvt. Ltd, Ferrari Construzioni Meccaniche etc.). However, they are not imported for use by farmers due to their higher initial costs and resulting uneconomical scale of production.

Research studies to mechanize vegetable transplanting operation in India led to development of finger type semi-automatic vegetable transplanters suitable for transplanting bare root seedlings (Chaudhuri *et al.,* 2002; PAU, 2004). Most of the vegetable transplanters developed outside India relied on the use of new non-commercial growing schemes (Boa, 1984; Suggs *et al.,* 1992; Tsuga, 2000). This approach requires the nursery growers to modify their inventory in anticipation of the machine's eventual acceptance by the farmers. Therefore the transplanters relying on non-commercial growth media and/or container to achieve their feeding function are not used in India. Transplanters that will transplant the seedling type popular with the farmers are needed at the moment in India to mechanize the vegetable transplanting operation.

2.3 Performance evaluation

The field performance of vegetable transplanters depends on the feeding rate of the seedling, planting rate of the seedling planting unit, spacing between seedlings in a row, row spacing, and achievable optimum speed of operation to minimize missed plantings in addition to field, crop, and other operating parameters. Most researchers and manufacturers have reported data on planting rate and seedling feed rate rather than on field performance of machines. The performance of the vegetable transplanting machines have also been reported by researchers in terms of transplanting efficiency, field capacity, cost economics viz. payback period and breakeven point. The comparative performance of manual and mechanical transplanting in terms of human performance and economics has also been reported. However no test codes have been formulated by Bureau of Indian standards (BIS) till date for testing vegetable transplanters.

2.3.1 Successful transplanting

A successful vegetable transplanting system transplants the seedling upright and firms the soil around the roots without damaging it. Srivastava *et al.* (2006) opined that an important performance criterion for transplanters is that seedlings must be oriented properly and in good contact with the soil. Planting angle is an indicator of performance of transplanter because it affects the yield of the crop (Todoric, 1972). Planting angle is the angle of inclination of the plant with the ground and can also be expressed as angle of inclination of seedling from vertical. A successful planting has been defined as having seedlings inclined less than 30° from the vertical (Munilla and Shaw, 1987).

2.3.2 Field capacities and labour requirement

Punjab Agricultural University (2004) reported that for manual raised bed transplanting of eggplant, onion (*Allium cepa* L.), and chile pepper about 185-260 man-hours·ha^{-1} are required. Satpathy (2003) reported the average field capacity of the transplanter developed to be 0.093 ha.h^{-1} for transplanting tomato crop and 0.107 ha·h^{-1} for chilly crop at a forward speed of 1 km·h^{-1} and 1.2 km·h^{-1}, respectively. For flat transplanting by manual method about 320 man-hours·ha^{-1} are required for transplanting tomato at 600 mm row-to-row spacing and 450 mm plant-to-plant spacing (Central Institute of Agricultural Engineering [CIAE], 2004). The semiautomatic transplanters require significant hand labor to feed the seedlings and operate (Parish, 2005).

Tsuga (2000) reported that in Japan before the mechanization of transplanting operation, the time required for manual seeding and transplanting of vegetables accounted for about 40% of the total time required for cultivation of the crop. Kim *et al.* (2001) observed that in Korea, manual transplanting of Chinese cabbage (B. campestris L. var. Pekinensis) required 184 man-hours·ha^{-1}.

CIAE (2004) reported forward speed as 0.9 km·h^{-1} and field capacity as 0.1 ha·h^{-1} for planting tomato at a 600 mm row spacing and 450 mm in-row plant spacing using a tractor-drawn two-row semiautomatic transplanter with pocket-type planting unit. The suitable forward speed of operation for a two-row tractor-mounted semiautomatic transplanter with pocket-type planting unit developed at PAU (2004) was found to be from 0.9 to 1.1 km·h^{-1} for various crops in order to have minimum of missed transplantings. A rotary cup type planting unit on a semiautomatic transplanter allowed for higher forward speed than that of a pocket-type planting unit (Labowsky, 2001). An average forward speed of 1.4 km·h^{-1} and field capacity of 0.14 ha·h^{-1} for planting tomato, cauliflower, chile peppers and eggplant using a three-row semiautomatic transplanter with rotary cup–type planting unit has been reported (Tamil Nadu Agricultural University [TNAU], 2004).

2.3.3 Human performance in transplanting operation

The performance of the operator is affected by the man-machine interaction and is an important consideration for evaluating the machine. The performance has been quantified in terms of number of seedlings fed, number of seedlings missed, body part discomfort scores, mental fatigue etc. These factors affect the design of the machine and therefore these have been investigated by researchers.

Marr (1994) opined that the transplanter has to be operated at a speed that allows careful placement and attention to problems that develop. Operators should not be so involved in placing plants in the machine that they cannot watch for problems that develop. Increasing forward speeds of travel increased the percentage of missed plantings and necessitates that two labourers feed the single row to maintain the percentage missing within acceptable limits (PAU, 2004). For reasonable seedling spacing, the feed rate clearly limited the maximum allowable travel speed of the transplanting machine (Srivastava *et al.*, 2006). However, with fully automatic transplanters less than 3% missed plantings have been reported at forward operating speed of 1.2–1.4 km·h^{-1} (Tsunga, 2000). Kim *et al.* (2001) reported that the field capacity of a prototype two-row automatic transplanter for cabbage was 0.1 ha·h^{-1} with 3.5% missed plantings. Splinter and Suggs (1968) developed a theoretical model for man-machine system in repetitive loading operation. It was observed that the tendency of operator to commit errors in feeding the seedlings increased in an exponential manner with the increase in speed. Results indicated that the limited feeding rate should be 72 plants·min^{-1}. However, it was observed that the operators tend to commit errors even at very slow feeding rate of 45 plants·min^{-1}. It was also reported that in rejecting any undesirable plant present among the plants to be fed, the operator tend to skip the feeding of next plant.

Splinter and Suggs (1959) showed that human error increases exponentially with planting rate and, from a human engineering standpoint, the transplanting speed should be limited to less than 1.5 miles per hour. Raj (1979) measured the mental fatigue of the subjects working on semi-automatic potato planters. It was reported that both the physical as well as the mental load increased with the increase in planting frequency and seed size. However, increase in operation time resulted in increase of only the mental fatigue. Singh (1994) conducted ergonomic study on a revolving magazine type potato planter. The effect of seat with respect to seed hopper, seed rate and duration of work was studied on physiological parameters like heart rate, pulmonary ventilation rate and metering performance in terms of missings and doubles. It was found that the feed rates and duration of work had linear relationship with physiological parameters and number of missings and doubles. Height of seat with respect to the metering drum for the inclined angle of 130°-135° between forearm and upper arm caused lesser fatigue to operator.

Dixit (1996) conducted ergonomic study on belt and cup type semi automatic potato planter. The effect of vertical and horizontal location of operator's seat with respect to hopper, different forward speeds and also the subjects was studied on physiological parameters like heart rate, pulmonary ventilation rate and stress on eyes of the operator during feeding operation. It was concluded that the seat should be located such that the angle between thigh and lower leg should be near to 75° so that it does not create obstructions during potato feeding.

Jadhav (2006) conducted ergonomic studies to determine the effect of subjects, vertical distance of operator's seat from ground, horizontal distance of operator's seat with respect to rotary finger and speed of operation on the physiological response like heart rate, muscle potential, and psychological response i.e. stress on eyes for rotary finger type transplanter. The most comfortable arm posture (angle between upper arm and lower arm was 90°) was at minimum arm reach with middle seat position. At middle seat position stress on eyes was minimum due to the easiness in distinction of the rotary fingers. Miss transplanting increased from 0.11 to 9.06 per cent with increasing forward speed (0.5 - 1.5 $km \cdot h^{-1}$). Optimum operating parameters reported were forward speed of 1.0 $km \cdot h^{-1}$; vertical distance of operator's seat from ground equal to 750 mm; and horizontal distance of operator's seat with respect to rotary finger equal to half arm reach.

2.3.4 Cost economics of transplanting operation

Tsuga (2000) observed that in Japan the minimum economically suitable area for use of a two-row, fully automatic, self-propelled vegetable transplanter is 8.2 ha with annual coverage area of 53 $ha \cdot yr^{-1}$ for cabbage. Such large land holdings are very less in India. A survey conducted to assess mechanization gaps in seeding, planting and transplanting of vegetable crops indicated that Indian vegetable growers expressed desire for a low cost vegetable transplanter costing less than thirty thousand rupees (Chaudhuri *et al.,* 1999).

Kavitha *et al.* (2007) developed a programme in Microsoft Visual basic 6.0 to work out the feasibility and sensitivity analysis of transplanter and was coded as TRANSPRICE. It was used to predict either the average value or range of maximum cost of machine depending upon whether an average value or range of values were assumed for the different fixed cost, variable cost and other variables. The feasibility analysis was carried out for operating speed of the transplanter from 0.8 km·h^{-1} to 1.6 km·h^{-1} at different manual transplanting labour wages ($ 1.1 to $ 1.78 per day) and at varying labour requirement (30 to 40 man-days·ha^{-1}).They found that the machine is economically feasible in places where manual labour is at 1.56 $/day and labour requirement of 35 man-days·ha^{-1} and 40 man-days·ha^{-1} even when operated at 1.0 km·h^{-1}. Important parameters, which affected the cost of transplanter were field efficiency, forward speed of the machine, available labour cost for manual transplanting of vegetable crops and man-days required for manual transplanting of vegetable. If the parameters were changed by 5 and 10 per cent, it had a corresponding change i.e. increase or decrease of 20 and 40 per cent, respectively in expected cost of investment on the machine.

Prasanna Kumar and Raheman (2008), calculated the cost of traditional manual method of transplanting in India as ₹2,600 ha^{-1}assuming an average labour requirement of 260 man-hours·ha^{-1}. They also did break even analysis of two-row tractor mounted semi-automatic transplanter (developed by PAU, 2004), having different initial costs. The field capacity was assumed as 0.1 ha·h^{-1} and its initial cost was varied from ₹25,000 to 40,000 depending on accessories. It was found that for a transplanter costing ₹25,000, it was essential to operate for the minimum of 226 h (22.6 ha)·per year to justify its purchase For a transplanter costing ₹40,000, a minimum 310 h (31 ha) of annual use was required to justify its purchase. CIAE (2004) reported the cost of operation of a two-row tractor-mounted bare root seedling transplanter (initial cost ₹26,500) for tomato as ₹2,050 h^{-1} considering 300 h of annual use. Prasanna Kumar and Raheman (2008) opined these costs to be economically feasible only in large commercial vegetable farms and cooperative or contract farming areas, where tractors were used extensively. However, Sharma *et al.* (2004) opined that custom hiring through private entrepreneurs or co-operatives will help to increase annual use of such equipment thereby making them economical. In general, Indian farmers allocate a relatively small proportion of their land to vegetables (Birthal *et al.*, 2007) and land holdings of less than 2 ha (small holdings) dominate Indian agriculture. Small holdings comprise about 78% of the operational holdings and account for 34.2% of the land area (GOI, 2002). Assuming identical productivity among different farm sizes, smallholders contributed 61% of total vegetable production in India (Birthal *et al.*, 2007) which indicated that the yield of vegetables in small holdings was higher than the national average yield. Higher yield of vegetables in the small holdings may be attributed to higher labor input of the smallholders (Kumar *et al.,* 2004). Prasanna Kumar and Raheman (2008) opined that a hand tractor operated, low-cost, automatic transplanter with suitable feeding and planting units for paper pot seedlings may be a better option for mechanizing transplanting operations in vegetable cultivation in small holdings. However in this regard, horticulturists, engineers, and tray manufacturers will need to collaborate to make automated mechanical transplanting an accepted practice (Parish, 2005).

The perusal of the literature in this chapter thus reveals that a low-cost vegetable transplanter utilizing simple mechanism is needed at the moment in India, that may transplant the seedling type popular with the farmers (i.e. plug seedlings) to mechanize the vegetable transplanting operation. Physical properties of plug seedlings need to be studied to design the transplanter. Besides, the effects of soil and machine parameters on transplanting operation need to be studied in absence of such studies done in the past. Human performance is affected by the design, type of seedling handled and operating conditions. Therefore, human capabilities and field requirements need to be considered for designing the transplanter. A semi-automatic manually-fed transplanter would therefore be suitable for Indian farmers.

Chapter III

Materials and Methods

This chapter deals with materials used and methods followed in conducting research work. The study was planned to first determine design and operational parameters for successful transplanting of plug seedlings through soil bin studies. A prototype vegetable plug seedling transplanter was then developed based on the findings of soil bin studies. The study was conducted in the following sequence:

i. Determination of operating parameters affecting mechanical transplanting of vegetable plug seedlings
ii. Determination of relevant physical properties of tomato and brinjal plug seedlings
iii. Design and fabrication of experimental plug seedling transplanting mechanism
iv. Testing of experimental plug seedling transplanting mechanism in soil bin to obtain design and operational values for successful transplanting
v. Statistical analysis of data and selection of optimum operating conditions
vi. Design and fabrication of prototype plug seedling transplanter based on optimum design values and operating conditions
vii. Performance and economic evaluation of the developed prototype plug seedling transplanter for vegetable crops

3.1 Determination of operating parameters affecting mechanical transplanting of vegetable plug seedlings

A successful vegetable transplanting system should have mechanism to i) open soil in form of furrow or a small pit, ii) placing plug seedling vertically upright in it and iii) closing and compacting soil around the root plug without damaging it. Such transplanting mechanisms either include conical cup or furrow opener to open soil for placement of plug seedlings in it and press wheels or compacting plates for closing and compacting the soil around the root plugs. It is difficult to feed and change spacing within the plug seedlings using a conical cup type transplanting mechanism as it requires varying the number of conical cups, changing cam shape or not feeding intermittent cups. Use of furrow opener to open soil, then placement of seedlings at desired spacing in it and subsequent furrow closure using a press wheel or compacting plate (ski type device) is possible using simple mechanisms. However, soil and machine operating parameters affect this method of mechanical transplanting and therefore need to be investigated to find out the optimum operating conditions for successful vegetable transplanting. Based on the literature reviewed, the major soil and machine parameters that affect soil cleavage opened by furrow opener are moisture content, bulk density of soil and forward speed of travel. These operating parameters also affect subsequent furrow closure and compaction of soil around the root plug.

3.2 Physical properties of tomato and brinjal plug seedlings

The easy passage of plug seedlings through seedling feed tubes without getting stuck and its subsequent vertical placement in furrow opener is influenced by the physical properties of plug seedlings such as canopy diameter, overall geometric dimensions and drop shatter height of the root plug. The size of root plug, stem length and canopy of plug seedlings govern the furrow opener size, depth of transplanting and the gap between the furrow closing cum compacting device. Also, these properties were used to achieve geometric and dynamic similarity with actual seedlings in form of dummy seedling for use in soil bin studies. The physical properties of tomato and brinjal plug seedlings relevant for simulating actual seedlings and the design of prototype transplanting unit were determined as follows:

3.2.1 Size, shape and weight

The size and shape of the plug seedlings canopy is important in determining the inner diameter of the seedling feed tubes and the chute. The size of the canopy of plug seedlings was specified by the critical canopy diameter and is defined as the minimum inner diameter of a circular pipe through which a healthy plug seedling, suitable for transplanting, can pass vertically without getting stuck. The diameter of the seedling feed tubes and the chute should be bigger than the critical canopy diameter to avoid any blockage in seedling feed tubes. Also, the diameter should not be unnecessarily much larger than critical canopy diameter as it reduces the parachute effect necessary for smooth dropping of seedlings into the furrow opener. The geometric dimensions and the weight distribution of root plug seedlings, stem and canopy were recorded along with critical canopy diameter for 10 randomly selected tomato and brinjal seedlings from the nursery with three replications each (Appendix A-1). Readings were taken using a vernier caliper up to an accuracy of 1 mm and digital weighing balance up to 1 gm accuracy. The average values for tomato and brinjal were used to fabricate geometrically and dynamically similar dummy seedlings (Plate 2) (Appendix A-2). Generally one month old seedlings are suitable for transplanting; however 45 day old tomato and brinjal seedlings were used to find the critical canopy diameter, to provide allowance for over grown older seedlings for delayed transplanting. The seedlings were dropped through PVC pipe of diameter 40, 50 and 60 mm to find critical canopy diameter. The critical canopy diameter is less than the actual maximum canopy diameter since seedling canopy, being flexible adjusts, itself to pass through hole of comparatively smaller size.

3.2.2 Drop shatter height

One month old healthy plug seedlings of tomato and brinjal having good root growth were used to determine the drop shatter height. On dropping seedlings in furrow opener the media generally gets shattered, which tend to clog the pusher mechanism. The drop shatter height is the maximum height of fall of plug seedlings on a flat M.S. plate which caused less than 25% of root media disintegration. The seedlings were dropped from increasing heights (200 mm to 500 mm) and respective root media disintegration in terms of reduction in weight of plug seedling was recorded. A graph of height versus root media disintegration was plotted and height corresponding to 25% root media disintegration (by weight) was selected as drop shatter height (Appendix A-3).

3.3 Design and fabrication of experimental setup

The experimental setup was designed and tested in soil bin. The different components of the setup were as follows:

i) Experimental transplanting mechanism - Fig. 4.1
ii) Furrow opener – Fig. 4.2
iii) Furrow closing cum compaction mechanism
    a) Press wheel furrow closing cum compaction device – Fig. 4.3
    b) Ski type furrow closing cum compaction device – Fig. 4.4
iv) Dummy seedlings- Plate 2.

The design and the material of construction of each component of experimental setup are discussed briefly in Chapter IV.

3.4 Soil bin experiments on transplanting mechanism

Soil bin experiments were conducted on transplanting mechanism to study the effect of soil parameters viz. moisture content, bulk density and machine parameters viz. speed of operation on furrow closure, uniformity in spacing and success of transplanting plug seedlings. Based on review and work requirement, different levels of independent and dependent parameters were selected and calculated, as given in Table 3.1. Observations for angle of inclination of stem with vertical, proper furrow closure and plant spacing were recorded for 36 different factorial combinations of speed of transplanting, moisture content and bulk density of soil using two experimental transplanting machine configurations. The transplanting machine configurations consisted of two independent furrow opening and closing mechanisms viz. i) shoe type furrow opener with press wheel furrow closing cum compaction system ii) shoe type furrow opener with ski type furrow closing cum compaction system. These were attached to a carriage mounted on soil bin rails and driven by endless winch-rope mechanism at forward speeds of 0.28, 0.49 and 0.69 $m \cdot s^{-1}$. The depth of transplanting could be varied by changing depth of operation of furrow openers. The soil in soil bin was prepared to proper tilth using rotary tiller. The desired moisture content and bulk density were obtained by spraying water on soil, pulverizing it using rotary tiller, levelling and then compacting soil using leveling blade and roller, respectively. Plant spacing between seedlings was kept 900 mm to enable manual feeding of dummy seedlings at higher speeds (0.69 $m \cdot s^{-1}$). Weights were added to the press wheel and the angle of ski with the horizontal surface was increased in trial runs until proper furrow closure was obtained.

3.4.1 Moisture content

The desired soil moisture content levels of soil were obtained in soil bin by spraying water in small increments using a boom sprayer and subsequent measurement of soil moisture content. Three soil samples of top 100 mm soil layer were randomly taken along the length of soil bin using a core sampler. The instant measurement of moisture content was done using microwave drying method, which was calibrated against the oven dry gravimetric method for moisture content determination of sandy loam soil, for acceptable accuracy. A cumulative three minutes intermittent microwave heating of 200 g soil sample was done with twenty seconds exposure at a time with power level setting of 210 W (i.e. 1.05 W/g of soil sample).The soil sample was kept in glass dish on turn table of microwave for uniform exposure to microwaves and drying of soil sample. The soil samples were weighed using a digital weighing balance with accuracy of 0.01g. Moisture content (% db) was determined using following formula:

$$M.C. = \frac{(w_i - w_f)}{w_f} \times 100 \qquad (3.1)$$

Where

$M.C.$ = moisture content , % dry basis
w_i = initial weight of soil sample, g
w_f = final weight of dried soil sample, g

3.4.2 Bulk Density

The desired bulk density of soil was obtained in soil bin by multiple passes of compaction roller and subsequent measurement of soil bulk density. Random three soil samples of top 100 mm soil layer were taken along the length of soil bin using a core sampler. Bulk density of soil was calculated on dry basis using following formula:

$$B.D. = \frac{W_s}{V_c} \qquad (3.2)$$

Where

B.D. = bulk density, $Mg \cdot m^{-3}$, ($g \cdot cm^{-3}$)
W_s = dry weight of soil sample, g
V_c = Volume of core sampler, cm^3

3.4.3 Angle of Inclination

The angle of inclination of the stem of dummy seedling was measured using a steel protractor having accuracy of 1^o. The protractor was kept on the soil bin rail with its base parallel to the rail. The protractor arm was adjusted to keep it visually in line with the stem line of the transplanted dummy seedling. A seedling was counted to be successfully transplanted if its stem was inclined less than 30° from the vertical.

3.4.4 Furrow closure

For a seedling to be counted as successfully transplanted, in addition to angle of inclination of stem from vertical, the plug of the seedling must be covered and compacted properly with soil. The furrow was said to be properly closed if the root plug of the seedling was not visible and covered completely with soil. Visual observations for furrow closure were recorded as "1" for proper furrow closure and "0" for the rest.

Table 3.1 Experimental plan for soil bin testing of experimental transplanting configurations

Sr. No.	Independent Parameters	Levels
	Soil Parameters	
1.	Moisture content of soil, % (db)	M1 = 6 M2 = 9 M3 = 12 M4 = 15
2.	Bulk density of soil, $Mg{\cdot}m^{-3}$ (db)	B1 = 1.10 B2 = 1.30 B3 = 1.45
	Machine Parameters	
3.	Machine configuration	A) Ski type B) Press Wheel type
4.	Speed of travel, $m{\cdot}s^{-1}$, ($km{\cdot}h^{-1}$)	S1 = 0.28 (1) S2 = 0.49 (1.75) S3 = 0.69 (2.5)
Replications		3
Number of experiments		4 x 3 x 2 x 3 x 3 = 216
	Dependent Parameters	
	Observations recorded for each seedling	**Units**
1.	Angle of inclination of seedling from vertical	degrees
2.	Furrow closure	(1-proper,0-improper)
3.	Transplanted	(1- ok, 0- not transplanted)
4.	Plant spacing	mm
	Performance parameters calculated	
1.	Successfully transplanted seedlings	% of total seedlings
2.	Transplanted seedlings	% of total seedlings
3.	Proper furrow closure	% of total seedlings
4.	Unsuccessful transplanting due to	Angle of inclination
	i) improper furrow closure	degrees
	ii) higher angle of inclination of seedling	degrees

3.4.5 Plant spacing

Plant spacing of 900 mm was targeted to enable manual feeding of dummy seedlings at higher speeds ($0.69\ m\cdot s^{-1}$). The distance between the stems of transplanted dummy seedlings was measured with accuracy of 5 mm using a steel tape. The distance was measured at closed furrow surface level.

