

**DESIGN AND DEVELOPMENT OF
MECHANICAL TRANSPLANTING SYSTEM FOR
FINGER MILLET (*Eleusine coracana* (L.) Gaertn)**

A Thesis submitted to

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DAPOLI – 415 712
Maharashtra State (India)**

In partial fulfillment of requirements for the degree

of

**DOCTOR OF PHILOSOPHY
(AGRICULTURAL ENGINEERING)**

in

FARM MACHINERY AND POWER

By

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M. E. (FMPE)**



**DEPARTMENT OF FARM MACHINERY AND POWER
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DAPOLI – 415 712, DIST. – RATNAGIRI M.S. (INDIA)
MARCH 2022**

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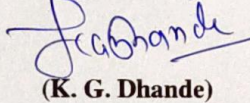
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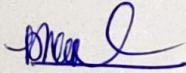
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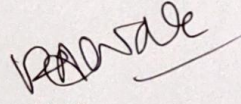
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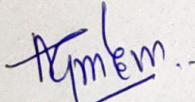
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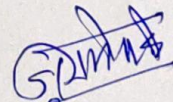
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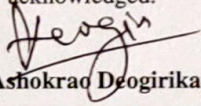
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AUGUST 2022**

CANDIDATE'S DECLARATION

I hereby declare that the experimental work and its interpretation of the thesis entitled "DESIGN AND DEVELOPMENT OF MECHANICAL TRANSPLANTING SYSTEM FOR FINGER MILLET (*Eleusine coracana* (L.) Gaertn)" or part of thereof has not been submitted for any other degree or diploma of any University nor the data have been derived from any thesis/publication of any University or scientific organization. The sources of material used and all assistance received during the course of investigation have been duly acknowledged.

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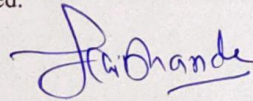
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The assistance and help received during the course of this project work and sources of the literature have been duly acknowledged.



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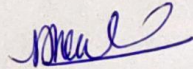
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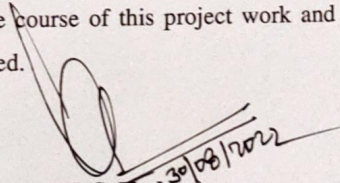
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LIST OF ABBREVIATIONS

Abbreviation	Description
Agril.	Agricultural
ANOVA	Analysis of Variance
Avg	Average
BBD	Box Behnken Design
BIS	Bureau of Indian Standard
C.A.E.T.	College of Agricultural Engineering and Technology
CCRD	Central Composite Rotatable Experiment Design
COA	College of Agriculture, Dapoli
Cm	Centimeter
DAS	Dys after sowing
db.	Dry basis
Dept.	Department
Dia. or dia.	Diameter
Dist.	District
Dr. B.S.K.K.V.	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
e.g.	Example
Engg.	Engineering
et al.	and others
etc.	et cetera, and other things
Fig.	Figure
G	Gram
G.I.	Galvanized iron
GSM	Gram per square meter
GU	granular urea
Ha	Hectare
H	Hour
HR	Heart rate
i.e.	that is
IS	Indian Standard
kg	Kilogram
kgf	Kilogram force

kJ	Kilojoules
kW	Kilowatt
km	kilometer
kN	Kilo Newton
m	Meter
m.c.	Moisture content
min.	Minute
Mm	Millimetre
MS	Mild steel
MT	million tonne
Reg. No	Registration Number
RSM	Response Surface Method
S	Second
m ²	Square meter
UB	Urea briquette
USG	Urea super granules
viz.	As follows
Wb	Wet basis

LIST OF SYMBOLS

Symbols	Description
%	Per cent
=	Equal to
+	Plus
×	Multiplication
/	Division
π	Pie
₹	Rupees
°	Degree
θ	Theta angle

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ABSTRACT

Finger millet is a staple food crop grown in more than 25 countries of Asia and Africa due to its ease of cultivation, drought tolerance, and high nutritional content. In locations with moderate rainfall, finger millet is often planted as a manually drilled or broadcasted crop that has disadvantages of weed infestation, prolonged crop duration, high seed rate, and non-uniform plant density. Transplanting is preferred in locations such as Konkan with heavy rainfall. The most significant obstacles in finger millet production are timely availability of labour during transplanting season followed by high wage rates. Mechanical transplanting is a possible solution over it. However, small land holding and socio-economic status of farmers of the region compels to use small machines. Hence, it was planned to develop finger millet transplanting system.

As mechanical transplanting system requires uniform seedlings, a manually operated four row seed cum fertilizer drum seeder was developed for uniform distribution of seeds for uniform growth of seedlings. A PVC pipe of 75 mm diameter was used for drums of seed and fertilizer. The rows of 12 (H_1) and 24 (H_2) orifices (3 mm diameter) equally spaced in circumferential lines that are spaced 100 mm on the drum are made for seed metering at 100 mm row spacing. Similar drums were made for fertilizer metering with three rows of orifices, spaced at 100 mm. The performance of drum seeder was tested in laboratory for seed rate, seed distribution efficiency and uniformity using both drums, wheels of 165 mm (D_1) and 230 mm (D_2) diameter at forward speeds of 1 (S_1), 1.5 (S_2) and 2 (S_3) km/h. The physical parameters like seedling shoot length, root length, canopy spread, thickness, width and weight of seedlings obtained on 25 to 50 days after sowing (DAS) were measured. The seed rate obtained with different operating combinations of drum seeder ranged from 6.24 to 24.03 kg/h with seed distribution efficiency ranged from 11.36 to 43.64% and uniformity coefficient 0.93 to 0.97. The depth of seed placement and seed density ranged from 10 to 20 mm and 230 to 960 plants per square meter respectively that observed to increase with speed of operation. The developed drum seeder sow seeds sparsely and uniformly as compared to manual method which resulted into healthy seedling growth in nursery. The operating combination of drum seeder i.e. 24 orifices, 165 mm diameter wheels and 1 km/h speed ($H_2D_1S_1$) that produced best quality seedling was chosen for performance evaluation of proposed transplanting system.

A 3.5 hp engine driven semi-automatic, self-propelled, gravity fed, walk behind type finger millet transplanting system with fertilizer metering mechanism, two drive wheels and a steering wheel, suitable for wet soil (18 – 20 % moisture) and small fields was designed and developed for bare root finger millet seedlings performed satisfactorily with specific operating conditions. The output speed of engine is altered with a reduction gearbox and sprockets. Two ground wheel driven revolving carousel type seedling metering mechanisms were used to meter seedlings. It was set to operate with seedling feed rate of 24, 31 and 38 seedlings/min., 0.3, 0.5 and 0.7 km/h speed at 250 mm row spacing using seedlings of 25, 30, 35, 40, 45 and 50 DAS. A cup feed type urea briquette metering mechanism is used for fertilizer application.

The transplanting system was developed and tested in laboratory in jacked up condition to evaluate the performance of seedling metering mechanism and to decide number of operators required for operation. This test revealed that two operators are required for efficient seedling feeding. The system was tested on plain land that produced similar results. Hence, the transplanting system was tested in field using seedlings of 35, 40, and 45 DAS, which gives minimum seedling damage and missing. The number of seedlings per meter, hill to hill distance and hill/m² observed were 35 to 37, 265 to 279 mm, and 28 to 30 hills, respectively. The Response Surface Method tool of 'Design Expert 10' programme was used to optimize the operational parameters. The best values for resulting solution were 0.498 km/h, 29.16 seedlings/min seedling feed rate, and 41.28 DAS seedling age. The performance of transplanting system was evaluated at 0.5 km/h speed, 31 seedlings/min seedling feed rate and 40 DAS seedlings that gave 4.75 seedlings/m, 247.5 mm hill to hill distance, 36.25 seedlings/m², 1.75 seedlings missed and damaged/m² with 73.4% transplanting efficiency and 1.2% seedling mortality. The field capacity and field efficiency of developed transplanter were observed to be 0.01 ha/h and 78.64% respectively at 0.5 km/h speed. The cost of transplanting with the developed system was found to be ₹ 19,278/ha, compared to ₹ 29,700/ha for hand transplanting.

Keywords: semi-automatic transplanter, revolving carousel metering mechanism, finger millet, transplanter, transplanting efficiency, transplanting

CHAPTER I

Introduction

Millets are grains other than wheat, rice, maize, and barley. Finger millet (*Eleusine coracana* (L.) Gaertn) has the greatest calcium level of all the primary cereals. The majority of its flour is made up of carbohydrates, followed by protein and fibre, and the least amount of fat. It is grown primarily for human use as well as for the manufacturing of alcoholic and non-alcoholic beverages (Fernandez *et al.*, 2003). Its straw is utilised as animal feed.

1.1. Area and production of finger millet

Finger millet is a staple food crop produced by subsistence farmers in more than 25 countries spanning Asia and Africa's semi-arid tropics due to its ease of cultivation, drought tolerance, and high nutritional content (Thilakarathna and Raizada, 2015). The crop's typical production under rainfed conditions is around 10 quintals per hectare, while it's about 25 quintals per hectare under irrigated conditions (Kumar *et al.*, 2013). The total area under finger millet in India is 891 thousand hectares (2018-19) which was mainly contributed by Karnataka, Maharashtra and Uttarakhand. From this area, 1,239 thousand metric tonnes of finger millet was produced in 2018-19. During this period, productivity of finger millet was recorded as 1390 kg/ha (Vennila and Murthy, 2021).

The area under finger millet in Maharashtra was 80 thousand hectares in 2018-19 with an average of 112.08 thousand hectares (Vennila and Murthy, 2021). In Maharashtra, finger millet varieties includes

- (a) Early varieties (115 to 120 days): Dapoli-1, HR-374, IE-28,
- (b) Middle varieties (120 to 135 days): E-31, Sharda. EC-28, Dapoli Safed,
- (c) Late varieties (135 to 150 days): A-16.

1.2. Finger millet cultivation methods and practices

1.2.1. Finger millet cultivated by sowing method

In Karnataka, finger millet is mostly cultivated as a drill-sown crop and by broadcasting. Broadcasting or drill sowing is practicable in locations with moderate rainfall, but it is not feasible in areas with severe rainfall, such as the Konkan, since seeds being swept away by strong rains. Weeding is not possible either manually or mechanically once the crop has reached a certain stage, hence the broadcasted crop has a big weed issue. High labour costs, especially for weeding, are a major stumbling block in the broadcasting strategy (Thilakarathna and Raizada, 2015). This difficulty

is easily solved with a drilled crop since it allows for both human and machine weeding. The direct sown crop, on the other hand, has a longer cropping season, a greater seed rate, and non-uniform plant density.

1.2.2. Finger millet cultivated by transplanting method

Under rain-fed circumstances, transplanting outperformed broadcasting and line sowing in terms of yield attributes and yield. The transplanted and line-sown methods made weed management easier. Weed infestation and dry matter were found to be at their lowest levels during transplanting (Pradhan *et al.*, 2014). It is more advantageous to raise seedlings in a nursery and then transplant them into the main field as it assures a shorter growing time, effective use of land, irrigation water, and fertilizers, early crop maturity, extended crop production, and better weed management. Seedling transplantation guarantees optimal plant density in the field, allows for intercropping, and reduces seed costs. Finger millet seedlings are cultivated on elevated seedbeds on around 1/10th of the area to be transplanted. The seeds are spread manually using the broadcasting method or in rows 100 mm apart on a 1 m width and convenient length raised seedbed. Traditionally, finger millet seeds are manually sowed and the needed basal dose of fertilizer is provided by hand to raise the seedling nursery. In such circumstances, the seed rate and fertilizer used, as well as their uniformity, are determined by the person sowing skill. The seeds should be sown at a greater seed rate and spread out densely to ensure that the requisite number of seedlings are produced. While this approach is low-cost and requires little expertise, it results in significant seed loss due to poor germination and subsequent plant establishment in the field. Because of the crowded population, some of these seedlings are unable to grow healthily and must be removed. It leads to the loss of seedlings as well as nutrients and fertilizer. Seeds that are dispersed appropriately can develop into healthy seedlings, and rejection can be reduced. The manual technique of sowing necessitates a stooping forward position, which is both uncomfortable and energy-intensive. The seed-cum-ferti drill for finger millet seeds for nursery growing can maintain the seed and fertilizer rate and uniform distribution, despite the inconvenient and nonstandard way of seed sowing. It can also reduce human drudgery.

1.3. Finger millet cultivation in Konkan region

In the Konkan region, seedlings are transplanted manually on damp soil in the rain-fed finger millet crop. The seedling may be put straight into wet soil, and the roots can be pushed with the thumb (Fig. 1.1). Another method involves punching holes of 30–50 mm depth using a bamboo stick (locally known as 'Thomba') with a 25 mm diameter and 1–1.5 m length with a pointed bottom end (Fig. 1.2). The fertilizer is first poured into the holes, after which seedlings are transplanted into the holes (Fig. 1.3), and the soil is covered over the roots and pressed with the feet (toe). The transplantation of an irrigated finger millet crop is done in the same way as paddy transplanting, by pounding water in a check basin. Manual transplanting can also be done by just placing seedlings into the hole dug by *Thomba* and not covering roots with soil. If sufficient soil moisture is available, the crop also stands in such condition.



Fig. 1.1 Finger millet seedling transplanting in wet field by thumb pressing roots



Fig. 1.2 Hole making in the wet soil by bamboo stick (*Thomba*)



Fig. 1.3 Manual finger millet seedling transplanting in rain fed condition

1.4. Need of finger millet transplanter in Konkan region

The land holdings in the Konkan area are quite small. The finger millet cultivation is preferred on the hilly or slopy lands in this region. Small land holdings restrict the use of tractors or other similar large machineries. Farmers in the area are unable to buy automated devices due to their financial situation. The finger millet seedling nursery is usually developed by manually spreading the seeds in a raised seedbed with a low seedling density. The seedling density influences seedling growth, hence seeds should be spread at the appropriate rate to ensure healthy seedlings. The seedlings are manually transplanted in the main field 30 DAS (Anonymous, 2017), which is a cumbersome task. Transplanting seedlings in a one-hectare area with a plant spacing of 600 mm × 600 mm takes an average of 197 man-hours (Gaikwad, 2010). The recommended plant spacing for finger millet is 300 mm × 100 mm or 200 mm × 150 mm, depending on the production area and the type of the crop. As a result, the number of man-hours necessary for 600 mm × 600 mm plant spacing for a one-hectare area is substantially higher. In comparison to rice farming, it takes less labour. It takes a long time and lot of efforts to dig holes in the field with *Thomba*, drop fertilizer, and finally plant seedlings manually. The seedlings are spaced at a random spacing of 100 to 150 mm. Farmers usually do not follow line transplanting, hinders mechanical weeding and interculturing operation. With an average plant spacing of 150 mm, around 4,44,444 holes must be hand dug each hectare, which is extremely time and labour intensive.

Due to a scarcity of labour during the transplanting season, high labour wages, small land holdings, and weed infestation in the broadcasted technique of sowing, farmers have been forced to ignore the crop. It is also consumed less frequently than rice. Manual transplantation is time-consuming and inconvenient for humans. To

plant the seedling in the field, the person must bend forward, resulting in biomechanical strains in the back and higher energy consumption than other working postures. For ergonomic reasons, it is not advised (Gaikwad, 2010). During squatting with movement activity, oxygen consumption is 31 – 35 % of VO₂ max, and during bending posture, it is 70 – 80 % of VO₂ max (Grandjean, 1988). This results in higher fatigue and reduced work capabilities.

Improvement of agronomic practices in finger millet is must for encouraging farmers to continue cultivation. The new farming techniques should address concerns such as labour shortages and hardship encountered by farmers, particularly women farmers. If mechanical techniques for seeding to raise nursery and transplanting the nursery raised healthy seedlings are available, farmers may be able to reduce their reliance on human labour. There are types of transplanters for paddy and vegetable transplanting, but none especially designed for finger millet transplantation. Vegetable transplanters are mostly operated in well tilled dry field condition while paddy transplanters are operated in puddled field condition. Finger millet transplanting necessitates different field conditions than paddy and vegetable transplantation. Finger millet is mostly grown in fields with slopes and small plots of land in wet fields that may or may not be ploughed (not puddled) depending on soil conditions and rainfall during the monsoon season. In light of the foregoing, it was necessary to develop a self-propelled semi-automatic walk-behind type two row gravity fed mechanical transplanting system for finger millet transplanting along with a fertilizer. The line transplanting along with basal dose of fertilizer will help in proper growth of crop. Also, it will facilitate the mechanization in weeding, interculturing and spraying if needed. The system should be able to operate with small engine and fed with bare rooted healthy finger millet seedlings for establishment in moist soil on small and sloped lands of the region. The research work is undertaken with following objectives:

Objectives

1. To standardize nursery raising method suitable for mechanical transplanting of finger millet.
2. To design and develop a mechanical transplanting system for finger millet seedlings.
3. To evaluate the performance of developed mechanical transplanting system for finger millet.

CHAPTER II

REVIEW OF LITERATURE

Researchers worldwide worked extensively for the design and development of various types of seed sowing machineries. They also worked on urea super granules (USG) application during transplanting, its techniques and machineries and the seedling transplanters to meet the need of the various crops, its agronomical requirements, field and land conditions, and the farmers' need. This work is reviewed with the objective to develop finger millet drum seeder cum fertilizer applicator and finger millet transplanter with fertilizer application facility. The literature cited is presented in this chapter under the following subheads.

2.1 Practices adopted for finger millet cultivation in India

2.2 Effect of seedling density on its growth and health

2.2.1 Effect of seed drill speed on the placement of seed and seed rate

2.2.2 Drum seeder performance evaluation

2.3 Physical properties of finger millet grains

2.4 Transplanting of seedlings

2.5 Transplanting systems and their performance evaluation

2.5.1 Manual transplanting

2.5.2 Manually operated transplanting system

2.5.3 Semi-automatic transplanter

2.5.3.1 Bullock drawn type

2.5.3.2 Walk-behind type

2.5.3.3 Tractor operated type

2.5.3.4 Self-propelled type

2.5.4 Automatic transplanters

2.5.4.1 Walk behind

2.5.4.2 Tractor operated

2.6 Selection of seedlings for mechanical transplanting

2.7 Seedling feed rate in semi-automatic transplanters

2.8 Effect of soil moisture content at the time of transplanting

2.9 Furrow opener and closer mechanisms for vegetable transplanters

2.10 Fertilizer application during transplanting *i.e.* co-situ placement

2.1 Practices adopted for finger millet cultivation in India

Intercropping of 40 – 45 day old pigeon pea seedlings with finger millet (2:8) was found to be promising and remunerative in light red soils of southern Karnataka. Transplanting paired row of pigeon pea with finger millet showed enhanced productivity of pigeon pea as well as finger millet grain yield than drill-sown pigeon pea under rain fed conditions (Anonymous, 2010a).

A comparative study for the labour requirement under direct seeding (broadcasting), seeding inline (seed drilling) and transplanting method showed that the transplanting is the most labour intensive method (Khadka *et al.*, 2012).

Cultivation practices that limit finger millet productivity are listed below (Michaelraj and Shanmugam, 2013).

1. In India, finger millet is cultivated on the poor, shallow marginal soils with poor water retention capacity, on sloppy lands mostly under rain fed conditions. It is produced under shifting cultivation in the hilly areas.
2. Finger millet sowing is done mostly by broadcasting method that hinders the intercultural practices for effective weed control. The weed infestation in such crops reduces the crop yield.
3. Proper manures and fertilizers are not applied to finger millet fields due to poor economic condition of the farmers (Khadka *et al.*, 2012).
4. Improved crop management practices are not adopted by the farmers due to socio-economic constraints.

The cultivation of finger millet is declining because 1. the maize crop is superseding it, 2. due to the socio-economic constraints, the farmers are not following the improved crop management practices, 3. it is mostly grown as broadcasted crop that restrict the inter-cultivation and mixed cropping, 4. no remunerative prices for the surplus produce of millet, 5. small millets despite low genetic potential are grown because of socio-economic conditions of the farmers and assured income under low input conditions etc. (Michaelraj and Shanmugam, 2013).

In Karnataka, finger millet is grown largely as drilled sown crop under rain fed condition. In drilled sown finger millet, the management of weeds is a very difficult task. As finger millet is having slow growth habit in the initial stages, the weed infestation causes the grain yield loss around 80-100 %. (Kumar *et al.*, 2015).

Finger millet cultivation is a labour intensive crop compared to other major cereals, requiring high labour input mainly during transplanting, weeding, harvesting,

threshing and grinding and that is the first challenge for promoting it. The women do the most of the management practices of finger millet cultivation like land preparation, seeding/transplanting, harvesting, and threshing (Thilakarathna and Raizada, 2015).

Finger millet can be cultivated by SRI technique *i.e.* System of Ragi Intensification technique. In this technique, 500 g of ragi seeds are treated and primed with jaggery, cow urine, warm water, and Vermicompost. A nursery is raised with this seed on 40 sq. m area for 1 acre *i.e.* 100 sq. m for 1 ha. The transplanting is done on 20 to 25 DAS at the spacing of 250 × 250 mm. Weeding is done on 15th, 25th and 40th days after transplanting. Irrigation is provided 4 times in Rabi season. The crop grown by this method showed 8 to 10 branches as compared to 1 to 3 branches per plant by traditional method. Tiller per plant observed 7 to 8 as compared to 3 to 4 by traditional method. The stems grow thicker and the roots go deeper (> 300 mm) by this method. The yield per hectare by this method observed to be 2.5 to 3.75 tons/ha as compared to 1 ton/ha by traditional method (Anonymous, 2016a).

In India, finger millet is cultivated either as rain fed or irrigated crop. The rain fed finger millet is cultivated during June – July in the areas having minimum annual rainfall of 400 – 450 mm. The irrigated finger millet may be cultivated in Rabi season *i.e.* September to October planting or summer irrigated crop *i.e.* January to February planting (Anonymous, 2016b).

Plant population of 4,00,000 to 5,00,000 per ha is optimum for getting higher yields of finger millet crop. Irrigated finger millet is grown as sole crop while the rain fed finger millet is grown as intercrop or mixed crop with non-cereal crops. The methods for finger millet cultivation are direct sowing and the transplanting. The broadcasting is the most common and easy method amongst the direct sowing methods but in this case it is very difficult to control the weed. Lines sowing with 225 to 300 mm inter row spacing and 80 to 100 mm intra row spacing is the better method. Better germination, reduced seed requirement and intercultural operation facilities can be achieved with line sowing as compared to broadcast method of sowing. Manual seed drilling is cumbersome method. Manual or bullock drawn seed-cum-ferti-drill with the row spacing of 75 to 100 mm are available that saves time and labour with the efficient use of nutrient (Anonymous, 2017a).

2.2 Effect of seedling density on its growth and health

The seedling density is the number of seedlings growing in an area of seedbed, expressed either on an area basis (seedlings per sq. meter) or on lineal basis (seedlings per lineal meter). Uniform spacing between seedlings within a drill row is extremely important to seedling density. The seed population and seed spacing both at planting time have effects on harvested yield and size of stalks for different plants (Robinson *et al.*, 1981).

The experiments were designed to identify the relative importance of dispersal distance, seedling density, and light conditions on pathogen-caused mortality of tropical tree seedlings of *Platypodium elegans*. It was observed that high seedling density increases disease levels, especially under shaded conditions (Augsburger and Kelly, 1984).

In a study on yield performance of rain fed lowland rice affected by nursery fertilizer under conditions of intermediate deep-water (150 – 500 mm) and flash floods, it was observed that by making a small investment in raising healthy and vigorous seedlings in the nursery, farmers could harvest an additional yield of up to 2 t/ha (Panda *et al.*, 1991).

The effect of seeding rates (40, 52, 64, 76, 88 and 100 g seeds/m²) on different characters of three rice cultivars was studied. It was found that at transplanting, dry weight of seedlings was the highest with 40 g seeds and the lowest with 100 g seeds (Kurmi and Sarmah, 1993).

The effects of three seeding densities of nursery and their effects on yield and yield parameters were investigated. The seedling vigor was expressed in terms of root length, height and leaf area of seedling at the time of transplanting. The low seeding in nursery recorded significantly higher plant height. It was also showed that rice plant grown from seedlings raised in the low seed density of nursery performed better productive tillers, grains/panicle and grain and straw yields than plant grown from seedlings raised in higher density nurseries (Lal and Roy, 1996).

Sparse sowing of hybrid rice seeds (25 g/m²) in nursery was advised to ensure healthy and vigorous seedlings for transplanting single seedling per hill with 4-5 tillers in 20-25 days old age to get maximum production (Paroda and Siddiq, 1996).

There was a significant decrease in leaf area index and dry matter production on hybrid rice with the increase in seedling density from the sowing rate of 20, 40 and

60 g/m² in the nursery. In addition, grain yield was the highest in plots transplanted with seedlings from nursery sown with 20 g seeds/m² (Hari *et al.*, 1997).

The rice seedlings grown in a nursery using seeding rate of 20, 40, 60 and 80 g seeds/m² were transplanted in main field using 1-3 seedlings/hill. It was found that increasing seeding rates decreased number of panicles/hill and number of grains/panicle and decreased paddy yields (Singh *et al.*, 1997).

The effect of sowing rates in nursery of hybrid rice (10, 15, 20, 25 or 30 g/m²) was studied. It was found that grain yield was the highest in plots transplanted with seedlings from nursery sown with 20 g seed/m² (Dong *et al.*, 1999).

Uniform spacing results in better germination and emergence and increases yield by minimizing competition between plants for available light, water, and nutrients (Griepentrog, 1998; Karayel and Ozmerzi, 2001).

It is necessary for seeds to be placed at equal intervals within rows with uniform spacing so the roots can grow uniformly (Karayel and Ozmerzi, 2001).

Effect of seedbed seed rate on the quality of the seedlings and the grain yield of three rice hybrids was studied. It was observed that the initial tillering in the nursery seedlings is highly influenced by nursery seed rate (Jayawardena *et al.*, 2004).

Seeding rate and row spacing are tied together. If the population is too high, plants compete with each other and often lodge. If the population is too low, a producer is wasting growing space and lowering yield. Seed placement is another important factor. Seeds should be planted between 0.75 and 1.5 inches deep, depending on soil type and tillage. Seeds can be planted shallower in heavy soils, such as high-clay soils. Uniform seed placement promotes uniform emergence, which is better than staggered emergence that can result in plant-to-plant competition. Growers should always follow their drill or planter instructions to make sure they are correctly calibrated and functioning properly to meter seed at desired rates and establish a uniform stand. (Robinson and Shawn, 2008).

Precision seeders place seeds at the required spacing and provide a better growing area per seed (Karayel, 2009).

It is suggested to use 200 g/m² paddy seeds as optimum for obtaining healthy vigorous seedlings that will perform better after transplanting (Wopereis *et al.*, 2009).