3.5 Data analysis

The analysis of the experimental data was done in three stages as follows:

i) Calculation of performance parameters

ii) Statistical analysis of the calculated performance parameters using SAS software

iii) Selection of optimum operating soil and machine parameters for maximum successful transplanting

The observed data was arranged to obtain i) per cent seedlings successfully transplanted (ST_P and ST_S), i.e. seedlings transplanted with inclination less than 30° from vertical and furrow properly closed, ii) per cent of proper furrow closure observed around seedling (FC_P and FC_S) iii) per cent seedlings transplanted (TR_P and TR_S), i.e. per cent of seedlings transplanted at any inclination from vertical, with or without proper furrow closure and shoot not buried partially or completely in soil and iv) uniformity in spacing between transplants, for both transplanting mechanisms (Appendix B-2). Arcsin square root transformation was done to normalize the per cent data prior to statistical analysis. The analysis of data was done using statistical package SAS at 1% level of significance. Independent statistical linear models were fitted to arcsin square root transformed dependent variables (Y) viz. successfully transplanted (ST_P and ST_S), furrow closure (FC_P and FC_S), and transplanted (TR_P and TR_S), as a function of moisture content (M), bulk density of soil (B) and speed of transplanting(S) and their interactions (M x B; M x S; B x S; M x B x S). Analysis of variance (ANOVA) was done for dependent variables and statistical parameters viz. R^2 and p-value were used to analyse the effect of independent variables. All possible pair wise comparisons of factor levels were done using least significant difference (LSD) to find out significantly different means. Optimum operating conditions of forward speed of transplanting, desirable moisture content and bulk density of soil were determined on the basis of statistical analysis result obtained for both the transplanting mechanisms.

The action of transplanting dummy seedlings was captured using a digital camera at the rate of 25 frames per second. This video file was cut into frames and analyzed using “Windows Movie Maker” software for the soil movement pattern, orientation of root plug dropped in furrow opener, seedling ejection from furrow opener, relative motion of seedling with soil, proper furrow closure and the manual feeding action of dummy plug seedlings.

3.6 Design and fabrication of prototype vegetable plug seedling transplanter

Based on the optimum operating conditions determined by data analysis and the requirements for proper transplanting, a prototype vegetable plug seedling transplanter was first designed and then fabricated accordingly. Design of experimental transplanting mechanism was modified to enable transplanting at varied plant spacings. Pre-modeling analysis was done using visual basic macro programming in “Microsoft Excel”, “Working model 2005” and “Engineering power tools” software. Part modeling, assembly and drawings were prepared using CAD software “Pro Engineer Wildfire 4.0”. The assembled prototype vegetable plug seedling transplanter, along with its components is shown in Fig. 5.2 and Plate 4. The design considerations and other details of the components are discussed briefly in Chapter V.

3.7 Performance evaluation of prototype vegetable plug seedling transplanter

The prototype vegetable transplanter was tested for transplanting one month old healthy tomato (variety- Himsona) and brinjal (variety - Pusa Uttam) plug seedlings over 0.1 ha for each crop (Plate 5 and Plate 7). The transplanter was operated at 0.44 $m \cdot s^{-1}$ (1.6 $km \cdot h^{-1}$) for recommended plant to plant and row to row spacing of 600 mm x 1200 mm, respectively for the varieties transplanted. Various performance parameters were calculated as follows:

3.7.1 Seedling mortality

To assess the damage to seedlings during mechanical transplanting, a control plot of 0.02 ha was transplanted manually with seedlings grown in same batch (Plate 6). Observations for mortality of seedlings occurring within three days after transplanting were recorded for both manually and mechanically transplanted seedlings. The seedling mortality was calculated considering equal number of plug seedlings transplanted in both manual and mechanical method as follows:

$$M = \frac{(S_{manual} - S_{mech})}{S_{total}} \times 100 \qquad (3.3)$$

Where

M =Seedling mortality, %

S_{manual} = Number of seedlings died within 3 days after manual transplanting

S_{mech} = Number of seedlings died within 3 days after mechanical transplanting

S_{total} = Total number of seedlings transplanted in mechanical transplanting

3.7.2 Plant spacing uniformity

Spacing between transplanted seedlings was recorded to calculate the uniformity in spacing. The average plant spacing was calculated along with standard deviation as indicator of spacing uniformity.

3.7.3 Transplanting efficiency

The transplanting efficiency was determined by the ratio of seedlings inclined less than 30° from the vertical and proper soil compaction around roots to the total number of seedlings transplanted. The angle of root plug axis of seedling with vertical was taken if the stem of seedling was not straight.

$$TE = \frac{S_{st}}{S_{total}} \times 100 \qquad (3.4)$$

Where

TE = Transplanting efficiency, %

S_{st} = Number of seedlings successfully transplanted with angle of inclination less than 30° from the vertical and proper soil compaction around roots

S_{total} = Total number of seedlings transplanted

3.7.4 Field efficiency of transplanter

Field efficiency of transplanter was determined by the ratio of the time required to actually transplant the seedlings to the total time required for completing the transplanting operation in field. The results are presented in the Table 5.2.

$$FET = \frac{T_{tr}}{T_{total}} \times 100 \qquad (3.5)$$

$$T_{total} = T_{tr} + T_{tu} + T_o \qquad (3.6)$$

Where

FET = Field efficiency of transplanter, %

T_{tr} = time required to actually transplant the seedlings, min.

T_{tu} = time required for taking turns at headland, min.

T_o = time required for initial adjustments, loading unloading plug trays,etc, min.

T_{total} = total time required to complete the transplanting operation in field, min.

3.7.5 Per cent miss in transplanting

The seedling feed tubes that were missed to feed by the operator, results in wide spacings between consecutive transplanted plug seedlings and was expressed as the per cent miss in transplanting. Per cent miss in transplanting was calculated using formula

$$\% miss = \frac{S_m}{S_f + S_m} \times 100 \quad (3.7)$$

Where

$\% miss$ = Per cent miss in transplanting

S_m = Number of seedlings missed by operator to feed in seedling feed tubes

S_f = Number of seedlings fed by operator in seedling feed tubes

3.7.6 Cost economics

The developed prototype of two-row tractor mounted vegetable plug seedling transplanter was compared with manual method for its economic feasibility and subsequent acceptability by vegetable growers. The projected transplanting field capacity and cost economics for different transplanting geometries were calculated as given in Table 5.3. The assumptions and calculations to determine estimated cost of two-row tractor mounted vegetable plug seedling transplanter are given in Appendix C. The total cost of operation was determined based on total fixed cost and variable costs. The total hourly cost of operation of the vegetable transplanter was calculated including the hourly cost of operation of matching tractor. It was converted into cost required for transplanting 10000 seedlings instead of on area basis for comparison with manual method, since transplanting geometries differed with plant type. The cost economics was calculated for ownership by the farmer and custom hiring basis. The break even period and payback period were also calculated.

3.8 Operation of vegetable plug seedling transplanter in field

The row spacing between the two transplanting units was adjusted by sliding and clamping them on the hitching frame square bar which was attached to the three point linkage of tractor. The minimum spacing of 450 mm could be maintained between two rows. The recommended plant spacing was achieved using the respective indexing plates (300, 450, 600, 900 mm). The operator loaded the seedling feed tubes with seedlings first. The whole transplanting unit is lowered completely using hydraulic depth control lever of tractor to begin transplanting as the tractor moved forward. The speed of travel was adjusted to match with feeding rate manageable by the operator. Operator fed seedling from seedling tray to intermittently rotating feed tubes. The whole transplanting unit was raised using hydraulic depth control lever during turns at the head land.

3.9 Time and motion study of vegetable plug seedlings transplanting operation

Time and motion study of manual transplanting of tomato, cabbage and brinjal seedlings were done at different locations in western Maharashtra and at IARI, New Delhi during the period between 2007 to 2010. The study was also done for the mechanical transplanting operation for tomato and brinjal plug seedlings using the developed two-row vegetable transplanter. The details about field, crop transplanted, labour and time spent for seedling placement, transplanting, feeding seedlings to metering tubes and other activities performed during manual and mechanical transplanting operation of the plug seedling were recorded (Table 6.1.a and 6.1.b). The details of the time and motion study of vegetable plug seedling transplanting operation are discussed in Chapter VI.

Chapter IV

Soil Bin Studies on Experimental Transplanting Mechanism for Vegetable Plug Seedlings

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4.1 Abstract

A successful vegetable transplanting system includes furrow opening and covering mechanism that transplants the seedling upright and firms the soil around the roots without damaging it. Many commercial vegetable transplanters are available outside India; however scientific study relating to transplanting mechanism and the factors affecting it has not been done. The present study was conducted in soil bin, to study the effect of soil parameters viz. bulk density, moisture content and machine parameters viz. speed of operation and transplanting configuration on furrow closure, angle of inclination of seedlings, success of transplanting and uniformity in spacing of plug seedlings in sandy loam soil. Observations for angle of inclination of stem with vertical, furrow closure and plant spacing were recorded for 36 combinations of speed of transplanting, moisture content and bulk density of soil for transplanting dummy seedlings using two experimental transplanting configurations. The soil and machine parameters significantly affected furrow closure and successful transplanting but not the uniformity in spacing of plug seedlings, for both press wheel and ski type transplanting configurations tested. Non-successful transplanting was observed to occur mainly because of higher angle of inclination of transplanted seedling in press wheel type of machine configuration and improper furrow closure in case of ski type machine configuration. Highest speed of travel suitable for successful transplanting was found to be 0.49 $m \cdot s^{-1}$ (1.75 $km \cdot h^{-1}$) with in moisture content range of 6% to 15% (db) at higher bulk density (1.45 $Mg \cdot m^{-3}$). In general, vegetable transplanting mechanism, consisting of shoe type furrow opener and pushing mechanism resulted in higher per cent of successful transplanting of plug seedlings with press wheel furrow closing cum compaction system than ski type furrow closing cum compaction system in sandy loam soils.

Keywords: Soil bin, vegetable transplanter, plug seedlings

4.2 Introduction

Vegetable transplanters are designed based on seedling type to be used. Seedlings of high value vegetable crops such as tomato, capsicum, cucumber, broccoli, brinjal, chilies etc are now being widely grown in plug trays by a large number of farmers in India for obvious advantages over bare root seedlings. Commercial vegetable transplanters for bare root and plug seedlings are available in several countries but are not popular in India mainly due to higher cost (Chaudhuri *et al.*, 1999) . A successful vegetable transplanting system transplants the seedling upright and firms the soil around the roots without damaging it. Srivastava *et al.* (2006) opined that an important performance criterion for transplanters is that seedlings must be oriented properly and in good contact with the soil. A successful planting has been defined as having seedlings inclined less than 30° from the vertical (Munilla and Shaw, 1987). Vegetable transplanter generally consists of a furrow opener that opens a small furrow to a desired depth; a metering mechanism that meters the seedlings to obtain the correct spacing in rows; place the seedlings vertically in a furrow or hole; and a furrow closing mechanism that covers the seedlings with a sufficient amount of soil, and firm the soil around seedlings. Opening of clear slit in soil is affected by furrow opener size, shape, soil moisture, bulk density and speed of operation. Once the seedling has been placed in the furrow, the furrow closing mechanism has to cover the roots of seedling and firm the soil around it. The furrow closing is also affected by soil moisture, bulk density, and speed of operation.

Transplanting efficiency could be increased by increasing the number of erect seedlings during the field operation. Finger type vegetable transplanter holds the seedling erect until the roots placed in furrow is covered and compacted by the press wheels. However such mechanism is more suitable for long bare root seedlings as there is possibility of soft stalked plug seedlings like tomato to break due to self weight of plug. Transplanters with pushing mechanism that pushes the plug seedling into furrow are commonly used for transplanting plug seedlings. Furrow opening and closing are critical components of mechanical transplanting process. Various types of furrow opening and closing system for mechanical transplanting have been developed but the effects of soil parameters viz. bulk density, moisture content and machine parameters viz. speed of operation and transplanting configuration on success of transplanting have not been adequetly established. Johnson *et al.* (1964) reported that the effect of furrow closing system with respect to the soil as well as seedling transplanted by transplanting machine and environment are not yet fully established.

Bosoi *et al.* (1987) designed and evaluated different designs of press wheel and reported optimum diameter of 450 mm and rim width of 80 mm. Suggs *et al.* (1987) used covering wheels set at an angle of 15° to the vertical to compress the soil around the roots and stems of the transplanted seedlings. Munilla and Shaw (1987) developed high speed transplanter consisting of a pair of packing wheels. mounted at an angle from vertical varying from 12° to 22° and a weight rack to provide additional pressure on the soil. They found that, the optimal dead weight required to produce sufficient compaction of soil around the seedlings was 45.4 kg at optimal angle 15° of press wheels. Werken (1991) evaluated press wheels with diameter of 400 mm and rim width of 60 mm with different loads of 100 N, 250 N and 500 N, for finger tray automatic transplanting system. He found that weight of 500 N on the press wheels was not desirable and weight of 100 N on the press wheel did not create desirable compaction near the seedling. Therefore 250 N load was recommended. Data revealed that a parallel position of the compaction systems ensured the best results but it was not able to keep the seedlings in vertical position. The seedlings formed an angle of 20° with the vertical in the direction of the travel. Geyer (2006) conducted study on influence of the press wheels on bedding in quality of vegetable transplanter and concluded that various design parameters of press wheels such as weight, angle, distance between the wheels, width and diameter of wheels had significant effect on the pressure exerted by the soil on the seedling root. He found that by increasing the weight and by increasing angle of press wheels and reducing the distance between two press wheels and decreasing width of press wheels increased the pressure on the roots. Altering the diameter of press wheels had only a minor effect on soil pressure.

The most common type of furrow closing cum compaction system used in many commercial models of vegetable transplanters available outside India is rolling type press wheel. However ski type furrow covering and compaction system are also being used in many commercial models of vegetable transplanters, for its simple and compact design. No studies have been carried out on performance of ski type furrow covering cum compaction system for transplanter in comparison to commonly used rolling type press wheels in sandy loam soil which is largest and important soil group of India. The studies conducted have only been concentrated to design parameters viz. diameter, width and inclination of press wheels used for covering and compaction system. Studies on effect of covering system with regard to proper furrow closure, variation in spacing of transplants and success of transplanting, are limited. Most researchers and manufacturers have reported data on planting rate and seedling feed rate rather than on performance of machines. There is a need to study the effect of soil and machine parameters on success of transplanting. Also there is need to evaluate other designs like ski type furrow closing mechanism in comparison to press wheel furrow closing mechanism in order to obtain the best design and optimum field operating conditions to achieve maximum successful transplanting in sandy loam soils. The understanding of transplanting process would help in further design refinements of the transplanting mechanisms. The objective of the work reported in this paper is to study the effect of soil parameters viz. bulk density, moisture content and machine parameters viz. speed of operation and transplanting configuration on performance of transplanting mechanisms in sandy loam soil and to suggest optimum field operating conditions to achieve maximum successful transplanting at higher transplanting rates. Two machine configurations for opening and closing furrow were tested for its performance in terms of successful transplanting and uniformity in spacing.

4.3 Materials and Methods

The experimental setup consisted of two independent furrow opening and closing mechanisms viz. i) shoe type furrow opener with press wheel furrow closing cum compaction system ii) shoe type furrow opener with ski type furrow closing cum compaction system. The experimental setup was attached to a carriage mounted on soil bin rails and driven by endless winch-rope mechanism at forward speeds of 0.28, 0.49 and 0.69 $m \cdot s^{-1}$. The depth of transplanting was varied by changing depth of operation of furrow openers.

4.3.1 Design and construction of experimental setup

4.3.1.1 Transplanting mechanism

To avoid shattering of plug and damage to the seedling, the seedling should be ejected from the furrow opener in the opposite direction with the same velocity of forward travel of the transplanter. This would also help to keep the seedling in vertical position. To achieve this, a mechanism consisting of a pusher driven by roller chain was designed and developed. The pusher pushes the seedling at regular intervals into the furrow at the same forward speed of the transplanter but in the opposite direction ($V_P = -V_F$). It consisted of chain and sprocket mechanism running parallel and above pusher (Fig. 4.1). The pusher was mounted on a sliding rail with a clamp, such that it could move to and fro in the furrow opener. An indexing pin was fixed in the roller chain revolving around two sprockets at the velocity equal to forward speed of travel of the transplanter ($V_C = -V_F$). The length of roller chain was kept 900 mm so that the indexing pin locked into the clamp and carried the pusher along with it every 900 mm of forward travel, maintaining a spacing of 900 mm between transplants. When the clamp reached the end of stroke, the indexing pin got disconnected with the clamp while moving along the perimeter of the sprocket. A return spring was used to pull the clamp to its original position. This mechanism ejected the seedlings from furrow opener in vertical position, with very little relative motion between seedling and the soil. The roller chain was driven by the sprocket mounted on the shaft of carriage wheels.

4.3.1.2 Furrow opener

For proper scouring, the soil failure plane should not occur before the edge AB which is possible for α greater than $(90+Ø)°$,where Ø is angle of soil-metal friction and β less than $(90-Ø)°$ (Fig. 4.2). The maximum value of Ø for sandy loam soil and steel is 27° (Gill *et al.* 1967 and Bernacki, 1972). Therefore a shoe type furrow opener with $\alpha = 135°$, $\beta= 60°$ and length more than stroke of pusher was fabricated using mild steel sheet. The sheet metal used for furrow opener should be sufficiently thick enough to resist deformation of shape, failure and with stand abrasion and wear throughout its intended life. The cross-section of the furrow formed by furrow opener should not be more than the plug size, so that the furrow wall supports the seedlings vertically straight after being ejected from the furrow opener. Therefore, the value of γ was kept equal to that of plug shape (30°), so that the side walls of furrow opener holds the seedling plug vertical as it falls into it. This would also helps in opening the furrow of same cross-section of seedling plug, assuming proper scouring of soil. The furrow opener was hardened using oil quenching and polished to reduce friction and adhesion of soil to its surface.

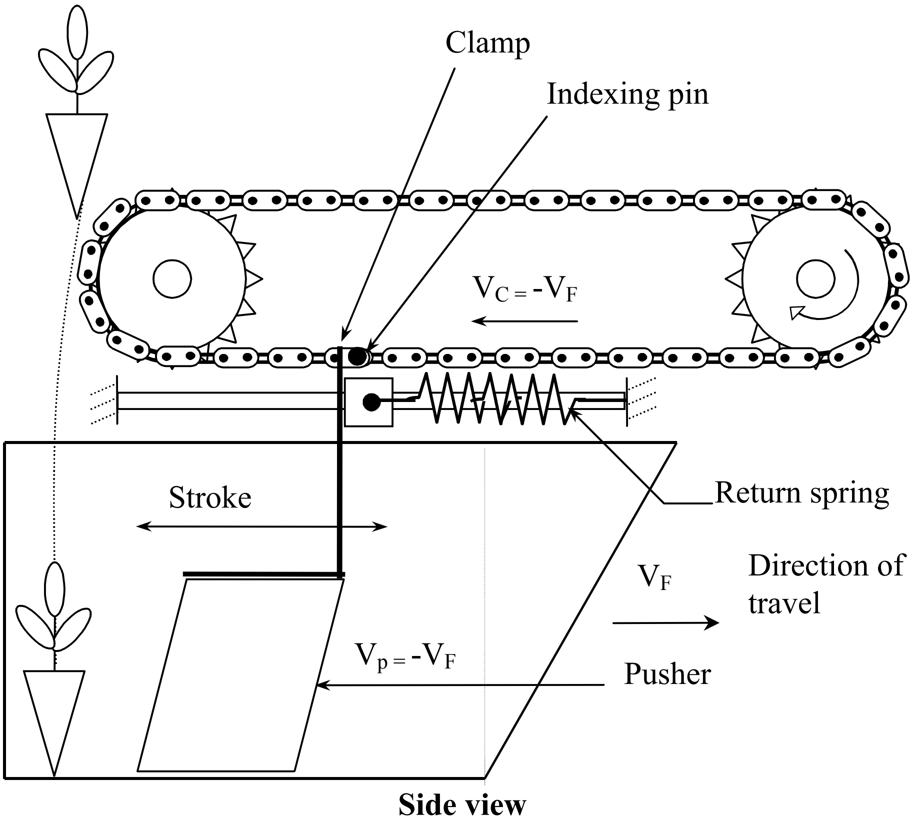

Fig. 4.1: Experimental transplanting mechanism

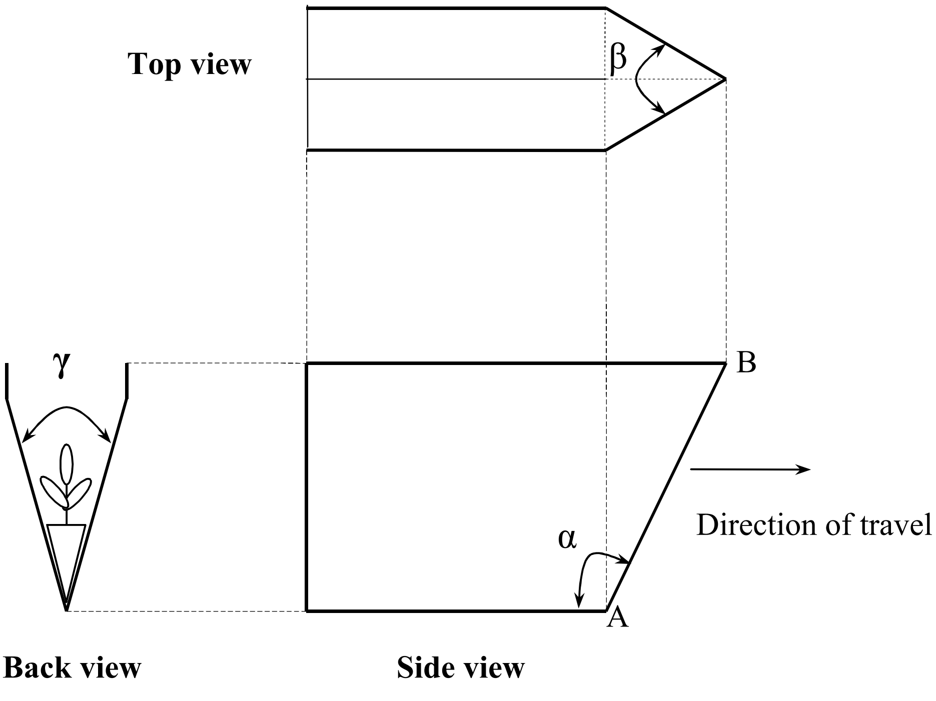

Fig. 4.2 : Furrow opener

4.3.1.3 Furrow closing cum compaction mechanism

Two mechanisms for furrow closing cum compaction viz. press wheel and ski type were designed keeping the following considerations in mind:

The size of furrow closing cum compaction mechanism should allow narrow row transplanting. It should cover the roots of the seedlings with soil completely, and subsequently compact the soil around the seedling without damaging its leaves, stem and roots. Therefore the compaction pressure exerted by furrow closing cum compaction mechanism should be less than the crushing strength of the seedling. However the compaction pressure should also be sufficient enough to establish good root soil contact. The furrow closing cum compaction mechanism should ensure vertically erect transplanting of seedlings. This is possible if the furrow is closed immediately after the seedling is ejected from the furrow opener in vertical position and compaction forces are perpendicular to the closed furrow surface.

i) Press wheel furrow closing cum compaction device

It consisted of two press wheels of diameter 350 mm and width 50 mm, mounted on axle bent downward and backward to obtain angles γ and δ (Fig. 4.3). The forces (F_C) in the contact surface between the wheel and the soil (Fig. 4.3) represent what might be considered a reasonable distribution. The lengths of the vectors represent the magnitude of the envisioned forces. The angle γ was kept equal to that of plug shape (30°) so that the press wheel exerts compaction forces (F_C) along the edges of plug (Fig. 4.3-Back view). However rotating press wheel would also exert compaction forces on soil as shown in side view (Fig. 4.3-Side view). This variability in force tends to tilt seedlings forward in the direction of motion of transplanter. However this tilting effect may not be transmitted to whole area of soil disturbed by press wheel. The tilting effect would be limited to the top layer and soil in near vicinity of area in contact with press wheel.

This effect being transmitted to the seedling can be reduced by providing angle δ (16°), such that the press wheels spread apart in front and come closer at back (Fig. 4.3-Top view). The part of press wheel coming in contact with soil at the beginning, now would be spaced wide apart, due to which the tilting effect occurring would not be transmitted to the plant. The area of soil disturbed by the press wheels (Fig. 4.3) would close the furrow and hold the seedling in position, as ejected from furrow opener.

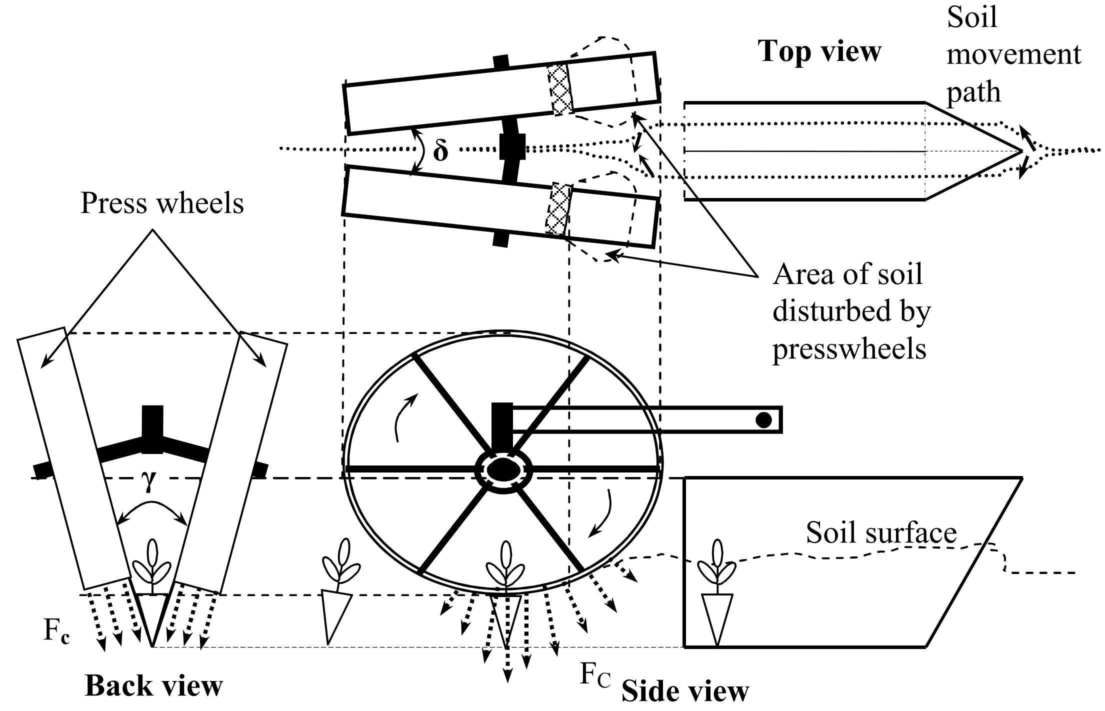

Fig. 4.3 Press wheel furrow closing cum compaction device

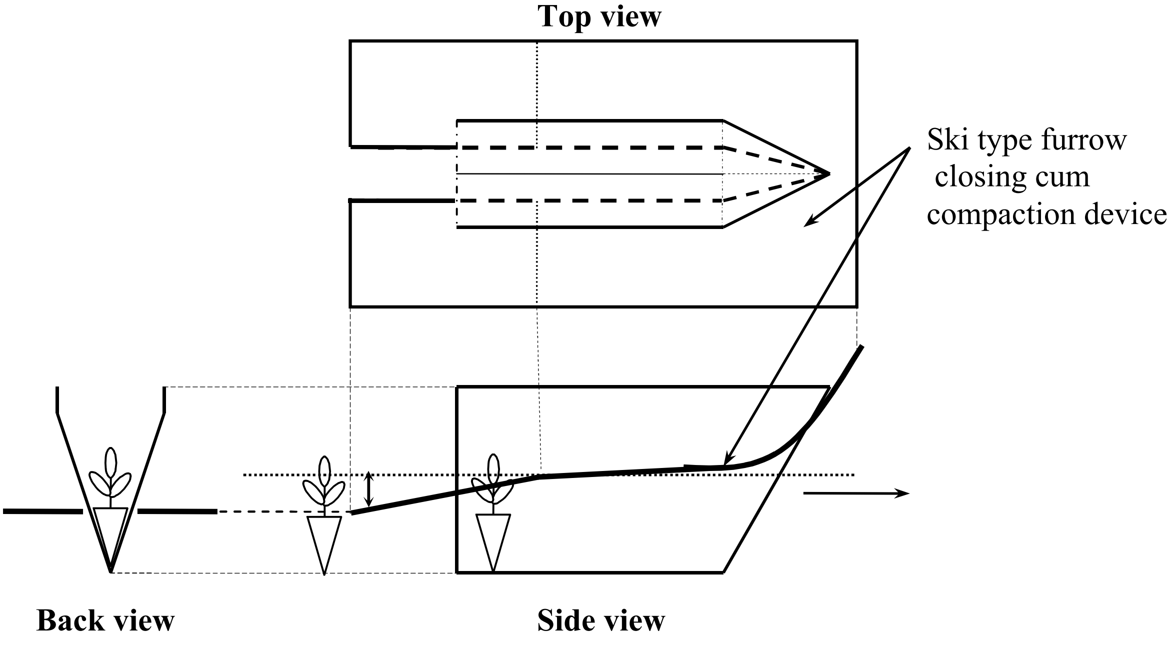

Fig. 4.4 Ski type furrow closing cum compaction device

As the press wheel advances over the root plug of seedling, the soil over it would be compacted anchoring the seedling firmly in soil. Providing angle δ would also help in bringing the press wheels closer to the furrow opener, thereby reducing the time lag between furrow opening and closing. This would help in transplanting close spaced seedlings at less speed (due to limited feeding rates) and would provide less opportunity time for seedling to tilt in furrow by self weight, between furrow opening and closing event.

ii) Ski type furrow closing cum compaction device

It consisted of a ski mounted around furrow opener as shown in Fig. 4.4. The depth of tail end of ski can be adjusted to achieve the desired furrow closing and compaction. The soil under ski gets compacted as it moves along with furrow opener. During movement of ski, top layer of soil under ski is confined by ski on the top, furrow opener side wall surface on one side and undisturbed soil mass on the side opposite to ski and furrow opener side wall surface. As soon as this compact mass of soil reaches open edge of furrow opener, the furrow wall of opened furrow offers unconfined surface to the compacted soil mass, thereby allows compacted soil mass to flow in open furrow. The plug seedling ejected from furrow opener is held in vertical position by the soil mass flowing in open furrow. The soil around the root plug of seedling and under the ski gets further compacted by the tail end of the ski. Preliminary soil bin studies were conducted to find out width of ski necessary to obtain furrow closure and compaction. A ski width of 100 mm on each side of furrow opener was found to be sufficient to obtain desired furrow closure.

4.3.1.4 Dummy seedlings

A seedling is considered to be successfully transplanted if the angle of inclination of the stem from the vertical is less than 30°, as defined by Munilla and Shaw, (1987). However, the stem of all the seedlings to be used for the experiment are not necessarily straight and perpendicular to the plug. Therefore it becomes difficult to judge whether the seedling is successfully transplanted or not, if the inclination of stem is $(30\pm5)^\circ$ from vertical. Also, the damage to the seedling can be confirmed if mortality occurs within three days from transplanting, which requires control plot to be transplanted manually at the same time. Owing to the huge quantity of seedlings and number of days required, the experiment was conducted in soil bin using dummy seedlings (Plate 3). The plug of the dummy seedling was made of wood with foam coating over it to simulate the actual plug. Plastic stem and the leaves were attached to the wooden plug to make the dummy seedlings. Geometric dimensions and mass distribution of dummy seedlings was kept equal to average values of one-month old brinjal seedlings ready for transplanting.

4.3.2 Experimental Method

Soil bin studies were conducted on experimental transplanting mechanisms developed to study the effect of soil parameters viz. bulk density, moisture content and machine parameters viz. speed of operation on furrow closure, uniformity in spacing and success of transplanting plug seedlings. Observations for angle of inclination of stem with vertical, proper furrow closure and plant spacing were recorded for 36 combinations of speed of transplanting, moisture content (% db) and bulk density of soil for transplanting dummy seedlings using two experimental transplanting mechanisms. A seedling was counted to be transplanted successfully if it's stem was inclined less than 30° from the vertical.

The experimental transplanting mechanisms were fixed to the carriage mounted on soil bin rails. They were operated simultaneously at factorial combinations of three levels of forward speed of transplanter (0.28, 0.49 and 0.69 $m.s^{-1}$), bulk density of soil (1.1, 1.3 and 1.45 $Mg.m^{-3}$), and four levels of moisture content of soil (6%, 9 % ,12% and 15% db) with three replications. The soil for each set of experiment was properly tilled using rotary tiller suitable for transplanting seedlings as is generally prepared in actual field. The desired moisture content and bulk density were obtained by spraying water on soil, pulverizing it using rotary tiller, levelling and then compacting soil using scraper and roller. Plant spacing between seedlings was kept 900 mm to enable manual feeding of dummy seedlings at higher speeds (0.69 $m.s^{-1}$). Weights were added to the press wheel and the angle of ski with the horizontal surface was increased in trial runs until proper furrow closure was obtained. The observed data was arranged to obtain i) per cent seedlings successfully transplanted (ST_P and ST_S) (i.e. seedlings transplanted with inclination less than 30° from vertical and furrow properly closed), ii) per cent of proper furrow closure observed around seedling (FC_P and FC_S) iii) per cent seedlings transplanted (TR_P and TR_S) (i.e. per cent of seedlings transplanted at any inclination from vertical, with or without proper furrow closure and shoot not buried partially or completely in soil) and iv) uniformity in spacing between transplants, for both transplanting mechanisms. Arcsin square root transformation was done to normalize the per cent data, prior to statistical analysis. The analysis of data was done using statistical package SAS at 1% level of significance. Independent statistical linear models were fitted to arcsin square root transformed dependent variables (Y) viz. successfully transplanted (ST_P and ST_s), furrow closure (FC_P and FC_s), and transplanted (TR_P and TR_s), as a function of moisture content (M), bulk density of soil (B) and speed of transplanting (S) and their interactions (M x B; M x S; B x S; M x B x S). Analysis of variance (ANOVA) was done for dependent variables and statistical parameters viz. R^2 and p-value were used to analyze the effect of independent variables. All possible pair-wise comparisons of factor levels were done using least significant difference (LSD) to find out significantly different means. Optimum operating conditions of forward speed of transplanting, desirable moisture content and bulk density of soil were determined on the basis of statistical analysis result obtained for both transplanting mechanisms.

4.4 Results and Discussion

Independent statistical linear models were fitted to arcsin square root transformed dependent variables (Y) viz. successfully transplanted (ST_P and ST_S), furrow closure (FC_P and FC_S), and transplanted (TR_P and TR_S) seedlings. The results are presented with the help of Tables 4.1, 4.2 and 4.3. All the models fitted were found to be significant at 1% level of significance except for TR_P which was significant at 5% level of significance (Table No. 4.1).

Table 4.1 Statistical parameters of the models

Machine configuration	Variable Y	Model p-value	R^2	C.V.	RMSE	Mean Y	%Mean Y
Furrow opener with press wheels	**ST_P**	<.0001**	0.749	12.920	0.652	5.045	77.336
	FC_P	<.0001**	0.828	7.561	0.421	5.565	94.037
	TR_P	0.0142*	0.473	6.236	0.348	5.585	94.725
Furrow opener with ski	**ST_S**	<.0001**	0.741	30.555	1.204	3.941	47.236
	FC_S	<.0001**	0.726	25.795	1.129	4.377	58.235
	TR_S	0.0007**	0.543	15.329	0.817	5.331	86.324

* Significant at 5% level of significance ** Significant at 1% level of significance

The factors affecting success of transplanting can be analyzed by looking into reasons for unsuccessful transplanting. The reasons for unsuccessfully transplanting of seedlings could be either improper furrow closure or more than 30° inclination of seedlings from the vertical or both. Higher inclination of seedlings from the vertical can occur because of i) seedlings already in inclined position at the time of furrow closure ii) bending forces (F_C) arising due to interaction of furrow closing and compaction device with soil iii) improper furrow opening and closing. To analyze the phenomena, the observed data was rearranged to obtain angles of inclination of the unsuccessful transplanted seedlings having i) higher angle of inclination (> 30° on either side of vertical) but having proper furrow closure ii) higher angle of inclination (> 30° on either side of vertical) having improper furrow closure. The results are presented graphically in Fig. 4.7. The effect of soil and machine variables on the performance parameters of transplanting mechanisms are discussed below.

4.4.1 Effect of moisture content on furrow closure and success of transplanting

Moisture content significantly affected proper furrow closure and success of transplanting in both press wheel and ski type machine configurations as evident from p values (Table 4.2). The variation in success of transplanting for press wheels and ski type machine configurations at different treatment combinations is shown graphically in Fig. 4.5. The effect of moisture content on the success of transplanting was observed to be more pronounced at higher moisture contents (M3 and M4) for ski type machine configuration (Fig. 4.5). This can be attributed to improper scouring of soil under ski, resulting from increased soil-metal adhesion and friction. This, in turn, would lead to improper furrow closure and low successful transplanting values. This was evident from more number of seedlings inclined at higher angles (> 30° on either side of vertical) observed at higher moisture contents for ski type furrow closing cum compaction mechanism (Fig. 4.3 a) As against this, number of non-successful transplants due to improper furrow closure was very less in case of press wheels. (Fig. 4.7 b). This can be attributed to direction of force (F_C) imparted to soil particles by the rolling motion of press wheels as against sliding motion of ski. (Fig. 4.3 and Fig. 4.4). During rolling the press wheels not only push the soil particles downward but also inward and forward in the open furrow, leading to proper furrow closure. Therefore best furrow closure and compaction can be obtained with help of rolling type mechanism (press wheels) as compared to sliding type mechanism (ski), in the range of 6% to 15% (db) moisture content. Also, moisture content was observed to significantly affect per cent of seedlings transplanted by ski type configuration (TR_S) but not press wheel type configuration.

Table 4.2 Effect of soil and machine parameters on performance parameters

Machine configuration	Variable Y	Main effect (p-values)			Interaction effect (p-values)			
		M	B	S	M x B	M x S	B x S	MxBxS
Furrow opener with press wheels	ST_P	0.0008**	<.0001**	<.0001**	<.0001**	0.0109*	<.0001**	0.0007**
	FC_P	<.0001**	<.0001**	0.0006**	<.0001**	<.0001**	<.0001**	<.0001**
	TR_P	0.480	0.551	<.0001**	0.083	0.487	0.966	0.168
Furrow opener with ski	ST_S	<.0001**	0.0007**	0.051*	0.0036**	0.558	0.206	0.318
	FC_S	<.0001**	0.0259*	0.0109*	0.084	0.334	0.674	0.258
	TR_S	0.0002**	0.0039**	0.325	0.0348*	0.673	0.015	0.192

* Significant at 5% level of significance ** Significant at 1% level of significance

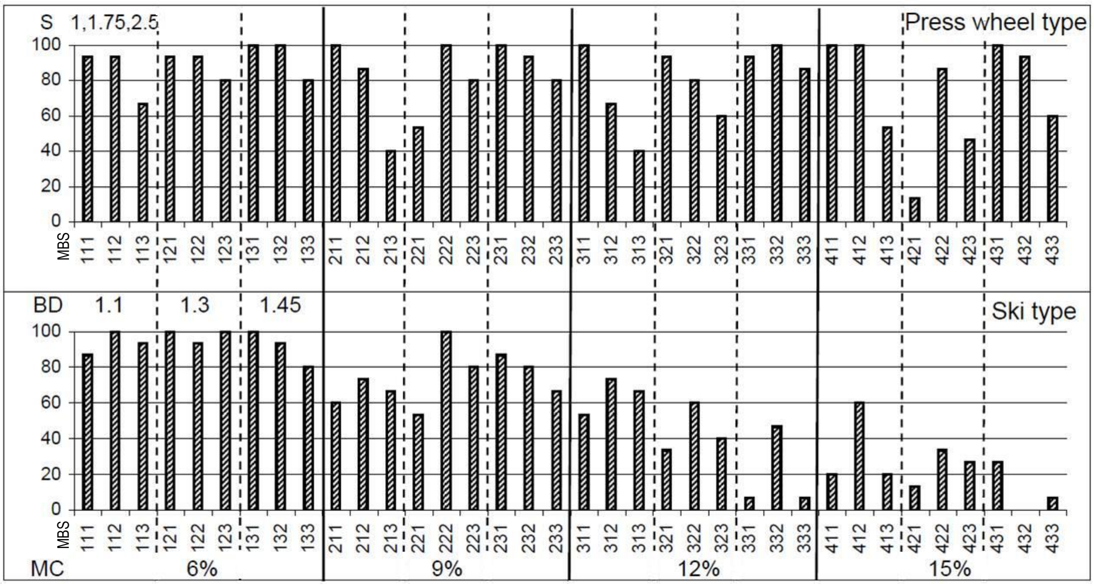

Fig. 4.5 Average per cent of seedlings successfully transplanted at different treatments arranged in group order of M,B,S

4.4.2 Effect of bulk density on furrow closure and success of transplanting

Bulk density also significantly affected furrow closure and success of transplanting in both press wheel and ski type machine configurations as inferred from p values (Table 4.2). This effect was more pronounced in case of press wheels (Fig. 4.6). It was observed that for higher bulk densities (B2 and B3); a uniform furrow slit was formed by the furrow opener at all the moisture content levels. On subsequent passage of press wheels, the soil movement in area disturbed by press wheels (Fig.4.3) would be less in forward direction due to resistance of soil to deformation under compacted condition. Further soil movement under compaction force from press wheel would be restricted after furrow closure, thereby reduced tilting effect being transferred to the transplanted seedling. This would result in less inclination of seedlings from the vertical on either side. The occurrence of above mentioned dynamics of soil and press wheel interaction under compacted soil conditions can also be inferred from less inclination obtained at higher bulk densities (Fig. 4.7 c). The unsuccessful transplanting resulting from more inclination of seedlings from vertical would be less at higher bulk densities for press wheel covering cum compaction system as observed in Fig. 4.7 d.

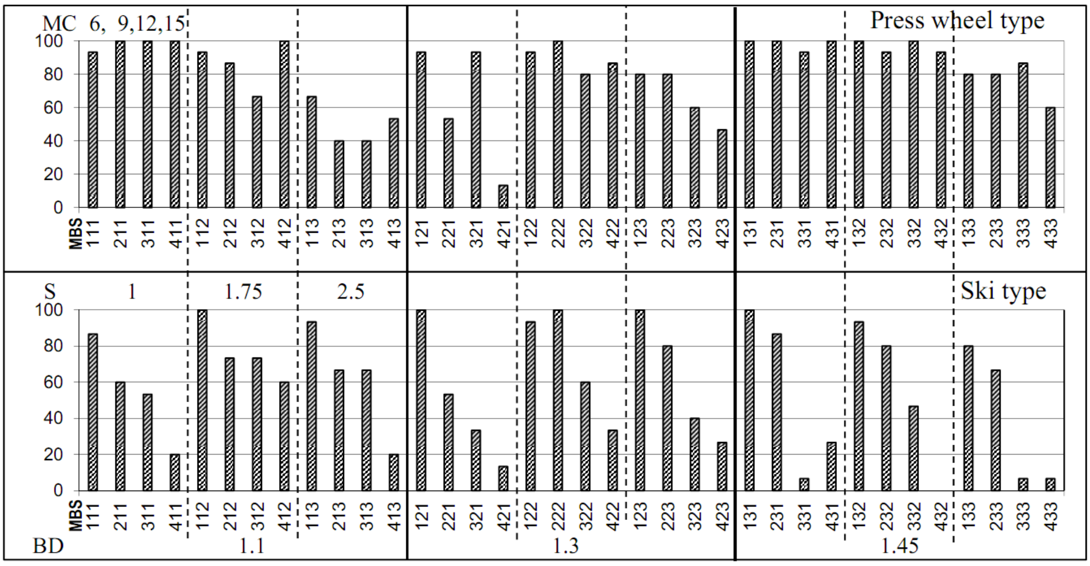

Fig. 4.6 Average per cent of seedlings successfully transplanted at different treatments arranged in group order of B,S,M

Therefore, for achieving maximum level of successful transplanting using press wheels; pre-compaction of top 60 mm layer (depth of transplanting) of sandy loam soil along the path of transplanting should be done using a compaction roller. This would help to achieve the desired bulk density of soil, reduce surface undulations of soil, uniform furrow opening by furrow opener, proper furrow closure by press wheels and reduced inclination of seedlings from the vertical. First irrigation after transplanting would relieve this top layer of soil off the compaction forces and would consolidate the soil around roots Thus, the recommended compaction of top layer of soil to achieve maximum successful transplanting would probably not lead to poor root development of the transplanted seedling. A reverse trend was observed in case of ski type mechanism. Increasing the bulk density of sandy loam soil reduced the mean successful transplanting and proper furrow closure values in ski type of furrow closing cum compaction system (Table 4.3). However, at lower moisture contents (6% and 9%) successful transplanting values comparable with that of press wheel type were observed (Fig 4.5). This may be attributed to significant interaction effect of moisture content and bulk density of soil as evident from the p-value (Table 4.2).