Seed spacing uniformity is an important indicator in evaluating seed drill performance, because a uniform distribution of seeds can not only provide maximum

space for each plant but also make uniform root size, which can increase yields and reduce harvest loss (Zhao *et al.*, 2010).

The seedling age mainly depends on the availability of water, labor, herbicides and other inputs. The use of higher seed rates than recommended, very high seeding densities in the rice nursery and the use of older seedlings for transplanting is a major reason of lower rice yield (Sarwar *et al.*, 2011).

In general, lowering seedling density produces seedlings with larger stem diameters and heavier shoots and roots (dry weight). Seedling height and shoot:root ratios are sometimes affected by seedbed density (Duryea and Landis, 2012).

A study was conducted for testing effect of different nursery management options viz. 1) fertilizer management in the nursery (0 and 20:20:0:13 kg NPKS/ha at 15 DAS), 2) seeding density (607 and 303 g/m²), and 3) seedling age (20 and 40 days old) at transplanting lowland rice variety Radha-4 on grain yield and yield components. It was observed that top-dressed fertilizer in the nursery had no consistent effect on grain yield. However, lower seeding density (303 g/m²) resulted in taller plants, more productive tillers m², less sterility and higher grain and straw yield. (Adhikari *et al.*, 2013)

An experiment was conducted with factorially combined four seed rates (10, 15, 20 and 25 kg/ha) and four row spacing (200, 300, 400 and 500 mm) to study its effect on the growth, yield and yield component of finger millet during 2011 – 2012 cropping seasons. It was not the seed rate but the row spacing significantly affected yield component of finger millet. The highest grain yield was recorded when finger millet was planted at 300 mm row spacing due to relative increment in yield components and reduction of lodging and blast diseases infestation. Planting finger millet at the lowest seed rate (10 kg/ha) at 300 mm row spacing gave the optimum grain yield of finger millet (Bitew and Asargew, 2014).

Higher yields can be achieved if the optimum plant population is maintained in rain fed crop. The mortality rate was observed higher in case of broadcasted finger millet. This in turn reduced the number of effective tillers per square meter area of field (Pradhan *et al.*, 2015).

It is recommended to have seed spacing of 80 to 100 mm for nursery raising for the SRI (System of Ragi Intensification) principle of Finger Millet cultivation (Anonymous, 2015a).

Finger millet seeds are very small (400 seeds/g), and the recommended seed rate of 10 kg per hectare will contain about 4 million seeds. A plant population of 4 – 5 lakhs per ha is optimum for getting higher yields while higher or lower population than the optimum will reduce the yield. Therefore, even when seed drill is used, thinning within the row leaving a spacing of 75 –100 mm between plants, must be followed. Wider row spacing (300 mm) and closer plant spacing of 75 mm help in better establishment of the crop (Anonymous, 2016b).

2.2.1 Effect of seed drill speed on the placement of seed and seed rate

An experiment was conducted to study the effect of the drill operating speed on the lettuce seed spacing within a row. Lettuce (*Lactuca sativa*) is characterized by small seeds, and they are usually sown in large numbers per unit area with a shallow drilling depth. Uniformity of seed size and shape has a considerable effect upon drilling precision as well, particularly in drills with a mechanical drilling unit. It was observed that an increase in the drill operating speed leads to decrease in drilling precision (Ivancan *et al.*, 2005).

Three vacuum precision seeders were tested for corn drill in laboratory over greased belt to quantify seed spacing distribution within row at 140, 170, and 200 mm row spacing and at ground speed 1.8, 3.6, and 5.4 km/h. Miss index (MI), multiple index, Quality Feed Index (QFI) and precision index were used for determining seed spacing uniformity of seeder. The results showed that the operating speed affected seeders miss index. The best QFI, MI, Multiple index and precision index was found to be 0.96, 2.32, 14.44 and 96.72, respectively at 1.8 km/h operating speed (Bozdogan, 2006).

The four different types of seed meters *i.e.* a finger pickup seed meter, a scoop-wheel seed meter, an air-pressure type seed meter and an air-blowing type seed meter were evaluated. The experiment was conducted at five different travel speeds on seed meter test bench *i.e.* laboratory test and in field in order to determine the effects of different travel speeds on seed spacing uniformity for corn crop with each seed meter. The seeding performance of the horizontal distribution of seeds within a row was described by using the coefficient of variation, the quality of feed index, the multiple index and the miss-seeding index. It was concluded that different travel speeds have statistically significant effects on seed spacing uniformity. Coefficient of variation increased and quality of feed index decreased as the travel speed of seed

planter increased. All four types of seed meters performed better on the seed meter test bench than in the field (Quanwei *et al.*, 2017).

2.2.2 Drum seeder performance evaluation

IRRI drum seeder for paddy was modified to suit to local conditions for adapting wet seeding in Andhra Pradesh and Karnataka. The eight-row drum seeder was adjusted to maintain spacing between lines only. However, intra-spacing adjustment was difficult. This could be adjusted with more distance between holes (Murthy, 2000).

A drum seeder was developed for sowing the onion seeds with a row spacing of 80 mm and plant spacing of 60 mm with 90 mm diameter PVC pipe with suitable holes (3 mm diameter) for dropping the single seed in the rows at specified spacing. The shovel type furrow openers were provided for placing the seeds at the proper depth. Manually operated drum seeder was having sowing width of 560 mm with seven rows. Field capacity of the drum seeder was 0.09 ha/h, saved 70 % of time in comparison to manual broadcasting. Onion yield obtained with drum seeder was 25 ton/ha compared to 18 ton/ha by broadcasting method (Rathinakumari *et al.*, 2003).

The feasibility and comparative performance study of four different drum type direct sowing devices for paddy was conducted. The mechanical drum seeders showed increased field capacity resulting in time saving and man-hour saving (78 % to 95 %) compared to manual line sowing. The highest saving was obtained for a commercial plastic drum seeder. The man-hour saving was negatively correlated with the machine weight. The lighter weight (8.00 kg) and simpler construction were the main reason of speedy operations of plastic drum seeder with highest amount of man-hour saving (95 %) (Baruah, 2006).

Apart from the net benefit in the paddy cultivation using the drum seeder, a farm research was conducted on transplanting paddy for the drudgery reduction of farmers. The data on drudgery aspects showed that direct sowing of seed resulting in expected outcome of the technology as low draft requirement, labor saving, natural resource conservation, better output/profits and less occupational health hazards (Singh and Hensel, 2012).

Compared to the broadcasting method of direct sowing of paddy seeds, drum seeder technology reduced the seed rate, reduced labour and increased returned to the farmers. The yield of 37.50 q/ha with direct sowing of sprouted/pre-germinated paddy

seeds by drum seeder as against 27 q/ha by traditional method of broadcasting was observed (Murumkar *et al.*, 2014).

When the paddy drum seeder was tested for the seed rate and uniformity, it was observed that as the seed drum empties the seed rate obtained increases steadily and steeply at the end *i.e.* the uniformity in seed rate was not maintained throughout its operation (Sivakumar *et al.*, 2005 and Karim *et al.*, 2015).

In the laboratory test and calibration of direct paddy drum seeder for pre-germinated paddy seeds, the seed rate was nearly constant for initial 10 m distance it travelled. For the next successive points *i.e.* up to 20 m distance it travelled, the seed rate increased continuously during actual field operation (Kumar *et al.*, 2017).

2.3 Physical properties of finger millet grains

Shivabasappa, *et al.*, (2012) determined some physical properties of finger millet grains at moisture content of 14.16 per cent (db.). The size, sphericity, surface area, mass of 1000 grains, volume of 1000 grains, true density, bulk density and porosity were 1.13 mm, 0.98, 4.15 mm², 2.87 g, 2171 mm³, 1293 kg/m³, 803 kg/m³ and 37.79 per cent (db.), respectively. The frictional properties of the finger millet grains viz., angle of repose, coefficient of internal friction and coefficient of external friction were also determined and the values were 29.09, 0.63 and 0.48, respectively. The terminal velocity of the grains was 2.94 m/s.

The physical properties of finger millet kernels were determined at different moisture content (Powar, 2018). These are mentioned below.

Table 2.1 Physical properties of finger millet kernels (Cv Dapoli 1) (Powar, 2018)

Sr. No.	Property	Moisture content, %				
		7.15	10.73	15.33	20.31	25.11
1	Geometric mean diameter,mm	1.38	1.42	1.48	1.50	1.54
2	Sphericity	0.92	0.93	0.94	0.95	0.96
3	Volume, mm ³	1.40	1.65	1.80	1.98	2.10
4	Surface area, mm ²	5.70	6.20	6.80	7.08	7.50
5	Thousand grains weight, g	2.1	2.20	2.37	2.52	2.79
6	Bulk density, kg/m ³	890	839	830	782	781
7	True density, kg/m ³	1667	1471	1429	1282	1111
8	Porosity, per cent	46.60	43.00	41.90	39.00	29.74
9	Angle of repose, degree	21.22	23.68	26.28	29.82	31.16
10	Terminal velocity, m/s	3.87	4.4	4.8	5.3	5.8
11	Static coefficient of friction					
	Plywood surface	0.40	0.41	0.43	0.45	0.46
	Steel surface	0.39	0.40	0.41	0.44	0.45
	Glass surface	0.37	0.37	0.39	0.40	0.41

2.4 Transplanting of seedlings

Transplanters are used for some crops because they result in earlier harvesting, enable warm season crops to be grown in regions too cold for direct seeding and develop better root systems (Orzolek, 1991).

The transplanting method is better over the seed sowing method as mentioned below (Chauhan, 2000 and Dixit *et al.*, 2007)

1. Saving in time in case of slowly growing seedlings and there is a saving of expensive seeds;
2. it reduces the time that crop occupies the land by 3 – 10 weeks resulting in less water requirement and allows better water management practices;
3. it helps the plants a better start over the weeds;
4. selection of vigorous seedlings can be done and thereby ensuring better establishment in the field;
5. better weeding and intercultural operations can be done;
6. permits optimum plant spacing, which is critical for higher yields;
7. it ensures better yields with more uniform maturity.

The Tamil Nadu Agricultural University has recommended the procedure for transplanting of finger millet seedlings as below.

- Let water into the bed, level the bed, if it is not leveled.
- Plant two seedlings per hill.
- Plant the seedlings at a depth of 30 mm.
- Plant 18 to 20 days old seedlings.
- Adopt a spacing of 300 × 100 mm for planting.
- Adopt 225 × 100 mm spacing for direct sowing.
- Root dipping with Azospirillum slurry prepared with 5 packets (1000 g/ha) of Azospirillum and 5 packets (1000 g/ha) of Phospho bacteria or 10 packets of Azophos (2000 g/ha) in 40 litres of water and dip the root portion of the seedlings in the solution for 15-30 minutes and transplant.

Among the yield attributes viz., finger length, number of fingerlets per finger, number of grains per finger and 1000 grain weight, finger length under finger millet transplanting was significantly higher than broadcasting and was found at par with line sowing during both the years. This showed its superiority over broadcasting for most of the yield attributes (Pradhan *et al.*, 2014).

Transplanting of seedlings is a process of raising seedlings in nursery beds and transplant these seedlings of 3 – 4 weeks age to main field. Finger millet crop is having fibrous, shallow, branched root system. When seedlings are pulled out, most of the roots are torn off but very soon fresh roots develop. For early Rabi and Kharif season, seedling should be transplanted at 250 × 100 mm and for late Kharif at 300 × 100 mm spacing at 30 mm depth respectively. To prevent transfer of blast from nursery to main field, leafy portion of seedlings should be dipped in 0.1 % carbendazim solution. In addition, dip root portion of seedlings in a solution of Azospirillum inoculants in 40 to 45 liters of water for about 30 min. Transplanting finger millet is more suitable and profitable under much delayed sowing conditions. Transplanted crop does not lodge during rains. Higher yields are obtained with transplanted crop compared to direct-seeded crop. Seed rate in broadcasting is 10 – 15 kg/ha, row seeding 3 – 4 kg/ha and transplanting 2 – 3 kg/ha (Anonymous, 2015b).

2.5 Transplanting systems and their performance evaluation

The mechanical transplanters are classified according to type of seedlings used viz. pot type, root washed type, mat type and linked paper chain pots transplanter, depending upon the way seedlings produced in the nursery (Kumar and Raheman, 2008). Pot type is used widely with big seedlings, which is suitable for vegetable crops such as tomato, cabbage and tobacco (Verma, 1984a). Root washed type seedlings are used in paddy transplanters.

As transplanting of plants is one of the major operations carried out by growers, it is very important to minimize the time and labour involved in this process. The transplanting system can be attractive if it is simple in use, reliable, possess a high transplanting capacity with good quality of the transplanting work and must do all this at reasonable cost (Werken, 1991).

The systems of the transplanting can be classified as (Natsis *et al.*, 2011)

- a. In manual transplanter, the human labours only place the transplants (seedlings) at the required distance in the furrow or in the holes made by the machines.
- b. In semi-automatic transplanting systems, labour feeds seedling in metering mechanism of transplanter while the placement of the transplants (seedlings) and covering soil around the plant roots is done by machine itself.
- c. In fully automatic transplanting system, transplants (seedlings) are picked by machine from transplant (seedling) tray and are placed in soil at proper spacing

and soil is covered around it. No intervention of human labour is needed other than maneuvering machine.

2.5.1 Manual transplanting

In general, during manual transplanting, the worker has to hold in one hand or tray, a bunch of uprooted seedlings. The worker use to transplant seedlings in the field using the small tools like sickle (*khurpi*), spade or peg to dig a hole in the soil and place the seedling root in it and cover it with soil. If the transplanting is done in the wet field, the worker use to press the seedling root with thumb in the wet soil. In finger millet manual transplanting, one person use to make holes in wet field in standing posture using wooden peg (*Thomba*) of about 30 mm diameter. One another person use to put granular fertilizer in the holes and the third person use to put the bare root seedling in the hole and cover roots with soil. The fertilizer placement and transplanting has to be done in the bending posture. The transplanting in bending posture requires an extra energy expenditure of 8 kJ/min and increases the heart rate by 51 % (Nag *et al.*, 1980).

Labour requirement for transplanting tobacco is approximately 1.12 h for 1000 plants (15 plants/min) (Pugh, 1983).

Manual transplanting requires approximately 25 % of the total labor requirement of rice production (Singh *et al.*, 1983).

In a study on cauliflower crop, it was observed that one per cent missing plants in the field results in reduction in yield up to 0.6 % (Saimbhi *et al.*, 1992).

Manual transplanting on a large scale is labour-intensive, expensive and less uniform compared with mechanical transplanters (Orzolek, 1996).

Seeding and transplanting operations that are mainly performed manually, account for 40 % of total working hours of cultivation (Tsuga, 2000).

In Korea, manual transplanting of Chinese cabbage (*B. campestris* L. var. *Pekinensis*) required 184 man-h/ha. Manual transplanting is labour intensive, expensive, and results in non-uniform distribution of plants in field (Kim *et al.*, 2001).

One of the major hindrances in vegetable cultivation is transplanting of seedlings which requires lot of labour (244- 310 man-h/ha) (Chaudhuri *et al.*, 2001).

Transplanting of paddy seedling is accepted practice by the farmers. It yields more compared to broadcasted paddy. The labours have to transplant about 3 lakh seedlings per hectare in the bending posture. Labour scarcity is the major problem during the peak season of transplanting (Choudhury, 2003).

The manual transplanting system is most time and labour consuming while the semi-automatic transplanter reduces the labour requirement and increase the accuracy. In case of fully automatic transplanting system, labour requirement is the least with highest time saving. Automated transplanter offer many advantages but are complicated and expensive. They also require a very high level of plant quality and uniformity (Parish, 2005).

With the success of the system of rice intensification (SRI), a similar method has also been introduced to finger millet, which in India is known as Ragi, and hence this strategy uses the same acronym (SRI). This method involves transplanting seedlings at the two-leaf stage with some soil attached to the root, at a distance of 300 × 300 mm in a square pattern. SRI method significantly improved finger millet grain yield while reduced the cost (Mukherjee, 2012).

About 156 person-days are required to produce rice from a hectare of land. Out of these, 45 person-days are needed for raising seedlings and transplanting which is about 29 % of the total labour required. For successful rice cultivation, availability of quality seeds and seedlings, land preparation, transplanting seedlings in optimum time (with uniform spacing) are important. These are time consuming and expensive as labour cost account the biggest input for rice production (Islam *et al.*, 2015).

In a study on operation wise labour requirement for finger millet showed that about 26 % of total labour required is engaged for threshing operation while next to that about 24 % labours are required for transplanting operation if done manually. It indicates transplanting is labour intensive operation next to threshing (Kamble, 2016).

The labour required for manual transplanting of vegetable seedlings is about 180 to 420 man-hour/ha. (Khadatkar *et al.*, 2018).

2.5.2 Manually operated transplanting system

The vegetable transplanter may have various seedling metering mechanisms such as pocket or vertical descending cups or buckets (Munilla and Shaw, 1987; Kim *et al.*, 2001), split cone cups or transplanting discs (Harrison *et al.*, 1990) to place the plants in an upright orientation in the soil.

The PAU 6-rows manual paddy transplanter was evaluated to mechanize operation in hills. Field capacity and labour requirement of the transplanter was 0.03 – 0.035 ha/h and 57 – 66 man-h/ha respectively. The labor requirement was 2 – 3 times less over the traditional methods. The operational cost was observed 73 % and 54 % less on use of transplanter compared to manual transplanter and hand transplanting.

Yield was increased in the range of 30 – 35 %. It was also observed that a transplanter with lesser width of coverage would be more useful (Singh and Vatsa, 2006).

Hill distance and depth of planting are equal and accurate in mechanized transplanting and allow proper sunlight, air and application of fertilizer that results increased in yields (Dixit and Khan, 2011).

A pull-type three rows transplanter (250 mm row spacing) was developed by improvising the functional components of existing six-row manual IRRI rice transplanter. In different puddling conditions as well as textural conditions, the field capacity was observed as 0.058 ha/h with field efficiency of 85.4 % at the draft of 261.7 N. Percentage of missing hills was found as 9.61 with the optimized growing seedling density of 60 g/mat. The energy cost with improved transplanter is graded as 'heavy'. A cost and time saving of 80.8 % and 91.3 % respectively as compared to hand transplanting was recorded with the developed unit (Selvan *et. al*, 2014).

A manually pulled-type two-row plug type rice transplanter with revolving magazine metering mechanism was developed and field evaluated for rice (*Oryza sativa*) crop. The seedlings of rice crop were grown in paper pot (80 GSM). Plug technology was developed for the efficient production of high-quality seedlings for transplanting. Seedling parameters like root length, plant height, stem thickness and stem width and machine parameters like plant to plant spacing, planting depth, field capacity, field efficiency, total time of operation, speed of operation were recorded during field evaluation. The cost and time saved over manual transplanting without considering paddy seed cost was about 59.9 and 79.85 %. The cost of transplanting with considering seed cost was Rs 3101/h. The field efficiency and field capacity of the transplanter was observed to be 83.22 % and 0.014 ha/h respectively (Ganapathi and Kumar, 2015).

A semi-automatic two-row tractor drawn vegetable transplanter was developed at PAU, Ludhiana and performance was studied and compared with traditional system of manual transplanting. The two-row vegetable transplanter was evaluated in field for brinjal and chillies and compared with manual transplanting of bare root seedling. Results of study for field performance evaluation of transplanter revealed that field capacity of transplanter was 0.09-0.12 ha/h and field efficiency was found 64 to 75 %. Average plant height, number of branches per plant, plant mortality, yield/m², seedling missing, and leaf area index was found more by machine transplanting while plant population, planting depth was found less by machine transplanting. Time

saving, labour saving, less cost of operation were achieved in machine transplanting as compared to manual transplanting (Kumar and Tripathi, 2016).

A hand held vegetable transplanter was tested for transplanting tomato, chili and capsicum seedlings. The transplanting capacity, theoretical field capacity and field efficiency was found to be 0.02 ha/h, 0.0243 ha/h and 82.30 % respectively (Patil *et al.*, 2015). The transplanting rate of such hand held device is merely 15 – 17 seedlings/min (Anonymous, 2017c).

A low cost manually operated single row vegetable transplanter was developed for transplanting of plug and pot type vegetable seedlings on ridges and mulch beds. It was evaluated for inter and intra-row spacing of 450 × 450 mm and 600 × 600 mm. Manual transplanting on ridges (MTR) and on plastic mulch beds (MTP) were compared with developed transplanter on ridges (MOTR) and on plastic mulch beds (MOTP). The transplanting rate using single labour was found to be 8, 5, 16 and 11 seedlings/min for MTR, MTP, MOTR and MOTP, respectively. The field capacity was calculated as 0.009-0.017; 0.007-0.0012; 0.019-0.033 and 0.013-0.024 ha/h for MTR, MTP, MOTR and MOTP for both the spacing respectively. Similarly, field efficiency was 30-41 %; 21-28 %; 61-79 % and 42-57 %. Moreover, cost of operation was found to be 2571-1416; 3770-2121; 1324-745 and 1884 – 1060 Rs/ha for MTR, MTP, MOTR and MOTP for both the spacing respectively. The time saving over manual transplanting is 52 and 50 % as in MOTR and MOTP, respectively. (Nandede *et al.*, 2017).

A single row manual vegetable transplanter for three vegetable crops *i.e.* brinjal, chilli and tomato was designed and tested at two different sites and compared it with traditional method of transplanting. The transplanting mean effective field capacity, field efficiency and labour requirement was 0.029 ha/h, 91.34 % and 35.87 man-h/ha respectively with single row manual vegetable transplanter. The transplanting mean effective field capacity observed from trial with traditional method was 0.014 ha/h, mean field efficiency was 90.64 % and mean labour requirement was 75.85 man-h/ha. The mean effective field capacity was 52.36 % higher over traditional method of transplanting. Significantly, lower labour was required with developed prototype over traditional method with an average saving of 52.83 % of time and labour (Kumar, 2018).

2.5.3 Semi-automatic transplanter

The semi-automatic transplanters are those in which the seedlings are to be fed manually to the seedling metering mechanism. The transplanter either creates furrows or holes in the field wherein the seedling metering mechanism drops the seedling at the set spacing. There is a mechanism to cover and compact the soil around the seedling placed in the field. These transplanters are less costly than the automatic transplanters. The efficiency and seedling missing percentage of the transplanting depends upon the skill of the person feeding the seedlings in the metering mechanism, speed of the operation and the type of the metering mechanism. The semi-automatic transplanters may be walk-behind type or riding type. These may be tractor mounted, power tiller operated or may be self-propelled type (Kumar and Raheman, 2011).

2.5.3.1 Bullock drawn type

A one row semi-automatic bullock drawn vegetable transplanter was developed that consisted of a furrow opener, a seedling drop tube, a pair of press wheels and a tray type seed metering mechanism. The developed transplanter had the ground wheel powered metering mechanism. The machine was evaluated in the field condition with a pair of bullocks using bare root seedlings of brinjal and chilli of 10 – 12 % moisture content. From the field studies, the average depth of planting brinjal and chilli was found to be 58 – 60 mm. The plant stand and plant mortality after 21 days of transplanting was found to be 70.78 – 72.76 % and 21.66 – 25.66 % respectively. The tray type metering mechanism maintained a plant-to-plant spacing of 525 mm. Draft developed by the vegetable transplanter was 21 kgf. The field capacity and field efficiency of the developed transplanter was 0.052 ha/h and 72.20 % respectively (Sahoo and Mahapatra, 2018).

2.5.3.2 Walk-behind type

The tendency of operators to commit errors in feeding the seedlings in a repetitive loading operation increased in an exponential manner with the increase in speed and the operators tend to commit errors even at very slow feeding rate of 45 plant/min (Splinter and Suggs, 1968).

When two operators were employed for feeding one row, the missing percentage reduced from 10.6 to 3.1 at the feeding rate of 68 plants/min. But the interference amongst the operators reduced the potential feeding rate (Suggs, 1979).

The manually fed transplanters were tested and it was observed that the work rate of 1300 – 1700 plants/operator/h was recorded with cabbages spaced 360 mm

apart. Plants that were within 30° of vertical were considered likely to produce upright plants (Boa, 1984).

A semi-automatic transplanter that has either gripper pockets or flexible discs attached to a conveyor chain to carry transplants from the loading operator's station to the furrow was developed. The grippers open automatically to receive the plant, close to grip the plant and open again at the furrow. The chains carrying the grippers are driven from the packing wheels with adjustments available to vary the plant spacing. The flexible steel discs, marked to show where to insert the plant, carry the plants to the furrow. These machines require two people per row for loading the grippers or discs, to achieve an acceptable rate. Both types are easily converted to handle tray plants by adding extensions to each gripper or disc to support the root media block (Hergert *et al.*, 1988).

A single row semi-automatic transplanter with single cone type metering mechanism with a drop chute for placing seedlings into a furrow by gravity was developed and evaluated. Two operators alternately place a single seedling at one time. The rotating plate strikes the cone opening it, and the seedling moves in the drop chute pipe. Bare root chilly seedlings transplanted with the machine had missing of 14.47 % and the machine had a low capacity (Garg and Dixit, 2002).

A tractor mounted semi-automatic vegetable transplanter was developed using a rotary cup-type planting unit with open cup bottoms and supported on a horizontal stationary plate with an opening through which the seedling was discharged. The transplanter was evaluated for transplanting of pot seedlings of tomato, chilli, cabbage, broccoli, onion and watermelon. The transplanting rate was 60–80 seedlings/min per row with minimum row spacing of 300 mm. A minimum plant spacing of 95 mm in a row for onion to maximum plant spacing of 633 mm for watermelon was reported (Craciun and Balan, 2005).

Even without automated plant handling, it is possible to improve the efficiency of mechanical transplanting by using some type of cassette to allow multiple loading locations in which the operator can place the plants. This type of planting device allows operator to rapidly place several seedlings and then have a brief time to untangle or remove seedlings from cells rather than having to maintain exact timing for each seedling (Parish, 2005).

Even though automatic transplanters have been developed, the semi-automatic transplanters are the mainstream machines, especially in open fields and in countries with small farm holdings (Srivastava *et al.*, 2006).

The walking-type semi-automatic transplanters are either self-propelled or hand tractor-operated machines. They are rare because the operator has to concentrate on operation of machine and feeding seedlings. Riding-type two-row or three-row semi-automatic transplanters are tractor mounted or tractor pulled machines, whereas those that are used with more rows are tractor pulled. The walking-type automatic transplanters are self-propelled machines for transplanting a maximum of four rows. Riding type automatic transplanters are either self-propelled (up to four rows) or tractor pulled (up to eight rows). A dibbling transplanter is one in which holes are made in the soil and seedlings are planted in the holes (Kumar and Raheman, 2008).

Semi-automated transplanters have been developed over the last decade. They fulfill three main tasks: 1) feeding the seedlings to the planting mechanism, one at a time; 2) opening a furrow or hole for insertion of the seedlings and 3) firming the soil around the roots of the seedlings. In many machines, an adjustable amount of water can be placed at the seedling placement position to assist in success of transplanting (Natsis *et al.*, 2011).

A walk-behind type hand tractor powered vegetable transplanter was evaluated for paper pot seedlings for transplanting tomato at 450 × 450 mm spacing in field at a forward speed of 0.9 km/h showed the field capacity of 0.026 ha/h. It resulted in the saving of 68 % labour and 80 % time over conventional method of manual transplanting. The planting rate of the transplanter was found to be 32 pot seedlings/min with 4 % missed planting and 5 % tilted planting. The soil covering efficiency of the developed vegetable transplanter was about 81 % and the quality of transplanting was satisfactory (Kumar and Raheman, 2011).

A hopper type semi-automatic (manually fed) walk-behind hand-tractor-powered vegetable transplanter was designed and developed for the transplanting of soil block seedlings. A low forward speed resulted in a low rate of field coverage by hand tractor, and increased cost of operation. On the other hand, an increase in forward speed increased both the missed plantings and the slip of hand tractor wheels. However, an increase in field coverage and a decrease in missed plantings can be achieved by employing an independent operator for the hand tractor and one labourer to feed each metering device. The planting efficiency was highest for plants with a

height 150 ± 20 mm. As the seedlings were fed to the metering device manually, an increase in planting rate increased missed plantings. The performance evaluation of the planting device under actual field conditions revealed that the planting efficiency of developed planting device was more than 97.5 %. As seedlings were fed to the metering device manually, an increase in planting rate increased missed plantings. The planting device can be adopted for any vegetable transplanter in which the seedlings are allowed to drop freely from metering device (Dihingia *et al.*, 2016).

Experiments were conducted in region of Menderes, Bayındır, Torbalı and Çeşme in İzmir. During the experiments, walk behind type semi-automatic and feed vegetable transplanter with one row (WBM) was compared with tractor mounted semi-automatic hand fed transplanter with three-row (TMM) and hand planting (CP) widely used in the regions aforementioned. Plant spacing, depth of planting and holding force to soil of tomato and pepper seedlings planted with WBM, TMM and CP were measured and take-root rates of these seedlings were calculated. In addition to field capacity of WBM, TMM and CP, total cost analysis of WBM, TMM and CP were comparatively given with fuel consumption of WBM and TMM. If the planting area is smaller than 11.93 ha/year or between 15.45 ha/year and 44.89 ha/year, CP must be chosen. If the planting area is between 11.93 ha/year and 15.44 ha/year, WBM must be chosen. Otherwise, TMM must be chosen (Aykas *et al.*, 2017).

2.5.3.3 Tractor operated type

A two-row tractor mounted vegetable transplanter was developed and evaluated at Punjab Agriculture University, Ludhiana for bare root seedlings. A pocket (picker wheel) type metering mechanism was used, which was driven from the ground wheel of the transplanter. The plant spacing in a row could be varied from 30 to 600 mm by changing the sprockets or the number of plant pockets on the metering device. The per cent miss planting was found to be about 2.0–3.5 at a forward speed of 0.8 – 1.0 km/h depending on plant spacing in the row and skill of the operator. An optional bed-forming attachment was provided with this machine so that both bed-forming and transplanting could be accomplished in a single pass leading to saving of time, energy and labour (Singh and Vasta, 2006).

TNAU Tractor mounted three row plug type vegetable transplanter was designed and developed for chilli, brinjal and tomato. It consisted of main frame with hitching system, ground wheel, shoe type furrow openers, compaction wheel, operator's seats, two depth control wheels and plug type metering mechanism. It

employed press wheels inclined at an angle of 15° with the vertical as soil covering device. The plant spacing can be adjusted. Power is transmitted from ground wheel to gear box through tractor mounted plug type transplanter. The impact of the seedling with soil block helps in its placement. The machine was tested at forward speed of 1.4 km/h. The average field capacity of transplanter was 0.14 ha/h. Average field efficiency of machine was 75 % for chilli, tomato and brinjal with 450 mm row spacing. The working width of machine was 1350 mm (Anonymous, 2006).

A tractor three-point hitch mounted machine capable of placing planting holes for a wide variety of spacing in plastic mulch beds with very little physical reconfiguration was designed and tested with two horticultural crops which have widely varying within-row and between-row spacing requirements: onions and potatoes. The piercing mechanisms were powered by pneumatic cylinders, and on-board controls allowed users to adjust number and spacing of holes. Switches enabled between-row spacing to vary by placing from one to four planting holes across a standard 760 mm bed. A dial was set to create the within-row spacing between 150 and 610 mm. These control settings and a fixed tractor speed acted as inputs to a microprocessor which calculated hole placement frequency and initiated cylinder activation. The machine has been in use for two planting seasons with promising results. Hole placement accuracy data were collected for both onions and potatoes. The potato tests were performed for a within-row spacing of 300 mm and produced 96 % of the planting holes within ± 10 % of the target spacing distance. The onion tests were performed for a within-row plant spacing of 150 mm and produced 98 % of the planting holes within ± 10 % of the target spacing distance (Lawrence *et al.*, 2007).

Manual planting of sugar-beet stecklings is a very laborious and time-consuming operation. To overcome the problems, and decrease the cost of operation to a reasonable level, a semi-automatic tractor mounted two row steckling transplanter was designed. The suitability of the steckling transplanter with regard to the agro-technical requirements of sugar-beet crop was studied and the main field performance parameters of the machine were measured. The results showed that the transplanter was able to place the stecklings with a row spacing of 650 mm and a plant spacing of 503 mm at a selected depth of 130 mm. Deviations of the steckling placements relative to their theoretical positions were 4.5 % and 3.6 % along the row and in a direction perpendicular to the row respectively. For a forward speed of 0.6 km/h and a

maximum planting depth (180 mm), the required draft was 4.05 kN. At a forward speed of 0.199-0.203 m/s, the required draft and drawbar power were 2.6-4.05 kN and 0.528-0.806 kW, respectively. The fuel consumption and power required for transplanting were 0.66 l/h and 0.410 kW, respectively (Kazmeinkhah, 2007).

A study was conducted on a tractor operated two row semi-automatic vegetable transplanter to assess its performance at different speeds, soil moistures and seedlings ages with respect to plants missing, planting angle, planting depth, plants in lying down position and plant mortality for two vegetable crops viz. tomato and chili. Best transplanting results were obtained at 10 % soil moisture content with 5-week seedlings in tomato and 17 to 19 weeks seedlings in chili crop. The machine could be operated at 1.0 km/h and 1.2 km/h speed with missing of 3 to 4 %. The labour and time saving of about 70 to 75 % and 75 to 78 % respectively was obtained with the use of semi-automatic vegetable transplanter over manual transplanting for tomato and chili crops. It was concluded that the plant missing dependent on the speed of operation, quality of the seedlings, size of seedlings, and number of operators etc. (Satpathy and Garg, 2008).

Field experiments were carried out to evaluate the performance of tractor operated small cotton transplanter, which is disc pocket arrangement with spring holders. The field experiments of the transplanter were conducted at four forward speeds of (0.5, 0.8, 1.2 and 1.5 km/h) and included the field capacity, field efficiency, and transplanting efficiency percentage of damaged, missed and floating seedlings. Also, transplanter slippage, fuel consumption, energy requirements and transplanting costs were studied and compared with manual transplanting. The highest theoretical and actual field capacities observed were 0.256 and 0.165 fed/h at forward speed of 1.5 km/h. The highest value of field efficiency was 83 %, transplanter efficiency was 94.3 %, energy requirement was 76.8 kw.h/fed and cotton productivity was 9.23 quintar/fed (0.4615 t/fed) at forward speed of 0.5 km/h. On the other hand, the lowest value of damaged, missed and loose seedlings was 1.86, 3.15 and 0.65 % respectively at 0.5 km/h. Also, the total costs of mechanical transplanting were lower than those under manual transplanting by 8.3, 36.0, 54.0 and 60.8 % at forward speeds of 0.5, 0.8, 1.2 and 1.5 km/h respectively (Genaidy, 2008).

A tractor operated two-row semi-automatic transplanter having a picker wheel type metering mechanism was developed and evaluated. It could transplant wash-root type seedlings of vegetables like cauliflower, tomato and chillies on the beds as well

as flat fields. All vegetable seedlings were transplanted using machine at row-to-row spacing of 670 mm instead of 600 mm since it was not possible in this mechanical transplanting due to high tread width of available tractors. The machine was first evaluated in laboratory to find forward speed of machine based on missing and optimal ergonomical parameters based on light workload ($75 < \text{HR} < 100$). It was observed that a person could put 30 seedlings/min in picking fingers. Based upon this, planter could be operated at a speed of about 1.0 km/h. The plants missing were about 2 to 3 % at a speed of about 0.8-1.0 km/h depending upon plant-to-plant spacing and skill of operator. Plant mortality and yield was comparable with manual transplanting. There is a savings of about 70 – 80 % in labour requirement in comparison to manual transplanting, depending upon crop spacing (Manes *et al.*, 2010).

A tractor operated semi-automatic onion transplanter was developed. Engineering physical properties like height, weight, diameter, moisture content and compressive strength etc. were determined for 6th, 7th, and 8th week age of onion seedlings. Two metering mechanism *i.e.* finger type and plug type were studied in laboratory with three different travel speed of 0.75, 1.00 and 1.25 km/h for different age groups of onion seedlings. It was observed that plug type metering mechanism at speed of 0.75 km/h with 7th week age seedling were more suitable for transplanting. The field trials of semi-automatic transplanter revealed that with the plug type metering mechanism, row to rows pacing of 20.4 – 21.20, plant to plant spacing of 110 – 116 mm and depth of placement was observed 28 – 40 mm. The missing percentage was 9.00 – 10.9. The capacity of the machine was 0.1088 – 0.1174 ha/h with field efficiency of 70.49 – 71.60 %. The draft of machine ranged between 450.00 – 469.80 kgf. The saving in cost of operation over manual transplanting was 40.17 % (Turbatmath *et al.*, 2011).

A tractor operated two-row vegetable transplanter with revolving magazine type metering mechanism was developed and field evaluated for Brinjal (*Solanum melongena* L.) crop. At the time of field evaluation of the vegetable transplanter, bulk density of soil varied between 1.163 and 1.279 g/cm³, and soil moisture between 8.47 and 9.43 %. The seedlings of brinjal crop were grown in 98 cell (single cell volume of 22 cm³) plug trays in soil less media. Plant missing varied from 2.22 to 4.44 %. Upright plants (plants having 0° to 30° planting angle), depth of planting, plant mortality after 20 days were in the range of 85 – 90 % , 50 to 60 mm

and 3.33 to 4 % (6.67 % when bare root seedlings were manually transplanted), respectively. The average field capacity of the machine was 0.122 ha/h for brinjal crop. The quality of feeding decreased with increase in plant missing, and ranged between 95.57 to 97.78 % (Kumar *et al.*, 2011).

A tractor operated two row semi-automatic vegetable transplanter was developed and tested in the field for brinjal and chilies and compared with manual transplanting of bare root seedling. The machine consisted of a frame, two lugged wheels, seedling tray, operator's seat, furrow opener, compaction wheels, finger guide tunnel, finger type metering mechanism and a water tank. Picking fingers had spring mounted rubber flapper, which opened before passing through the tunnel and closed during passage. Power from the ground wheel shaft was supplied to the planting mechanism through chain and sprockets. The plant spacing could be changed by changing the sprockets or number of fingers. A furrow shaper was provided to maintain the shape of the channel between the two transplanting beds. The transplanter showed the field capacity of 0.09 – 0.12 ha/h and field efficiency of 64 to 75 %. Average plant height, number of branches per plant, plant mortality, yield/m², seedling missing, and leaf area index was found more while plant population, planting depth was found less by machine transplanting. Time saving, labour saving, operational cost saving were observed in machine transplanting as compared to manual transplanting (Kumar and Tripathi, 2016).

An auger type metering mechanism which consisted of an auger type metering device, a seedling delivery tube, a furrow opener, a furrow closer, a power transmission system and a frame was developed for metering of paper pot seedlings for transplanting. The setup was evaluated in simulated field conditions (soil bin) in order to select the operating parameters of the metering device. Evaluation was carried out with pot seedlings of 100-150 mm height at five forward speeds *i.e.* 1.6, 1.8, 2.0, 2.2 and 2.4 km/h. Data on intra row spacing, angle of inclination of seedling, soil coverage and conveying efficiency (CE), feeding efficiency (FE), transplanting efficiency (TE) and overall efficiency (OE) were determined. The CE, FE, TE and OE were found to be higher than 90 % for forward speeds 1.6 to 2.0 km/h. Further, the increase in forward speed above 2.0 km/h resulted the FE higher than 90 %, however, the TE and OE reduced below 55 %. Moreover, increase in the seedling tilting greater than 15 % (angle of inclination of seedling >30° from vertical plane) was observed beyond the forward speed of 2.0 km/h. The developed auger type metering

mechanism was found to be suitable for metering of vegetable pot seedlings up to the forward speed of 1.6 to 2.0 km/h effectively at a planting rate of 53 to 65 seedlings/min (Chilur, *et al.*, 2018).

Performance evaluation of a single row semi-automatic tractor operated transplanter was carried out for transplanting of 200 – 250, 250 – 300, and 300 – 350 mm corn seedlings at three forward speed levels of 0.3, 0.4 and 0.5 km/h under actual field conditions in terms of plant spacing, planting depth, and missing plant index. The transplanter precisely plants seedlings into ground. The effect of seedling height on the planting depth was found to be significant. In addition, plant missing percentage increased with increasing of forward speed. The effect of forward speed of tractor on depth of planting was found non-significant at 5 % level. An increase seedling height affects significantly on the increase in mean planting depth due to the very long seedlings caused by the blocking of the worker in determining correct position of seedlings within the picking fingers. The effect of forward speeds on plant spacing was found significant while there was no significant difference in plant spacing between seedling heights. The practical results show that plant spacing varied from 153.1 mm to 165 mm. The missing plant increased with the increase in the transplanter forward speed and the seedling height. The highest missing plant was noticed of 11.23 % by transplanting corn seedlings with the height of 300-350 mm at forward speed of 0.5 km/h due to delay time while pulling the seedlings from seedlings box and the difficulty of feeding seedlings faced by the operator in putting seedlings while feeding in to the picking fingers (Hassen and Almubarak, 2019).

In order to increase the speed and precision of cultivation, the semi-automatic tomato transplanter with conical distributor cup was designed and constructed. In this machine, a semi-automatic distributor transmits transplants through conical bowls into fall tube and transfers to furrow formed by furrower. In field evaluation of machine, these parameters considered were distance between cultivated seedling, cultivation depth and angle, and amount of physical damage to seedlings. The transplanter was tested at 1, 2 and 3 km/h forward speeds and 50 and 100 mm cultivation depth at. The results showed that interaction between forward speed and the cultivation depth had no significant effect on the variables studied, the factor of forward speed had significant effects only on the variables of deployment angle and physical damage to the seedlings, and the factor of cultivation depth was only effective on the variable of the seedling deployment angle. The most appropriate forward speed and cultivation

depth were 2 km/h and 50 mm, respectively. A theoretical capacity of 0.008 ha/h was determined for the machine with a forward speed of 2 km/h and in one cultivation row (Javidan and Zamani, 2019).

2.5.3.4 Self-propelled type

The performance of an eight-row self-propelled paddy transplanter was evaluated. The field capacity, field efficiency and fuel consumption of the transplanter was 0.19 ha/h, 78 % and 6.25 l/ha, respectively. Cost of mechanical transplanting was Rs. 789/ha as compared to Rs. 1625/ha in case of manual transplanting considering the annual maximum usage of machine as 90 hectares. It was observed that with the reduction in the annual usages of the machine, the operating cost of the machine increased (Manjunatha *et al.*, 2009).

A self-propelled riding type paddy transplanter was tested for its feasibility in small size fields of the valley lands of Kashmir region during *Kharif* season of 2007-08. The little higher transplanting cost by machine than manual transplanting could be reduced by increasing its working hours. It was concluded that the mechanical paddy transplanter might be very useful in the region during labour scarcity and to enhance the timeliness of operation for large land holdings (Dixit and Khan, 2011).

A multi-stage rotating cup type metering mechanism for transplanting of vegetable seedlings of tomato, brinjal and chili raised in paper pots was developed. The developed setup consisted of a seedling feeding wheel, metering wheel, fixed slotted plate, seedling delivery tube, furrow opener, furrow closer and a power transmission system. Its evaluation was carried out with pot seedlings of tomato, brinjal and chili of 80 – 110 mm height at five forward speeds (0.6, 0.9, 1.2, 2.2 and 3.2 km/h) and two plant spacing (450 and 600 mm) in controlled soil bin condition. The mean values of feeding efficiency, conveying efficiency, planting efficiency and overall efficiency of the multistage metering unit were observed to be higher than 90 % for forward speeds of 0.6 to 2.2 km/h. With further increase in speed to 3.2 km/h, the feeding and conveying efficiency were observed to be higher than 90 %, whereas, the planting efficiency drastically reduced to around 50 % due to the problem in getting the pot seedlings vertically in the furrow. In addition, the seedlings were falling into furrow at an angle greater than 70° to the vertical, hence not suitable for transplanting (Nandede and Raheman, 2015).

The design, fabrication, testing and evaluation of a pneumatic transplanter was done. The designed pneumatic transplanter consists of 2 pneumatic cylinders, a compressor, a battery, 2 solenoid valves, a plant feeding pipe, a base plate, a switch board, 3 switches - one for the forward motion, one for the cylinder extension and retraction and one for the opening and closing of valves, tubes - to carry the compressed air, tube fittings, 2 pair of wheels and 4 DC motors. By using pneumatic components, the production process is made more economical since these components are cheap, durable and the cost of repair is significantly lower than other systems (Manzoor *et al.*, 2016).

2.5.4 Automatic transplanters

In automatic transplanting system, the seedling handling system is automated. No intervention of human being is needed to feed the seedling to the metering mechanism. These transplanters are more accurate and costlier than the semi-automatic transplanters. But these transplanters require standardized seedlings or must be grown in the seedling trays of specific size.

2.5.4.1 Walk behind type

A 9.75 kW walk-behind type hand tractor powered two-row fully automatic vegetable transplanter for individual paper pot seedlings was developed by considering the power availability, paper pot dimensions and space availability in the hand tractor after the complete removal of rotavator tillage assembly. It consisted of two sets of feeding conveyor, metering conveyor, seedling drop tube, furrow opener, soil covering device, an automatic feeding mechanism, a depth adjustment wheel and hitching arrangement. Horizontal slat-type chain conveyor was used as feeding conveyor and horizontal pusher type chain conveyor was used as metering conveyor. The automatic feeding mechanism, with a timing shaft, cam and clutch, was used to coordinate the working of feeding and metering conveyors. The vegetable transplanter carried 108 seedlings on two feeding conveyors in upright orientation, fed them to the metering conveyors and planted the min upright orientation in furrows. The performance of the vegetable transplanter was evaluated for transplanting tomato at 450 × 450 mm spacing in the field at a forward speed of 0.9 km/h. Field capacity of the transplanter was found to be 0.026 ha/h. It resulted in the saving of 68 % labour and 80 % time over the conventional method of manual transplanting. The planting rate of the transplanter was found to be 32 pot seedlings/min with 4 % missed planting and 5 % tilted planting. The soil covering efficiency of the developed

vegetable transplanter was about 81 % and the quality of transplanting was satisfactory (Kumar and Raheman, 2011).

2.5.4.2 Tractor operated

A fully automatic transplanter was evaluated for the cell mold and pulp mold pot cabbage seedling. It was observed that this machine fed vegetable seedling automatically and enabled continuous transplanting work on 2 ridges simultaneously at a planting speed of 60 hills/row/min. The working speed was 0.33 to 0.39 m/s at the hill spacing of 300 and 600 mm row spacing with one operator (Tsuga, 2000).

The labour requirement for transplanting tomato seedling using the automatic vegetable transplanter was 103 man-h/ha. This included the labour requirement of 25 man-h/ha for refilling of missed plantings and correct placement of tilted plantings (Kumar and Raheman, 2011).

The performance of tractor operated 3-row multistage automatic vegetable transplanter was evaluated in field using tomato seedlings transplanted at 600 × 450 mm at average forward speed 2 km/h. Per cent missed planting, per cent tilted planting, seedling spacing in a row, depth of planting and plant mortality was found to be 4 to 5 %, 8 to 9 %, 450±15 mm, 70±15 mm and 3 to 4 % respectively. Field capacity of the transplanter was found to be 0.114 ha h with field efficiency of 30.06 %. Overall performance of transplanter was found satisfactory (Nandede *et al.*, 2013).

A tractor operated automatic portray tomato seedling transplanter was developed and tested in the field at 1, 1.5 and 2 km/h forward speeds and of 50 and 100 mm cultivation depths. Results showed that forward speed and cultivation depth has effect on distance between planted seedlings, seedling establishment angle and damage to seedlings at the level 5 %. With a forward speed of 1 km/h, the theoretical capacity of the single-row machine was 0.06 ha/h (Zamani, 2014).

2.6 Selection of seedlings for mechanical transplanting

A single row semi- automatic transplanter (using bare root seedlings), which had single cone type metering mechanism with a drop chute for placing seedlings into a furrow by gravity was developed. The transplanted seedlings were not erect in case of bare root seedlings (Garg and Dixit, 2002).

Field-grown bare-root transplants are generally cheaper than tray-grown plants, but may have higher mortality rate in field after transplanting (Parish, 2005).

A tractor operated semi-automatic onion transplanter was developed. For the performance evaluation of the transplanter, the engineering physical properties like

height, weight, diameter, moisture content and compressive strength etc. were determined for 6th, 7th, and 8th week age of onion seedlings (Turbatmath *et al.*, 2011)

One downside is that overgrowth of the taproot due to a poor environment or aging can cause root deformation, with the root circling in the bottom of the plug tray, which may interfere with separation of the seedlings from the tray. The most important factors for mechanical transplanting of seedlings are that the seedlings should be easily separated from the trays and at the same time, the roots should be evenly distributed in the rhizosphere soil so that the soil is not broken during transplantation. Late transplanting also makes mechanical planting difficult due to overgrowth of leaves (Kang *et al.*, 2012).

The gravity fed metering mechanism of the transplanters require seedling with proper weight for the easy falling and remaining erect in the open furrow. Feeding of seedlings consists of singulation, selection, alignment and transfer of seedlings to the planting device, which are difficult to accomplish with bare-root seedlings (Suggs *et al.*, 1987). The seedlings with a heavy soil block around the root portion (weight, 83–90 g) tend to fall with the plant in an upright orientation when the height of the fall is sufficient. (Sivakumar and Durairaj, 2014).

It was observed that the (media 4) soil + vermicompost (4:1) + paper cone seedlings fell down successfully due to the weight of the seedling when compared to other media (Sivakumar Divaker Durairaj, 2014).

Operationally, machine transplanting differs from manual transplanting method in nursery raising, seed rate, seedling age and transplanting system (Islam *et al.*, 2015).

In designing a machine for transplanting, harvesting of these seedlings, physical properties such as weight, bulb diameter, shape factor, height, compressive strength, coefficient of friction on different surfaces are of paramount importance (Pandirwar *et al.*, 2015).

The weight of seedlings affects the ease with which seedlings flows in different components of the machine. Because of gravitational effect, the heavier seedlings drop better than lighter seedlings. In case of older seedlings, their higher weight can support the length of leaves, are not much affected by the length of the leaves, and roll down at lower angle of static friction. The diameter, weight, height of onion seedlings increased with age making them hardy, which is desirable for designing/selection of transplanter components. (Pandirwar *et al.*, 2015).

In a study of design, development and field evaluation of manually operated rice transplanter for system of rice intensification, a 2-row plug type rice transplanter with revolving magazine metering mechanism was developed and field evaluated for rice (*Oryza sativa*) crop. The seedlings of rice crop were grown in paper pot (80 GSM). While rotating the top circular plate funnel coincides with the hole of bottom circular plate resulting in dropping of paper cone placed on the respective funnel of top circular plate due to gravity through seedling tube (Ganapathi and Kumar, 2015).

In soil bin studies on plug and finger-type onion seedling transplanting mechanisms, it was observed that the furrow closure was unaffected by the age of seedling with finger mechanism, because seedlings were released in furrow slit by finger itself in definite position irrespective of size and weight of seedlings (Pandirwar *et al.*, 2018).

When the transplant enters the fall pipe, it reaches the end of the tube due to its weight, and then inserted into the furrow in the soil (Javidan and Mohammadzamani, 2019).

It indicated that in finger type transplanter, the weight of the seedlings have no role compared to the gravity fed transplanters.

2.7 Seedling feed rate in semi-automatic transplanters

In a study of a theoretical model for man-machine system in repetitive loading operation, it was found that the tendency of operators to commit errors feeding the seedlings increased in an exponential manner with the increase in speed. Results indicated that the feeding rate should not exceed 72 plants/min. However, it was observed that the operators tend to commit error even at very slow feeding rate of 45 plants/min. It was also reported that in rejecting an undesirable plant present among the plants to be fed, the operators tend to skip the feeding of next plant (Splinter and Suggs, 1968).

Regero HD B4T transplanter with tomato transplants was tested in a field having permanent beds formed at 1700 mm on corner. Planting depth was adjusted to approximately 75 mm with the packing wheels set as close as possible to the cup mechanism. The tomato plants were approximately 150 to 200 mm total length, including a root ball approximately 38 mm long. The plant spacing was 400 mm. The planting rate, for one person feeding two rows was limited to 30 to 35 plants/min/row. The packing wheels were adjusted as close as possible to the furrow opener (Pelletier and Hergert, 1988).

It was found the hand feeding of Model - 5000 transplanter was limited to well under 2 seedlings/s, whereas automatic feeding can reach at least 5 seedlings/s. It was inferred that humans unable to feed seedlings much faster than one seedlings/s without making errors, which cause skips in field. Once the error started to occur as a result of operators not being able to respond quickly enough, the errors increase exponentially as the rate of transplanting is increased (Brewer, 1994).

A tractor drawn 2-row vegetable transplanter with revolving magazine type metering mechanism was developed and field evaluated for brinjal (*Solanum melongena* L.) crop. The transplanter was having provision for two operators to sit. The seedling feeding rate was observed to be 37.59 seedlings/min/row (Satapathy and Garg, 2008).

Average seedling feed rates for manually fed transplanters are generally less than 45 seedlings/min, which translates to maximum forward speed of travel of 0.22 m/s (0.8 km/h) for close spaced vegetable crops (300 mm plant spacing) and 0.67 m/s (2.4 km/h) for wide spaced vegetable crops (>900 mm plant spacing). 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/min with 3 % miss was observed in laboratory study, however the average transplanting rates reduced to 32.12 and 33.28 seedlings/min with 3.8 % and 3.2 % miss in field conditions. Thus, manual seedling feeding rates limited the maximum allowable travel speed of the transplanter (Gaikwad, 2010).