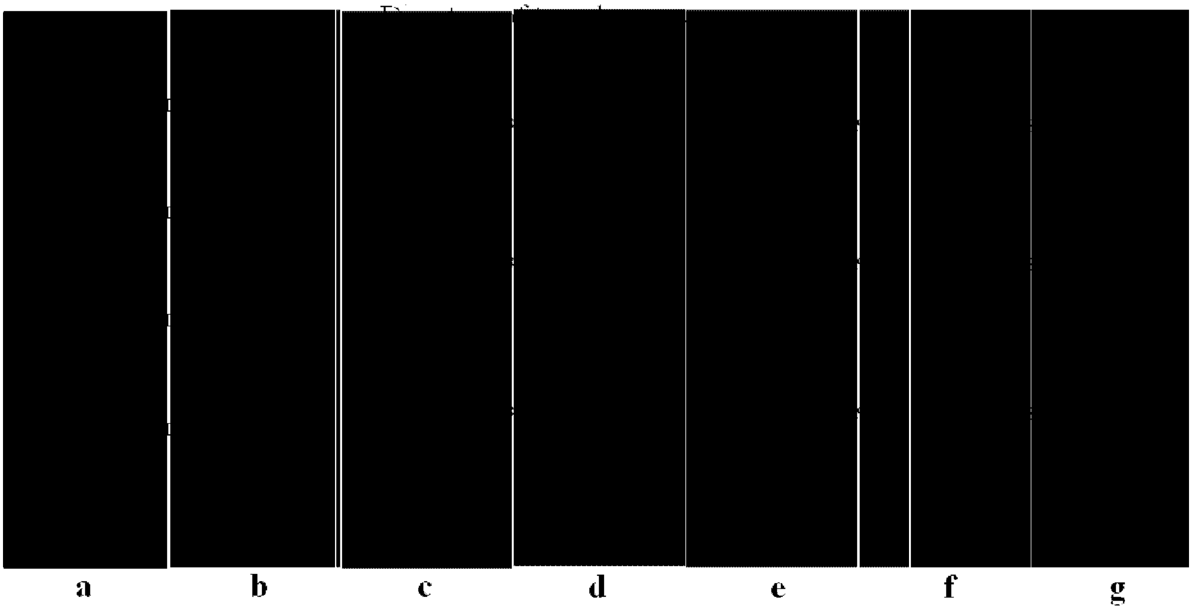

Fig. 4.7 Angle of inclination of seedlings from vertical for different factor combinations

4.4.3 Effect of speed of travel on furrow closure, angle of inclination of seedling and success of transplanting

To achieve higher field capacity, it is desirable to transplant at higher speeds of travel, if seedling feeding rate is not the limiting factor. It was observed that speed of transplanting significantly affected furrow closure (FC_P), transplanting (TR_P) and success of transplanting (ST_P) at 5% level of significance for press wheel furrow closing cum compaction system (Table 4.2). With increasing speeds, the inclination of transplanted seedlings in direction of transplanting increased for press wheel type mechanism; thereby leading to lower successful transplanting values (Fig. 4.7 f). The non-successful transplanting because of more than 30° angle of inclination in direction of travel was significantly more at higher transplanting speed (0.69 $m \cdot s^{-1}$) as observed in Fig.4.7 e. This was attributed to the higher forward force imparted to the seedling plug and soil around it by the press wheels at higher speeds of forward travel. The press wheel imparted its rolling motion to the soil in contact which further gets transferred to the plug seedling. The presence and aggravation of this tilting effect at higher speeds could be observed in (Fig. 4.7 f) and Fig. 4.7 e. The mean value of successful transplanting at highest speed tested (S3) was found to be significantly different from the lower speeds (S1 and S2, Table 4.3). Angle of inclination of seedlings at speeds S1 (0.28 $m \cdot s^{-1}$) and S2 (0.69 $m \cdot s^{-1}$) were within acceptable levels for press wheel type mechanism. These speeds (S1 and S2) are suitable for transplanting close spaced (300 mm plant spacing) and wide spaced (900 mm plant spacing) seedlings, respectively considering limited manual seedling feeding rates and more successfully transplanted seedlings obtained as compared to S3 (Fig 4.8). For press wheel type mechanism, maximum successful transplanting at higher speed of travel (S3) was achieved by operating at high bulk density (B3) of soil (Fig 4.8). Since increased number of unsuccessful transplants at higher speed of travel is attributed to increased inclination of seedlings (Fig. 4.7 e); a mechanism to hold the seedlings in vertical position until the root plug is compacted by the soil from the sides, would increase the per cent of successfully transplanted seedlings at higher travel speeds.

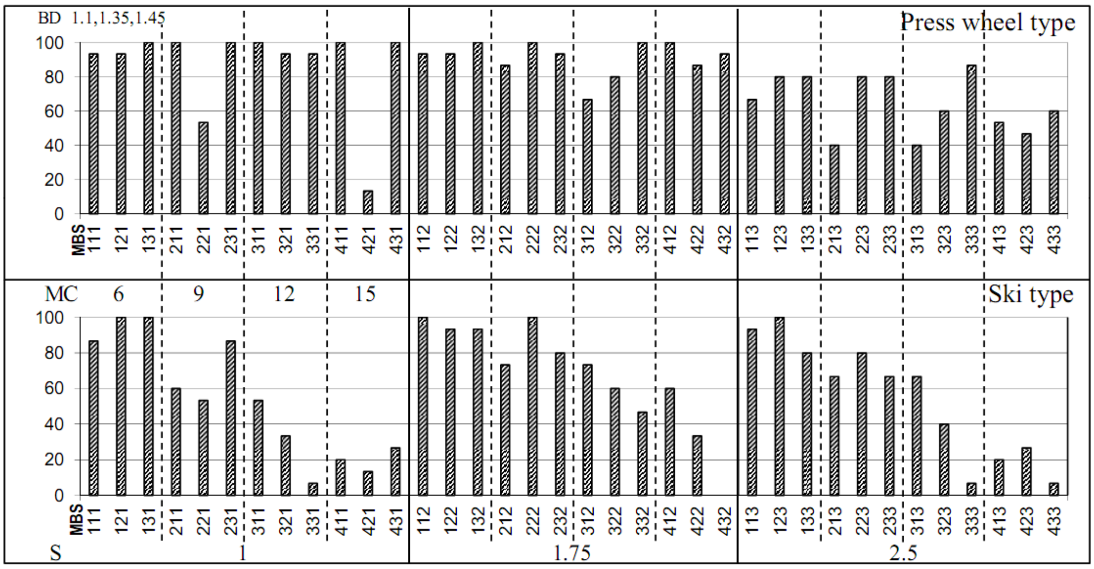

Fig. 4.8 Average per cent of seedlings successfully transplanted at different treatments arranged in group order of S,M,B

The tilting effect was not observed in ski type furrow closing cum compaction system as seedlings inclined equally on either side from vertical. However a little shift in inclination from backward to forward direction with increasing speeds was observed (Fig. 4.7 g). Speed of travel significantly affected successful transplanting for ski type mechanism at 5% level of significance only (Table 4.2). The mean values of successful transplanting at all the speeds tested were not significantly different for ski type mechanism (Table 4.3, Fig. 4.8). Therefore, this mechanism can be used for transplanting at higher speeds with some design modifications to reduce effect of moisture content.

4.4.4 Interaction effects of soil and machine parameters on furrow closure, and success of transplanting

Two factor and three factor interactions of moisture content, bulk density and speed of travel significantly affected furrow closure and success of transplanting for press wheel type mechanism (Table 4.2).

Table 4.3 Pair wise comparisons of factor levels

	Means			t-grouping#		
	ST	**FC**	**TR**	**ST**	**FC**	**TR**
Press Wheel						
M 1	5.3848*	5.7392*	5.5934	A	A	A
M 2	5.1047	5.6911	5.50036	A	A	A
M 3	5.0627	5.6942	5.64614*	A B	A	A
M 4	4.6285	5.135	5.60113	B	B	A
LSD	**0.4694**	**0.303**	**0.2508**			
B 1	4.9925	5.73917*	5.57114	B	A	A
B 2	4.7021	5.26918	5.63564*	B	B	A
B 3	5.4409*	5.68628	5.54899	A	A	A
LSD	**0.4065**	**0.2624**	**0.2172**			
S 1	5.153	5.34475	5.72229*	A	B	A
S 2	5.4543*	5.73917*	5.68854	A	A	A
S 3	4.5282	5.6107	5.34494	B	A	B
LSD	**0.4065**	**0.2624**	**0.2172**			
Ski						
M 1	5.5531*	5.6911*	5.7392*	A	A	A
M 2	4.8813	5.3936	5.6717	A	A	A
M 3	3.2147	3.9133	4.9938	B	B	B
M 4	2.1146	2.5084	4.9197	C	C	B
LSD	**0.8671**	**0.813**	**0.5885**			
B 1	4.3839*	4.6637*	5.588*	A	A	A
B 2	4.1441	4.5058	5.4507	A	A	A B
B 3	3.2949	3.9604	4.9545	B	A	B
LSD	**0.751**	**0.704**	**0.5096**			
S 1	3.6781	3.9056	5.4991*	A	B	A
S 2	4.3428*	4.6768*	5.2448	A	A	A
S 3	3.8019	4.5475	5.2494	A	A B	A
LSD	**0.751**	**0.704**	**0.5096**			

#Means with the same letter are not significantly different
*Highest value of mean among the pair

However, only interaction effect of moisture content and bulk density had significant effect on success of transplanting in case of ski type mechanism (Table 4.2). Interaction of moisture content and bulk density would affect soil dynamic properties (adhesion, cohesion and friction) and flow characteristics. Therefore, for sliding type of furrow closure mechanisms like ski where flow characteristics of soil are important, interaction effect of moisture content and bulk density would be significant. However, absence of interaction effect of soil parameters (M and B) with machine parameters (S) makes it ideal mechanism for transplanting plug seedlings as it would be easy to control machine parameters separately.

4.4.5 Effect of soil and machine parameters on uniformity of plant spacing

No significant linear model could be fitted for uniformity in plant spacing as a function of soil and machine parameters varied under soil bin conditions. The experimental transplanting mechanism developed was driven by wheels which rolled over soil bin rails without skid. Therefore there was less chance of variations to be observed in uniformity of spacing. The only variation in spacing could be because of inclined transplanting of seedlings. The mean value of seedling spacing obtained at different speeds of transplanting are presented in Table 4.4. The standard deviation of ±23.3mm and ±20.2mm were observed for press wheel and ski type configurations, respectively which were within acceptable limits. Thus, the developed experimental transplanting mechanisms transplanted seedlings at uniform spacing. However, higher variation in spacing may be expected in field conditions owing to high-skid values of ground wheel.

Table 4.4 Uniformity in seedling spacing at different speeds

Speed	Press wheel		Ski	
(km·h^{-1})	Mean(mm)	S.D.(mm)	Mean(mm)	S.D.(mm)
1	906.4	24.4	905.4	22.0
1.75	907.4	23.3	904.8	20.2
2.5	906.7	26.2	906.7	24.6

4.4.6 Optimum soil and machine parameters

Average seedling feed rates for manually fed transplanters are generally less than 45 seedlings min^{-1}, which translates to maximum forward speed of travel of 0.22 m.s^{-1} (0.8 km.h^{-1}) for close spaced vegetable crops (300 mm plant spacing) and

0.67 $m\cdot s^{-1}$ (2.4 $km\cdot h^{-1}$) for wide spaced vegetable crops (>900 mm plant spacing). However, for vegetable transplanters with automatic feed systems, higher seedling feed rates of 100 $seedlings.min^{-1}$ are achievable; which would allow transplanting at higher travel speeds up to 0.5 $m\cdot s^{-1}$ (1.8 $km\cdot h^{-1}$) for close spaced crops and about 1.5 $m\cdot s^{-1}$ (5.4 $km\cdot h^{-1}$) for wide spaced crops. Therefore, for vegetable transplanters with manual seedling feed system, optimum combination for achieving maximum successful transplanting would be; press wheel type of machine configuration operated at slower speeds (0.28 $m\cdot s^{-1}$); in moisture content range of 9% to 15%, with low soil compaction levels (1.1 $Mg\cdot m^{-3}$) for close spaced crops (Fig. 4.8). Secondary tillage and leveling of seedbed should be done before transplanting. For wide spaced vegetable crops higher speed up to 0.49 $m.s^{-1}$ would be optimum in moisture content range of 6% to 15% and compacted soil condition (1.45 $Mg\cdot m^{-3}$) (Fig. 4.8). Comparable transplanting can also be obtained at the same conditions but at lower bulk density of 1.1 $Mg\cdot m^{-3}$ (Fig. 4.8). Similar operating conditions would be suitable for vegetable transplanters with automatic seedling feeding systems for close spaced crops. Ski type machine configuration can be used for transplanting close spaced and wide spaced vegetable crops at higher speeds with some design modifications to reduce effect of moisture content.

4.5 Conclusions and Recommendations

The following conclusions were drawn from the experiment

1) Moisture content, bulk density of soil and forward speed of travel significantly affected success of transplanting for both press wheel and ski type furrow closing cum compaction system.
2) Moisture content had profound effect on furrow closure and thereby success of transplanting with ski type machine configuration.
3) Pre-compaction of soil up to the depth of transplanting improved successful transplanting in case of press wheel type of machine configuration and vice versa for ski type of machine configuration.
4) Speed of travel significantly affected the angle of inclination of transplanted seedling. It increased with speed of travel in press wheel type of machine configuration. However, the effect was absent in ski type of machine configuration indicating possibility of operation at higher speeds.

5) Moisture content, bulk density of soil and forward speed of travel did not significantly affect uniformity in plant spacing for both press wheel and ski type furrow closing cum compaction system.
6) Unsuccessful transplanting was mainly because of higher angle of inclination of transplanted seedling in press wheel type of machine configuration and improper furrow closure in case of ski type machine configuration.
7) Optimum combination for manually fed vegetable transplanters for close spaced vegetable crops was press wheel type of machine configuration operated at slower speed (0.28 $m \cdot s^{-1}$) in moisture content range of 9% to 15% (db), with low soil compaction level (1.1 $Mg \cdot m^{-3}$).
8) Highest speed of travel suitable for successful transplanting was found to be 0.49 $m \cdot s^{-1}$ (1.75 $km \cdot h^{-1}$) in wide moisture content range of 6% to 15% db at higher bulk density (1.45 $Mg \cdot m^{-3}$).
9) In general, vegetable transplanting mechanism consisting of shoe type furrow opener and pusher mechanism gave higher values of successful transplanting of plug seedlings with press wheel furrow closing cum compaction system than ski type furrow closing cum compaction system in sandy loam soils.

Plate 2. Dummy plug seedlings

Plate 3. Testing of experimental transplanting mechanisms in soil bin

Plate 4. Tractor mounted two-row vegetable plug seedling transplanter

Plate 5. Field evaluation of prototype vegetable plug seedling transplanter

Plate 6. Manually transplanted tomato plug seedlings (control plot)

a) Tomato b) Brinjal

Plate 7. Plug seedlings transplanted using developed vegetable plug seedling transplanter

Chapter V

Design of Semi-Automatic Plug Seedling Transplanter for Vegetable Crops

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5.1 Abstract

Over the past few years, plug tray seedling technology has gained momentum in India due to several advantages over traditional open field soil bed raising of vegetable seedlings. Seedlings of high value vegetable crops such as tomato, capsicum, cucumber, broccoli, chilies etc are now being widely grown in plug trays by a large number of nurseries in India and sold on pre-ordered basis to vegetable farmers. After taking the delivery of seedlings from the nursery, the farmer has to transplant them in the field within a day to minimize their mortality. Traditional method of transplanting of plug seedlings is manual and labour-intensive operation. Increased cost of labour in the past decade has made the transplanting by hand uneconomical. Imported vegetable transplanters have not been adopted by vegetable growers due to their high costs. The objective of this study was to develop a two row tractor mounted semi automatic mechanical transplanter for sowing plug seedlings of vegetable crops in sandy loam soils which is the largest soil group of India. Based on the optimized operating conditions obtained in soil bin experiments, a prototype vegetable transplanter was fabricated and tested for its performance for transplanting tomato and brinjal seedlings grown in plug trays. The vegetable transplanter successfully transplanted tomato and brinjal plug seedlings without any mortality at uniform plant spacing at average forward speed of 0.44 $m \cdot s^{-1}$ (1.58 $km \cdot h^{-1}$). The maximum forward speed of transplanting was limited by the maximum rate of manually feeding seedlings to the seedling feed tubes. Average feed rates of 32.7 $seedlings \cdot min^{-1}$ were obtained with 3.5% miss in feeding plug seedlings by the operator. The average total cost of transplanting 1000 plug seedlings, using the two-row tractor mounted vegetable transplanter was found to be ₹70.24.

Keywords: Vegetable transplanter, transplanting mechanism, plug seedlings

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5.2 Introduction

India is the second largest producer of vegetables in the world with an estimated annual production of 125.88 million tonne from 7.8 million ha, which accounts for about 13.3% of total world vegetable production (Indian Horticulture

Database 2008). Although, annual growth rate of 2.6 per cent in total vegetable production has been recorded during the last 10 years, the average yield of vegetables in India is still lower than that in many Asian countries. One of the major constraints in increasing vegetable productivity is the low level of mechanization (Chatterjee *et al., 1995*). At present, the mechanization level of seeding/planting, weeding, harvesting and post-harvest operation of most vegetable crops in our country is very low. Vegetable seedlings have been traditionally grown on soil beds in open field for a long time in India. In a survey, Chaudhari *et al.* (1999) found that transplanting of vegetable crops was being carried out manually all over India. Subsequent research and studies led to development of finger type semi-automatic vegetable transplanters suitable for transplanting bare root seedlings (Chaudhuri *et al.*, 2002 and PAU, 2004). Most of the vegetable transplanters developed outside India relied on the use of new non-commercial growing schemes (Boa, 1984; Suggs *et al.,* 1992; Tsuga, 2000). This approach required the nursery growers to modify their inventory in anticipation of the machine's eventual acceptance by the farmers. Therefore the transplanters relying on non-commercial growth media and/or container to achieve their feeding function are not used in India. Transplanters that will transplant the seedling type popular with the farmers are needed at the moment in India to mechanize the vegetable transplanting operation. Over the past few years, plug tray seedling technology has gained momentum due to several advantages over traditional methods of growing seedlings on soil beds in open field. A major portion of the area under vegetable cultivation in India is now sown with plug seedlings grown in nursery. Seedlings of high value vegetable crops such as tomato, capsicum, cucumber, broccoli, chilies, brinjal etc are now being widely grown in plug trays by a large number of nurseries in India and sold on pre-ordered basis to farmers. After taking the delivery of seedlings from the nursery, the farmer has to transplant them in the field within a day to minimize their mortality. Transplanting of plug seedlings is a manual and labour-intensive operation. On an average, about 197 man-hours are required to transplant seedlings in one hectare area with a plant spacing of 600 mm x 600 mm. Timely transplanting of vegetable crops is very critical for good yields. Manual labour can hardly meet the transplanting requirements of vegetable seedlings, in peak season. Besides the quantum of labour, manual transplanting involves considerable drudgery and human discomfort. Increased cost of labour in the past decade has made the manual transplanting uneconomical. To date, locally produced vegetable transplanters for vegetable plug seedlings are not available in India. Imported vegetable transplanters have not been adopted by vegetable growers due to their high costs and the resultant uneconomic scale of production. Therefore to reduce farmers' dependence on manpower during peak periods for vegetable transplanting operation, there is a need to develop a low-cost vegetable transplanter utilizing simple mechanisms for Indian soil conditions. In view of the above investigation, the present study was undertaken to design and develop a tractor-operated semi automatic mechanical transplanter for sowing plug seedlings of vegetable crops in sandy loam soils which covers major cultivable area of India. Since tomato and brinjal shares the major area sown by vegetable plug seedlings in India (Indian Horticulture Database, 2008) and morphological being tender and hardy, respectively tomato and brinjal were selected to establish the design and test the vegetable transplanter.

5.3 Material and Methods

Experiments were first conducted in soil bin to determine the optimum soil-machine parameters for the transplanting mechanism of plug seedling. The design of the experimental setup and the details of soil bin studies have been discussed in the previous paper and are not included here as it is beyond the scope of this paper. The results of the soil bin experiments concluded in selecting vegetable transplanting mechanism consisting of, shoe type furrow opener and kicker mechanism with press wheel furrow closing cum compaction system for sandy loam soil. Optimum combination for manually fed vegetable transplanters for close spaced vegetable crops (300 mm plant spacing) was found to be; press wheel type of machine configuration operated at slower speeds (around 0.28 $m \cdot s^{-1}$) in moisture content range of 9% to 15%, with low soil compaction levels (1.1 $Mg \cdot m^{-3}$). However, highest speed of travel suitable for successful transplanting was found to be 0.49 ms^{-1} (1.75 $km \cdot h^{-1}$) in wide moisture content range of 6% to 15% at higher bulk density (1.45 $Mg \cdot m^{-3}$) of soil. Based on the optimum operating conditions of forward speed, moisture content and bulk density of soil, a prototype of a tractor mounted semi automatic transplanter for vegetable plug seedlings was designed and fabricated. The developed vegetable transplanter consisted of mainframe which could be attached to standard three-point hitch arrangement of the tractor. Two independent manually fed transplanting units were attached to the hitching frame at 750 mm row to row spacing which was adjustable. An independent transplanting unit consisted of drive cum compaction wheel, a pusher type metering mechanism, shoe type furrow opener, press wheel type furrow closing cum compaction device, a frame to hold seedlings tray and operator's seat (Fig. 5.2).