A 9.75 kW walk-behind type hand tractor powered 2-row fully automatic vegetable transplanter for individual paper pot seedlings was developed by considering the power availability, paper pot dimensions and space availability in the hand tractor after the complete removal of rotavator tillage assembly. The performance of the vegetable transplanter was evaluated for transplanting tomato at 450 × 450 mm spacing in the field at a forward speed of 0.9 km/h. The planting rate of the transplanter was found to be 32 pot seedlings/min with 4 % missed planting and 5 % tilted planting (Kumar and Raheman, 2011).

The performance results obtained revealed that the 8 row semi-automatic onion transplanter operated with average travel speed of 0.20 m/s gave the field capacity of 0.083 ha/h. The average plant to plant spacing was 113 mm with the average row to row spacing of 208 mm. Accordingly, the seedling feeding rate

obtained was 73 seedlings/min/person. It was sit behind type transplanter (Turbathmath *et al.*, 2011).

A 2-row plug type rice transplanter with revolving magazine metering mechanism was developed and field evaluated for rice (*Oryza sativa*) crop. The field efficiency and field capacity of the transplanter as observed to be 83.22 % and 0.014 ha/h respectively. The seedling feed rate was observed to be 18.66 seedling/min/row (Ganapathi and Kumar, 2015)

A hopper-type planting device was developed for the walk-behind hand-tractor-powered vegetable transplanter. The vegetable transplanter had a horizontal conveyor-type seedling-metering device. Two different seedling feed rate *i.e.* 31.17 and 41.08 seedlings/min/row were used. Missed planting percentage was 0 and 5.30 at 31.17 and 41.08 seedlings/min/row seedling feeding rate (Dihingia *et al.*, 2016).

One row semi-automatic bullock drawn vegetable riding type transplanter was designed and developed. It consisted of a furrow opener, a seedling drop tube, a pair of press wheels and a tray type seed metering mechanism. The metering mechanism of the developed transplanter was powered by the ground wheel. The transplanter was evaluated for bare root brinjal and chilli seedling transplanting at the spacing of 525 mm and a speed of 1 km/h. The calculated seedling feed rate was 31.74 seedlings/min (Sahoo, *et al.*, 2018).

2.8 Effect of soil moisture content at the time of transplanting

The performance of a semi-automatic vegetable transplanter was evaluated in the field which was irrigated and prepared at 16-18 % soil moisture content and then periodical checking of soil samples was done to attain the desired level of soil moisture (Satapathy and Garg, 2008).

The field was irrigated and prepared at 16 – 18 % moisture content and then periodical checking of soil samples was done to attain the desired level of soil moisture. The moisture content of 10 % was found to be better with respect to plant missing, laying down plants, upright plants and plant mortality. Lower per cent of upright plant at higher moisture content was due to lesser soil flow towards the planting furrow, which resulted in poor soil coverage. On the other hand, at lower moisture content of 6 % there was closing of planting the furrow before the plants were released due to excessive soil flow (Satapathy and Garg, 2008).

Field performance of the 2-row hand tractor operated AVT was evaluated for transplanting paper pot seedlings of tomato at 450 × 450 mm spacing in three well

prepared plots each of 25×3 m size. The soil was lateritic sandy clay loam having bulk density of 1.32 g/cm^3 at 9.0 ± 2 % moisture content (dry basis). Twenty-five day old pot seedlings of average height 120 mm and potting mix moisture of around 5 % (dry basis) were selected (Kumar and Raheman, 2011).

During the evaluation of the two row revolving magazine type vegetable transplanter, the bulk density of soil varied between 1.163 and 1.279 g/cm^3 , and soil moisture between 8.47 and 9.43 % (Narang *et al.*, 2011).

The soil was lateritic sandy clay loam having bulk density of 1.32 g/cm^3 at 9.0 ± 2 % moisture content (dry basis) (Kumar and Raheman, 2011).

The vegetable transplanter was used in sandy loam soil with bulk density 1.25 g/cm^3 and the moisture of 12 % of dried basis (Zamani, 2014).

The design, construction and evaluation of tractor operated fully automatic tomato transplanter was done. The used seedlings were in four-leaf in the cultivation time. Land used has a sandy loam soil with bulk density 1.25 g/cm^3 and the moisture of 12 % on dry basis (Zamani, 2014).

A hopper-type planting device for a walk-behind hand-tractor-powered vegetable transplanter was tested in the plots contained inceptisol soil of a sandy loam texture with a bulk density of 1.30 g/cm^3 and a moisture content of 11 ± 2 % (dry basis) (Dihingia *et al.*, 2016).

A tractor operated two row transplanter was operated at an average speed of 1.0 to 1.2 km/h in sandy loam soil at moisture content of 8 to 9.50 % (Kumar and Tripathi, 2016).

A two row vegetable transplanter was developed, considering the tractive power of the walk-behind hand tractor. It consisted of two sets of metering conveyors, steel trays, hopper-type planting devices, seedling drop tubes, furrow openers, soil-covering devices, as well as a depth-adjustment wheel, a dog clutch, and a hitch arrangement. The performance of the hopper-type planting device was evaluated under actual field conditions using the developed 2-row hand-tractor-powered vegetable transplanter. Two plots of 23×10 m were prepared for the planting of tomato seedlings at 450×450 mm spacing. A total of 1000 seedlings were planted in each plot, with 50 plants in each row. The plots contained inceptisol soil of a sandy loam texture with a bulk density of 1.30 g/cm^3 and a moisture content of 11 ± 2 % (dry basis). Twenty eight-day-old soil block tomato seedlings with an average

moisture content of the soil block at the time of the extraction of the plants with their soil blocks from the tray cells was 22 ± 2 % (dry basis). The mass of each seedling, with its soil block, was 68.47 ± 3.22 g (Dihingia *et al.*, 2016).

A two row trolley type transplanter was tested in the field at mulched and bare bed condition. The moisture content of the mulched bed varied between 13.54 to 14.05 % while that of bare bed varied between 12.82 to 13.62 % (Thorat *et al.*, 2017).

A low cost manually operated two row vegetable transplanter was tested in the vertisol type soil having moisture content 16-18 % (db) (Nandede *et al.*, 2017).

Design, development and performance evaluation of manually operated two row trolley type vegetable transplanter was done. It was observed that on mulch bed cost of operation were least. The reason seems to be moisture retains in case of mulch bed (14.05, 14.37 and 13.54 % m.c.) was helpful for easy penetration and opening of jaw into the soil compared to bare soil (13.07, 13.62 and 12.82 % m.c.) for 4, 5 and 6 weeks aged chili seedlings (Thorat *et al.*, 2017).

Testing of the developed transplanter was evaluated in research farm of ICAR-Central Institute of Agricultural Engineering, Bhopal. Ridges and furrows were made by tractor operated ridge and furrow former. Height and top width of ridge was 200 mm and 50 mm. The length of ridge was 10 m length. Moisture content of the soil was 16 – 18 % (db) soil type is vertisol (Nandede *et al.*, 2017).

2.9 Furrow opener and soil closing mechanisms for vegetable transplanters

A spiked opener was used for an automatic vegetable transplanter for dry field operation. As the opener was lowered to open a furrow, the centre and side spikes pulverized soil in the furrow to form a soft - landing region for potted plants to absorb the impact and to prevent tumbling. The press wheel was set at an angle of approximately 45° with respect to the ground and slightly opened to the forward direction in order to obtain a more normal closure of the furrow around the transplants without excessive compaction of the soil (Huang and Splinter, 1968).

Hand - fed lettuce seedling block transplanter was developed with the furrow opener called Iseki hiller. The furrow opener was fitted with extended side plates to prevent the furrow from collapsing before the seedling was vertically positioned. The furrow opener could open the furrow of 152.4 mm width with 203.2 mm high side plates and 101.6 mm depth. As the soil in the greenhouse was very loose and dry, so simple curved scraper plates were used to close the furrow. The furrow closers were

attached to the side plates of the furrow opener. They were adjusted to change the amount of soil pushed into the furrow by changing their spacing and by varying their distance from the ends of the side plates (Chow *et al.*, 1980).

A pair of press wheels tilted outwards at top is the most commonly used device for closing the furrow and compacting of soil (Srivastava *et al.*, 2006).

The furrow opener of the vegetable transplanter was designed in such a way that it only opens the soil and facilitates backward flow of soil for self-filling of furrow. The wedge angle was calculated considering the mechanics of a vertical tillage tool to suit the types of soil condition (Mahapatra, 2006).

In transplanters for use on raised beds and nurseries where soil is moist, a shovel-type furrow opener is used (Kumar and Raheman, 2011).

A pair of press wheels of diameters 300 mm and 65 mm width was used to close and compact the soil at the root zone of the seedling, such that the seedlings can stand erect. The inner sides (at the soil engaging end) of the press wheels were tilted for better compaction. Considering the agronomical requirement of the plants and to accommodate the seedlings in between these two press wheels a clearance of 75 mm was kept (Sahoo *et al.*, 2018).

2.10 Fertilizer application during transplanting *i.e.* co-situ placement

Replacing part of the conventional fertilizer with starter fertilizers increased plant mortality, decreased uniformity, and reduced cured-leaf yield of bare root transplants (Peedin and McCants, 1973).

The purpose of a starter fertilizer is to supply a small amount of nutrients in the early stages of growth before the root system is sufficiently developed to reach banded fertilizer (Costigan, 1984).

Traditional placement of soluble fertilizers in bands contributes to losses and reduces the availability of the fertilizer nutrients (Randall and Hoef, 1988; Randall *et al.*, 1985).

Application of fertilizer using machine is important as it is possible to achieve uniformity of fertilizer in root zone of all plants (Bansal and Leeuwfstein, 1987).

The agronomic performance of urea briquette (UB) applicator in transplanted rice showed that the applicator-placed UB consistently increased grain yields over the split-applied drilled urea, and the additional yields ranged from 0.23 to 1.48 t/ha (5 to 83 %) for 25 to 63 kg N/ha. Agronomic responses of transplanted rice to the UB placed by the applicator and by hand were statistically equal. Modified rice hill

spacing may be considered as a requirement for efficient use of the applicator. The results demonstrate that UB applicator could deep place UB and achieved agronomic efficiency that was achieved by hand deep placement of UB (Savant *et al.*, 1992).

The central concept of co-situ application is to apply the nutrients in the intensive rooting zone with release patterns synchronized to the demand of the plant over the complete growing season. Therefore, co-situ application minimizes the reaction and interaction of the nutrients with the soil and thus greatly increases fertilizer efficiency (Shoji and Kanno, 1994).

Field studies were conducted from 1994 to 1997 to determine the effects of starter fertilizer, conventional phosphorus (P) fertilizer rate, delayed fertilization, and the P concentration of transplants on early growth, nutrient uptake, date of flowering, yield, quality, and cured leaf nutrient content of flue-cured tobacco grown on high P soils. Starter fertilizer increased early season growth and nutrient uptake and resulted in slightly accelerated flowering. Yield and visual quality were not affected except for a slight visual quality improvement in one experiment. Phosphorus fertilization rate had little effect on most parameters measured, with only a small yield increase in one experiment. Delayed fertilizer application lengthened the growing season slightly, but did not have detrimental effects on yield or quality index. Lower than normal transplant P tissue concentration did not affect subsequent growth, yield, or quality. These experiments indicate that there is little advantage to using starter fertilizer on flue-cured tobacco grown on high-P sandy soils and that delayed fertilization is not detrimental to final yield and quality. This study also confirms that the use of height-restricting low-P nutrient regimes during greenhouse production of seedlings is not detrimental to field performance (Rideout and Gooden, 2000).

A research on urea deep placement as an option for increasing nitrogen use efficiency showed that rather than applying urea, a nitrogen fertilizer, to the soil surface in tiny granules, the urea is compacted into briquettes and placed several inches below ground. These briquettes release nitrogen slowly, dramatically reducing the amount of fertilizer washed away by rain or absorbed by the air. Urea super granules were placed several inches below ground (70 – 100 mm), within one week of transplanting. Applying urea, a nitrogen fertilizer, to the soil surface in tiny granules through broadcasting has negative economic effect and negative environmental impact (Walter, 2005).

Application of urea super granules (USG) @ 75 kg/ha produces 5.88 % more yield than granular urea application at 2 – 3 equal splits (Hasanuzzaman *et al.*, 2009).

During laboratory test of the manually operated urea super granule applicator, dispensing efficiency was more than 98 %. The urea super granule applicator was designed for 0.14 ha/hour considering walking speed of 1.75 km/h. However, the average field capacity was 0.12 ha/hour during field operation. The field capacity varied widely with soil condition, field condition and skill of the operator. The average depth and distance between USG placement in the field was 66 mm and 395 mm during field operation. Manual application capacity of USG also varied with the skill of the operator. Average manual application capacity was observed around 0.12 ha/day (0.016 ha/h) (Hossen *et al.*, 2013).

The effective field capacity and field efficiency of a pull type two rows granular urea (GU) applicator at a forward speed of 1.78 km/h was 0.11 ha/h and 78.89 % respectively. The average distance between two dropped GU from left hopper and right hopper were 406.4 mm and 408.9 mm respectively. The average missing rate of GU dropped during field operation was 1.65 % for GU size of 2.83 g. The depth of GU placement was 70 – 100 mm in puddle field. The pulling force and draft of the developed applicator varied between 5– 11 kg (49.03 – 107.87 N) and 3 – 6.62 kg (29.42 – 64.92 N) respectively. The draft power was 0.027 kW for 55.38 N pulling forces at 1.78 km/h speed. The application rate of the GU applicator was 170 kg/ha. The manufacturing cost of the applicator was only Rs 5160. The weight and the drawbar power of the applicator were 15 kg and 0.03 kW respectively. Therefore, one person (man or women) is enough to pull the machine. Overall performance of the applicator found quite satisfactory (Alam *et al.*, 2014).

An automated dibble fertilizer applicator for lettuce transplanter was developed and tested in field. Eco-long (N-P-K : 14-11-13), which is a slow-releasing coated granular fertilizer, was chosen as the starter fertilizer for winter lettuce. The test Ecolong was coated with a thin layer of bio-degradable polymer forming a relative smooth surface of granules. It had uniform grade, with average granular diameter of 5.5 mm, density of 0.96 g/ml, and atmospheric humidity of approximately 60 % at the time the tests were carried out. Because the starter fertilizer was placed beneath the seedlings, transplanting depth should be made slightly deeper according to practical transplanting conditions. The discharge rate was estimated from the cell volume and density of the metered materials (Nguyen *et al.*, 2014a).

There is considerable potential for the use of starter fertilizer as part of an overall broadcast fertilizer to enable winter lettuce growers to increase profitability through increased marketable yields (Nguyen *et al.*, 2014b).

Deep placement or subsurface placement of urea ensures better distribution of ammoniacal nitrogen within anaerobic layer of soil and prevent any loss by surface drain-off (Savant and Stangel, 1990; Gaudin, 2012; Gaudin and D'Onofrio, 2015).

A metering device made of mild steel (MS) sheet consisting four cups of 25.4 mm diameter was designed to uniformly apply the granular urea (GU). Maximum missing percentage and over falling percentage were found 3 %. The average distance between applied GU was found 0.40 m. The effective field capacity of the GU applicator was found 0.14 ha/h at a speed of 2.21 km/h and field efficiency was found 78.4 % (Karim *et al.*, 2015).

The review of literature leads to the conclusion that finger millet transplanting has to be done in wet soil. Single seedling per hill can be transplanted (Anonymous, 2016a). Considering the small land holdings in Konkan region (Shahare and Bhatt, 2011), a small size semi-automatic, self-propelled, gravity fed type two row finger millet transplanter need to be developed. The unit should be small enough such that small engine could satisfy its power need. The wet soil condition and the limitation of the seedling feed rate in semi-automatic transplanting system (Kumar and Raheman, 2011), the speed of operation below 0.9 km/h was considered suitable considering the transplanting operation has to be carried in wet field. The seedling feed rate should not exceed 40 seedlings/min (Splinter and Suggs 1968, Manes *et al.*, 2010, Gaikwad, 2010, Dihingia *et al.*, 2016). The row spacing should be 250 mm to facilitate interculturing operation (Anonymous, 2017a, Bitew and Asargew, 2014, Pradhan *et al.*, 2015). The seedling age, seedling feed rate and the forward speed of operation has pronounced effect on transplanting was observed at laboratory and at field level (Adhikari *et al.*, 2013, Islam *et al.*, 2015). The operational parameters effect can be studied using RSM with BBD techniques (Singh *et al.*, 2010, Pasma *et al.*, 2013, Patel *et al.*, 2019, Mayer *et al.*, 2009) and performance need to be evaluated in the field for validation. The next chapter deals with methodology used for design, fabrication and testing of the same.

CHAPTER III

MATERIAL AND METHODS

This chapter deals with the study of existing manual finger millet nursery raising and transplanting methods adopted in Konkan region. It includes the material required and methods followed for the standardization of nursery raising. The development of finger millet transplanting system with fertilizer application unit and its performance evaluation is discussed in this chapter under following sections.

- 3.1 Study of existing methods of nursery raising and manual transplanting of finger millet.
- 3.2 Standardizing the nursery raising method and seedling stage (age, height) required for mechanical transplanting system through laboratory trials.
- 3.3 Selection of seedling feed rate for developed finger millet transplanter
- 3.4 Design of a two row mechanical transplanting system for finger millet seedlings.
- 3.5 Development of a two row mechanical transplanting system for finger millet seedlings.
- 3.6 Evaluation of the developed mechanical transplanting system.
- 3.7 Cost analysis of newly developed mechanical transplanting system.

3.1 Study of existing methods of nursery raising and manual transplanting of finger millet

The study of the existing practices of the finger millet nursery raising methods and its transplanting methods was done. It is discussed as follows.

3.1.1 Study of existing nursery raising methods for finger millet

The nursery raising methods followed by the local farmers and University were studied. The study was conducted on the fields of eight farmers with field size ranging from 0.09 to 0.2 ha (average 0.012 ha) in four different villages for knowing the farmers practices while in University, it was conducted on single field. The parameters like method of sowing, seedling density, labour required, and seedling parameters, etc. were studied and are discussed in next chapter.

3.1.2 Study of conventional methods of finger millet transplanting

The conventional methods of finger millet transplanting followed by the local farmers and the University were studied. The method of transplanting, time and labour required, seedling density, and drudgeries in transplanting were studied and are discussed in the next chapter.

3.2 Standardizing the nursery raising method and seedlings stage (age, height) required for mechanical transplanting system through laboratory trials

This section deals with development of nursery raising method for raising maximum number of uniform seedlings and standardization of seedling stage required for the mechanical transplanting. Considering seed size, quantity required and as the manual sowing is labourious and cannot maintain the seed placement uniformity, it was planned to design and develop drum seeder for finger millet sowing to overcome these issues. It was assumed that the seed drill could sow the seeds at required spacing and could produce uniform seedlings for transplanting reducing drudgery of labour.

The seedlings of 25 to 30 DAS are suggested for manual transplanting but according to the thickness and width of the seedling, selective seedlings should be used for mechanical transplanting. More number of seedlings damage was occurred in this category. These seedlings were tried with the developed gravity feed mechanical transplanting system. However, it was observed that most of the seedlings were falling horizontal *i.e.* failing to stand erect on the ground and were being covered under soil due to soil covering device. Considering this, tests were conducted with older seedlings of 35, 40, 45, and 50 DAS age also to use with the developed transplanter as these seedlings have more stem thickness, width and weight. These seedlings had 3 to 5 mm stem thickness and 6 to 9 mm stem width and were heavy enough to facilitate easy dropping under gravity through the seedling tube and its stand in the soil. The seedlings of these ages were observed to be of 600 to 800 mm height. Such seedling height and its canopy spread were obstructing the free fall through the seedling tube (Fig. 3.1). These seedlings then de-topped because the sword shape down curved leaves of the seedlings being hooked to the edge of the seedling feed cup (Fig. 3.2). The seedling de-topping is not the regular or recommended practice of the finger millet cultivation however; it was followed in present study. As the developed transplanting system was of the gravity feed type, seedlings with heavier root *i.e.* attached with soil were needed that could give the effect of plug type seedlings. The aged seedlings helped for the easy uprooting from the field due to its strong stem, created less damage and offered availability of maximum number of seedlings ready for the transplanting. The height of seedlings about 450 mm can pass through the seedling cup and the seedling tubes. Hence, these seedlings were considered ideal for the transplanting purpose.



Fig 3.1 Seedling uprooted from field



Fig 3.2 De-topped seedlings used for transplanting

The transplanter was operated with seedlings of 25 to 50 days old with predetermined speed and seedling feed rate. Following observations were recorded.

Standardizing the nursery raising method and seedlings stage (age, height) required for mechanical transplanting system through laboratory trials has the following systematic procedure.

1. Design of finger millet drum seeder cum fertilizer applicator according to the agronomical requirements and design considerations.
2. Laboratory and field evaluation of developed drum seeder cum fertilizer applicator.
3. Evaluation of physical parameters of the seedlings grown by developed drum seeder cum fertilizer applicator and the manual method.
4. Performance testing of different aged finger millet seedlings to standardize its suitability with developed transplanting system.

3.2.1 Design considerations for development of finger millet drum seeder cum fertilizer applicator

1. Size of seed and seed rate required.
2. Size of granular fertilizer and quantity required per hectare.
3. Row spacing required for sowing.
4. It should distribute the seeds and granular fertilizer evenly at optimum depth and cover soil properly.
5. It should be light in weight to operate by a single person.
6. It should be easy to fabricate, operate, and maintain.

3.2.2 Physical properties of finger millet seed

Physical properties of seeds at 10.21 % are Geometric mean diameter 1.46 mm, Sphericity 0.92, Volume 1.75 mm³, Surface area 6.73 mm², Thousand grains weight 2.40 g, Bulk density 724 kg/m³, True density 1429 kg/m³, Porosity 49.32 %, Angle of repose 22.95°, Terminal velocity 4.60 m/s, Static coefficient of friction on Plywood, Steel and Glass surface 0.39, 0.39, 0.37 respectively (Powar, 2018). To transplant finger millet seedling on one hectare area, nursery need to grow on 0.1 ha area (100 m²). As per package of practice recommended by University, application rate of Cv Dapoli 1 seed is 55 g/m² and urea is 100 g/m². The drum size suitable for sowing 0.1 ha area was designed.

3.2.3 Design of seed and fertilizer drum

a. Design of seed drum

The volume of seed drum assumed 10 % more than the volume of the required quantity of seeds so that it could be easily accommodated in drum (Chate, 2017).

Volume of seed drum is given by,

$$V_d = 1.1 V_s \quad \dots \text{(Eqn 3.1)}$$

$$V_s = \frac{W_s}{Y_s} \quad \dots \text{(Eqn 3.2)}$$

V_d = Volume of seed drum, mm³,

V_s = Volume of seed, mm³,

W_s = Weight of seed, g,

Y_s = Bulk density of seed, g/mm³,

Putting value of V_s in equation 3.1

$$V_d = \frac{1.1 W_s}{Y_s} \quad \dots \text{(Eqn 3.3)}$$

The seed drums of drum seeder cum fertilizer applicator are shown in Fig. 3.3.

b. Design of fertilizer drum

The physical properties of granular urea like loose bulk density 720-820 kg/m³, particle density 1200-1300 kg/m³, mean diameter 2.2 mm, crushing strength 1.5-3.5 kg/granular, and coefficient of friction 0.3 (Fulton and Port, 2016) were considered to decide the drum size and orifice size on it. The application rate of urea is 100 g/m² and that of finger millet seeds it is 55 g/m². Hence, same drums with more orifices were used for fertilizer metering. The fertilizer drums of drum seeder cum fertilizer applicator are shown in Fig. 3.4.

3.2.4 Seed and fertilizer metering

Front pair of drums was used for fertilizer while rear pair for seed. Based on diameter of finger millet grains and granular urea, 3 mm diameter orifices were made for seed and fertilizer metering on the seed and fertilizer drums respectively along the circumference. The drums with 12 and 24 orifices spaced equally were prepared for both seed and fertilizer. Two rows of orifices, spaced at 100 mm distance, were drilled on each seed drum to drill seeds at 100 mm row spacing as recommended by Dr BSKKV, Dapoli. For fertilizer metering, band of three rows of 3 mm diameter orifices spaced 100 mm were made on the fertilizer drum.

3.2.5 Design of furrow openers and soil covering device

The assumptions made for the design of furrow openers are as below.

1. Average manual power as 0.1 hp (0.0746 kW).
2. The furrow opened by the furrow opener is trapezoidal in shape.
3. The working top width, bottom width and depth of furrow opener as
a = 52 mm, b = 25 mm, h = 35 mm respectively

$$\therefore \text{Cross section of furrow opener (A)} = \left(\frac{a+b}{2}\right) \times h \quad \dots \text{(Eqn 3.4)}$$

$$= \left(\frac{5.2 + 2.5}{2}\right) \times 3.5 = 1347.5 = 1350 \text{ mm}^2 \quad \dots \text{(Eqn 3.5)}$$

The value of the actual soil resistance is calculated as (Varshney *et al.*, 2004).

$$F_x = A \times P_k \quad \dots \text{(Eqn 3.6)}$$

Where, F_x = Soil resistance, kgf

A = Cross section of furrow, cm^2

P_k = Specific soil resistance for the light soil, kg/cm^2

Specific soil resistance P_k when working to 15 cm depth under light, medium and heavy soils is 0.12, 0.15, and 0.20 kg/cm^2 respectively (Varshney *et al.*, 2004).

Therefore for light soil,

$$F_x = A \times P_k = 13.5 \times 0.12 = 1.62 \text{ kgf}$$

Soil resistance was assumed 3 to 5 times higher than actual average (F_x).

Total draft at the tip of tine (D_t) = 3 to 5 times of F_x , kgf(Eqn 3.7)

$$D_t = 1.62 \times 3 = 4.86 \text{ kgf} = 4.86 \times 9.81 \text{ N} = 47.68 \text{ N}$$

Maximum speed of operator was considered 1.5 km/h (0.42 m/s)

$$\text{Power} = \text{Draft (N)} \times \text{Speed (m/s)} \quad \dots \text{(Eqn 3.8)}$$

$$= 47.68 \times 0.42 = 20.02 \text{ W} = 0.02 \text{ kW}$$

$$\begin{aligned} \text{Number of furrows} &= \frac{\text{Available power}}{\text{Operational power per row}} \quad \dots(\text{Eqn 3.9}) \\ &= \frac{0.0746}{0.02} = 3.73 \text{ furrows} \approx 4 \text{ rows} \end{aligned}$$

Hence, four row seed cum fertilizer drill is designed (Fig. 3.5).