5.3.1 Design considerations

The basic considerations in the design of vegetable transplanter were cost, simplicity of design for fabrication by local manufacturers, ease of operation in field, and ergonomics to suit Indian farming population. To reduce material cost and increase longitudinal stability of tractor, emphasis was given to minimize the total weight and keep C.G. of transplanter close to hitch point.

5.3.1.1 Furrow opener

For shoe type furrow opener, proper scouring can occur at α greater than (90+Ø)°, (Ø - angle of soil-metal friction) and β less than (90-Ø)° (Fig. 4.2). The maximum value of Ø for sandy loam soil and steel is 27° (Gill *et al.,* 1967 and Bernacki, 1972). Therefore, a shoe type furrow opener with α = 135°, β = 60° and length more than stroke of kicker (50 mm) was fabricated using mild steel sheet. The cross-section of the furrow formed by furrow opener should not be more than the plug size so that the furrow wall holds the seedlings vertically straight after being ejected from the furrow opener. The value of γ was kept equal to that of plug shape (30°) so that the side walls of furrow opener held the seedling plug vertically as it fell into it. The furrow opener was hardened using oil quenching and polished to reduce friction and adhesion of soil to its surface.

5.3.1.2 Metering mechanism

An important criterion for successful transplanting of seedling is that the seedling is maintained in vertical position both during and after transplanting. The plug seedling should be ejected from the furrow opener in the opposite direction with the same velocity of forward travel of the transplanter to avoid shattering of plug and damage to the roots of seedling. To achieve this, a mechanism consisting of a pusher driven by flat plate positive inverse cam and indexing plates was designed (Fig. 5.1). The indexing plate drives the pusher in first half of the stroke and rotates the seedling feeding unit by 60° in return stroke. The plug seedling held in feed tube is dropped into the furrow opener as soon as the covering lid is opened by stationary cam for every 60° rotation. The pusher block pushes the seedling into the furrow at the same forward speed of the transplanter but in the opposite direction ($V_P = -V_F$). Thus using this mechanism the seedlings were ejected from furrow opener in vertical position, with very little relative motion between seedling and the soil.

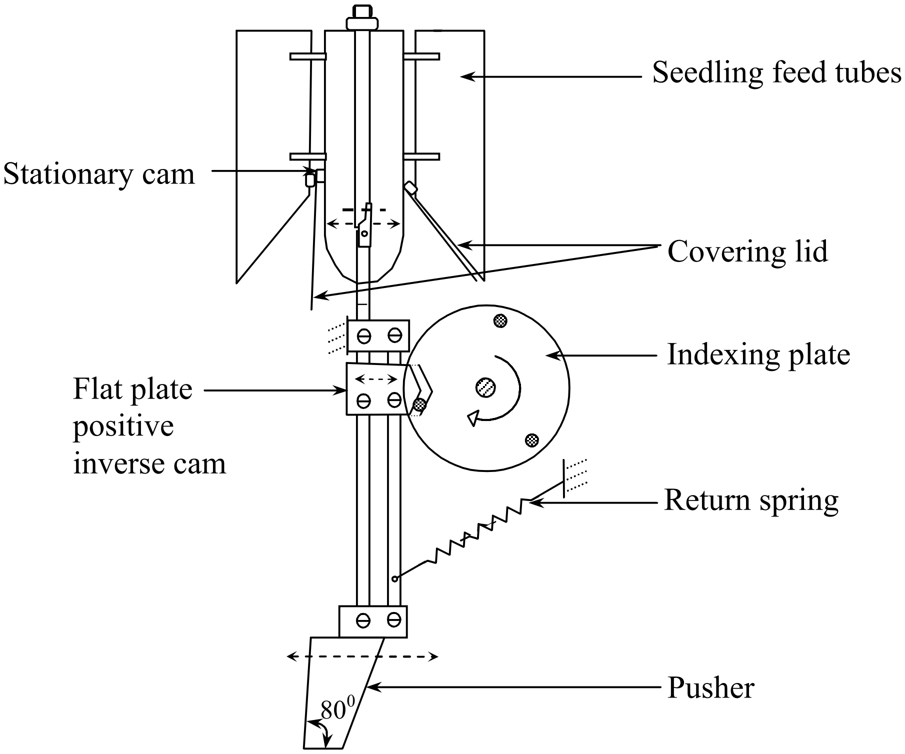

Fig. 5.1 Seedling metering mechanism

5.3.1.3 Press wheel furrow closing cum compaction mechanism

The press wheels should cover the roots of the seedlings with soil completely, and subsequently compact the soil around the seedling without causing any damage to it’s leaves, stem or roots. Therefore it should exert compaction pressure less than the crushing strength of the seedling stem and roots, but sufficient enough to make good root soil contact. Soil compaction pressure of 29.42 kPa was found to sufficiently compact the soil around seedlings in soil bin studies. Further, the size of press wheels should allow narrow row transplanting and ensure vertically erect transplanting of seedlings. This is possible if the furrow is closed immediately after the seedling is ejected from the furrow opener. This was achieved by using small diameter press wheels and providing angle δ so as to bring the area of soil disturbed by press wheels closer to furrow opener (Fig. 4.3 Top view). Therefore, press wheels of diameter 35 cm were mounted on axle, bent downward and backward to obtain angles $\gamma = 30°$ and $\delta = 16°$ (Fig. 4.3 and 5.2). However, it was observed in soil bin studies that press wheels imparted tilting effect to the transplanted seedlings, resulting in inclination of transplanted seedlings in the direction of travel. Therefore the angle (θ) of pusher was increased to 80°, so that seedlings would be ejected with little backward inclination from vertical (Fig. 5.1). The tilting effect from press wheel brings seedling to vertically erect position after transplanting. The overall dimensions of transplanter, press wheel width and position of operator's seat were adjusted such that compaction pressures of about 29.42 kPa were obtained at press wheels. Assuming the average weight of 68 kg of operator the press wheel width of 70 mm would achieve the desired compaction pressures. The depth of transplanting was varied by using the depth adjustment bolt (Fig. 5.2).

5.3.1.4 Drive cum compaction wheel

It was observed in the soil bin studies conducted earlier that pre-compaction of soil up to the depth of transplanting helped in opening a uniform furrow slit by the furrow opener and also improved the success of transplanting in case of furrow closing cum compaction mechanism. Therefore a 150 mm wide compaction wheel was used to compact the soil in the path of transplanting before being opened by the furrow opener. This compaction wheel was also used to provide drive to the metering mechanism using chain and sprocket transmission (Fig. 5.2).

5.3.1.5 Double parallel link mechanism

A double parallel link mechanism similar to that used in universal drafting machine was used to keep the vegetable transplanter frame parallel to the ground (Fig. 5.2). This mechanism allowed opening of furrow to uniform depth and subsequent application of uniform compaction pressure by the press wheels. The vertical movement of the double parallel link mechanism was restricted within limits by diagonally placed restraining link chains such that drive cum compaction wheel moved independent of mainframe during transplanting and the whole transplanter unit could be lifted parallel to the ground during transportation to the field and taking turns at head land.

5.3.1.6 Ergonomic considerations

A modified two dimensional workspace template (Kumar *et al.*, 2009) in vertical plane was used to decide the location of plug tray and foot rest with respect to seat. The angle between thigh and lower leg was adjusted to 75^0 (Dixit, 1996) to avoid contact with press wheels. Provision for adjustment of seat position in vertical and horizontal direction was also provided for accommodating majority of farming population.

5.3.2 Operation and testing of the vegetable transplanter

The row spacing between the two transplanting units was adjusted by sliding and clamping them on the hitching frame bar which was attached to the three point linkage of tractor. The minimum spacing of 450 mm can be maintained between two rows. The recommended plant spacing was achieved using the respective indexing plates (300, 450, 600, 900 mm). The operator first loaded the seedling feed tubes with seedlings. The whole transplanting unit was lowered completely using hydraulic depth control lever of tractor to begin transplanting as the tractor moved forward. The speed of travel was adjusted to cope up with feeding rate manageable by operator. Operator fed seedling from seedling tray to intermittently rotating feed tubes. Maximum feeding rate of 44 seedlings$\cdot$min^{-1} with 3% miss was observed in laboratory study. Assuming the same feeding rate possible in field, the maximum transplanting speeds for 300, 450, 600, 900 mm plant spacings were 0.22, 0.33, 0.44 and 0.67 m$\cdot$s^{-1}, respectively. The prototype vegetable transplanter was tested for transplanting one month old healthy tomato (variety- Himsona) and brinjal (variety - Pusa Uttam) plug seedlings in 0.1 ha area for each crop. The transplanter was operated at 0.44 m$\cdot$s^{-1} (1.6 km$\cdot$h^{-1}) for recommended plant to plant and row to row spacing of 600 mm x 1200 mm, respectively for the varieties transplanted. To assess the damage to seedlings during mechanical transplanting, a control plot of 0.02 ha was transplanted manually with seedlings grown in the same batch. Observations for mortality of seedlings occurring within three days after transplanting were recorded for both manually and mechanically transplanted seedlings. Spacing between transplanted seedlings was recorded to calculate the uniformity in spacing. The transplanting efficiency was determined by the ratio of seedlings inclined less than 30° from the vertical and proper soil compaction around roots to the total number of seedlings transplanted. The angle of root plug axis of seedling with vertical was taken if the stem of seedling was not straight. Field transplanting efficiency was determined by the ratio of the time required to actually transplant the seedlings to the total time required to complete the transplanting operation in field.

5.3.3 Cost Economics

The assumptions and calculations to determine estimated cost of two-row vegetable transplanter are given in Appendix C-1. The cost economics for different transplanting geometries were also calculated. The optimum tractor size required to operate the increasing number of transplanting units mounted on a single hitching frame, along with its cost economics, was calculated on the basis of longitudinal stability of tractor in three point hitch raised condition. Total hourly cost of operation was determined based on fixed cost and variable costs assuming current rates of the variables involved.

The cost economics was calculated assuming ownership of transplanter by the farmer with an annual operation of 250 hours. It was assumed that farmer operated the machine on custom hiring basis after transplanting his own fields. Also, the cost economics was calculated considering ownership of machine by an entrepreneur, offering custom hiring services of vegetable transplanter. Custom hiring rates for the two-row vegetable transplanter were calculated assuming IRR of 25%. All other assumptions were similar to that considered in ownership by a farmer (Appendix C-3). The breakeven point for owning versus custom hiring of two-row vegetable transplanter was found out in terms of hours of operation per year, (Fig. 5.3). The minimum land holding to justify ownership of two-row vegetable transplanter was also calculated, considering an average field transplanting capacity of 0.14 $ha\cdot h^{-1}$ for transplanting geometry of 600 mm x 600 mm.

5.4 Results

The comparative performance of manual and mechanical transplanting, using the developed prototype of two row tractor mounted vegetable plug seedling transplanter, is given in Table 5.1. The field capacity and cost economics for different transplanting geometries were calculated and are given in Table 5.2. The optimum tractor size required to operate the increasing number of transplanting units along with its cost economics are given in Table 5.3.

Table 5.1 Comparative performance of manual and mechanical transplanting

Sr No	Transplanting	Manual (Control plot)		Mechanical	
	Crop	Tomato	Brinjal	Tomato	Brinjal
1	Speed ($km\cdot h^{-1}$)	-	-	1.54	1.62
2	Transplanting geometry (mm x mm)	600 x1200	600 x1200	600 x1200	600 x1200
3	Spacing (mm)	631.3±14.5	640.8±12.6	632±25.1	628.9±20.4
4	% miss	0	0	3.8	3.2
5	% mortality	0	0	0	0
6	Avg. transplanting rate ($seedlings.min^{-1}.person^{-1}$)	3.175	3.249	32.12	33.28
7	Transplanting efficiency,%	100	100	94.48	97.12
8	Field efficiency transplanter %	-	-	73	75.63
9	Cost (₹$\cdot$1000 $seedlings^{-1}$) (₹$\cdot ha^{-1}$)	85.31 (1185)	83.51 (1160)	72 (1000)	68.48 (965)
10	Avg. cost (₹$\cdot$1000 $seedlings^{-1}$) (₹$\cdot ha^{-1}$)	84.41 (1172.5)		70.24 (982.5)	

Table 5.2 Comparative performance of manual and mechanical transplanting (two-row transplanter) for different transplanting geometries

Plant Spacing (mm)	Row Spacing (mm)	Operating Speed (m·s^{-1})	Avg. speed (m·s^{-1})	Area covered (ha·h^{-1})	Transplanting cost (₹·ha^{-1}) Mechanical	Transplanting cost (₹·ha^{-1}) Manual	Profit ₹·ha^{-1}	BEP ha·yr^{-1}
300	450	0.22	0.16	0.05	4890	6319	1429	1.90
300	600	0.22	0.16	0.07	3667	4740	1073	2.54
300	750	0.22	0.16	0.09	2934	3792	858	3.17
450	450	0.33	0.24	0.08	3260	4213	953	2.86
450	600	0.33	0.24	0.10	2445	3160	715	3.81
450	750	0.33	0.24	0.13	1956	2528	572	4.76
450	900	0.33	0.24	0.16	1630	2107	477	5.71
600	600	0.44	0.32	0.14	1834	2370	536	5.08
600	750	0.44	0.32	0.17	1467	1896	429	6.35
600	900	0.44	0.32	0.21	1222	1580	358	7.62
600	1200	0.44	0.32	0.28	917	1185	268	10.16
900	900	0.66	0.48	0.31	815	1053	238	11.43
900	1200	0.66	0.48	0.42	611	790	179	15.24

Table 5.3 Tractor matching for optimum number of transplanter units

Sr. No.	Details		No. of transplanter units 1	2	3	4	5	6
1	Total cost, Rs		9788	16431	23075	29719	36363	43006
2	Total m/c wt. (unit + main frame), kg		105	170	235	300	365	430
3	Total load (m/c + operator), kg		170	300	430	560	690	820
4	Matching tractor size, kW (HP)		15 (20)	22.4/ 26 (30/35)	22.4/ 26 (30/35)	29.8 (40)	37.3 (50)	44.7 (60)
5	Min. hitch frame width required for desired row spacing,(mm)	450	300	700	1150	1600	2050	2500
		600	300	850	1450	2050	2650*	3250*
		750	300	1000	1750	2500	3250*	4000*
		900	300	1150	2050	2950*	3850*	4750*
		1200	300	1450	2650*	3850*	5050*	6250*
6	BEP, h		-36.85	35.64	19.36	15.5	13.72	12.74
7	Payback period, yr		-0.89	0.86	0.47	0.38	0.33	0.31
8	Field capacity ha·h^{-1} (600mm x 600mm spacing)		0.07	0.14	0.21	0.28	0.35	0.42
9	Area covered·day^{-1} (ha)		0.42	0.85	1.27	1.70	2.12	2.54
10	Min. operation to justify purchase (ha·yr^{-1})		-2.6	5.03	4.1	4.38	4.85	5.4

* Increase hitching frame width to accommodate the required transplanter units

5.5 Discussion

5.5.1 Comparative performance of manual and mechanical transplanting

The average feed rates of 44 seedlings·min^{-1} were obtained with 3% miss in laboratory studies. However the average transplanting rates reduced to 32.12 and 33.28 seedlings·min^{-1} with 3.8% and 3.2% miss in field conditions owing to the reduced field efficiencies of transplanter (73% and 75.63%) for tomato and brinjal, respectively. The non productive time during turning at head lands, loading and unloading of plug trays and initial adjustments to start the transplanting operation were the major reasons for the reduced field transplanting efficiency values. The overall turning time could be reduced by transplanting in rows along the length of field thereby reducing number of turns required. Provision to load multiple plug trays at a time would reduce the non productive time in loading and unloading single plug. The forward speeds of 0.43 m·s^{-1} and 0.45 m·s^{-1} could only be maintained in field while transplanting tomato and brinjal, respectively. However soil bin studies revealed that the travel speed of 0.49 m·s^{-1} (1.75 km·h^{-1}) was optimum to achieve higher successful transplanting rates, if seedling feeding rates were not the limiting factor. Thus manual seedling feeding rates limited the maximum allowable travel speed of the transplanter for plant spacings below 600 mm. In operator's opinion the transplanting done using developed transplanter was far more comfortable than manual method of transplanting. The transplanting efficiency for brinjal (97.12%) was observed to be higher than tomato (94.48%) owing to its more hardy and straight stem of shorter length as compared to tomato which are soft and droop immediately after transplanting. However, zero mortality was observed in both manual and mechanical transplanting after three days, thus indicating higher vigor of plug seedlings and ability of the prototype vegetable transplanter to transplant seedlings without any damage. The average plant to plant spacing observed in both methods of transplanting were comparable and close to the targeted plant spacing of 600 mm. The variations in spacing in mechanical transplanting can be attributed to the variations in skid values owing to inherent field variations in moisture content, bulk density and small surface undulations.

5.5.2 Tractor matching for optimum number of transplanter units

The results presented in Table 5.3 show that three-row vegetable transplanter requires least area of operation (4.10 ha) to justify its purchase. However a two-row vegetable transplanter was recommended for use as it allowed transplanting at all possible row spacings in between tractor tread width. As against this, to enable transplanting at different row spacings using three row unit or higher, the tractor tread width must be adjustable, such that tractor tyre moves in space between rows. Use of single unit of vegetable transplanter is not justifiable as transplanting costs were found to be higher than manual method. In general, for sandy loam soils a 22.4-26 kW (30-35 HP) tractor is suitable for operation of two or three row vegetable transplanter. Higher tractor size along with wider hitch frame size would be required for use of more than three row vegetable transplanter units at a time, which possibly would not be adopted by many farmers due to small fragmented land holdings in India.

5.5.3 Cost economics

Most of the researchers have reported the transplanting capacities in terms of area transplanted per hour rather than seedlings transplanted per hour and breakeven point in terms of area rather than hours of operation. However, the field capacity and cost economics for different transplanting geometries, given in Table 5.3, show that the area covered per hour using vegetable transplanter and its BEP (ha·yr^{-1}) vary widely with transplanting geometry and operating speed. Therefore, to compare the performance of vegetable transplanters, transplanting capacities should be reported in terms of seedlings transplanted per hour and BEP in terms of hours of operation.

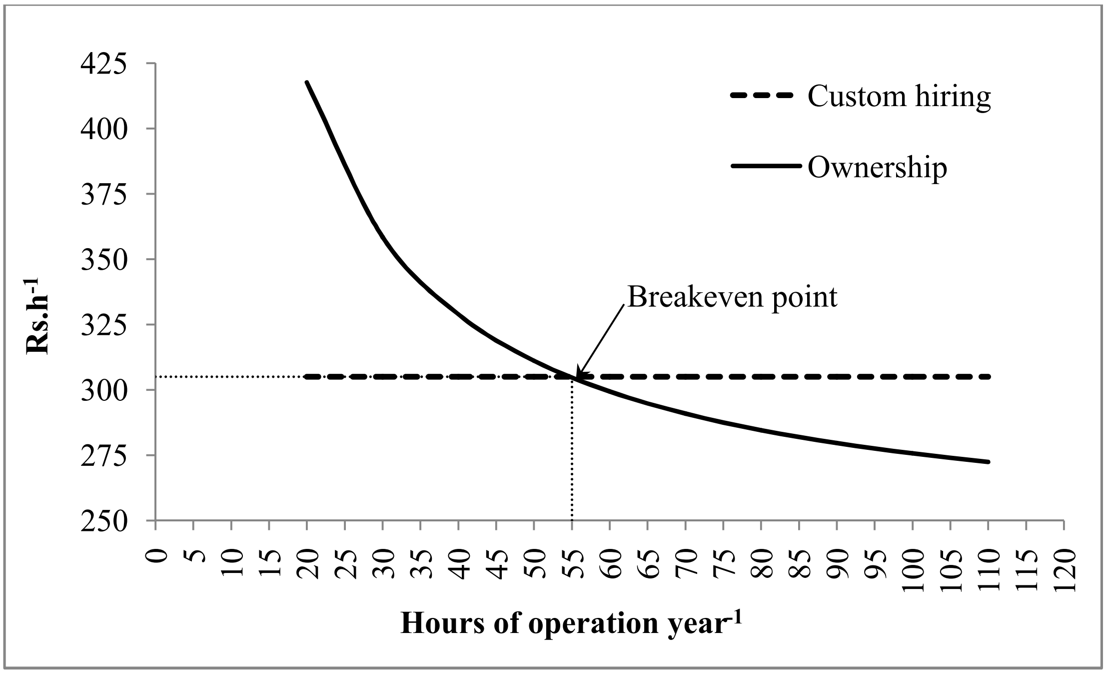

Fig. 5.3 Cost curves for owning V/s custom hiring two-row vegetable transplanter

The cost of transplanting plug seedlings using two-row vegetable transplanter (₹70.24 per 1000 seedlings) (assuming ownership by farmer) was found to be less than manual transplanting (₹84.41 per 1000 seedlings) with average payback period of 10.32 months (222 h) for annual utility of 250 hours (Table 5.1 and Table 5.3). The rate of custom hiring a two-row vegetable transplanter calculated considering IRR of 25% was found to be ₹305 h^{-1} (₹2200 ha^{-1}). With this custom hiring rate the payback period was found to be 14.66 months (306 h) for an annual utility of 250 h (Appendix C-5). This custom hiring rate was also found to be less than the current average manual transplanting cost of ₹2370 ha^{-1}. The breakeven point for owning a two-row vegetable transplanter as against custom hiring it was found to be 55 hours of operation. This translates to a minimum land holding of 7.7 ha by a vegetable grower to justify its ownership. Thus mechanized transplanting can eventually be accepted by vegetable growers having vegetable cultivation area less than 8 ha, if custom hiring services of vegetable transplanter are available. However, owning the two-row vegetable transplanter was also justified if farmer operates the machine on custom hiring basis after transplanting his own fields.

5.6 Conclusions

The following conclusions were drawn from the experiment

1) Transplanting efficiency of 94.48% and 97.12% was obtained for tomato and brinjal plug seedlings, respectively.
2) Average cost for transplanting 1000 tomato/brinjal plug seedlings using developed vegetable transplanter was ₹70 assuming 250 h of operation per year as against ₹84 when done manually.
3) The average payback period was found to be 10.32 months (222 h) for owning the transplanter by vegetable grower as against 14.66 months (306 h) for a entrepreneur offering custom hiring services.
4) The Breakeven point (BEP) was found to be 35.64 h which was 14.64% of annual utility of vegetable transplanter.
5) Seedling feed rate restricted the maximum allowable travel speed of the transplanter for plant spacings below 600 mm.
6) Use of single unit of vegetable transplanter was not found economically justifiable as transplanting costs are higher than manual method.
7) A minimum vegetable cultivation area of 7.7 ha was required by a vegetable grower to justify ownership of two-row vegetable transplanter against custom hiring it.
8) Two-row vegetable transplanter was recommended for use by farmers to reduce transplanting costs, and timely and uniform transplanting of vegetable seedlings grown in plug trays.

Table 6.1.a Time and motion study details of plug seedling transplanting operation

		Survey No.	1	2	3	4	5	6
		Pattern of transplanting	**T1**	**T1**	**T3**	**T1**	**T2**	**T2**
			Furrow/border irrigated				Drip Irrigated	
		Details	Open field bed transplanting				Open bed	Mulch bed
Field Details	1	Location	Nimgaon (M.S.)	Tadavale (M.S.)	Tadavale (M.S.)	Nagthane (M.S.)	CPCT, IARI (New Delhi)	CPCT, IARI (New Delhi)
	2	Field size (ha)	0.41	0.20	0.41	0.11	0.02	0.10
Crop details	3	Crop	Tomato	Cabbage	Cabbage	Brinjal	Tomato	Tomato
	4	Variety	Abhinav	Saint	Saint	-	Himshikhar	Himshikhar
	5	No. of seedlings	10000	10000	20000	3000	290	1865
	6	Tray size (no.of cups)	70	104	104	104	187	345
	7	Plant to plant spacing (mm)	450	450	450	600	450	450
	8	Row to row distance (mm)	900	450	450	600	1200	1200
Labour details	9	Labour (Men)	0	3	4	4	2	4
	10	Labour (Women)	12	8	10	0	0	0
	11	Labour Rate (Men) Rs.day^{-1}	120	150	150	130	130	130
	12	(Women) Rs.day^{-1}	60	100	100	80		
Time study (seedlings stacked at border of field initially)	13	Seedling placement time (min)	-	-	-	-	10	70
	14	Transplanting time (min)	-	-	-	-	48	168
	15	Non productive time (min)	141	134	247	48	6	29
	16	Productive time (min)	4179	4705.78	5311.28	775.92	58	238
	17	Non productive time (sec/seedling)	0.85	0.80	0.74	0.96	1.24	0.93
	18	Productive time (sec.seedling^{-1})	25.07	28.23	15.93	15.52	12.00	7.66
	19	Total time (sec.seedling^{-1})	30.24	34.98	20.45	16.48	13.24	8.59
	20	Total time-lunch time (sec.seedling^{-1})	25.92	29.04	16.67	16.48		
	21	Seedlings.min^{-1}.person^{-1}	2.31	2.07	3.60	3.64	4.53	6.99
	22	Total man-hours/10000 seedling	72.00	80.66	46.32	45.77	36.78	23.86
	23	Cost (Rs/10000 seedlings)	617.14	1309.46	756.23	850.08	443.13	683.09

(M.S.) – Maharashtra State , CPCT – Centre for Protected Cultivation Technology, IARI – Indian Agricultural Research Institute

Table 6.1.b Time and motion study details of plug seedling transplanting operation

		Survey No.	**7**	**8**	**9**	**10**	**11**	**12**	**13**
		Pattern of transplanting	**T3**	**T3**	**T5**	**T5**	**T4**	**T4**	**T6**
		¤	Manual (Control plot)		Mechanical transplanter				
		Details	Furrow/border irrigated		Furrow/border irrigated		Manual seedling feeding		
Field Details	1	Location	AED, IARI New Delhi	AED, IARI New Delhi	AED, IARI New Delhi	AED, IARI New Delhi	CPCT IARI New Delhi	CPCT IARI New Delhi	AED, IARI New Delhi
	2	Field size (ha)	0.02	0.02	0.05	0.05	-		-
Crop details	3	Crop	Tomato	Brinjal	Tomato	Brinjal	Tomato	Brinjal	Dummy
	4	Variety	Himsona	Pusa Uttam	Himsona	Pusa Uttam	Himsona	Pusa Uttam	seedlings
	5	No. of seedlings	250	250	655	675	655	675	750
	6	Tray size (no.of cups)	187	187	187	187	187	187	30
	7	Plant to plant spacing (mm)	600	600	600	600	-	-	-
	8	Row to row distance (mm)	1200	1200	1200	1200	-	-	-
Labour details	9	Labour (Men)	2	2	2	2	2	2	2
	10	Labour Rate (Men) Rs.day^{-1}	130	130	130	130			
Time study (seedlings stacked at border of field initially)	11	Seedling placement time (min)	12	10.50	-	-	26.7	16.91	11.12
	12	Transplanting time (min)	42	41.60	-	-			
	13	Non productive time (min)	14.70	15	3.49	2.98	3.6	3.2	0.515
	14	Productive time (min)	64	62	16.9	17.3	23.6	18	11.12
	15	Non productive time (sec.seedling^{-1})	3.53	3.60	0.32	0.26	0.33	0.28	0.04
	16	Productive time (sec.seedling^{-1})	15.36	14.88	1.55	1.54	2.16	1.60	0.89
	17	Total time (sec.seedling^{-1})	18.89	18.48	1.87	1.80	2.49	1.88	0.93
	18	Seedlings.min^{-1}.person^{-1}	3.18	3.25	32.12	33.28	24.08	31.84	64.46
	19	Total man-hours/10000 seedling	52.47	51.33	5.19	5.01	6.92	5.23	2.59
	20	Cost (Rs/10000 seedlings)	852.58	834.17	720	648			

AED – Agricultural Engineering Division, CPCT – Centre for Protected Cultivation Technology, IARI – Indian Agricultural Research Institute

Chapter VI

Comparative Time-Motion Study and Cost Analysis of Manual and Mechanized Transplanting Operation of Vegetable Plug Seedlings

6.1 Abstract

In India, transplanting of plug seedlings is done manually and is a labour-intensive operation. On an average, about 197 man-hours are required to transplant seedlings in one hectare area with a plant spacing of 600 mm x 600 mm. A tractor operated two row vegetable transplanter was developed to mechanize this labour intensive operation to reduce labour costs and enhance timeliness of transplanting operation. Economy of the effort done to accomplish a job and the manner in which it is done are extremely important factors in optimizing a given operation process. Use of time and motion study is one of the techniques to achieve this economy. The objective of this paper is to analyze the results of time and motion study of the manually and mechanical plug seedling transplanting operation, and suggest improvements to optimize the given operation. Time and motion study of manual transplanting of tomato, cabbage and brinjal seedlings were done at different locations in Western Maharashtra and at IARI, New Delhi during the period 2007 to 2010. The study was also done for the mechanical transplanting operation for tomato and brinjal plug seedlings using the two-row vegetable transplanter. Different transplanting and seedling feeding patterns were observed and tested. Seedling placement at transplanting location followed by transplanting was found to be more efficient way of manually transplanting seedlings. Mechanical transplanting increased transplanting rates possible per person by about ten times than manual method of transplanting. It was observed that, for increasing seedling feed rates operator should pick/pull up as many seedlings possible at a time from the tray and then place one by one in seedling metering tubes.

Keywords: Time and motion study, vegetable transplanting, plug seedlings

6.2 Introduction

India being the second largest producer of vegetable crops and the second most populous country in the world, has a considerable agricultural workforce involved in the cultivation of vegetable crops. Over the past few years, plug tray seedling technology has gained momentum in India due to several advantages over the traditional bare root seedlings grown in open field conditions. Seedlings of high value vegetable crops such as tomato, capsicum, cucumber, brinjal, chilly etc. are now being widely grown in plug trays by a large number of nurseries in India and sold on pre-ordered basis to farmers. After taking the delivery of seedlings from the nursery, the farmer has to transplant them in the field within a day to minimize their mortality. At present, transplanting of plug seedlings is done manually which is a labour-intensive operation. On an average, about 23-25 man-days are required to transplant seedlings in one hectare area with a plant spacing of 600 mm x 600 mm. Besides the quantum of labour, manual transplanting involves considerable drudgery and human discomfort. The labour has to stoop forward while placing the seedling on the bed, and has to squat to move to next planting position. This results in bio-mechanical stresses in the back and the knees causing higher fatigue and reduced work capabilities of the labour.

Economy of the effort done to accomplish a job and the manner in which it is done are extremely important factors in optimizing a given operation process. Use of time and motion study is one of the techniques to achieve this economy. It is important to determine and optimize three major cost factors viz. material, overhead, and labour costs, to maintain economy of an operation process. Time and motion study deals mainly with labour costs. Yet it is affected by many complex variables such as the understanding of the whole field of motivation. Manual transplanting of plug seedlings being a repetitive, labour-intensive and unorganized operation, needs to be optimized to a preferable work method in order to enhance timeliness and reduce cost of the operation. Although complete mechanization by use of transplanters is the obvious solution to enhance timeliness of operation, the high cost of imported transplanters and unavailability of locally manufactured vegetable transplanters for plug seedlings has restricted farmers to stick to manual method. In view of the above, time and motion study of transplanting plug seedlings of tomato, cabbage and brinjal were done at few locations in Western Maharashtra and at IARI, New Delhi.

6.3 Material and Methods

The transplanting operation is generally performed by a group of people each assigned a specific activity or all doing the same activitiy independently or combination of both. Assuming that plug seedlings are available at the border of field, the sequence of manual operations normally practiced during transplanting operation are:

I) Carrying plug trays to the location of transplanting

II) Marking the place of transplanting at equal spacing using a stick length equal to the spacing desired

III) Placing the seedlings at marked position on the beds

IV) Making small grooves with fingers in soil at the place of transplanting

V) Placing the seedling in the groove, covering plug with soil and slightly compacting it with both hands

VI) Moving to next transplanting position

VII) Carrying the empty trays back to border of field

The activity II and III are performed by the same or different person. It is skiped in case of drip irrigated field and seedlings are placed directly along emitter's location on lateral. Activity IV and V are always performed by the same person. After performing the activities I to V the person moves to next transplanting position and repeats the sequence of actions until the plug tray is empty. However, in mechanical transplanting, the operator has to pull the seedling plug out of plug tray and place one at a time in the seedling feed tubes. The time required for all other activities other than those mentioned above such as time required for initial adjustments, repairing break down, lunch and rest time etc. which do not contribute to transplanting activity were classified as non productive time. The details about field, crop transplanted, labour and time spent for seedling placement, transplanting, feeding seedlings to metering tubes and other activities performed during manual and mechanical transplanting operation of the plug seedling were recorded (Table 6.1.a and 6.1.b). The study was conducted at different locations in western Maharashtra and New Delhi during the period 2007 to 2010. The transplanting was done on either open bed or plastic mulch beds which were irrigated by furrow or drip irrigation method.

Different patterns of manual transplanting were observed to be followed in the areas surveyed. These patterns of manual transplanting based on sequence of activities performed during transplanting operation were categorized as follows:

1) T1 - The transplanting activities II, III, IV, V and VI were performed by an individual person while moving along a row. The filled plug trays were carried to the

transplanting location and empty ones back to the border of field (activity I and VII) by the same person or another person who was specifically assigned this activity.

2) T2 - For drip irrigated field with laterals already laid along rows, activity II was skipped. A single or more than one person performed activity I, III, VI and VII until all seedlings were placed and then assisted others to do rest of activities. Other persons simultaneously performed rest of the activities (IV, V and VI).

3) T3 - same as T2 except activity II was done by one or more persons for furrow/border irrigated fields.

In mechanized transplanting operation, the operator pulled the seedling plug out of plug tray and placed one seedling at a time in the seedling metering feed tubes. A seedling metering mechanism consisting of six feed tubes arranged in a circle was fabricated for use in prototype vegetable transplanter (Fig. 5.1). Different seedling feeding pattern were tested to find the best method to feed the seedling metering feed tubes in case of mechanical transplanting operation and are as follows:

1) T4 - the operator pulled one seedling plug at a time out of plug tray and placed it in the seedling feed tubes. The operator used his both hands simultaneously or alternately to increase feeding rates.

2) T5 – same as T4 except that the seedling plugs were pre loosened to reduce time and effort to pull them out of plug trays.

3) T6 – plug seedlings are removed from plug trays and arranged in a separate tray with plain bottom (as are generally delivered by nursery growers to the farmers, if plug trays are reusable). The operator picked up as many seedlings possible at a time from the tray and then placed them one by one in seedling feed tubes.

Dummy seedlings were used to perform experiment T6. Non-productive time required in field, such as bringing trays from border of field to transplanter, loading and unloading plug trays on transplanter etc. was recorded. To compare the different manual transplanting patterns the total time required to transplant single seedling was calculated excluding the lunch time, as the lunch break was not taken in all surveyed transplanting operations. The seedling feed rates per minute were calculated to compare the seedling feeding methods tested. The transplanting geometries were different for the areas surveyed; therefore transplanting cost per 10000 seedlings was calculated instead of cost on area basis (Table 6.1.a and 6.1.b)

6.4 Results and Discussion

The details of time and motion study of manual plug seedling transplanting and mechanical plug seedling transplanting operation are presented in Table 6.1 and 6.2.

6.4.1 Manual transplanting

Different patterns of manual transplanting were observed to be followed in the areas surveyed. The non productive time spent per seedling was found to be almost equivalent for manual transplanting in all surveyed locations (0.74 to 1.24 $sec·seedling^{-1}$) except for control plot planted manually (3.53 to 3.60 $sec·seedling^{-1}$). This showed that unnecessary extra time was not spent by labour in all areas surveyed and therefore no survey location of the experiment could be discarded as an outlier. The productive time varied from 7.66 to 28.23 $sec·seedling^{-1}$. The variation observed was due to different patterns followed in transplanting. Similar variation was observed for total time required per seedling (8.59 to 29.04 $sec·seedling^{-1}$), (Table 6.1 a and 6.2.a). The comparative performance of different patterns of manual transplanting arranged in ascending order for total time required to transplant single seedling and cost per 10000 seedlings is given in Table 6.2 a. Pattern T2 required least time per seedling as activity II was performed. The emitters laid on drip lateral provided position of transplanting and the labour transplanted the seedling in wet soil with comparatively less effort. However, for furrow or border irrigated fields, pattern T3 required least average time per seedling for transplanting operation. This was because the seedling placement activity (III) which required very less time as compared to transplanting activity (IV, V), was performed separately by a group of people. It could therefore be inferred that the activities requiring less time and more physical movement to change location should be performed separately by an efficient group of labour. Pattern T1 required highest transplanting time per seedling and therefore would not be recommended for timeliness of operation. The cost of transplanting could not be compared directly as the wage rates varied much (60-150 $₹·day^{-1}$) in the areas surveyed, however it would be proportional to transplanting time if similar wage rates were assumed. Therefore pattern T3 would be recommended method of transplanting. Thus seedling placement at transplanting location followed by transplanting is more efficient way of manually transplanting seedlings as compared to simultaneous seedling placement and transplanting operation.

Table 6.2.a Time and cost comparision of different patterns of manual transplanting arranged in ascending order

Pattern	Survey/Expt No.	Total time (sec.seedling^{-1})	Pattern	Survey/Expt No.	Cost (₹/10000 seedlings)
T2	5	8.6	T2	5	443
T2	6	13.2	T1	1	617
T1	4	16.5	T2	6	683
T3	3	16.7	T3	3	756
T3	8	18.5	T3	8	832
T3	7	18.9	T1	4	850
T1	1	25.9	T3	7	852
T1	2	29.0	T1	2	1309

Table 6.2.b Time required for different patterns of feeding seedlings to metering feed tubes arranged in descending order

Pattern	Survey /Expt	Crop	Non-productive time	Productive time	Total time	Seedlings ·min^{-1}
	No.		(sec·seedling^{-1})			
T6	13	Dummy	0.04	0.9	0.93	64.5
T5	10	Brinjal	0.3	1.5	1.80	33.28
T5	9	Tomato	0.3	1.6	1.87	32.12
T4	12	Brinjal	0.3	1.60	1.88	31.84
T4	11	Tomato	0.3	2.2	2.49	24.1

The transplanting was done only by female labours at site 1 and only male labours at site 4 using T1 pattern of transplanting . The average number of seedlings transplanted by each labour in both the cases (750 seedlings·male labour^{-1} and 833 seedlings·female labour^{-1}) were comparable. It was observed that average time required by female labour to transplant vegetable seedlings was about 56% more than that required by male labour. However, the average labour rates for female worker were 63.56% of the male workers and were found to be proportional to their working rates (man-hours per 10000 seedlings).

6.4.2 Mechanical transplanting

In mechanical method of transplanting done using prototype two row vegetable transplanter, the average transplanting rate observed was 30.3 seedlings·min^{-1}·person^{-1} as against 3.2 seedlings·min^{-1}·person^{-1} in manual (control plot) method of transplanting. Also the average cost of mechanical transplanting

10000 seedlings (₹684) was less than manual method (₹843). Thus mechanical method of transplanting done using manually fed vegetable transplanter increased transplanting rates possible per person by about ten times than manual method of transplanting (Table 6.1.b).

Different methods of feeding seedlings to feed tubes were tested. It was observed that non productive time for handling tomato seedlings was little higher than brinjal as it was comparatively soft and fragile. Pre loosening of plug seedlings (T5) did not show marked difference in total time required per seedling as compared to T4 for brinjal, however it was significantly less (1.87 sec) as compared to tomato (2.49 sec - T4). This could be attributed to the extra time needed to pull out tomato seedlings gently out of plug trays. Besides, the root development was not proper in case of tomato plug seedlings used in T4, and therefore more care was required to pull the seedlings out of tray to avoid shattering of root plugs. T6 method of feeding seedlings was found to have highest possible transfer rates among the tested methods (Table 6.2.b). This was attributed to the time saving in pulling/handling individual seedling separately and moving hand repeatedly from tray to seedling feed tubes. Thus it would be recommended for operator to pick/pull up as many seedlings possible at a time from the tray and then places one by one in seedling metering tubes. This would either need seedlings to be removed from plug trays and arranged in a separate tray with plain bottom, or wetting root plug before transplanting that facilitates easy removal of seedling from plug tray. Seedling feed rate limited the maximum allowable travel speed of the transplanter for plant spacings below 600 mm. Therefore increasing feeding rates would enable faster transplanting rates in field and would further reduce cost of transplanting as compared to manual method.

5.6 Conclusions

The following conclusions were drawn from the time and motion study

1. Placement of seedling at transplanting location followed by transplanting was more efficient way of manually transplanting plug seedlings.
2. The average time required by female labour to transplant vegetable seedlings was found to be about 56% more than that required by male labour. However the average labour rates for female worker were 63.56% of the male workers and were found to be proportional to their working rates (man-hours per 10000 seedlings).

3. Mechanical transplanting done using manually fed vegetable transplanter increased transplanting rates possible per person by about ten times than manual method of transplanting.
4. For increasing seedling feed rates, the operator should pick/pull up as many seedlings possible at a time from the tray and then place one by one in seedling metering tubes.

Parts of prototype vegetable plug seedling transplanter

No.	Part	No.	Part
1	Furrow opener	11	Footrest
2	Pusher	12	Indexing plate
3	Seedling feed tube	13	Cover
4	Flat plate positive inverse cam	14	Operator’s seat
5	Chain sprocket transmission	15	Drive cum compaction wheel
6	Spring	16	Hitching frame
7	Press wheels	17	Clamps
8	Depth adjustment bolt	18	Double parallel link mechanism
9	Plug tray	19	Restraining link chain
10	Seedling feed tubes	20	Transmission chain cover

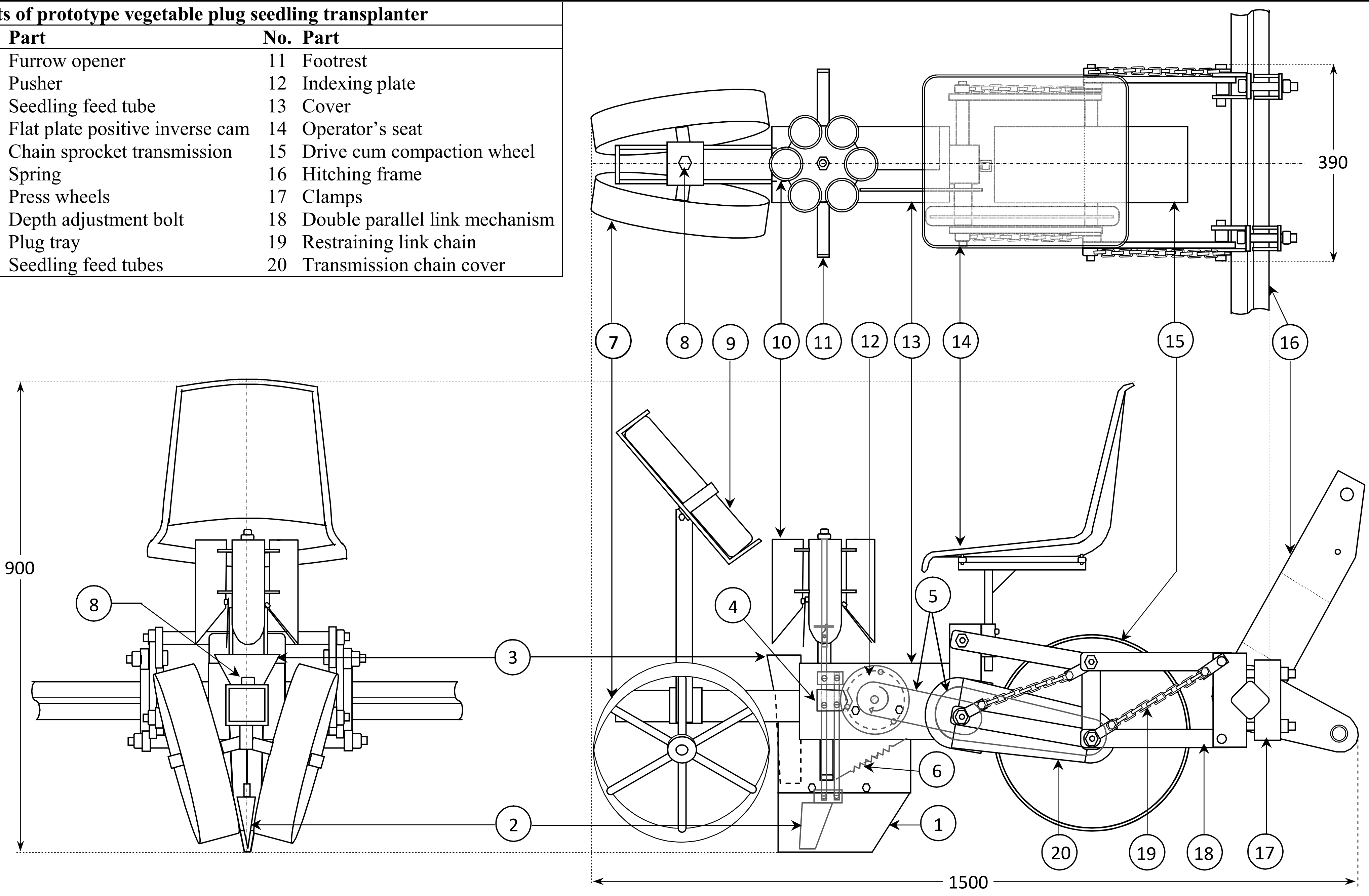

Fig. 5.2 Prototype vegetable plug seedling transplanter

All dimensions in mm

Chapter VII

Summary and Conclusions

Transplanting of plug seedlings is a manual and labour-intensive operation. In peak season manual labour can hardly meet the requirements of transplanting vegetable seedlings. Besides the quantum of labour, manual transplanting involves considerable drudgery and human discomfort. Increased cost of labour in the past decade has made the manual transplanting uneconomical. As of now indigenous transplanters for vegetable plug seedlings are not available in India. Imported vegetable transplanters have not been adopted by vegetable growers due to their high costs and the resultant uneconomic scale of production. Therefore in order to reduce farmer’s dependence on manpower during peak periods for vegetable transplanting operation, there is a need to develop a low-cost vegetable transplanter utilizing simple mechanisms for Indian soil conditions. In view of the above investigation, the present study was undertaken to design and develop a tractor-operated semi-automatic mechanical transplanter for sowing plug seedlings of vegetable crops in sandy loam soils which covers major cultivable area of India. Since tomato and brinjal share the major area sown by vegetable plug seedlings in India (Indian Horticulture Database 2008) and morphological being tender and hardy respectively, tomato and brinjal were selected to design and test the vegetable transplanter.