3.2.6 Design of main frame of the drum seeder cum fertilizer applicator

The main frame of drum seeder cum fertilizer applicator was designed to accommodate a handle to pull, axles of front and rear wheels, soil-covering plate and two pairs of drums respectively for seed and granular fertilizer.

3.2.7 Design of ground wheel

The ground wheel of 230 mm and 165 mm diameter were designed to get the desired seed rate with the combination of orifice spacing on the drums as the drums were ground wheel driven (Fig. 3.6). The theoretical seed spacing (mm) was calculated (Table 3.1) considering the number of orifices on the seed drum and assuming that seeds will drop from bottom side only.

$$\text{Orifice spacing (mm)} = \frac{\pi \times \text{Drum diameter (mm)}}{\text{No. of orifices on drum}} \quad \dots(\text{Eqn 3.10})$$

Theoretical seed spacing (mm)

$$= \frac{\text{Ground wheel diameter (mm)}}{\text{Drum diameter (mm)}} \times \text{Orifice spacing (mm)} \quad \dots(\text{Eqn 3.11})$$

Table 3.1 Seed spacing (mm) calculated with the combination of wheel diameter and orifice position on drum

	Particulars	Wheel diameter, mm			
		165 (D ₁)		230 (D ₂)	
1	No. of orifices	12 (H ₁)	24 (H ₂)	12 (H ₁)	24 (H ₂)
2	Drum diameter, mm	75	75	75	75
3	Orifice spacing, mm	19.6	9.8	19.6	9.8
4	Seed spacing (S _s), mm	43.12	21.56	60.10	30.05
5	Seed rate, kg/ha	5.81	11.90	3.96	7.93

Seed spacing according to seed rate *i.e.* 5.5 kg/ha (Anonymous, 2016e) and 100 mm row spacing for nursery raising on 1/10th of hectare was found to be 4.5 mm.

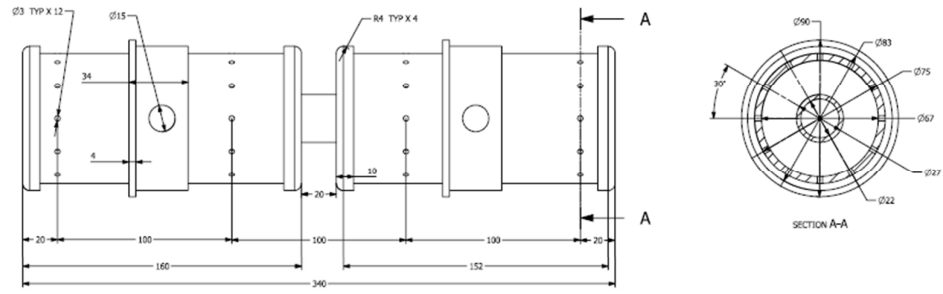
3.2.8 Design of handle

A handle of drum seeder with provision to change operating height was designed considering operation of seeder by male as well as female workers of Maharashtra. The selected anthropometric data of male and female workers of Maharashtra is presented in Table 3.2 for consideration.

Table 3.2 Selected anthropometric data of male and female workers of Maharashtra for handle design (Gite *et al.*, 2006).

Particulars	Male workers		Female workers	
	5 th percentile	95 th percentile	5 th percentile	95 th percentile
Grip diameter, mm	42	55	39	52
Middle finger palm grip diameter, mm	23	35	21	31
Hand breadth, mm	69	87	64	80

To design the handle grip diameter and length of grip, the 95th percentile value of middle finger palm grip diameter (lower) and higher value of 5th percentile value of inside grip diameter of female workers of Maharashtra was considered. The length of grip, higher value of 95th percentile of male worker population was considered suitable for all male and female operators (Gite *et al.*, 2006). Based on above, the grip diameter of 35 mm (lower) and 39 mm (higher) was selected for design with 190 mm length of grip to accommodate both hands if required was finalized. A 20 mm square pipe of 940 mm long welded with 25 mm round pipe of 190 mm at grip end. A 5 mm thick rubber grip was fixed on round pipe. This is suitable for both male and female workers of Maharashtra region. The specifications of manually operated finger millet drum seeder cum fertilizer applicator are given in Table 3.3.

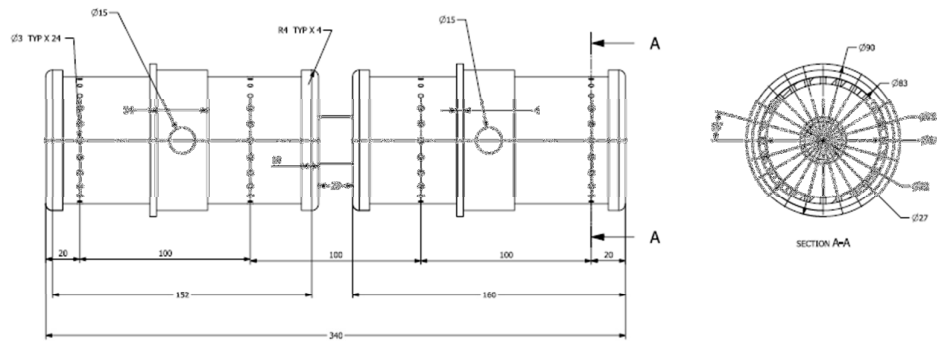


Front view

Side view

Seed drum with 12 orifices

All dimensions are in mm
Scale: 1:5



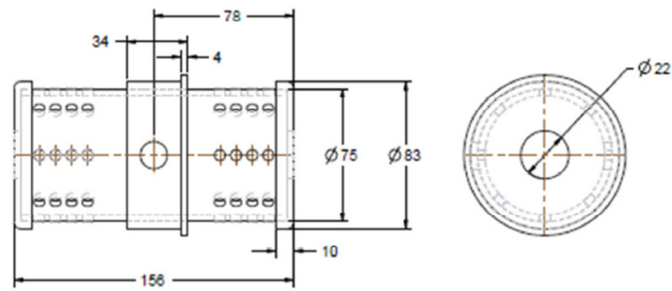
Front view

Side view

Seed drum with 24 orifices

All dimensions are in mm.
Scale: 1:5

Fig 3.3 Seed drums of the drum seeder cum fertilizer applicator



Front view

Side view

All dimensions are in mm.
Scale: 1:5

Fig 3.4 Fertilizer drums of the drum seeder cum fertilizer applicator

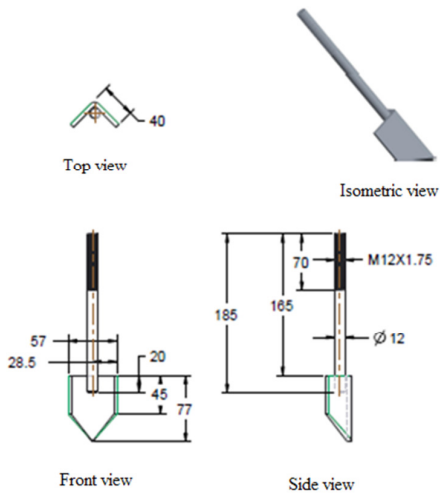
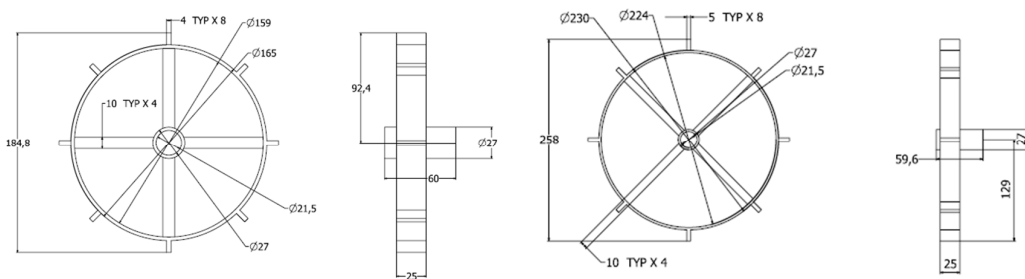


Fig 3.5 Furrow openers of the drum seeder cum fertilizer applicator



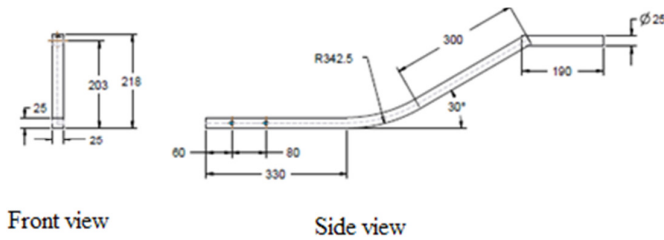
All dimensions are in mm.

Scale: 1:5

a. 165 mm diameter. Wheel

b. 230 mm diameter wheel

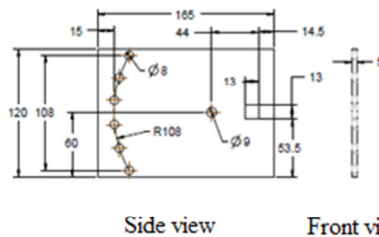
Fig 3.6 Wheels used for the drum seeder cum fertilizer applicator



Front view

Side view

Handle bar



Side view

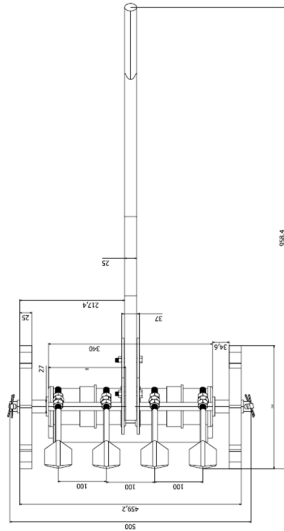
Front view

All dimensions are in mm

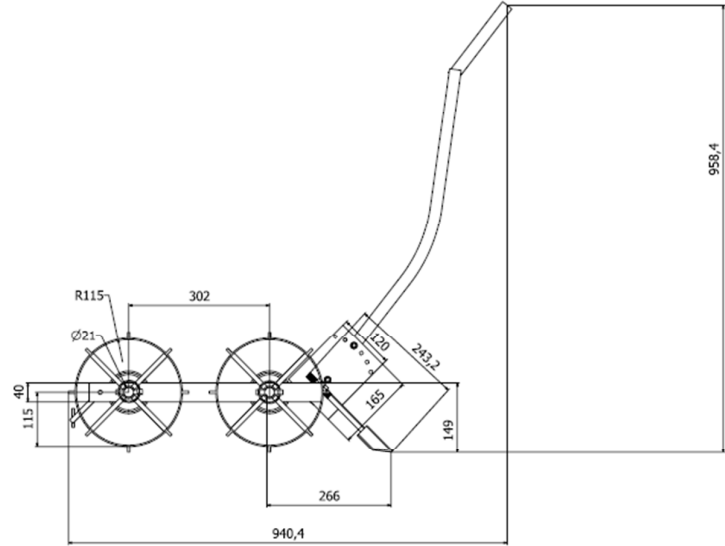
Scale:1:6

Plate for angle of handle adjustment

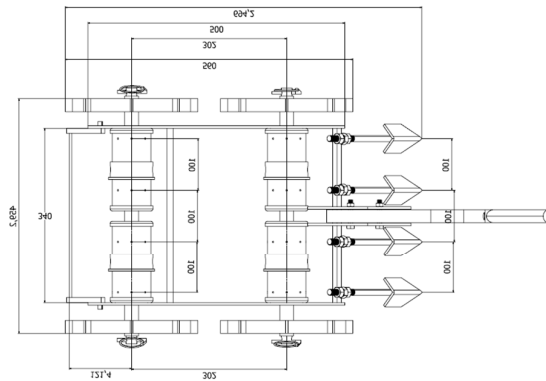
Fig 3.7 Components of the drum seeder cum fertilizer applicator handle



Front view



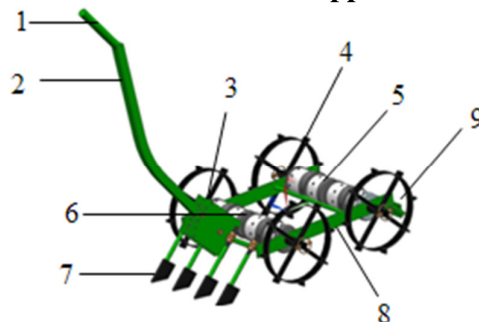
Side view



All dimensions are in mm
Scale: 1:6

Top view

Fig 3.8 Developed drum seeder cum fertilizer applicator for finger millet nursery



1. Handle grip, 2. Handle, 3. Arrangement for changing angle of handle, 4. Ground wheel, 5. Fertilizer drums, 6. Seed drums, 7. Furrow openers, 8. Main frame, 9 Soil covering plate.

Fig 3.9 Isometric view of drum seeder cum fertilizer applicator

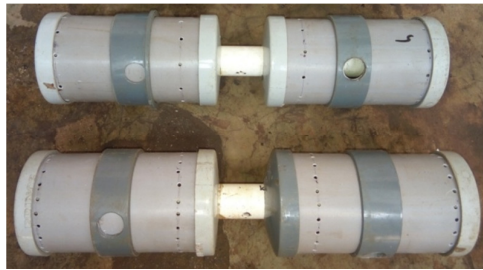
Table 3.3 Specifications of manually operated finger millet drum seed cum fertilizer applicator

S. N.	Particulars	Parameter	Values
1	Overall dimensions	Length, mm×Width, mm × Height, mm	1070 × 520 × 1100 with 165 mm wheel 1070 × 520 × 1070 with 230 mm wheel
		Empty Weight, kg	12.63 kg with 165 mm wheel, 13.73 kg with 230 mm wheel
2	Ground wheel	No. of wheels	4
		Materials and type of wheels	MS and Lugged wheel
		Effective diameter, mm	165, 230
		Lug height, mm	12.5
3	Metering mechanism	Seed metering drum (material PVC)	Drum with single line of 3 mm diameter orifices
		Fertilizer metering drum (material PVC)	Drum with three lines of 3 mm diameter orifices
		Number of orifices on the drum	12, 24
		Number of drums for seed	2
		Number of drums for fertilizer	2
		Size of drum	75 mm Diameter and 140 mm length
4	Drum capacity	Seed drum capacity, kg	0.360
		Fertilizer drum capacity, kg	0.480
5	Furrow openers and covering device	No. of furrow openers	4
		Furrow spacing, mm	100
		Width of furrow opener, mm	52
		Seed covering device	Scraper plate type
6	Theoretical field capacity, ha/h	At forward speed 1, 1.5 and 2 km/h	0.04, 0.06, 0.08
7	Labour required, person		1
8	Cost		Rs 2000
9	Special feature		Drums can be changed easily according to the seed spacing, wheels can also be changed, adjustable handle height.

3.2.9 Development of finger millet drum seeder cum fertilizer applicator for nursery raising

3.2.9.1 Development of seed and fertilizer drums

The seeder should be lightweight to pull easily by an operator. Hence, two drums of 400 g capacity each *i.e.* total capacity of the seed drill as 800 g of seeds and 800 g of fertilizer was considered. The volume of drum obtained is sufficient to seeding 0.095 ha area for nursery raising which is sufficient for transplanting on 0.95 ha *i.e.* one ha area. According to Eqn 3.3, the required volume of the seed is 607.73 cm³. The 75 mm diameter PVC pipe of 140 mm length was used for seed drum to accommodate desired volume. For seed and fertilizer metering, a pair of drums was mounted on the UPVC pipe of 22 mm ID and 27 mm OD by drilling holes of 27 mm on both end caps of the drum. These drum assemblies were fixed on drum seeder axles of GI pipe of 21 mm diameter (Fig. 3.10).



a. Seed metering drums



b. Fertilizer metering drums

Fig 3.10 Seed and fertilizer metering drums fitted on PVC pipe

3.2.9.2 Main frame of the drum seeder cum fertilizer applicator with furrow openers and soil covering device

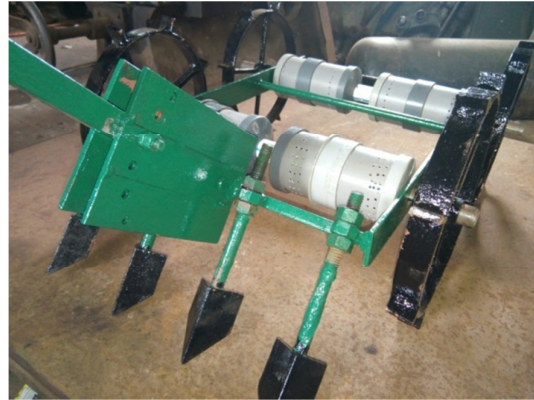
As per Fig. 3.8 and Fig. 3.9, the main frame was fabricated (Fig. 3.11.a) from MS flat, MS bars to accommodate furrow openers (Fig. 3.11.b), handle, seed and fertilizer drums mounted on the axles of the ground wheels (Fig. 3.11.c) and soil covering device (Fig. 3.11.d).



a. Main frame



b. Furrow openers



c. Seed and fertilizer drums mounted on the axles of the ground wheels



d. Soil covering device of the developed seed drill

Fig 3.11 Main frame of developed seed cum fertilizer drill with mountings

3.2.9.3 Ground wheel

The ground wheels of two different base diameters *i.e.* 230 mm and 165 mm were fabricated with MS flat 25×5 mm and MS square bar, (Fig. 3.12) to alter seed rate in combination with orifice spacing on the drums.

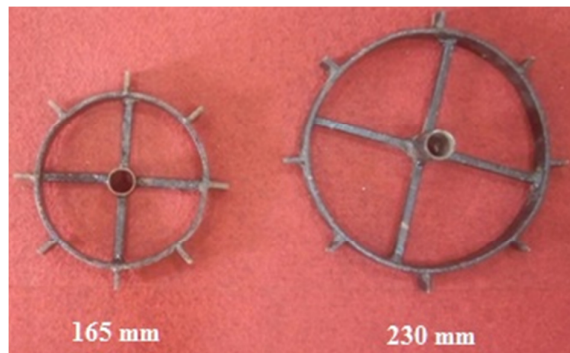


Fig 3.12 Ground wheels of the drum seeder cum fertilizer applicator

3.2.9.4 Handle

The handle was fabricated with a 20 mm square GI pipe of 915 mm total length including grip. The arrangement was provided for handle to change its angular position in vertical plane to adjust its height according to operators' need (Fig. 3.12).

The developed drum seeder cum fertilizer applicator is shown in Fig. 3.14.



Fig 3.13 Arrangement for changing the angle of handle in vertical plane



Fig 3.14 Developed manually operated finger millet drum seeder cum fertilizer applicator for nursery raising

3.2.10 Evaluation of manually operated finger millet drum seeder cum fertilizer applicator

3.2.10.1 Laboratory tests of the manually operated finger millet drum seeder cum fertilizer applicator

The developed drum seeder was evaluated in laboratory in jacked condition to determine the effect of number of orifices on drum, operating speeds and different diameter wheels on seed rate. It was also tested on sticky plate to determine number of seeds/m and uniformity coefficient. The independent and the dependent parameters of the tests are mentioned below.

a. Independent variables:

- i. No. of orifices on drum: 12 (H_1) and 24 (H_2)
- ii. Diameter of ground wheel, mm: 165 (D_1) and 230 (D_2)
- iii. Speed of operation, km/h: 1 (S_1), 1.5 (S_2) and 2 (S_3)

b. Dependent parameter: Seed rate

The seed rate was determined in jacked condition of drum seeder. The number of rotations to be given to the ground wheel and hence drums as per the forward speed and ground wheel diameter was determined with the Eqn 3.12. The seed drums were filled to the 3/4th of its capacity once only at the beginning of each test. The drums were rotated manually for 10 min at required number of rotations according to the forward speed and ground wheel diameter. The seeds dropped were collected and weighed for each test at 2, 6 and 9th min of run. The mean of these three readings was considered for determination of seed rate (kg/ha) by Eqn 3.13.

$$\text{Rotational speed of ground wheel, rev/min} = \frac{\text{Operating speed of drill (m/min)}}{\pi \times \text{Wheel diameter (m)}} \quad \dots(\text{Eqn 3.12})$$

Seed rate, kg/ha =

$$\frac{\text{Seed collected, g} \times 10000}{\pi \times \text{Ground wheel dia.} \times \text{RPM of ground wheel} \times \text{Width of seed drill}} \quad \dots(\text{Eqn 3.13})$$

3.2.10.2 Laboratory tests of manually operated finger millet drum seeder cum fertilizer applicator on sticky plate

The drum seeder was operated over aluminum plate of 500 mm × 3000 mm size at three speeds *i.e.* 1, 1.5, 2 km/h using 165 and 230 mm diameter wheels. Grease was applied on the plate to make it sticky. The drum seeder was operated about 4 m before the sticky plate so that average set speed could be attained when the drum seeder pass over the sticky plate (Fig. 3.15). A line perpendicular to the direction of travel was marked at 4 m distance before (*i.e.* starting point) and at 3 m after the sticky plate (*i.e.* end point) (Fig. 3.16). Total length of travel for each run was 10 m. Time required to travel 10 m distance at a particular speed was determined and accordingly it was run between starting point and the end. Test was repeated for three times for each speed and wheel diameter. Number of seeds/m and seed spacing was measured to determine seed distribution efficiency and seed uniformity coefficient.

i. Seed distribution efficiency

The sticky belt test was used to determine the seed distribution efficiency using the following formula (Eqn 3.14) (Ghosal and Sarkar, 2013).

$$S_e = \left[1 - \frac{Y}{d} \right] \times 100 \quad \dots(\text{Eqn 3.14})$$

where,

S_e = Seed distribution, %;

Y = average numerical deviation of number of seeds/m length of row from average number seeds/m run;

d = average number of seeds/m length of row.

ii. Seed uniformity coefficient

The spacing between two consecutive seeds was recorded for each run for a length of 1 m run in each row on the sticky plate (Fig. 3.17). The average value was found out and the coefficient of uniformity was determined by following formula (Bandhiya *et al.*, 2016).

$$\text{Coefficient of uniformity, \%} = \left(1 - \frac{\sum |X - \bar{X}|}{N \bar{X}} \right) \times 100 \quad \dots(\text{Eqn.3.15})$$

where,

X = Spacing between two consecutive seeds, mm;

\bar{X} = Theoretical spacing, mm; and

N = No. of seeds.



Fig 3.15 Setup for sticky plate test in the field



a. Starting point of the sowing



b. End point of the sowing

Fig 3.16 Sticky plate test for evaluation of drum seeder

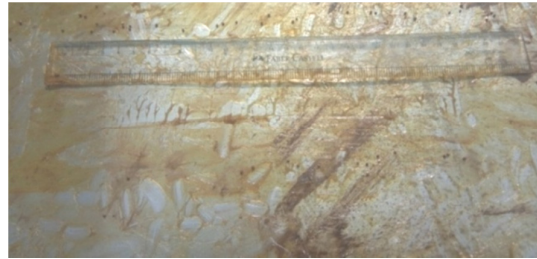


Fig 3.17 Seed distribution pattern obtained on the sticky plate

3.2.10.3 Field tests of the manually operated finger millet drum seeder cum fertilizer applicator

The numbers of seedlings required if two seedlings are transplanted per hill are determined for plant spacing of 150 mm × 150 mm, 150 mm × 200 mm or 200 × 200 mm. The seedlings are raised in 1/10th of the hectare area. Hence, the developed drum seeder was operated in field at different combinations of number of orifice (12 and 24), wheel diameter (165 and 230 mm) and operating speed (1, 1.5 and 2 km/h). The combination that could give the desired uniform size seedlings could be selected for raising of seedling for mechanical transplanting system.

The sowing operation was done on field at Department of Agronomy, Dr BSKKV, Dapoli. The seedbed of the experimental site was prepared twice by rotatilling soil to get the fine tilth (Fig. 3.18). The field was divided in 6 subplots, each of 3.75 × 7 m size and these were arranged in the 3 × 2 design. The finger millet sowing was done with developed drum seeder (Fig. 3.19).

a. Depth of seed placement

The depth of seed placement was observed at the time of sowing. The soil-covering device was kept in lifted condition to avoid covering of soil over the seed placed in row so that depth of seed placement could be measured.

b. No. of plants/m²

The numbers of plants per square meter were recorded on 15th day after sowing for all the operational combinations (Fig. 3.20). The observations were compared with the required number of seedlings for transplanting at 20 × 15 plant spacing in the main field. The operational combination that could give the number of seedlings close to the required one was considered optimum.

3.2.10.4 Cost of operation

The operating cost of newly developed drum seeder was determined using IS-9164-1979 test code. The cost analysis was done based on fixed cost, variable cost and operating cost for drum seeder.



Fig 3.18 Field preparation for nursery raising of finger millet



Fig 3.19 Sowing of finger millet seeds for nursery raising

3.2.11 Standardization of nursery raising method suitable for mechanical transplanting of finger millet

The seedlings required for any type of mechanical transplanter must be uniform in size to suite its specific seedling metering and planting mechanism. The automatic transplanters are designed to pick up specific size of the seedling as per the

requirement with its picking mechanism whereas in case of gravity fed transplanters, plug or paper pot seedlings are mostly preferred as weight of the seedlings have significant role on its placement in the soil (Sivakumar and Durairaj, 2014, Pandirwar *et al.*, 2015, Javidan and Mohammadzamani, 2019, Ganapathi and Kumar, 2015, Garg and Dixit, 2002). The bare root seedlings may have problems in placing it in soil if its weight is not sufficient to allow its free flow through the seedling metering mechanism (Javidan and Mohammadzamani, 2019). The bare root finger millet seedlings are transplanted in manual finger millet transplanting. Hence, it was planned to use the bare root seedlings for the gravity fed transplanting system to be developed.

The assumptions made for finger millet seedlings for the gravity fed transplanter to be developed were i) the seedling should meet the agronomical requirement of the crop cultivation, ii) seedling should be bare root type, iii) it should have sufficient weight to allow it to flow freely through the seedling metering and planting mechanism, iv) it should have sufficient length so that it should remain upright when its roots are covered with soil, v) the feeding mechanism should not damage seedling, vi) single seedling should be fed, vii) seedlings stem should have sufficient width and thickness for easy pickup by operator and, viii) seedling stem should be stiff enough to stay erect in the seedling metering mechanism.

It was tested in the laboratory and in the field. The performance of the drum seeder was evaluated and compared with manual sowing method. Seeds were sown by both methods at five days interval so that the different physical parameters of seedlings could be measured on same day. The observations of physical parameters were recorded on 25 to 50 days after sowing (DAS). The numbers of seedlings damaged during uprooting in both the methods of sowing were determined.

a. Shoot length, root length and canopy spread

The root length, shoot length and canopy spread of the seedlings sown manually and by drum seeder were compared. The finger millet seedlings grow as a fan *i.e.* leaves spread laterally in a plane. Hence, the width of the seedling canopy spread was measured to determine the size of seedling cup.

b. Stem thickness and width

The seedling height (Fig. 3.21), stem thickness and width (Fig. 3.22) of seedlings of manually and drum seeder sown method were measured by standard procedure (Garg and Sharma, 1999) using scale and Vernier caliper (Least count 0.1 mm). The readings obtained were compared for the performance of the drum seeder.

c. Number of leaves and weight of seedlings

The seedling weight was taken just after uprooting it from the field. The seedlings were shaken before weighing it so that the maximum of its loose soil should be separated. A digital weighing balance (Least count 0.1 g) was used to measure the seedling weight (Fig. 3.23). The number of leaves were counted. The number of leaves and weight of the seedlings may indicate its health and growth.

The number of seedlings in 1 m length were measured, leaving initial and final 1 m length to avoid effect of operational error that might occurred at beginning and end of run. Effect of sowing method on physical parameters of finger millet seedlings was studied to standardize the sowing method for finger millet nursery raising. Growth of height and canopy spread of finger millet seedlings at different ages is shown in Fig. 3.24.



Fig 3.20 Nursery of finger millet at 15 DAS



Fig 3.21 Measurement of height of the seedling



a. Stem thickness

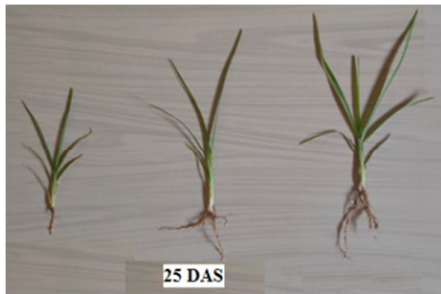


b. Stem width

Fig 3.22 Measurement of seedling stem thickness and width using Vernier caliper



Fig 3.23 Measurement of seedling weight



(a)



(b)



(c)



(d)



Fig 3.24 Growth of height and canopy spread of finger millet seedlings at different ages

3.3 Selection of seedling feed rate for developed finger millet transplanter

Generally, 18 to 30 days old finger millet seedlings are transplanted (Anonymous, 2015b, Anonymous, 2015c, Anonymous, 2016a, and Anonymous, 2016d) at plant spacing 150 mm × 150 mm, 200 mm × 150 mm, 200 mm × 200 mm and 250 mm × 250 mm. The fertilizer should be applied using 80:40 kg N and P₂O₅ at the time of transplanting for obtaining maximum productivity (Anonymous, 2019). In conventional practice of finger millet transplanting, plant population varies between 2,60,000 to 5,50,000 without maintaining standard plant spacing. Some farmers transplant single seedling per hill while some transplant 2 – 3 seedlings per hill. A minimum plant population of 3,00,000 seedlings per hectare maintained by the farmers can be obtained with plant spacing of 250 × 75 mm. It can facilitate interculturing operation. Kumar and Tripathi (2016), reported that plant population was found less by machine transplanting while the average plant height, number of branches per plant, plant mortality, yield/m², seedling missing, and leaf area index was found more by machine transplanting and also time saving, labour saving, less cost of operation were achieved in machine transplanting as compare to manual transplanting.

The forward speeds of semiautomatic seedling transplanter ranges between 0.15 (Nandede *et al.*, 2017) to 2.4 km/h (Chilur *et al.*, 2018) in dry field condition according to seedling spacing required. The forward speeds of 0.48 and 0.67 km/h were selected to enable manual feeding of seedlings for obtaining recommended plant spacing of 100 mm (Anonymous, 2018). Manual seedling feed rate for semiautomatic transplanter governs seedling spacing and limits its forward speed (Khadatkar *et al.*, 2018). The reported planting rate in the semi-automatic vegetable transplanters for bare-root seedlings varied from 35 to 45 seedlings/min (DARE, 2006, pp. 109-128;

Satpathy and Garg, 2008; Manes *et al.*, 2010). Dihingia *et al.*, (2017) concluded that to overcome missed plantings, either forward speed of the machine has to be reduced or within-row plant spacing has to be increased. To reduce missed plantings and tendency of seedlings to tilt forward while planting, forward speed has been restricted to 0.9 km/h.

In present study, 0.5 km/h forward speed was considered, as transplanter has to operate in wet soil condition and operators need to feed seedlings in seedling metering mechanism while walking. A variation of 40 % was considered to decide the upper and lower limits of forward speed *i.e.* 0.7 and 0.3 km/h respectively. Seedling feed rate of 40 seedlings/min was another limiting factor. Hence, a maximum seedling feed rate assumed 38 seedlings/min while other two seedling feed rates were decided with 20 % reduction *i.e.* 31 and 24 seedlings/min. Table 3.4 shows estimated plant spacing and population with selected operating parameters of transplanter.

Table 3.4 Estimated plant spacing and plant population according to the forward speed and seedling feed rate finalized at 250 mm row spacing

Sr. No.	Forward speed, km/h	Seedling feed rate, seedlings/min	Plant to plant distance, mm	Plant population, lakh/ha
1	0.3	24	208.3	1.67
		31	161.2	2.50
		38	131.5	3.07
2	0.5	24	347.2	1.15
		31	268.8	1.48
		38	219.2	1.82
3	0.7	24	486.1	0.82
		31	376.3	1.06
		38	303.7	1.31

3.4 Design of a two row mechanical transplanting system for finger millet seedlings

The fragmented and slopy lands that are situated on hilly regions have limitations of mechanization. Hence, in Konkan region, the most of cultivation operations are done manually using hand tools (Shahare, 2012). Finger millet transplanting is one of them that consume time and labour. In manual transplanting method, the plant spacing is not maintained properly that restricts the use of the mechanical intercultural machineries or tools. The labours have to work in bending posture during the manual transplanting that creates the physical health problems in the workers. The labour scarcity during peak season, time available for transplanting, quantity of labour required and drudgery in the transplanting operation demands the mechanical transplanting system. The operating parameters of the transplanter that

affect its performance are its forward speed (Srivastava *et al.*, 2006), furrow opening and closer mechanism and seedling metering mechanism speed (Dihingia *et al.*, 2016, Kumar and Raheman, 2011). In addition, the morphological characters of the seedling, agronomical requirements and available field condition *i.e.* moisture content (Satpathy and Garg, 2008, Kumar and Raheman, 2011, Thorat *et al.*, 2017) and bulk density of soil and depth of seedling placement required and ergonomic parameters of the operator (Manes *et al.*, 2010) also affects the transplanter performance. Considering this, it was planned to design and develop a small semiautomatic walk behind type, self-propelled and gravity fed finger millet transplanter using small portable engine. It was fabricated in the workshop of Department of Farm Machinery and Power (FMP), CAET, Dr BSKKV, Dapoli. The design considerations, working principle, procedure for development, power transmission system and various functional components of newly developed finger millet transplanter are as follows.

3.4.1 Design considerations

Small and sloped land holdings under finger millet cultivation, labour issues for manual transplanting, benefits of inline transplanting and physical parameters of seedlings reached to theoretical considerations that were involved for design and development of mechanical transplanting system for finger millet are as below. Transplanter should be

- i. semiautomatic, self-propelled and gravity fed type.
- ii. run by small capacity engine.
- iii. compact and light in weight to work in small fields and easy for shifting from one field to another.
- iv. suitable for traditional nursery seedlings.
- v. workable in wet field with minimum slippage.
- vi. have simple seedling metering mechanism for desired spacing.
- vii. capable of opening furrow to a desired depth and properly covering seedling roots.
- viii. easy for construction and operation at reasonable cost.

3.4.2 Design parameters

The developed transplanting system should meet requirements of finger millet transplanting. Terms, parameters, formulae associated with transplanter design are described in following sections.

3.4.3 Size of machine

The size of field to be transplanted, available field days, field capacity, field efficiency, annual usages, capital cost and weight of the machine are the parameters that decide the size of the machine. The larger machine with higher field capacities may satisfy the need of timeliness operation on large fields but if the annual usages are less, then its economics restricts its selection. The small size machines may require longer time for the operation but it can satisfactorily and economically be operated in small fields. The economic viability of transplanter is mainly depending to number of plants that can be transplanted by machine per unit of time, compared to efficiency achieved by hand transplanting (Gutierrez *et al.*, 2009).

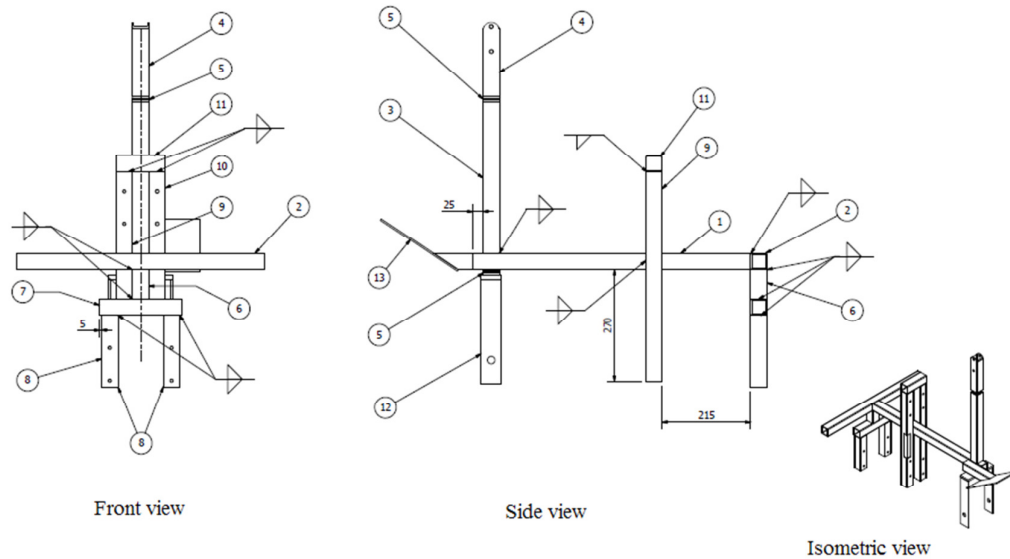
Considering above limitations and requirement, it was planned to design a two row finger millet transplanter with carousel type seedling metering mechanism. The size of the machine was planned to be small enough to be operated with small portable engine and to match the small land holdings with easy maneuverability.

3.4.4 Forward speed of transplanting system

The seedling-feeding rate is the limiting factor for forward speed of manually fed semiautomatic transplanters (Srivastava *et al.*, 2006, Ganapathi and Kumar, 2015). The field speed of semiautomatic transplanter was 0.6 km/h (Guarella and Perellano, 1990 in Gutiérrez *et al.*, 2009) and it ranged between 0.9 to 1.4 km/h (Kumar and Raheman, 2011). Higher missed plantings with an increase in forward speed of semi-automatic vegetable transplanter were observed (Dihingia *et al.*, 2016, Kumar and Raheman, 2011). The planting rates between 35 to 45 seedlings/min are recommended to keep missed plantings within acceptable limits (Kumar and Raheman, 2008, Satpathy and Garg, 2008, Singh, 2008, Dihingia *et al.*, 2016, Manes *et al.*, 2010, Sahoo *et al.*, 2018). 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). Transplanter has to be operated at a speed that allows careful placement and attention to problems that develop during operation. Operators should not be so involved in placing plants in machine that they cannot watch for problems that develop (Marr, 1994). As proposed transplanter need to be operated on slopy terrain and wet field condition during rainy season, with walk behind and manual metering of seedlings, operational speeds were assumed lower *i.e.* 0.3, 0.50 and 0.70 km/h compared to speed of existing semiautomatic transplanters (0.9 to 1.4 km/h).

3.4.5 Main frame

The square pipe of 40 mm size and 3 mm thickness was used for the fabrication of the mainframe as shown in Fig. 3.25.



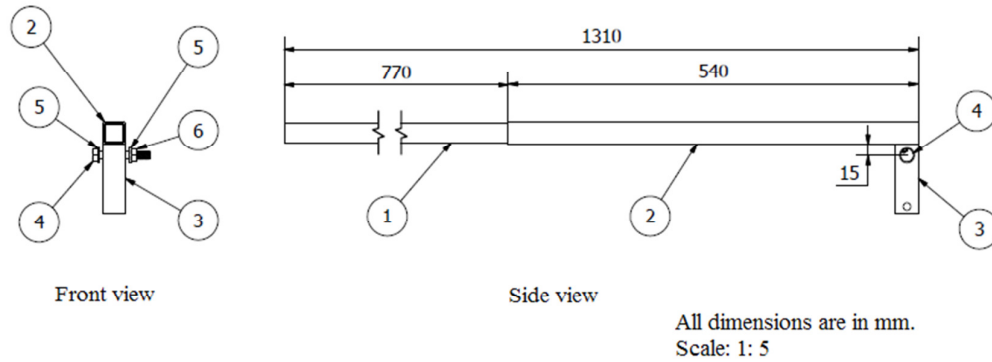
1. Central square pipe, 2. Rear square pipe for wheel mounting, 3. Head tube, 4. Head set, 5. Bearing, 6. Rear axle bracket support, 7. Rear axle bracket, 8. Place for mounting rear wheel axle bearing, 9. & 10. Sprocket mounting, 11. Square pipe for connecting sprocket mounting, 12. Steering wheel fork, 13. Engine mounting plate

Fig 3.25 Main frame of the developed finger millet transplanter

The main frame of the transplanting system is designed with single steering wheel at front and provision for mounting two driving wheels at the rear. It is having the necessary provisions to mount engine, seedling metering mechanism, seedling tray and power transmission system from engine to two rear wheels, seedling and fertilizer metering mechanism with compact and sturdy structure.

3.4.6 Handle

The handle of the transplanter is made up of MS square pipe 25 mm size having length 1310 mm (Fig. 3.26). The arrangement of the handle is made such that it can be used from either front or rear side. This facilitates steering the machine from rear side during operation in field and for pulling the machine from front side on or off the field if needed.



1. Square pipe, 2. & 3. Square pipe, 4. Bolt, 5. Flat washer, 6. Nut.
Fig 3.26 Handle of the developed finger millet transplanter

3.4.7 Furrow opener

The furrow opener was designed according to the theory suggested by Kostritsyn, 1956. In pure cutting of the soil, major failures other than separation were not considered. Kostritsyn considered two basic shapes of cutters (Fig. 3.27). The leading angled edge of the cutters designated as the wedge of the cutter while the parallel edges called the sides. The forces acting on a cutter could be separated into several components (Fig. 3.28) and these components must be in equilibrium so that

$$P = P_1 + P_2 + P_3 \quad \dots(\text{Eqn 3.16})$$

Where,

P = total force (draft) on the cutter, kgf

P_1 = component of resistance resulting from normal force on cutter wedge, kgf

P_2 = component of resistance resulting from tangential force on cutter wedge, kgf

P_3 = component of resistance resulting from tangential force on side of cutter, kgf

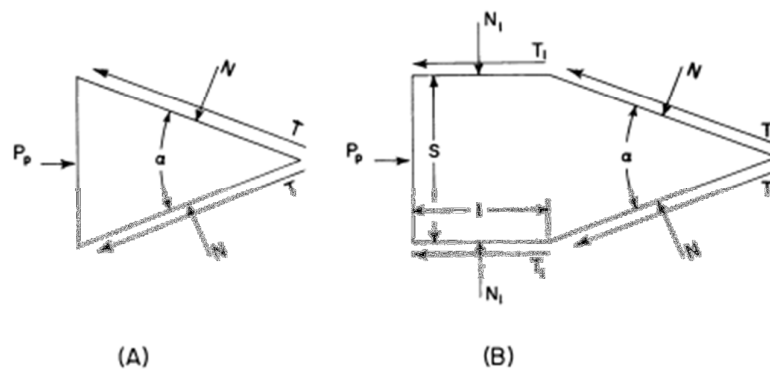


Fig 3.27 Shape and acting forces on two soil cutters (Kostritsyn, 1956)

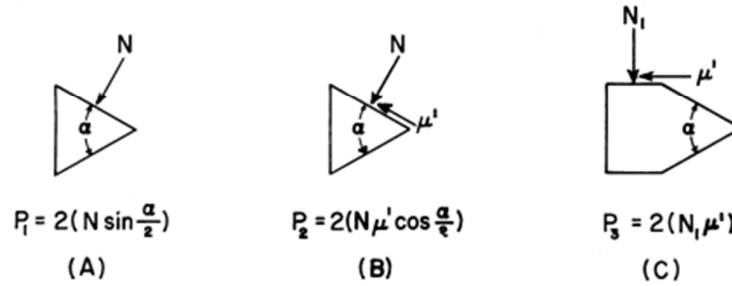


Fig 3.28 Components of forces on a soil cutter (Kostritsyn, 1956)

Figure 3.28 shows the resistance forces resolved into horizontal components so that equation 3.16 can be written

$$P = 2N \sin \frac{\alpha}{2} + 2N\mu' \cos \frac{\alpha}{2} + 2N_1\mu' \quad \dots(\text{Eqn 3.17})$$

Where,

α = wedge angle of the cutter, deg

μ' = coefficient of sliding friction,

N = normal force on the wedge of cutter, kgf

N_1 = normal force on the side of cutter, kgf

The cutting force for a particular cutter can be calculated if magnitude of the normal forces is specified. The normal forces resulted from the resistance of the soil to deformation, the measures of the resistance can be defined as

$$N = K_1 F_1 \quad \dots(\text{Eqn 3.18})$$

where

K_1 = specific resistance to deformation, kgf

F_1 = area of the wedge of cutter, cm^2

and

$$N_1 = K_2 F_2 \quad \dots(\text{Eqn 3.19})$$

where,

K_2 = specific pressure of soil, kg/cm^2

F_2 = area of the side of cutter, cm^2

With equations 3.18 and 3.19, equation 3.17 can be rewritten to give

$$P = 2K_1 F_1 \sin \frac{\alpha}{2} + 2K_1 F_1 \mu' \cos \frac{\alpha}{2} + 2K_2 F_2 \mu' \quad \dots (\text{Eqn 3.20})$$

Equation 3.20 provides a means for experimentally studying cutting.

The maximum deformation for a given situation can be calculated in the direction if soil movement is known. The maximum deformation occurs when point α

reaches the widest part of the wedge section of the cutter. The maximum deformation is given by the equation

$$L_{\max} = \frac{S}{2\cos(\alpha/2 + \delta)} \quad \dots(\text{Eqn 3.21})$$

where

S = width of cutter, mm

δ = angle of soil-metal friction, deg

α = wedge angle of cutter, deg

L_{\max} = maximum deformation, mm

The soil deformation along the wedge will vary from zero at the tip to the maximum shown in equation 3.21, so that average soil deformation L_0 can be calculated by the relation

$$L_0 = \frac{0 + L_{\max}}{2} = \frac{S}{4\cos(\alpha/2 + \delta)} \quad \dots(\text{Eqn 3.22})$$

$$K_1 = K_{el} + K_{pl}, \quad \dots(\text{Eqn 3.23})$$

Where

K_{el} = stress from elastic deformation, kg/cm^2

K_{pl} = stress from plastic deformation, kg/cm^2 . He further considered that K_2 represented only the elastic deformation.

These definitions imply that the soil deforms plastically and elastically as the wedge of the cutter advances. On the sides of the wedge, however, the soil has "adjusted itself" by plastic now so that only the elastic rebound of the soil causes the stress. The magnitude of K_2 in the K_1 direction gives

$$K_{el} = K_s \frac{1}{\cos \alpha/2} \quad \dots(\text{Eqn 3.24})$$

$$K_{pl} = \frac{1}{L_0} \quad \dots(\text{Eqn 3.25})$$

Associated with this minimum deformation is the constant K_0 given by

$$K_0 = \frac{1}{L_{00}} \quad \dots(\text{Eqn 3.26})$$

where

L_{00} = diameter of soil particles, mm

K_0 = maximum stress to cause deformation.

$$K_{el} = K_0 - K_{pl} \quad \dots(\text{Eqn 3.27})$$

The root spread of the finger millet seedling is about 30 to 40 mm. Hence, to accommodate the seedling root, a furrow of 70 mm width is required. It was assumed to have maximum deformation of 70 mm with the help of angle of soil-metal friction as $40^{\circ}30'$ and wedge angle as 35° and therefore, from equation 3.22,

$$70 = \frac{S}{2\cos(35/2 + 40^{\circ}30')}$$

$$S = 74.6 \cong 75 \text{ mm.}$$

Hence, the width of the furrow opener was finalized as 75 mm.

Now,

$$L_0 = \frac{0 + L_{\max}}{2} = \frac{S}{4\cos(\alpha/2 + \delta)} = \frac{75}{4\cos(35/2 + 40^{\circ}30')} = 35.18$$

$$K_{pl} = K_1 - K_{el} \quad \dots(\text{Eqn 3.28})$$

Let particle size diameter = 2 mm

Therefore,

$$K_0 = \frac{1}{L_{00}} = \frac{1}{2} = 0.5$$

$$K_{pl} = \frac{1}{L_0} = \frac{1}{35.18} = 0.028$$

$$K_{el} = K_0 - K_{pl} = 0.5 - 0.028 = 0.528$$

$$K_{el} = K_2 \frac{1}{\cos \alpha / 2}$$

$$0.528 = K_2 \frac{1}{\cos 35 / 2}$$

$$K_2 = 0.50$$

$$K_1 = K_{el} + K_{pl} = 0.528 + 0.028 = 0.556$$

$$P = 2K_1 F_1 \sin \frac{\alpha}{2} + 2K_1 F_1 \mu' \cos \frac{\alpha}{2} + 2K_2 F_2 \mu'$$

$$F_1 = \text{area of wedge cutter} = 150 \text{ sq. cm}$$

$$F_2 = \text{area of side cutter} = 0 \text{ sq. cm}$$

$$\mu' = \text{Soil metal friction in sandy loam after rain} = 0.31 \text{ (Gill and Berg, 1968)}$$

$$P = 2 \times 0.556 \times 150 \times \sin \frac{35}{2} + 2 \times 0.556 \times 150 \times 0.31 \times \cos \frac{35}{2} + 0$$

$$= 50.15 + 49.37 + 0 = 99.52 \text{ kgf} = 99.52 \times 9.8 = 975.3 \text{ N (as 1 kgf} = 9.8 \text{ N)}$$

Therefore,

$$\text{Power, } W = \text{Draft (N)} \times \text{Speed (m/s)}$$

Assume maximum speed of 0.7 km/h

Therefore,

$$\text{Power, } W = 975.3 \times 0.7 \times 1000 / 3600 = 189.64 \text{ W} = 0.189 \text{ kW} = 0.2.$$

The power required for opening two furrows $0.4 \text{ kW} = A$

A furrow opener was fabricated with MS plate, keeping wedge angle 35° , such that the seedlings can be conveyed without any injury to the root system (Fig 3.29).

Power required for four soil covering devices having 105 mm long bars inclined at 30° with line of travel and depth of operation as 50 mm can be calculated as

$$\text{Width of operation of each bar} = 105 \times \tan 30^\circ = 60.62 \text{ mm}$$

$$\text{Depth of operation} = 50 \text{ mm}$$

$$\text{Number of bars} = 4$$

$$\text{Assumed unit soil resistance} = 0.9 \text{ kg/cm}^2$$

$$4 \times 6.06 \times 5 \times 0.9 = 109.08 \text{ kg} = 9.8 \times 109.08 = 1068.98 \text{ N (as } 1 \text{ kgf} = 9.8 \text{ N)}$$

Therefore,

$$\text{Power, } W = 1068.98 \times 0.7 \times 1000 / 3600 = 207.85 \text{ W} = 0.207 \text{ kW}$$

The power required for soil covering = $0.207 \text{ kW} = B$

Total power for furrow opening and soil covering {A+B}

$$0.4 + 0.207 = 0.607 \approx 0.6 \text{ kW (i.e. } 0.8 \text{ hp)} = C$$

The power required for the operation of the seedling metering mechanism and fertilizer metering mechanism was assumed 10 % of the power required for the furrow opening and closing.

$$0.6 \times 0.1 = 0.06 \text{ kW}$$

3.4.8 Power required for transmission

The total power required for the transplanter is the sum of the power required for opening furrows, operation of the seedling metering mechanism and fertilizer metering mechanism and forward motion.

The power required to develop force to overcome rolling resistance and to pull the machine while opening furrows at a desired speed of operation is the power required for forward motion of transplanter. Singh *et al.*, 1976 considered the tractive efficiency as 46 % when the performance tests with rigid power tiller wheels on soft

soil with 10 to 11 % moisture content were conducted. As in the present study, the traction wheels to be operated in the soil with 18 to 20 % moisture content, the tractive efficiency was assumed to be 40 %. The factor of safety was assumed as 1.5 for calculating actual power required for the forward motion (Patil, 2018). The transmission efficiency was considered as 90 % for chain and sprocket drives used.

Power required at axle for forward motion, furrow opening and closing

$$= \frac{0.6}{0.40 \times 0.9} = 1.7 \text{ kW} \quad \dots(\text{E})$$

The total power required for the operation of the developed transplanting system is calculated by summing (D) and (E) values estimated above.