Physical properties of tomato and brinjal plug seedlings relevant for simulating actual seedlings and the design of prototype transplanting unit were determined. An experimental plug seedling transplanting mechanism that could eject seedlings at the same speed of forward travel, but in opposite direction, was designed and fabricated. Soil bin studies were conducted subsequently using dummy seedlings on experimental transplanting mechanism to study the effect of soil parameters viz. moisture content, bulk density and machine parameters viz. speed of operation on furrow closure, uniformity in spacing and success of transplanting plug seedlings. The soil bin studies were conducted on two independent furrow opening and closing mechanisms viz. i) shoe type furrow opener with press wheel furrow closing cum compaction system ii) shoe type furrow opener with ski type furrow closing cum compaction system. The observed data was statistically analyzed after initial data preprocessing and transformation using “SAS” software. Optimum operating conditions and design values for successful transplanting of plug seedlings were determined. A prototype vegetable plug seedling transplanter was then designed based on the findings of soil bin studies and the optimum operating conditions and design values obtained. The basic considerations in the design of vegetable transplanter were cost, simplicity of design for fabrication by local manufacturers, ease of operation in field, and ergonomics to suit Indian farming population. Pre-modeling analysis was done using visual basic macro programming in "Microsoft excel"; "Working model 2005" and "Engineering power tools" software. Part modeling, assembly and drawings were prepared using CAD software "Pro Engineer Wildfire 4.0". A prototype of two row tractor mounted, semi automatic vegetable transplanter for plug seedlings was fabricated according to the design values obtained. The prototype was tested in field for transplanting one month old tomato and brinjal seedlings. Performance parameters like transplanting efficiency, seedling mortality, per cent miss in transplanting, field efficiency of transplanter etc. were calculated along with its cost economics for comparison with currently practiced manual method of plug seedling transplanting. Based on the results, the following conclusions were drawn:

I) Soil bin studies on experimental transplanting mechanism

1) Moisture content, bulk density of soil and forward speed of travel significantly affected success of transplanting for both press wheel and ski type furrow closing cum compaction system.
2) Moisture content had profound effect on furrow closure and thereby success of transplanting with ski type machine configuration.
3) Pre-compaction of soil up to the depth of transplanting improved successful transplanting in case of press wheel type of machine configuration and vice versa for ski type of machine configuration.
4) Speed of travel significantly affected the angle of inclination of transplanted seedling. It increased with speed of travel in press wheel type of machine configuration. However, the effect was absent in ski type of machine configuration indicating possibility of operation at higher speeds.
5) Moisture content, bulk density of soil and forward speed of travel did not significantly affect uniformity in plant spacing for both press wheel and ski type furrow closing cum compaction system.

6) Unsuccessful transplanting was mainly because of higher angle of inclination of transplanted seedling in press wheel type of machine configuration and improper furrow closure in case of ski type machine configuration.
7) Optimum combination for manually fed vegetable transplanters for close spaced vegetable crops was; press wheel type of machine configuration operated at slower speed (0.28 $m{\cdot}s^{-1}$) in moisture content range of 9% to 15% (db), with low soil compaction level (1.1 $Mg{\cdot}m^{-3}$).
8) Highest speed of travel suitable for successful transplanting was found to be 0.49 $m.s^{-1}$ (1.75 $km{\cdot}h^{-1}$) in wide moisture content range of 6% to 15% (db) at higher bulk density (1.45 $Mg{\cdot}m^{-3}$).
9) In general, vegetable transplanting mechanism consisting of shoe type furrow opener and pusher mechanism gave higher values of successful transplanting of plug seedlings with press wheel furrow closing cum compaction system than ski type furrow closing cum compaction system in sandy loam soils.

II) Performance evaluation of prototype vegetable plug seedling transplanter

1) Transplanting efficiency of 94.48% and 97.12% was obtained for tomato and brinjal plug seedlings, respectively.
2) Average cost for transplanting 1000 tomato/brinjal plug seedlings using developed vegetable transplanter was ₹70/- as against ₹84/- when done manually.
3) The average payback period was found to be 10.32 months (222 h) for owning the transplanter by vegetable grower as against 14.66 months (306 h) for a entrepreneur offering custom hiring services.
4) The Breakeven point (BEP) was found to be 35.64 h which was 14.64% of annual utility of vegetable transplanter.
5) Seedling feed rate restricted the maximum allowable travel speed of the transplanter for plant spacings below 600 mm.
6) Use of single unit of vegetable transplanter was not found economically justifiable as transplanting costs are higher than manual method.
7) A minimum vegetable cultivation area of 7.7 ha was required by a vegetable grower to justify ownership of two-row vegetable transplanter as against custom hiring it.

8) Two-row vegetable transplanter was recommended for use by farmers to reduce transplanting costs, and timely and uniform transplanting of vegetable seedlings grown in plug trays.

III) Time-motion Study of manual and mechanized transplanting operation

1) Mechanical transplanting done using manually fed vegetable transplanter increased transplanting rates possible per person by about ten times than manual method of transplanting.
2) For increasing seedling feed rates, the operator should pick/pull up as many seedlings possible at a time from the tray and then place one by one in seedling metering tubes.

Abstract

India is the second largest producer of vegetables in the world with an estimated annual production of 125.88 million tons from 7.8 million ha, which accounts for about 13.3% of total world vegetable production (Indian Horticultural Database 2008). However the average yield of vegetables in India is still lower than that in many Asian countries. One of the major reasons of low productivity is the low level of mechanization. Mechanized cultivation, along with other improved crop production practices, is critical and important to increase crop yield. One cultivation practice that would benefit from mechanization in vegetable production is transplanting of good-quality vegetable seedlings. Vegetable seedlings have been traditionally grown on soil beds in open field for a long time in India. However, over the past few years, plug tray seedling technology has gained momentum in India for its several advantages over open field nursery raising. A large number of such nurseries have been operating in Karnataka, Maharashtra and several other states where seedlings are grown in plug trays and sold on pre-ordered basis to farmers. After taking the delivery of seedlings from the nursery, the farmer has to transplant them in the field within a day to minimize their mortality.

Transplanting of plug seedlings is a manual and labour-intensive operation. In peak season manual labour can hardly meet the transplanting requirements of vegetable seedlings. Besides the quantum of labour, manual transplanting involves considerable drudgery and human discomfort. Increased cost of labour in the past decade has made transplanting by hand uneconomical. To date, locally produced transplanters for transplanting vegetable plug seedlings are not available in India. Imported vegetable transplanters have not been adopted by farmers due to their high costs and the resultant uneconomic scale of production. In view of the above investigation, the present study was undertaken to design and develop a tractor-operated semi-automatic mechanical transplanter for mechanizing plug seedling transplanting operation. Since tomato and brinjal shares the major area sown by vegetable plug seedlings in India (Indian Horticultural Database 2008) and morphological being tender and hardy respectively, tomato and brinjal were selected to establish the design and test the vegetable transplanter.

An experimental plug seedling transplanting mechanism that can eject seedlings at the same speed of forward travel, but in an opposite direction was designed and fabricated. Two independent furrow opening and closing mechanisms viz. i) shoe type furrow opener with press wheel furrow closing cum compaction system ii) shoe type furrow opener with ski type furrow closing cum compaction system were tested in soil bin using dummy seedlings. The effect of soil parameters viz. moisture content, bulk density and machine parameters viz. speed of operation on furrow closure, uniformity in spacing and success of transplanting plug seedlings were studied. The observed data was statistically analysed using "SAS" software. Optimum operating conditions and design values for successful transplanting of plug seedlings were determined. A prototype vegetable plug seedling transplanter was then designed using CAD software "Pro Engineer Wildfire 4.0" based on optimum operating conditions and design values obtained in soil bin studies. A two row tractor mounted, semi-automatic vegetable transplanter for plug seedlings was fabricated and tested in field for transplanting one month old tomato and brinjal seedlings.

Transplanting efficiency of 94.48% and 97.12% were obtained for tomato and brinjal plug seedlings, respectively. Average cost for transplanting 1000 tomato/brinjal plug seedlings using the vegetable transplanter was estimated to be ₹70/- as against ₹84/- when done manually. Assuming an annual use of the two-row vegetable plug seedling transplanter as 250 h, the average payback period and the breakeven point (BEP) were found to be 222 h and 35.64 h, respectively. Use of single row unit of vegetable transplanter was not found to be economically justifiable. A two-row vegetable transplanter was recommended for use by farmers to reduce transplanting costs, and timely and uniform transplanting of vegetable seedlings grown in plug trays.

सारांश

7.8 मिलियन हेक्टेयर खेती क्षेत्र से 125.88 मिलियन टन के अनुमानित वार्षिक उत्पादन के साथ भारत विश्व में सब्जियों का दूसरा सबसे बड़ा उत्पादक देश है। विश्व के कुल शाकीय उत्पादन में भारत की हिस्सेदारी लगभग 13.3 प्रतिशत है (भारतीय बागवानी डाटाबेस 2008)। हालांकि बहुत से एशियाई देशों की तुलना में अभी भी भारत में सब्जियों की औसत पैदावार कम ही है । कम उत्पादकता का एक बड़ा कारण मशीनीकरण का निम्न स्तरीय होना भी है। मशीनीकरण अन्य उन्नत फसल उत्पादन अभ्यासों के साथ खेती फसल पैदावार बढ़ाने में अत्यंत महत्वपूर्ण है। शाकीय उत्पादन में मशीनीकरण से लाभ उठाने के लिए अपनाए जाने वाले खेती अभ्यासों में अच्छी क्वालिटी का पौध रोपण करना भी शामिल है। सामान्यतः भारत में पारम्परिक रूप से खुले खेतों में शाकीय पौध तैयार की जाती हैं परन्तु पिछले कुछ वर्षों से अपनी अनेकों खूबियों के कारण उपरोक्त पौध प्रणाली की तुलना में प्लग ट्रे सीडलिंग प्रौद्योगिकी अधिक प्रचलित हुई है। कर्नाटक, महाराष्ट्र तथा अन्य बहुत से राज्यों में ऐसी बहुत–सी नर्सरियां प्रचालन में हैं जहां प्लग ट्रे में पौध को उगा कर उन्हें किसानों को पहले से प्राप्त आदेशों के आधार पर बेचा जाता है। नर्सरी से पौध की आपूर्ति प्राप्त करने के पश्चात किसानों द्वारा उन्हें एक दिन के भीतर ही रोपित कर दिया जाना चाहिए ताकि पौध की मृत्यु दर को कम किया जा सके।

प्लग पौध का रोपण कार्य हाथ से किया जाने वाला कार्य है जिसमें अधिक मजदूरी की आवश्यकता होती है। व्यस्त सीजन में शाकीय पौध को हाथ से रोपित किए जाने हेतु मुश्किल से मजदूर मिल पाते हैं। हाथ से किए जाने वाले पौध–रोपण कार्य में मजदूरों की संख्या के अलावा उन्हें थकावट भी अधिक होती है। पिछले दशक में बढ़ी हुई मजदूरी लागत के कारण हाथ से किया जाने वाला पौध–रोपण आर्थिक दृष्टि से किफायती नहीं रहा है । आजतक भारत में स्थानीय रूप से विकसित ट्रांसप्लांटर उपलब्ध नहीं हैं। महंगी कीमतों और इसके परिणामस्वरूप इनके गैर किफायती उत्पादन स्तर के कारण आयातित शाकीय ट्रांसप्लांटर्स को अभी तक किसानों द्वारा पूरी तरह से अपनाया नहीं जा सका है।

उपरोक्त विश्लेषण को ध्यान में रखते हुए मशीनीकृत प्लग पौध रोपण कार्य के लिए एक ट्रैक्टर चालित अर्ध–स्वचालित यांत्रिक ट्रांसप्लांटर की डिजाइन व विकास पर वर्तमान अध्ययन किया गया। भारत में चूंकि शाकीय प्लग पौध द्वारा बुवाई

किए जाने वाले प्रमुख क्षेत्रों में टमाटर तथा बैंगन की हिस्सेदारी कहीं ज्यादा है (भारतीय बागवानी डाटाबेस 2008) तथा आकृतिविज्ञान की दृष्टि से कोमल तथा कठोर होने के कारण क्रमशः टमाटर व बैंगन का चयन शाकीय ट्रांसप्लांटर की डिजाइन और परीक्षण के लिए किया गया।

एक ऐसी परीक्षणात्मक प्लग सीडलिंग पौध–रोपण कार्यप्रणाली का डिजाइन तैयार कर उसका निर्माण किया गया जिसमें कि ट्रैक्टर आगे बढ़ने के साथ–साथ उसी गति से विपरीत दिशा में ट्रे में से पौध को धकेला जा सके। दो स्वतंत्र कूंड खोलने व बंद करने की कार्यप्रणाली यथा 1) प्रेस व्हील फरो क्लोजिंग के साथ शू–टाइप फरो ओपनर एवं सघनता प्रणाली तथा 2) स्की टाइप फरो क्लोजिंग के साथ शू–टाइप फरो ओपनर एवं सघनता प्रणाली का परीक्षण डमी पौध का इस्तेमाल करते हुए मृदा बिन प्रयोगशाला में किया गया। नमी मात्रा, व्यापक सघनता जैसे मृदा मापदंडो और फरो बंद होने पर ऑपरेशन की गति, अन्तराल में एकरूपता जैसे मशीन मापदंडो तथा प्लग पौध के रोपण की सफलता के प्रभाव का अध्ययन किया गया। हासिल किए गए आंकडों का सांख्यिकीय विश्लेषण “SAS” साफटवेअर का उपयोग करते हुए किया गया। प्लग पौधों के सफल रोपण के लिए अनुकूल प्रचालन परिस्थितियों और डिजाइन मूल्यों का निर्धारण किया गया। मृदा बिन अध्ययन में हासिल अनुकूल प्रचालन परिस्थितियों और डिजाइन मूल्यों पर आधारित ''प्रो इंजीनियर वाइल्डफायर 4.0'' कैड साफटवेअर का उपयोग करते हुए तब एक प्रोटोटाइप शाकीय प्लग पौध ट्रांसप्लांटर की डिजाइन तैयार की गयी। प्लग पौध के लिए एक दो पंक्ति वाले ट्रैक्टर माउंटिड अर्ध–स्वचालित शाकीय ट्रांसप्लांटर का निर्माण कर उसका परीक्षण एक माह पुरानी टमाटर और बैंगन पौध के रोपण के लिए किया गया।

टमाटर तथा बैंगन प्लग पौध के लिए पौध–रोपण प्रभावशीलता क्रमशः 94.48 एवं 97.12 प्रतिशत हासिल की गयी। शाकीय ट्रांसप्लांटर का उपयोग करते हुए 1000 टमाटर/बैंगन प्लग पौधों के रोपण की औसत लागत हाथ से की गयी रोपाई की तुलना में ₹84/– के मुकाबले ₹70/– थी। दो पंक्ति वाले शाकीय प्लग पौध ट्रांसप्लांटर का 250 घंटे का वार्षिक उपयोग मानते हुए औसत पे–बैक अवधि तथा ब्रेक–इवन प्वाइंट (बी ई पी) क्रमशः 222 घंटा तथा 35.64 घंटा पाया गया। शाकीय ट्रांसप्लांटर की एकल पंक्ति इकाई किफायती नहीं पाई गई। दो पंक्ति वाला शाकीय ट्रांसप्लांटर किसानों द्वारा रोपण लागत घटाने और प्लग ट्रे में उगाई गई शाकीय पौध की समय से तथा एकसमान रोपण करने में उपयुक्त पाई गई।

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Appendices

Appendix A-1 Physical properties of 30 days old tomato and brinjal seedlings

	Tomato							Brinjal						
	Weight (gm)		Canopy Dimensions (mm)					Weight (gm)		Canopy Dimensions(mm)				
Sr. No.	Total Seedling	Plug	Stalk height	X	Y	Z	*CCD	Total Seedling	Plug	Stalk height	X	Y	Z	*CCD
1	17.32	15.37	59	104	61	65	50	18.69	15.65	37	86	71	80	50
2	17.7	15.70	60	106	62	66	50	18.1	15.18	35	91	64	74	50
3	16.12	14.27	58	93	61	63	40	17.6	14.73	34	88	62	72	50
4	17.38	15.47	59	111	56	62	50	18.18	15.25	35	92	64	74	50
5	17.58	15.65	59	113	56	62	50	19.96	16.77	41	95	76	85	60
6	16.57	14.66	60	96	63	65	50	17.39	14.54	33	86	62	71	50
7	17.5	15.58	59	112	56	62	50	16.72	13.87	34	72	69	75	40
8	17.13	15.16	61	99	65	67	50	17.95	15.04	35	90	64	73	50
9	17.83	15.82	60	107	62	67	50	17.48	14.62	33	87	62	72	50
10	16.79	14.94	57	107	54	59	50	17.17	14.26	36	75	71	77	40
11	17.6	15.58	63	102	67	69	50	17.92	14.97	35	83	69	77	40
12	18.24	16.18	62	109	64	69	50	19.28	16.17	39	91	73	82	50
13	18.09	16.05	61	107	63	68	50	18.84	15.78	38	88	72	81	50
14	17.1	15.22	58	109	55	60	50	17.14	14.32	32	85	61	70	50
15	16.88	15.02	57	108	54	60	50	20.91	17.57	47	97	85	93	60
16	20.31	17.97	71	118	77	81	60	18.8	15.75	37	88	72	80	50
17	17.08	15.12	61	99	65	67	50	18.32	15.28	39	82	75	82	40
18	19.36	17.17	65	116	68	73	60	18.43	15.42	36	86	70	79	50
19	18.42	16.30	65	107	70	73	50	19.39	16.32	39	99	68	79	60
20	18.79	16.72	63	120	60	67	60	18.25	15.26	36	85	70	78	50
21	19.51	17.27	69	113	74	78	50	18.3	15.3	36	85	70	78	50
22	18.2	16.15	61	109	64	68	50	17.68	14.72	37	78	73	79	40
23	17	15.13	58	109	54	60	50	17.92	14.97	35	83	69	77	40
24	17.32	15.37	59	104	61	65	50	17.73	14.76	37	78	73	79	40
25	16.54	14.72	56	106	53	58	50	20.11	16.87	45	92	82	90	50
26	17.65	15.66	60	106	62	66	50	17.7	14.82	34	88	63	72	50
27	18.68	16.57	63	112	65	70	50	19.02	15.9	41	86	78	85	50
28	17.72	15.68	63	103	67	70	50	17.52	14.57	37	77	72	78	40
29	17.35	15.44	59	111	56	61	50	17.98	15.07	35	90	64	74	50
30	16.92	14.97	61	98	64	66	50	18.2	15.18	39	81	75	81	40
Mean	17.69	15.70	60.90	107.13	61.97	66.23	50.67	18.29	15.30	36.90	86.13	69.97	78.23	48.00
SD	0.94	0.82	3.35	6.24	5.97	5.36	3.65	0.94	0.82	3.35	6.24	5.97	5.36	6.10
CV	5.31	5.25	5.49	5.83	9.63	8.09	7.21	5.14	5.39	9.07	7.25	8.53	6.85	12.71