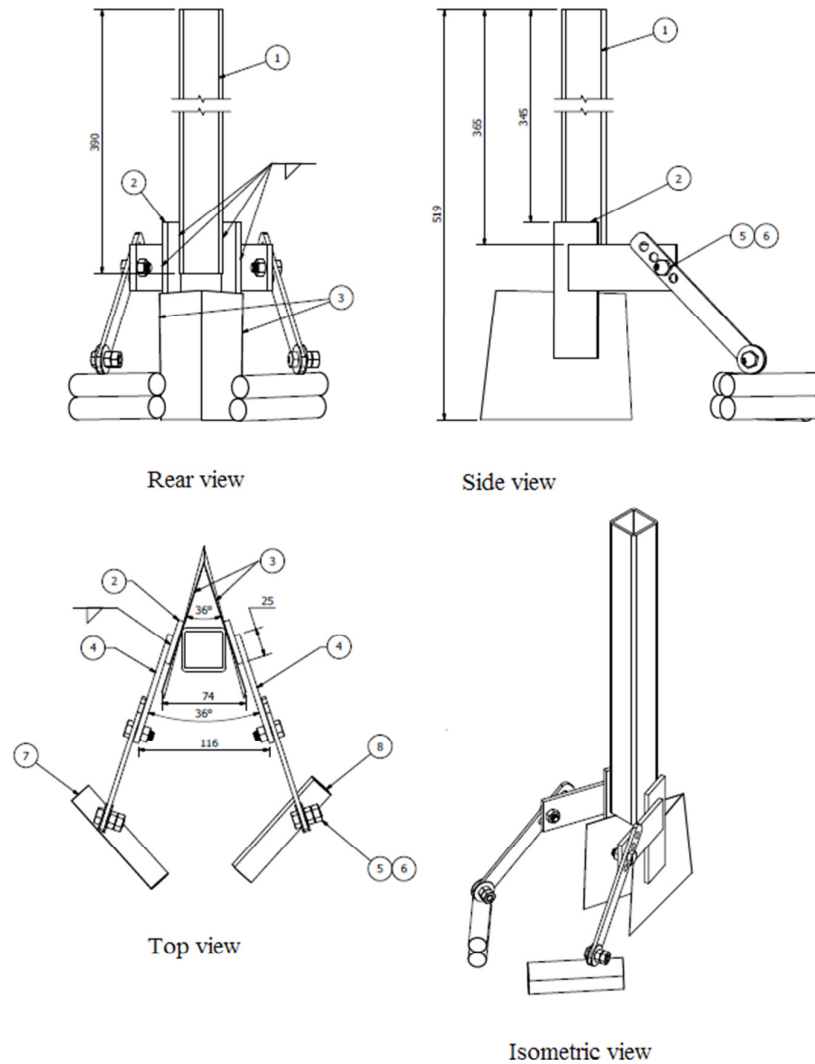
$$0.06 + 1.7 = 1.76 \text{ kW engine out put}$$

Considering the factor of safety, the total power required is estimated as

$$1.5 \times 1.76 = 2.64 \text{ kW} = 3.5 \text{ hp} \quad \dots(\text{F})$$

3.4.9 Soil covering device

Design of soil covering or closure unit for wet soil requires different considerations than that for dry soil. As the soil of opened furrow is wet, the stationary inclined plates for the covering this soil over the roots of the seedling may act as barrier for the forward motion of the transplanter as wet soil may get accumulate at these plates due to its lump formation. Press wheels could not be used due to space limitation at the furrow opener. Hence, it was planned to develop a soil-covering device with flexible hinge joint at furrow opener such that each of the soil-covering unit on either side of the furrow opener can swing in vertical plane around hinge point and can cover soil around the seedling roots due to its weight (Fig. 3.29). The movement of the soil covering device in vertical plane facilitates it to pass over wet soil if got accumulated underneath it. It was made up of MS rods welded to the swinging MS flats. The rods were placed horizontally at 25° angle with line of travel of the machine such that rods placed on the both the sides of furrow opener could have wider opening at front and narrower closing rear end. This facilitated the gathering of the loose soil over the seedling roots.



All dimensions are in mm.
Scale: 1:2

1. Shank / mounting pipe, 2. Plate for mounting furrow closure, 3. Cutting wedge, 4. Cutting plates, 5. Hinge point of soil covering unit, 6. Nut and bolt arrangement for soil covering unit mounting, 7. and 8. Soil covering rods.

Fig 3.29 Furrow opener and soil covering device of the developed finger millet transplanter

3.4.10 Prime movers for transplanting mechanism

Total power required for transplanting system was calculated to be 2.64 kW. To satisfy this power requirement, a single cylinder engine of 51.5 cc, rated power 2.64 kW (3.5 hp) and speed 3000 rev/min was selected as prime mover. The manipulation of power required, available through prime mover, was done through power transmission system of chain and sprocket where reduction in rotary speed obtained through engine was done. Power transmission system is explained further.

3.4.11 Transmission system of transplanter

An engine, mentioned above, was used for transplanter as prime mover. A worm and pinion type reduction gearbox was used to reduce obtained engine output speed by $1/9^{\text{th}}$. The gearbox output shaft speed was maintained at 200 rev/min using engine throttle *i.e.* engine speed was approximately at 1800 rev/min during the trials. As it was not possible to measure the engine speed, the rotary speed of gearbox output shaft was measured with digital tachometer. The combinations of the chain and sprocket were designed to get the desired rotary speeds at the driving wheels, seedling metering and fertilizer metering mechanism shafts. The rotary speeds obtained at these shafts were measured with tachometer. The flow of power transmitted from this gearbox to different shafts is as shown in Fig. 3.30 while Fig. 3.31 shows schematic diagram of power transmission system of the transplanter. The diameter of the ground wheels was designed based on the rotational speed obtained at the driving shaft to get the forward speeds of 0.3, 0.5 and 0.7 km/h. The chain drive was given through sprocket of the rear wheels (on rear axle) to the parallel metering mechanism shaft through different sprockets to obtain different rotary speeds of carousel to achieve the targeted seedling-feeding rate. This shaft was provided with bevel gears at its ends (Fig. 3.32). Two vertical shafts (Fig. 3.33) were engaged through bevel gears on the horizontal shaft such that the vertical shafts should be rotated around its axes for operating horizontally rotating seedling metering mechanism.

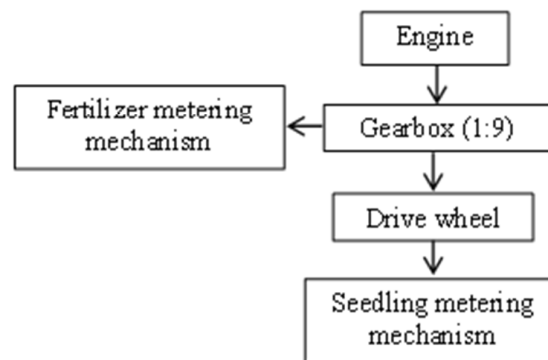


Fig 3.30 Power transmission in the developed finger millet transplanter

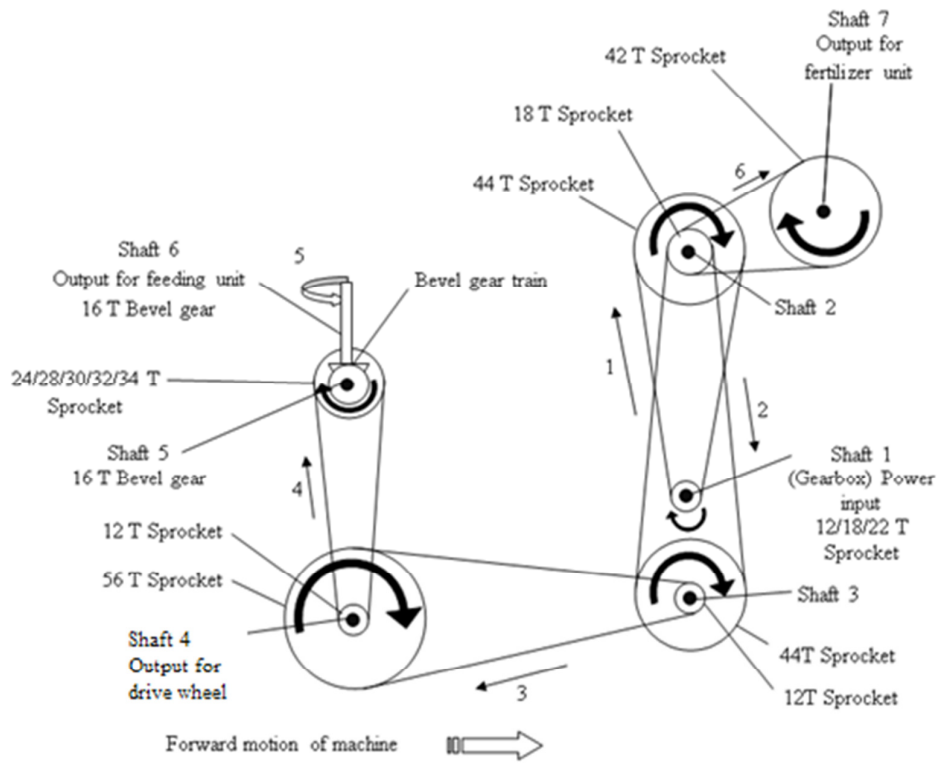
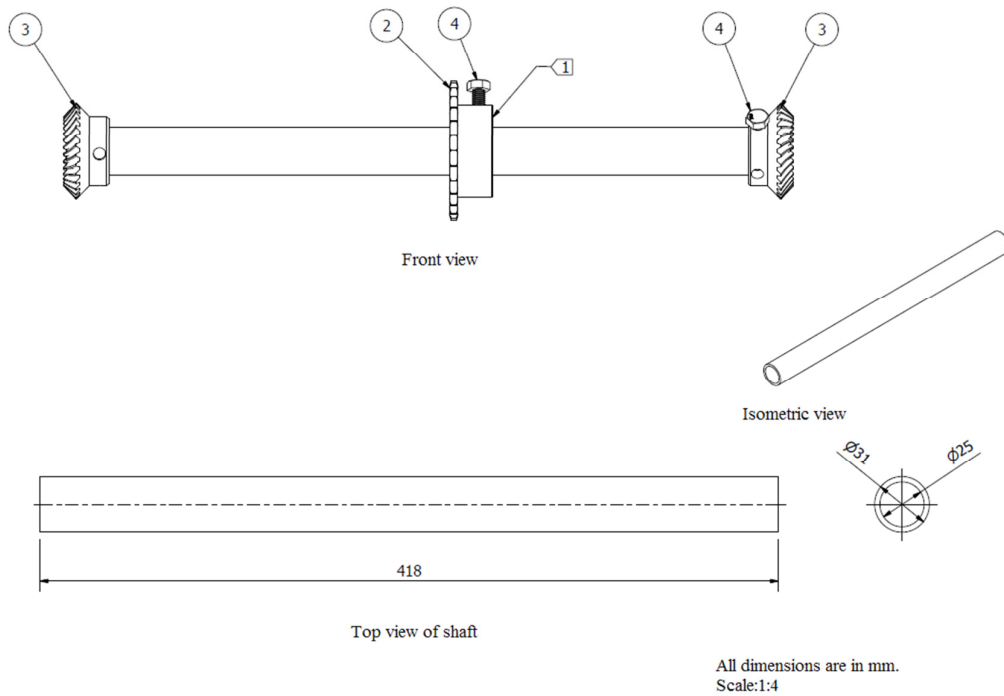
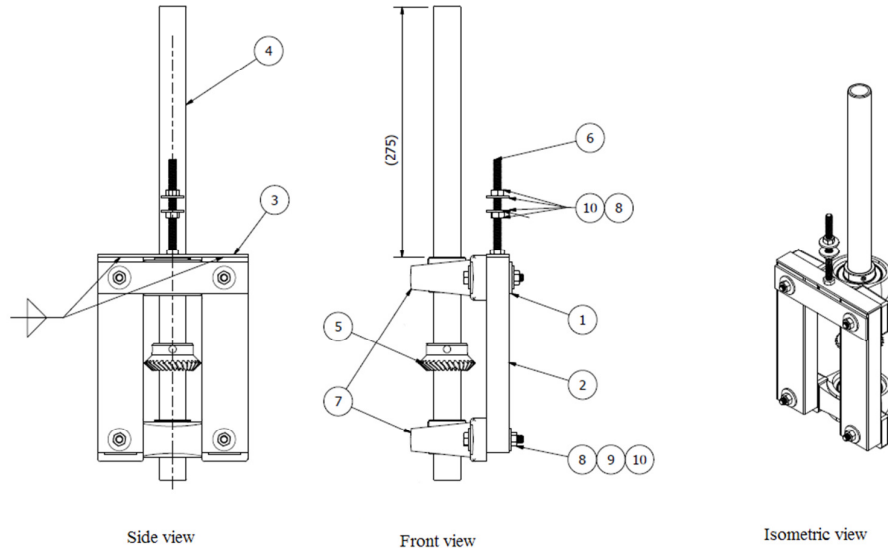


Fig 3.31 Schematic diagram of power transmission system of the transplanter



1. Drive shaft, 2. 28T sprocket, 3. 16T bevel gear, 4. Bolt

Fig 3.32 Horizontal shaft of seedling metering mechanism with bevel gears



All dimensions are in mm.
Scale: 1:3

1. Flat plate for fixing vertical shaft holder, 2. Shaft holder for mounting bearing, 3. Flat plate, 4. Vertical pipe for mounting carousel, 5. 16T bevel gear, 6. Bolt for holding wooden metering plate, 7. P206 bearings, 8., 9. and 10. Nut bolt and washer

Fig 3.33 Vertical shaft of seedling metering mechanism with bevel gears

$$\text{Power (kW)} = \text{Torque (N.m)} \times \text{Speed (rev/min)} / 9.5488 \quad \dots(\text{Eqn 3.29})$$

Therefore, torque at engine output shaft at this engine speed was calculated as

$$\begin{aligned} \text{Torque (N.m)} &= 9.5488 \times \text{Power (kW)} / \text{Speed (rev/min)} = 9.5488 \times 1.4 / 1800 \\ &= 0.00742 = T_1 \end{aligned}$$

By the relation $N_1 \times T_1 = N_2 \times T_2$ i.e. $\frac{N_1}{N_2} = \frac{T_2}{T_1}$, the torque at the driving

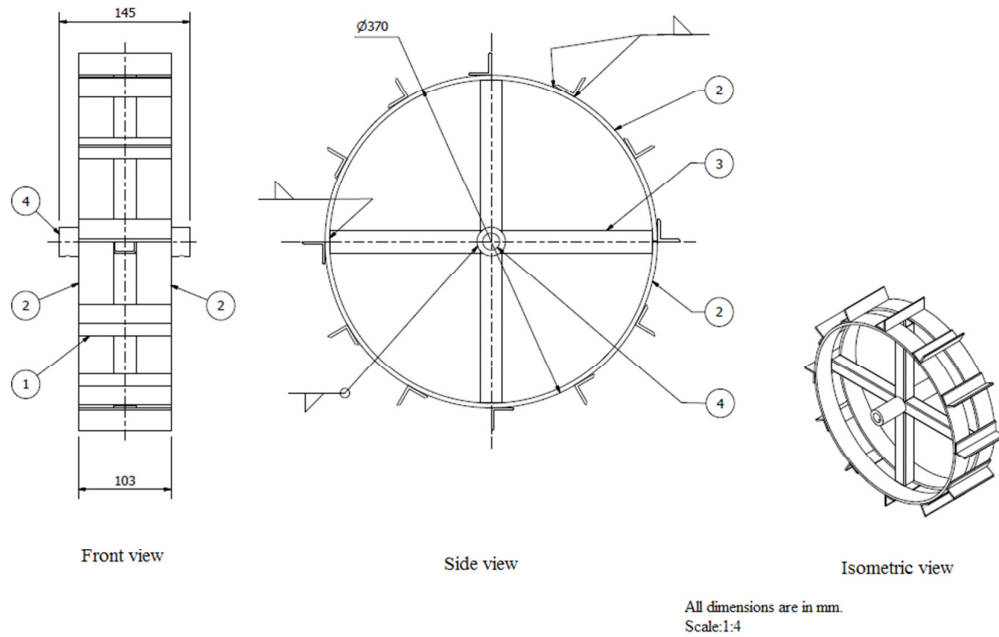
shaft and hence, the power was determined. Similarly, the speed available at the shafts for seedling metering mechanism and fertilizer metering mechanism was calculated. The operating and machine parameter used for evaluation are presented in Table 3.6.

3.4.12 Size of drive wheel

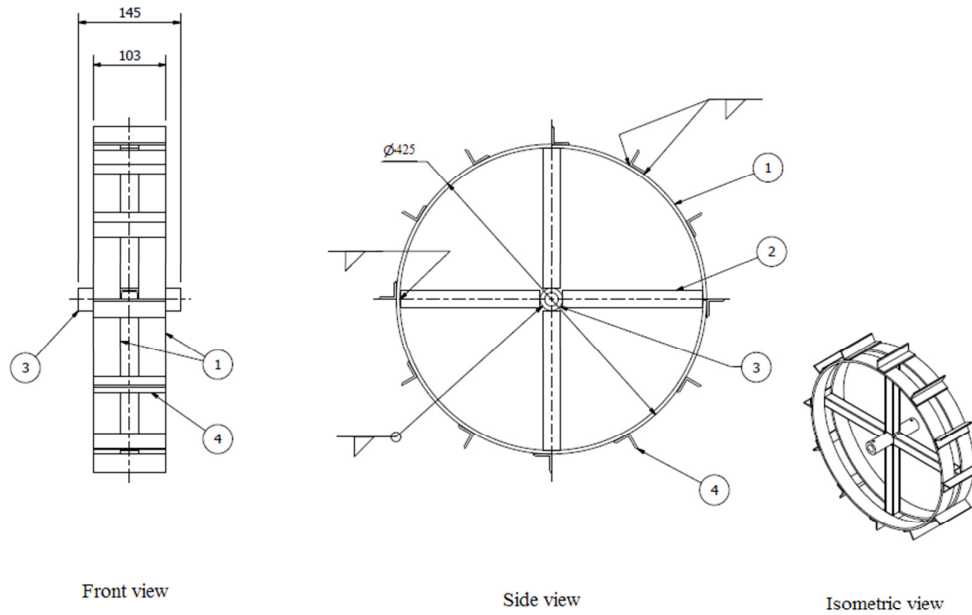
The drive wheel of transplanter working in wet soil must be able to produce sufficient traction when the transplanter has to open a furrow in field at predetermined speed and depth. It should have minimum slippage to avoid multiple transplanting. Drive wheel is a traction device that supports a vehicle by distributing the weight of the machine over large contact area, reduce soil compaction and prevent it from bogging down (Soemengat, 1962). The cage wheel exerted three times more pull in comparison with tyres in flooded soil conditions (Verma, 1984b). It was found that the maximum tractive efficiency and the maximum drawbar power of the wheels are

significantly influenced by the lug angle, lug pitch, wheel slip and soil type (Triratanasirichai *et al.*, 1990). A two row self-propelled paddy transplanter (Shahare and Bhat, 2011) and four-row self-propelled paddy transplanter (Gaikwad, 2013) at CAET, Dapoli provided ground wheel of 450 mm and 480 mm diameter, respectively. A three-row pull-type transplanter evaluated with 500 mm, 600 mm and 700 mm ground wheel diameter of which 500 mm diameter was optimized (Selvan *et al.*, 2014). It was observed that smaller diameter of cage wheel gave the maximum draft with minimum drawbar power due to sinking and sticking of soil over lug plates that caused lower tractive efficiency while wheel sinking reduces with increase in wheel diameter (Pradhan *et al.*, 2018 and Raheman and Snigdharani, 2019).

Hence, drive wheels of 370 mm and 425 mm diameter having 103 mm width were selected for transplanter considering overall height of transplanter and constraint of space on the transplanter (Fig. 3.34). The 370 mm diameter ground wheel was used to obtain 0.3 and 0.5 km/h while 425 mm diameter ground wheel was to obtain 0.7 km/h forward speed respectively using suitable combinations of sprockets.



a. Drive wheel with 370 mm diameter



All dimensions are in mm.
Scale: 1:4

b. Drive wheel with 425 mm diameter

1. Flat plate ring, 2. Square pipe, 3. Bush, 4. Angle

Fig 3.34 Drive wheels used for developed finger millet transplanter

3.4.13 Seedling metering mechanism

Revolving magazines or carousels are for putting the seedling manually in the feeding cups so that it could be taken up to the seedling feeding tubes under gravity to land it in the furrow opened by furrow openers.

a. Working principle of seedling metering mechanism

The working principle of the seedling metering mechanism is such that when the seedlings are placed in the seedling cups of carousel while it is rotating, the seedling get fall through the notch in the plate when the bottom of the cup exposed to the notch. A seedling conveying tube is mounted on transplanter just below this notch to carry seedling collected from seedling feed cup in vertical position to land in furrow. The revolving speed of carousel with respect to forward speed of machine determines plant spacing in row.

b. Determination of seedling feed rate

The experimental levels of seedling feed rate was decided considering the average plant spacing as 250×75 mm against 200×150 mm to have the plant population of 3,00,000 plants/ha. Considering 20 % variation of plant population on either side, the assumed plant populations were 2,40,000, 3,00,000 and 3,60,000

plants per hectare. Hence, seedlings to be transplanted per meter length of travel to meet these targeted plant populations at 250 mm row spacing were calculated as 6, 7.5 and 9 respectively. The average speed of operation was assumed 0.5 km/h and considering 40 % variation in speed, the minimum and the maximum speed of 0.3 and 0.7 km/h respectively. As per assumed average forward speed and number of seedlings/m to be transplanted, the seedling feed rate of transplanter for two rows was calculated as 50, 62 and 76 seedlings/min *i.e.* 25, 31 and 38 seedlings/min for each row. Accordingly, the levels of seedling feed rate decided to be 24, 31 and 38 seedlings/min/row.

c. Design of seedling metering mechanism

The number of seedling feed cups or cells of the carousel can be determined as per required plant spacing and speed ratio between the revolving carousel and the ground wheel (Raulaji, 2014). It can be calculated as follows

$$Z = \frac{\pi \times D \times (1 + \alpha)}{N_t \times S} \quad \dots(\text{Eqn 3.30})$$

where,

Z = No. of feeding cups or cells, No.

D = diameter of transmission wheel, mm

α = traction wheel slip, %

N_t = Speed ratio between traction wheel to revolving carousel, No.

S = Plant spacing within rows, mm

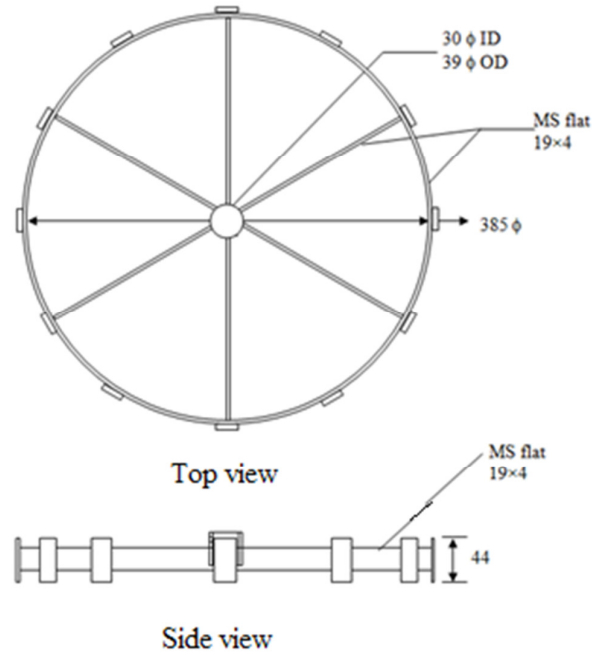
The equation 3.30 gives different arrangements to get desired plant spacing. The wheel diameter, number of cups on the carousels and sprocket combinations were used to achieve the desired seedling feed rate.

The carousel consisted of MS flat 25 × 3 mm ring (Fig. 3.35) to externally mount the seedling feed cups (Fig. 3.36). Stationary circular wooden plate with an curved elliptical notch having minor axis equal to the diameter of the seedling feed cup was made (Fig 3.37). The carousel was fixed while the wooden plate was mounted below the carousel in bearing fit manner on 19 mm diameter revolving vertical shaft in such a way that bottom of seedling cups should rotate in surface contact with the top surface of the circular plate. The carousel diameter was 460 mm when measured from the centre to centre of the opposite cups mounted on it. The top ends of the cups were given an inclined cut on its outer side to get better exposure of the cup that ease the seedling feeding. Two carousels *i.e.* one for each row to be

transplanted was provided. The maximum canopy spread width of the finger millet seedlings was observed to be 200 mm for 50 DAS seedlings. The seedling can be easily being passed through PVC pipe of 75 mm diameter. (Sahoo and Mahapatra, 2018). Hence, the PVC pipe 75 mm diameter was used for the seedling feed cups. To get desired seedling feed rates, two pairs of carousels were fabricated, each having 12 and 16 feeding cups respectively. A 16 cups carousel was used as 8 cups carousel by closing eight alternate cups with plastic paper. Hence, for experimentation 8, 12 and 16 cups carousels were used (Fig 3.38). Seedling metering shaft speed using different sprocket combination at 200 rev/min gearbox output shaft is presented Table 3.5.