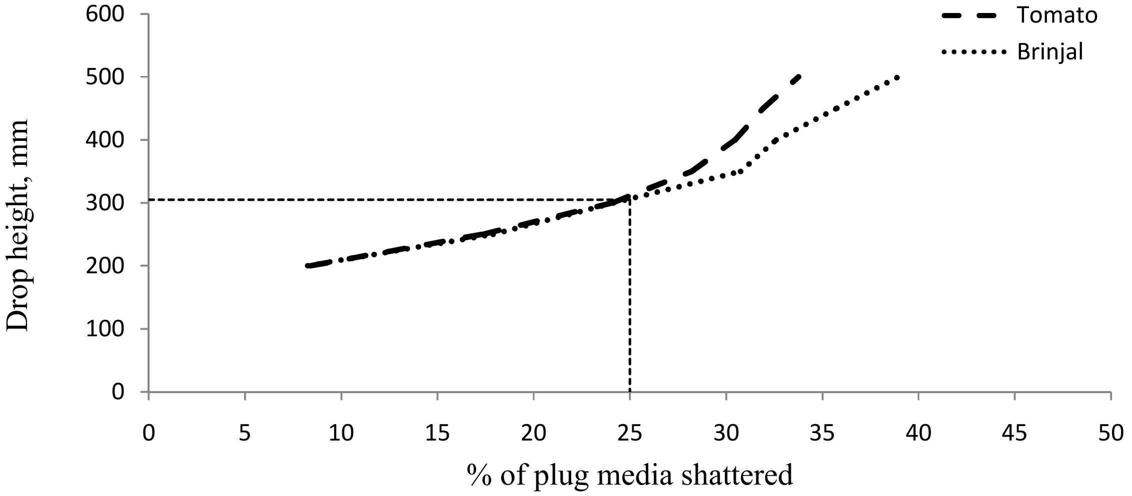
*CCD – Critical canopy diameter measured for 45-day old plug seedlings

Appendix A-2 Dimensions of plug seedling

Details	Mean weight (gm)		Min. stalk Height (mm)	Maximum. Dimensions (mm)			
	Total	Plug		X	Y	Z	Critical canopy dia.
Original	17.99	15.50	36.90	107.13	69.97	78.23	60
Dummy	**18**	**15.5**	**40**	**110**	**70**	**80**	**60**

Appendix A-3 Drop shatter height of plug

Drop height (mm)	% of growing media shattered							
	Tomato				Brinjal			
	R I	R II	R III	Mean	R I	R II	R III	Mean
200	8.2	8.38	8.66	8.41	8.31	8.51	7.97	8.26
250	17.77	17.26	17.03	17.35	18.51	16.69	18.48	17.89
300	24.67	24.1	23.54	24.1	26.07	23.56	22.84	24.16
350	28.83	27.6	28.19	28.21	31.34	30.26	30.67	30.76
400	30.8	29.54	31.04	30.46	32.56	32.9	32.35	32.6
450	32.81	30.22	32.78	31.94	35.49	35.74	36.04	35.76
500	33.7	34.1	33.47	33.76	37.71	40.99	38.17	38.96



Appendix B-1 Description of observations recorded in soil bin studies

Obs.	Description
SP	Average spacing between transplants in given replication,(mm)
Angle	Average percentage of seedlings with angle of inclination within 30^0 from vertical in given replication, (expressed in decimals)
FC	Average percentage of seedlings with proper furrow closure around seedling plugs in given replication, (expressed in decimals)
TR	Average percentage of seedlings transplanted in given replication, (expressed in decimals)
ST	Average percentage of seedlings successfully transplanted in given replication, (expressed in decimals)

Appendix B-2 Average values of observations recorded in soil bin studies

Rep 1	Ski					Press wheels				
Treatment	**SP**	**angle**	**FC**	**TR**	**ST**	**SP**	**angle**	**FC**	**TR**	**ST**
M1B1S1	900	1.00	1.00	1.00	1.00	902	1.00	1.00	1.00	1.00
M1B1S2	902	1.00	1.00	1.00	1.00	900	1.00	1.00	1.00	1.00
M1B1S3	904	1.00	1.00	1.00	1.00	898	0.80	1.00	1.00	0.80
M1B2S1	906	1.00	1.00	1.00	1.00	900	1.00	1.00	1.00	1.00
M1B2S2	900	1.00	1.00	1.00	1.00	900	1.00	1.00	1.00	1.00
M1B2S3	914	1.00	1.00	1.00	1.00	894	0.80	1.00	1.00	0.60
M1B3S1	908	1.00	1.00	1.00	1.00	908	1.00	1.00	1.00	1.00
M1B3S2	904	1.00	1.00	1.00	1.00	904	1.00	1.00	1.00	1.00
M1B3S3	904	0.60	1.00	1.00	0.60	906	0.60	1.00	1.00	0.60
M2B1S1	904	0.80	1.00	1.00	0.80	896	1.00	1.00	1.00	1.00
M2B1S2	902	0.80	1.00	1.00	0.80	906	1.00	1.00	1.00	1.00
M2B1S3	904	0.60	1.00	1.00	0.60	904	0.60	1.00	1.00	0.40
M2B2S1	902	0.60	1.00	1.00	0.60	906	0.80	1.00	1.00	0.80
M2B2S2	904	1.00	1.00	1.00	1.00	902	1.00	1.00	1.00	1.00
M2B2S3	896	1.00	1.00	0.80	0.80	896	0.60	1.00	1.00	0.60
M2B3S1	900	0.80	1.00	1.00	0.80	900	1.00	1.00	1.00	1.00
M2B3S2	902	0.80	1.00	1.00	0.80	908	1.00	1.00	1.00	1.00
M2B3S3	900	0.80	1.00	1.00	0.80	910	1.00	0.60	0.60	0.60
M3B1S1	900	0.80	0.80	1.00	0.80	910	1.00	1.00	1.00	1.00
M3B1S2	904	1.00	1.00	1.00	1.00	900	1.00	1.00	1.00	1.00
M3B1S3	906	1.00	1.00	1.00	1.00	904	0.40	1.00	1.00	0.40
M3B2S1	894	1.00	0.80	1.00	0.80	908	1.00	1.00	1.00	1.00
M3B2S2	898	0.80	1.00	1.00	0.80	908	0.80	1.00	1.00	0.80
M3B2S3	904	0.60	1.00	1.00	0.60	910	0.60	0.80	1.00	0.40
M3B3S1	904	0.60	0.40	1.00	0.20	906	1.00	1.00	1.00	1.00
M3B3S2	906	1.00	0.80	1.00	0.80	904	1.00	1.00	1.00	1.00
M3B3S3	910	0.60	0.60	1.00	0.20	908	1.00	1.00	1.00	1.00
M4B1S1	904	0.80	0.40	1.00	0.40	906	1.00	1.00	1.00	1.00
M4B1S2	908	1.00	0.40	1.00	0.40	902	1.00	1.00	1.00	1.00
M4B1S3	912	0.80	0.40	0.40	0.40	900	0.60	1.00	1.00	0.60
M4B2S1	910	0.60	0.20	1.00	0.20	910	1.00	0.40	1.00	0.40
M4B2S2	902	1.00	0.60	1.00	0.60	916	1.00	1.00	1.00	1.00
M4B2S3	898	0.60	0.60	0.80	0.40	900	0.80	0.80	1.00	0.80
M4B3S1	904	0.80	0.60	0.80	0.60	906	1.00	1.00	1.00	1.00
M4B3S2	910	0.60	0.20	0.60	0.00	922	1.00	1.00	1.00	0.80
M4B3S3	900	0.60	0.20	0.80	0.20	916	1.00	1.00	1.00	0.60

Rep 2	Ski					Press wheels				
Treatment	SP	angle	FC	TR	ST	SP	angle	FC	TR	ST
M1B1S1	904	1.00	1.00	1.00	1.00	904	1.00	1.00	1.00	1.00
M1B1S2	906	1.00	1.00	1.00	1.00	910	1.00	1.00	1.00	1.00
M1B1S3	904	0.80	1.00	1.00	0.80	914	0.80	1.00	1.00	0.80
M1B2S1	908	1.00	1.00	1.00	1.00	912	1.00	1.00	1.00	1.00
M1B2S2	912	1.00	1.00	1.00	1.00	908	1.00	1.00	1.00	1.00
M1B2S3	912	1.00	1.00	1.00	1.00	916	1.00	1.00	1.00	1.00
M1B3S1	906	1.00	1.00	1.00	1.00	908	1.00	1.00	1.00	1.00
M1B3S2	890	1.00	1.00	1.00	1.00	914	1.00	1.00	1.00	1.00
M1B3S3	910	0.80	1.00	1.00	0.80	906	0.80	1.00	1.00	0.80
M2B1S1	902	1.00	0.60	1.00	0.60	916	1.00	1.00	1.00	1.00
M2B1S2	906	0.80	1.00	1.00	0.80	912	1.00	1.00	1.00	1.00
M2B1S3	910	0.60	1.00	1.00	0.60	910	0.40	1.00	1.00	0.40
M2B2S1	908	0.80	1.00	1.00	0.80	910	0.20	1.00	1.00	0.20
M2B2S2	906	1.00	1.00	1.00	1.00	914	1.00	1.00	1.00	1.00
M2B2S3	912	1.00	1.00	1.00	1.00	912	1.00	1.00	1.00	1.00
M2B3S1	920	0.80	0.80	1.00	0.80	908	1.00	1.00	1.00	1.00
M2B3S2	902	1.00	1.00	1.00	1.00	912	1.00	1.00	1.00	1.00
M2B3S3	904	1.00	0.80	1.00	0.80	904	1.00	1.00	1.00	0.80
M3B1S1	906	1.00	0.60	1.00	0.60	912	1.00	1.00	1.00	1.00
M3B1S2	902	1.00	0.60	1.00	0.60	906	0.60	1.00	1.00	0.60
M3B1S3	906	1.00	0.60	1.00	0.60	910	0.20	1.00	1.00	0.20
M3B2S1	916	0.20	0.20	0.40	0.20	904	0.80	1.00	1.00	0.80
M3B2S2	916	0.60	0.40	1.00	0.40	914	0.80	1.00	1.00	0.80
M3B2S3	912	0.20	0.60	1.00	0.20	910	0.60	1.00	1.00	0.60
M3B3S1	910	0.20	0.00	1.00	0.00	910	1.00	1.00	1.00	1.00
M3B3S2	908	1.00	0.80	0.60	0.60	908	1.00	1.00	1.00	1.00
M3B3S3	906	0.20	0.20	0.25	0.00	908	1.00	1.00	1.00	0.80
M4B1S1	906	0.60	0.20	1.00	0.20	908	1.00	1.00	1.00	1.00
M4B1S2	902	1.00	0.80	1.00	0.80	910	1.00	1.00	1.00	1.00
M4B1S3	904	0.40	0.20	0.80	0.20	912	0.60	1.00	1.00	0.60
M4B2S1	906	0.60	0.40	1.00	0.20	912	1.00	0.00	1.00	0.00
M4B2S2	908	1.00	0.00	0.80	0.00	902	0.60	1.00	1.00	0.60
M4B2S3	910	0.40	0.40	1.00	0.20	910	0.60	0.40	1.00	0.20
M4B3S1	908	1.00	0.00	1.00	0.00	904	1.00	1.00	1.00	1.00
M4B3S2	906	0.40	0.00	0.60	0.00	908	1.00	1.00	1.00	1.00
M4B3S3	914	0.60	0.00	0.40	0.00	904	0.60	1.00	1.00	0.60

Rep 3	**Ski**					**Press wheels**				
Treatment	**SP**	**angle**	**FC**	**TR**	**ST**	**SP**	**angle**	**FC**	**TR**	**ST**
M1B1S1	908	0.80	0.60	1.00	0.60	910	0.80	1.00	1.00	0.80
M1B1S2	905	1.00	1.00	1.00	1.00	910	1.00	1.00	1.00	0.80
M1B1S3	910	1.00	1.00	1.00	1.00	903	0.40	1.00	1.00	0.40
M1B2S1	905	1.00	1.00	1.00	1.00	900	0.80	1.00	1.00	0.80
M1B2S2	900	0.80	1.00	1.00	0.80	905	0.80	1.00	1.00	0.80
M1B2S3	900	1.00	1.00	1.00	1.00	908	0.80	1.00	1.00	0.80
M1B3S1	908	1.00	1.00	1.00	1.00	908	1.00	1.00	1.00	1.00
M1B3S2	910	0.80	1.00	1.00	0.80	908	1.00	1.00	1.00	1.00
M1B3S3	903	1.00	1.00	1.00	1.00	898	1.00	1.00	1.00	1.00
M2B1S1	908	1.00	0.40	1.00	0.40	908	1.00	1.00	1.00	1.00
M2B1S2	905	0.80	0.60	1.00	0.60	905	0.60	1.00	1.00	0.60
M2B1S3	913	0.80	1.00	1.00	0.80	915	0.60	1.00	1.00	0.40
M2B2S1	893	0.40	0.40	0.80	0.20	885	0.60	1.00	1.00	0.60
M2B2S2	908	1.00	1.00	1.00	1.00	910	1.00	1.00	1.00	1.00
M2B2S3	908	0.60	1.00	1.00	0.60	908	0.80	1.00	1.00	0.80
M2B3S1	903	1.00	1.00	1.00	1.00	910	1.00	1.00	1.00	1.00
M2B3S2	910	0.80	0.60	0.80	0.60	900	0.80	1.00	1.00	0.80
M2B3S3	923	0.40	1.00	1.00	0.40	913	1.00	1.00	1.00	1.00
M3B1S1	898	0.60	0.60	1.00	0.20	910	1.00	1.00	1.00	1.00
M3B1S2	903	0.80	0.60	1.00	0.60	908	0.40	1.00	1.00	0.40
M3B1S3	910	0.80	0.40	1.00	0.40	903	0.60	1.00	1.00	0.60
M3B2S1	910	0.40	0.00	0.40	0.00	913	1.00	1.00	1.00	1.00
M3B2S2	895	0.60	0.60	0.80	0.60	895	0.80	1.00	1.00	0.80
M3B2S3	903	0.40	0.60	0.80	0.40	900	0.80	1.00	1.00	0.80
M3B3S1	900	0.20	0.00	0.60	0.00	900	1.00	0.80	0.80	0.80
M3B3S2	908	1.00	0.20	0.00	0.00	920	1.00	1.00	1.00	1.00
M3B3S3	900	1.00	0.40	0.25	0.00	913	1.00	1.00	1.00	0.80
M4B1S1	908	0.40	0.00	0.80	0.00	910	1.00	1.00	1.00	1.00
M4B1S2	910	1.00	0.60	1.00	0.60	905	1.00	1.00	1.00	1.00
M4B1S3	905	0.40	0.20	0.40	0.00	903	0.40	1.00	1.00	0.40
M4B2S1	908	0.60	0.00	0.60	0.00	910	1.00	0.00	1.00	0.00
M4B2S2	908	1.00	0.40	0.80	0.40	903	1.00	1.00	1.00	1.00
M4B2S3	903	0.60	0.20	0.80	0.20	910	0.40	1.00	1.00	0.40
M4B3S1	913	1.00	0.20	1.00	0.20	900	1.00	1.00	1.00	1.00
M4B3S2	910	0.80	0.20	0.00	0.00	905	1.00	1.00	1.00	1.00
M4B3S3	913	0.40	0.00	0.60	0.00	910	0.60	1.00	1.00	0.60

Appendix C-1 Bill of material for fabrication of prototype two-row vegetable transplanter

Sr. No.	Component	Material of construction	Specifications	Weight (kg)/Nos	Rate /kg(Nos)	Cost, ₹
A	**Vegetable Transplanter unit**					
1	Material cost	MS	(65+5(scrap)) kg	70x1	40	2800
2	Fabrication cost		@ 60% of mtrl. cost		60%	1680
3	Springs	Spring steel	K= 0.1kg/cm	1	10	10
4	Cycle roller chain	steel	12.7 pitch x 3mm x 200	1	135	135
5	Sprockets	MS	(16+28) teeth	44	2.5	110
6	Cycle free wheel		18 teeth	1	60	60
7	PVC pipes	PVC	63mm dia x 5'	5	18	90
8	Acrylic Sheet	Acrylic	4mm	1	30	30
9	Seat	Polypropelene	380(L)x400(B)x400(H)	1	200	200
10	Painting					200
	Production cost of single transplanter unit					***5315***
B	**Main Frame**					
1	Material cost	MS		43x1	39	1677
2	Fabrication cost		@ 50% of material cost		50%	838.5
	Production Cost of Frame					***2516***
C	**Total Production Cost**					
1	Main Frame		B1+B2	1	2516	2516
2	Transplanter unit		SUM(A1:A10)	2	5315	10630
	Total Production cost (Material + Fabrication)					***13146***
D	Profit		@ 25% of "C"		25%	3286
E	***Selling price of 2 row transplanter* (C+D)**					***16432***

Appendix C-2 Calculation of cost of operation of prototype vegetable transplanter

The following assumptions were taken to calculate the cost of operation of machine.

Assumptions:

i.	Average annual use	250 hours
ii.	Life of machine	10 yrs
iii.	Salvage value, (% of initial cost)	10 %

A. Fixed cost

Cost of vegetable transplanter, ₹ = 16500

Depreciation/h, ₹ = ((16500-1650)/(10*250)) = 5.94

Interest on investment / h @ 10 p.c.p.a,

₹ = [(16500+1650)/2]*[0.1/250] = 3.63

Taxes, insurance & shelter charges / h @ 2 % of initial cost / annum,

₹ = (16500*0.02)/(250) = 1.32

Total fixed cost of vegetable transplanter / h, ₹ = 10.89

Annual fixed cost of vegetable transplanter / h,

₹ = 10.89 * 250 = 2722.5

B. Variable cost

Repair and maintenance cost, / h @ 5 % of initial cost /annum,

₹ = (16500*0.05) / (250) = 3.3

Assumptions:

i. Two operators are required to feed seedlings in vegetable transplanter

ii. Wage rate of ₹ 130 / man / day of 8 hours

Labour cost of two persons (₹ / h) = 130*2/8 = ₹ 32.5

Total operating cost (₹ / h) = 3.3 + 32.5 = ₹ 35.8

Total cost of operation of vegetable transplanter (₹/ h)= 10.89 + 35.8 = ₹ 46.69

Total cost of operation of vegetable transplanter (₹ / h) = ₹ 47

Appendix C-3 Calculation of cost of operation of Tractor

The following assumptions were taken to calculate the cost of operation of 35 hp tractor

Assumptions:

i.	Initial cost	₹ 3,25000
ii.	Average annual use	1000 hours
iii.	Life of machine	10 yrs
iv.	Salvage value	10 % of initial cost

A. Fixed cost

Cost of tractor , ₹ = 325000

Depreciation/h, ₹ = ((325000-32500) / (10*1000) = 29.25

Interest / h @ 10 p.c.p.a, ₹ = [(325000+32500)/2]*[0.1/(1000)] = 17.875

Taxes, insurance and shelter charges / h @ 2 % of initial cost/ annum,

₹ = (325000*0.02) / (1000) = 6.5

Total fixed cost of tractor / h, ₹ = 53.62

Annual fixed cost of tractor / h, ₹ = 53.625 * 1000 = 53625

B. Variable cost

Repair and maintenance cost, / h @ 5 % of initial cost/ annum,

₹ = (3,25000*0.05) / (1000) = 16.25

Fuel charges @ 2.5 l / h = 2.5 *35.5 = 88.75

Lubrication charges @ 30 % of fuel charges = 26.6

Assumptions:

i. Wage rate of driver = ₹ 180 / man/ day of 8 hours

Labour cost of one person (₹ / h) = 22.5

Total operating cost (₹ / h) = 16.25 + 88.75 + 26.6 + 22.5 = 154.1

Total cost of operation of Tractor (₹ / h) = 53.62 + 154.1 = 207.75

Total cost of operation of Tractor (₹ / h) = ₹ 208

Total cost of operation of Tractor with vegetable transplanter (₹ / h)

(₹ 207.75 + 46.69) = ₹ 254.44

Appendix C-4 Calculation of breakeven point and payback period for ownership

Break Even Point (BEP)

BEP, hour per annum = Annual fixed cost / (Custom fee, ₹ / h - operating cost, ₹ / h)
= Annual fixed cost / (C)

Annual fixed cost, ₹ / year (vegetable transplanter) = 2722.5

A. Cost of manually transplanting seedlings

Average time (h) required to transplant 1000 seedlings by one person = 5.25
Cost of manually transplanting 1000 seedlings = 130/8*5.25 = 85.31

B. Cost of mechanically transplanting seedlings

Average feeding rate of operator (seedlings/min) = 32.12
No. of seedlings mechanically transplanted /h = 32.12*60*2 = 3854.4
Average time (h) required to transplant 1000 seedlings =1000/4080 = 0.259
Operating cost of mechanically transplanting 1000 seedlings
₹ = 0.259*(254.44) = 66.01

C. Profit/h = (cost of manually transplanting 1000 seedlings - cost of mechanically transplanting 1000 seedlings)/1000 *no. of seedlings sown / hr mechanically

Rs / h = (85.31-66.01) /1000*3854.4 = 74.38

BEP, h / year = 2722.5/ 74.38 = 36.59

Therefore, BEP is achieved at about 14.64 per cent of the annual utility of 250 hours of vegetable plug seedling transplanter

Payback period

Payback period, year = initial cost of machine / average net annual profit

Initial cost of machine = ₹ 16500/-

Average net annual profit
= (custom fee, ₹ / h – total operating cost, ₹ / h) * annual utility (h)
₹ = 74.38*250 = 18597.13
Payback period, Year = 16500 / 24378 = 0.677 = 0.88 years
= 222 h

Appendix C-5 Calculation of custom hiring rates and payback period

Assumptions

1) The labour wages increase at same rate for next 10 years as observed during previous years. A polynomial equation was fit ($y = 0.157x^2 - 624.2x + 61971$ $R^2 = 0.998$) to predict future wages

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
₹·day^{-1} (Operator)	120	181	189	197	206	215	225	235	245	255
₹·day-^{1} (Driver)	180	222	262	273	285	297	311	325	339	353

2) The diesel cost increase 10% /year for next 10 years as observed during previous years

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
₹·L^{-1}	35.5	39.05	42.96	47.25	51.98	57.17	62.89	69.18	76.09	83.7

3) Internal rate of return (IRR) is 25 % - (The expected Net income for ten years was calculated to get IRR of 25%)

Custom hiring rate

Total cost of operation of Tractor with vegetable transplanter (₹ / h)	= ₹ 254.44
Total operating cost incurred /year =254.44*250 (annual utility)	= ₹ 63610
Expected net income for first year considering IRR of 25%	= Rs 76332
Custom hiring rate/hour for first year = 76332 / 250 = 305.32	= **₹ 305**
Similarly custom hiring rate/hour for second year	= ₹ 336

Profit/year = (custom hiring rate/hour – actual cost of operation/hour)*annual utility

Ist year	= (305 -254.44) *250	= ₹ 12722
IInd year	= (336 -259) *250	= ₹ 14285

Payback period

Payback period (years) = initial cost of machine / average net annual profit

= 16500 / (12722+14285)/2 = 1.22 years = **306 h**