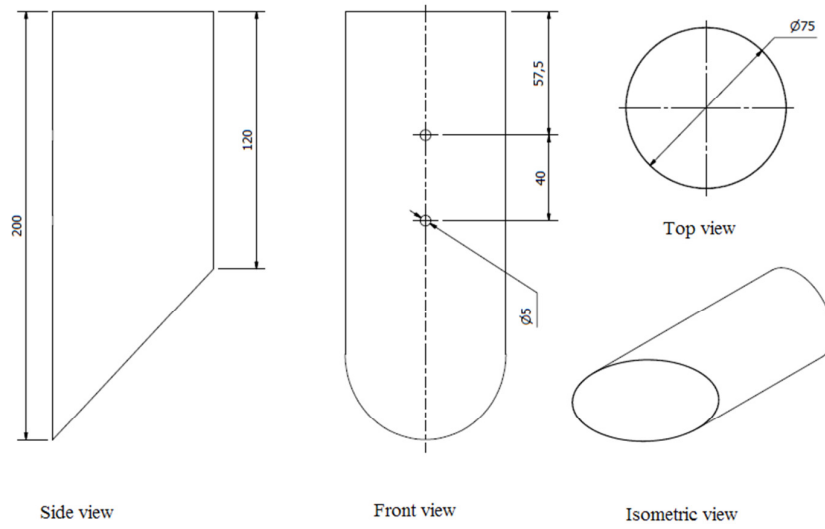
Table 3.5 Combinations of the ground wheel diameter, mm, number of teeth of sprocket on gearbox shaft, number of teeth of sprocket on carousel shaft, and number of cups on carousel at 200 rev/min gearbox shaft speed

Sr. No.	Operating and machine parameters	Speed, km/h								
		0.3	0.3	0.3	0.5	0.5	0.5	0.7	0.7	0.7
1	Seedling feed rate, seedlings/min	24	31	38	24	31	38	24	31	38
2	Ground wheel diameter, mm	370	370	370	370	370	370	425	425	425
3	Speed ratio between gearbox and carousel shaft	0.42	0.4	0.5	0.64	0.52	0.64	0.64	0.79	0.64
4	No. of cups on carousel	12	16	16	8	12	12	8	8	12
5	Driving wheel shaft speed, rev/min	4.8	4.8	4.8	7.2	7.2	7.2	8.8	8.8	8.8
6	Fertilizer metering shaft speed, rev/min	23.38	23.38	23.38	35.06	35.06	35.06	42.86	42.86	42.86
7	Seedling metering shaft speed, rev/min	2.05	1.91	2.4	3.07	2.53	3.07	3.09	3.76	2.53
8	Seedling feed rate, seedlings/min/ row	24.59	30.60	38.25	24.59	30.38	36.89	24.75	30.06	37.13
9	Plant spacing, mm	225.9	181.5	145.2	338.9	274.3	225.9	472.6	389.2	315.1
10	Briquette spacing, mm	213.8	213.8	213.8	237.6	237.6	237.6	272.2	272.2	272.2



All dimensions are in mm.
Scale: 1:5

Fig 3.35 Carousel ring



All dimensions are in mm.
Scale: 1:3

Fig 3.36 Feeding cup (cell) made up of PVC pipe

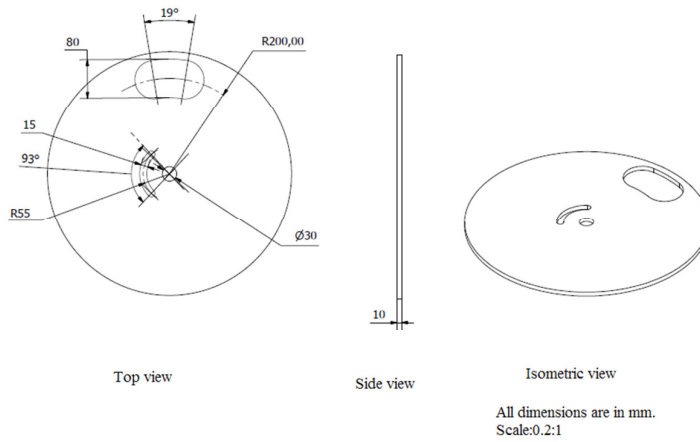
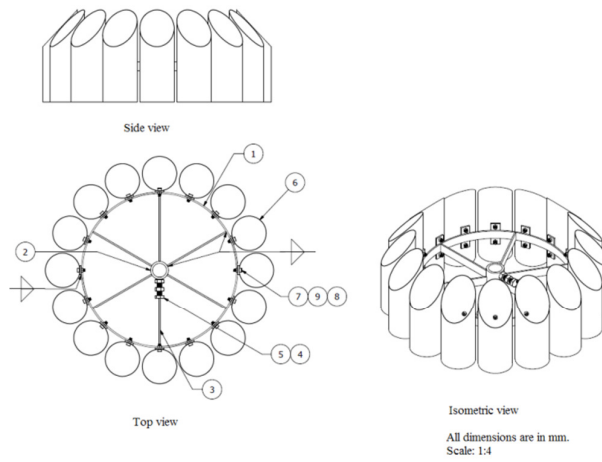
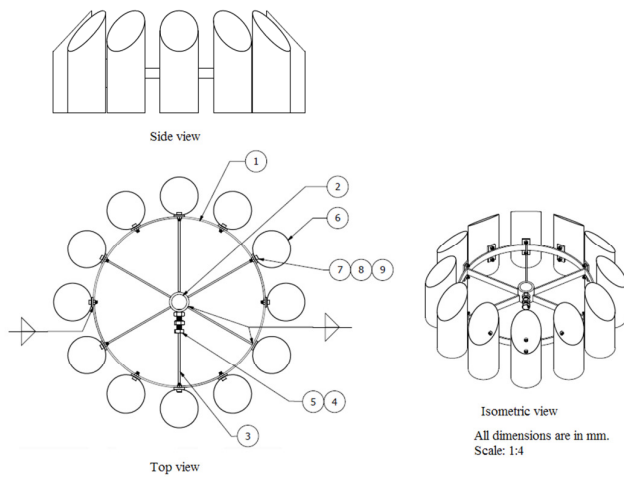


Fig 3.37 Seedling metering plates



a. Sixteen cups carousel



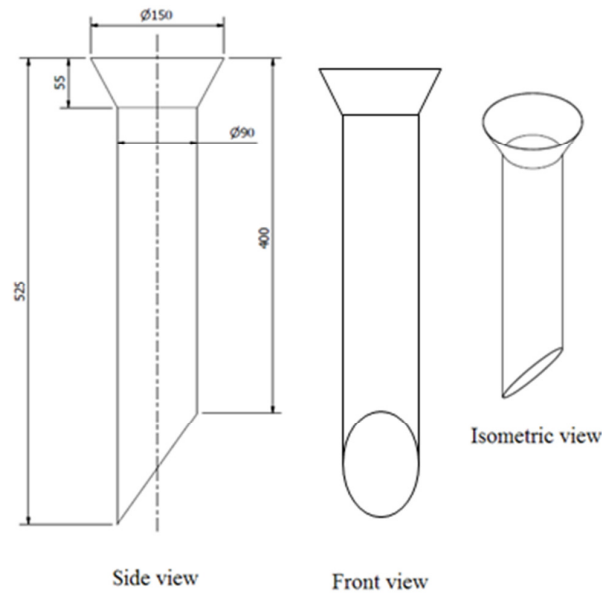
1. Central ring, 2. Central pipe, 3. Rib bar, 4. and 5. Nut and bold for fixing ring on seedling metering shaft, 6. Seedling feed cup, 7., 8. and 9. Nut, bolt and washer for fixing cup on the ring

b. Twelve cups carousel

Fig 3.38 Revolving carousels developed for the seedling metering in transplanter

d. Seedling conveying tube

Considering spread of 50 DAS seedling, a 90 mm diameter PVC pipe having height 525 mm was used as a seedling conveying tube to guide the seedlings up to the opened furrow. This tube has given a slant cut from its rear side at bottom end such that the seedling should not bend forward or injured due to the forward motion of the tube after dropping the seedling in the furrow. This tube had given the funnel shape having 150 mm top diameter for proper collection of the seedling in the tube (Fig 3.29). Using clamps, the tubes were mounted on the transplanter at center to center distance of 250 mm just below the notch in seedling metering plates.

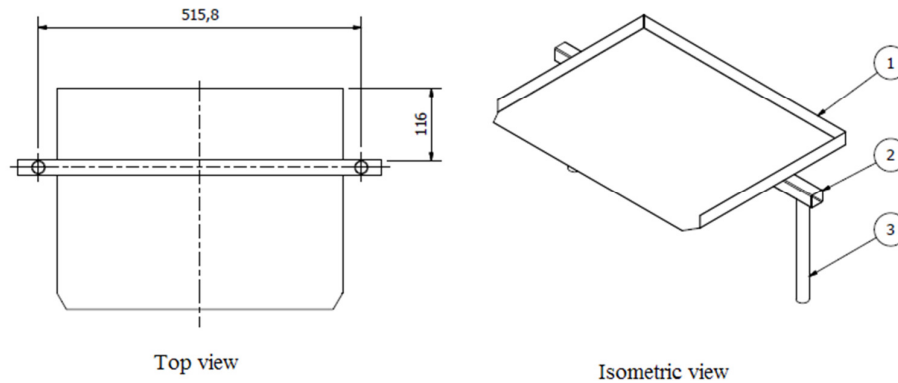


All dimensions are in mm.
Scale: 1:3

Fig 3.39 Seedling conveying tube

e. Seedling tray

The seedling tray is necessary to keep seedling stock during transplanting in the field. A tray was designed to hold about 200 bare root finger millet seedlings. The position of tray fixed in between two rows above carousel. The details of the tray are given below in Fig 3.40.



All dimensions are in mm.
Scale: 0.2:1

1. Seedling tray plate, 2. Square pipe, 3. Circular pipe for mounting

Fig 3.40 Seedling tray for the developed finger millet transplanter

3.4.14 Fertilizer metering mechanism

Assumptions for designing of fertilizer metering mechanism were

1. The mechanism should deliver one urea briquette for every seedlings in row.
2. Hopper size of mechanism must be sufficient for covering 100 m² area in one fill.
3. Mechanism should be lightweight.
4. Weight of each urea briquette as 3 g.
5. Targeted briquette spacing 250 mm × 250 mm.
6. Urea briquette damage in hopper as 20 %.

Hence,

$$\text{Number of briquettes in } 100 \text{ m}^2 \text{ area} = \frac{100}{0.25 \times 0.25} = 1600$$

Assuming 20 % briquette damage in hopper, number of briquette required

$$= \frac{1600}{0.8} = 2000$$

$$\text{Weight of urea briquette} = 2000 \times 3 = 6000 \text{ g} = 6 \text{ kg.}$$

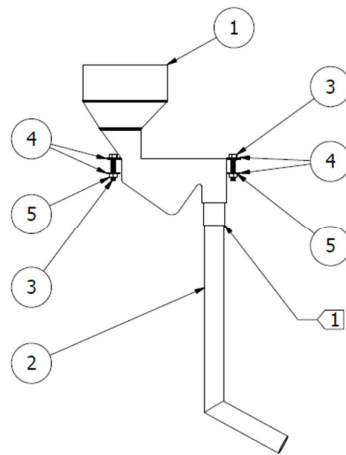
If one hopper for each row is considered, then capacity of each hopper should be of 5 kg urea briquette to have free board.

Based on the above assumptions, a fertilizer metering mechanism was selected having hopper capacity 5 kg. Two separate mechanisms were mounted on transplanter for each row (Fig. 3.41).

The fertilizer metering mechanism was operated by chain drive. The rotary motion was given from the engine gearbox shaft to the fertilizer metering shaft

through chain-sprocket. Commercially available plastic molded cup type metering rotor was modified for metering single urea briquette per revolution. The briquette spacing varies as per speed of operation are given in Table 3.5.

The fertilizer metering mechanism was also evaluated in plain land and field condition to know its performance (Fig. 3.42). The actual number of briquettes dropped compared to the theoretical number of briquettes to be dropped was observed at different speeds of operation with replications for each experiment. The average value of the replications was considered for the determination of distribution efficiency. Fertilizer metering shaft speed using different sprocket combination at 200 rev/min gearbox output shaft was determined.



1. Hopper, 2. Fertilizer tube, 3, 4 and 5. Nut, bolt and washer.

Fig 3.41 Fertilizer metering assembly of the developed finger millet transplanter



a. Urea briquettes dropped on plain land through metering mechanism



b. Urea briquettes dropped in field through metering mechanism

Fig 3.42 Measurement of spacing between urea briquettes dropped through metering mechanism

Briquette distribution efficiency: The percentage of briquette distributed was determined (Behera *et al.*, 1995)

$$\text{Briquettedistribution efficiency \%} = \left(1 - \frac{y}{d}\right) \times 100 \quad \dots(\text{Eqn 3.31})$$

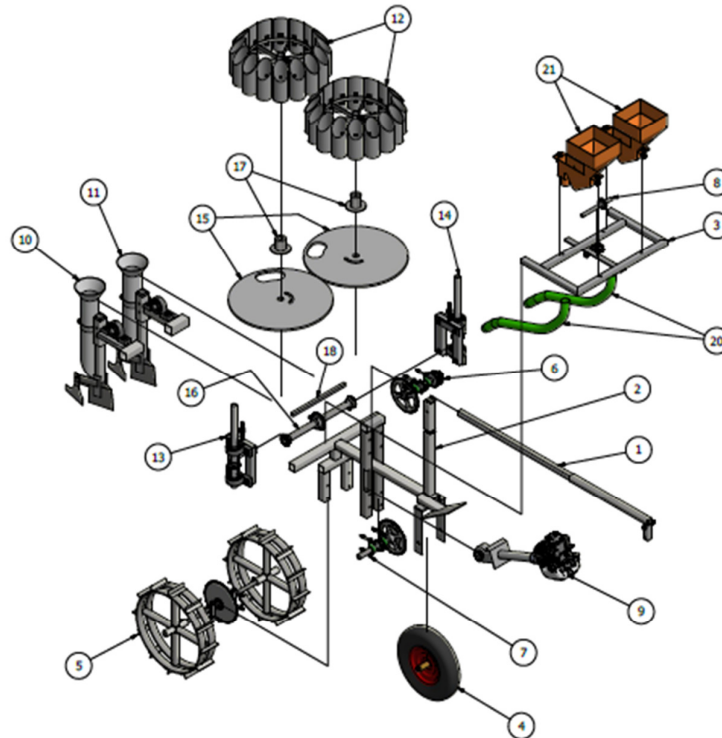
where, y = Average numerical deviation of the number of briquettes/m length of row from the average number of briquettes per meter length;

d = Average numbers of briquettes/m length of row

The quantity of urea briquettes in the hopper and dropped during the trial was measured. After trial, the hopper was emptied, the quantity of the briquette damaged was measured, and its percentage was determined.

$$\text{Briquette damaged, \%} = \frac{\text{Quantity of briquettes damaged after trial}}{\text{Quantity of briquette before trial}} \times 100 \quad \dots(\text{Eqn 3.32})$$

The developed transplanting system is as shown in Fig. 3.43 and Fig. 3.44.



1. Handle, 2. Main frame, 3. Hopper bracket, 4. Front wheel, 5. Drive wheel assembly, 6. Drive shaft assembly, 7. Drive shaft assembly, 8. Fertilizer metering mechanism shaft, 9. Engine and gearbox assembly, 10. Back support assembly (1), 11. Back support assembly (2), 12. Cup assembly, 13. Rear vertical assembly (R), 14. Rear vertical assembly (L), 15. Wooden seedling metering plate, 16. Cup driving shaft assembly, 17. Bush with plate, 18. Square pipe to hold vertical assembly, 19. Chain drive, 20. Hopper pipe, 21. Briquette metering hopper.

Fig 3.43 Exploded view of developed finger millet transplanting system

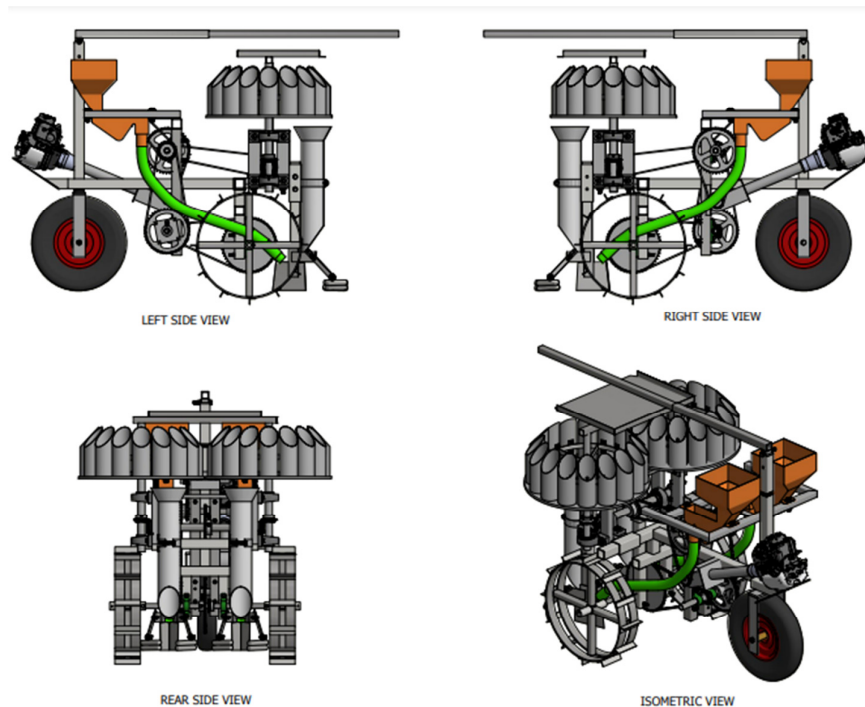


Fig 3.44 Views of developed finger millet transplanting system

3.5 Development of a two row mechanical transplanting system for finger millet seedlings

The self-propelled two row semiautomatic transplanter was fabricated and developed at Workshop, CAET, Dapoli (Fig. 3.45). The development of the transplanting system is mentioned below.

3.5.1 Working of newly developed finger millet transplanter

The newly developed two rows, self-propelled, gravity fed transplanter for finger millet used a single cylinder engine of 51.5 cc, rated power 2.6 kW (3.5 hp) and speed 3000 rev/min as a power source. The main components of the developed transplanter are furrow opening system, seedling metering mechanism and fertilizer metering mechanism. The engine gives power to drive wheel, seedling metering, fertilizer metering and soil covering mechanism. The furrow openers fixed to main frame opens furrow, seedlings manually fed in mechanism drops into opened furrow and covering device covers soil around seedlings. Two operators are required to walk behind the transplanter for operating and seedling feeding to the seedling metering mechanism. The transplanter can work in the wet soil condition (18 to 20 % soil moisture content). It requires bare root finger millet seedlings for transplanting. It can work at the forward speed of 0.5 km/h and at the seedling feed rate of 24 to 38 seedlings per minute per row.



Fig 3.45 Fabrication of trasplanting system

3.5.2 Main Frame

The main frame of the transplanter was made up of 40 mm square pipe as per Fig. 3.25. The engine, a handle, urea briquette applicator, power transmission system, drive wheels, seedling tray and furrow openers of transplanter are mounted on frame.

3.5.3 Handle

The handle of the transplanter was fabricated as per Fig. 3.26 using MS square pipe 25 mm size having length 1310 mm (Fig. 3.46). The arrangement of the handle was made such that it can be inserted in the vertical pipe of the steering wheel either from front side or from rear side. This facilitates steering the machine from rear side during operation in field and for pulling from front side off the field.



a. Position of handle for pulling machine off the field

b. Position of handle for steering machine while transplanting

Fig 3.46 Handle of developed finger millet mechanical transplanting system

3.5.4 Furrow opener

Furrow opener was designed as mentioned in Section 3.3.8. It was made up of MS plate 2 mm thickness. The bottom edge of the furrow opener was supported with MS plate 25 mm wide and 2 mm thick collar. It was fitted on MS square pipe 40 × 40 mm size (Fig. 3.47). Two 42 × 42 mm size brackets of MS flat 45 × 5 mm of 200 mm length were prepared and mounted on rear end of transplanter for holding the furrow openers. These were fixed on brackets with nut and bolt arrangement.



a. Front side



b. Rear side



c. Side view



d. Top view

Fig 3.47 Views of furrow opener with soil coverig device

3.5.5 Soil covering device

Soil-covering device was designed as mentioned in 3.3.9 and as shown in Fig. 3.47. It was made up of two pairs of two MS rods of 20 mm diameter having length 105 mm welded one above other along the length. Each one of pair attached on either side of furrow opener to MS flat 18 × 4 mm × 165 mm long to get wider opening at front and narrower closing at rear. Flats were hinged with furrow opener such that it can swing in vertical plane during covering soil when excess soil is pulled.

3.5.6 Transmission system of the transplanter

A single cylinder engine of 51.5 cc, rated power 2.6 kW (3.5 hp) and speed 3000 rev/min (Fig. 3.48) was used for the transplanter as a prime mover. To get the desired speed at engine output shaft, a worm and pinion type 1:9 gearbox was used (Fig. 3.49). The speed was further reduced with chain and sprocket to rear drive wheel, seedling feeding carousel and fertilizer metering mechanism.



Fig 3.48 Engine (prime mover) used for the developed finger millet transplanter



Fig 3.49 Worm and pinion type gearbox (1:9)

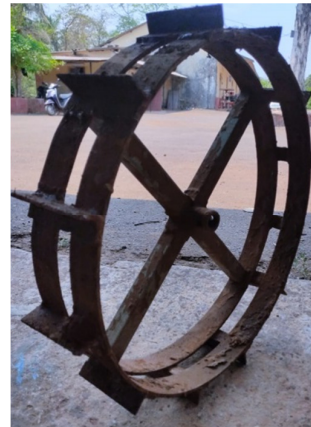
The transmission system was fabricated using chain and sprocket as per Fig. 3.31. The speed of 0.3, 0.5 and 0.7 km/h was obtained by putting the gear of 12, 18 and 22 teeth respectively on gearbox output shaft and using drive wheels of 370 and 425 mm respectively. The sprocket size, drive wheel selected for different desired speeds were determined and are given in Appendix VI. Similarly, the sprocket size, drive wheel and number of seedling feed cups on carousel selected for getting desired seedling feed rate were determined and are presented in Appendix VII.

3.5.7 Drive wheels

Two pairs of drive wheels, each having diameter of 370 mm and 425 mm, were fabricated as per Fig. 3.34 to achieve the required forward speed of the machine. These were fabricated with MS flat 40×5 mm with 12 equally spaced lugs of MS angle $25 \times 25 \times 3$ mm on its periphery. The boss 32 mm OD, 19 mm ID and 60 mm length and four arms made of MS square pipe 25×25 mm (Fig 3.50). For deciding the sprocket and ground wheel combinations to get the desired seedling feed rate, 3 % variation in the seedling feed rate than the assumed was considered acceptable.



a. 370 mm diameter



b. 425 mm diameter

Fig 3.50 Traction wheels of developed mechanical finger millet transplanter

3.5.8 Seedling metering mechanism

a. Seedling metering mechanism transmission

The ground wheel driven seedling metering mechanism was developed using two pairs of bevel gears so as to convert the rotary motion of wheels in vertical plane to the rotary motion of the metering mechanism in the horizontal plane. (Fig. 3.51).

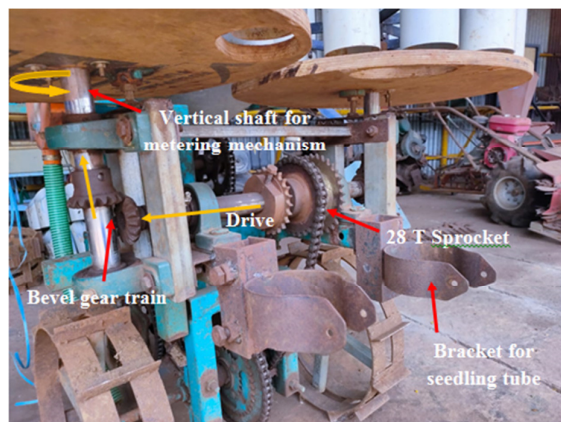


Fig 3.51 Drive for revolving carousel of seedling metering mechanism

b. Seedling feeding cup carousel

The carousel ring was fabricated of MS flat 25×3 mm as per Fig. 3.35. The seedling feed cups as per Fig. 3.36 were mounted on the ring. Two different carousels with 12 and 16 feed cups were fabricated as per Fig. 3.38 (Fig. 3.52).

c. Seedling metering plate

Two stationary circular wooden plates as per Fig. 3.37 were fabricated (Fig. 3.53) with an elliptical notch having minor axis equal to the diameter of the seedling feed cup. The top side was laminated with sun mica to provide smooth surface. The plate has another curved elliptical notch near to its axis to change its angular position.



i. Top view



ii. Side view

a. 12 cup carousel

b. 16 cup carousel

Fig 3.52 Seedling metering carousel of developed finger millet transplanter

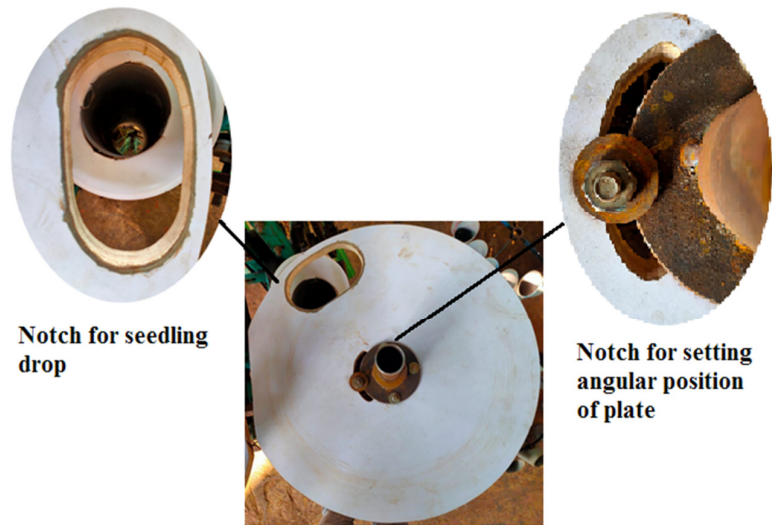


Fig 3.53 Seedling metering plate of developed finger millet transplanter

3.5.9 Seedling conveying tube

Seedling feeding tube of 90 mm diameter PVC pipe with funnel at top (top diameter 150 mm) was mounted using bracket below the notch in seedling metering plate. It carry seedling delivered from seedling feed cup to furrow opener. Seedling conveying tube as per Fig. 3.39 was fixed to frame by MS bracket (Fig. 3.54).

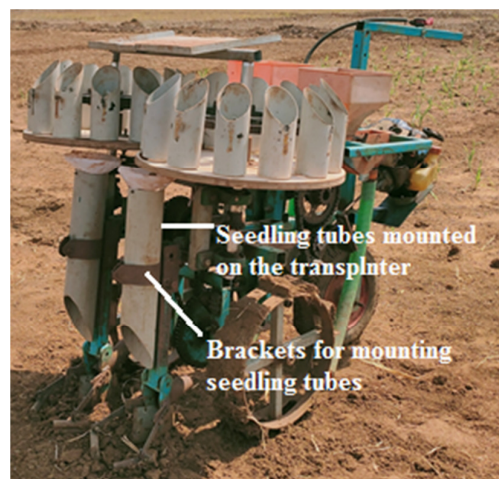


Fig 3.54 Seedling conveying tube mounted on the transplanter

3.5.10 Fertilizer metering mechanism

Two seed metering mechanisms with hoppers of manually operated seed drills were selected for development of fertilizer metering system. Plastic molded five cups type seed metering rotor was modified to meter single fertilizer briquette in one revolution (Fig. 3.55). Gearbox of engine was driving fertilizer metering mechanism through chain and sprocket mechanism (Fig. 3.56). Speed ratio of gearbox and fertilizer metering mechanism is given in Appendix VIII.



Fig 3.55 Seed metering rotor used for fertilizer metering mechanism



Fig 3.56 Fertilizer metering mechanism

3.5.11 Seedling tray

A seedling tray of 420×340 mm was fabricated as per Fig. 3.40 using 18 gauge galvanized sheet. The tray was provided with 25 mm collar from three edges. It was welded on 580 mm long 25 mm MS square pipe. This square pipe was welded perpendicular to two 20 mm diameter circular MS pipe of 200 mm length for easy mounting on hollow pipe of metering mechanism. The tray accommodates approximately 200 seedlings at a time. The tray was kept inclined towards the operator such that the operator could easily pick up seedling (Fig. 3.57).



Fig 3.57 Seedling tray of the developed finger millet transplanter

3.6 Evaluation of the developed mechanical transplanting system

3.6.1 Evaluation of metering mechanism of transplanter in laboratory

A semiautomatic self-propelled gravity fed two rows transplanting system was developed. It was evaluated in laboratory as per experimental plan in Table 3.6. Finger millet seeds were sowed on every fifth day for six days resulting in seedlings of 25, 30, 35, 40, 45 and 50 days age on single day. Seedling quality was observed best for 24 orifices, 165 mm diameter wheels and 1 km/h speed ($H_2D_1S_1$) operating combination of drum seeder. Hence, this operating combination of developed drum seeder was selected for raising seedlings for performance evaluation of developed transplanting system. A sufficient quantity of sorted and aligned seedlings was kept on seedling tray of transplanter. Transplanter was operated in jacked condition for 10 min such that only carousel could work for seedling metering. Initially single operator was employed to feed both carousels and later two operators were employed to feed single carousel separately to find number of seedling conveyed, missed and damaged and its percentage was determined.

Table 3.6 Experimental plan and parameters of finger millet transplanting system for laboratory evaluation

Sr. No	Parameters	Levels
Independent parameters		
1	Age of the seedlings, DAS	6 (25, 30, 35, 40, 45 and 50)
2	Speed of operation, km/h	3 (0.3, 0.5 and 0.7)
3	Seedling feed rate, seedlings/min	3 (24, 31, 38)
4	Replication	4
Dependent parameters		
1	Hill to hill distance, mm	
2	No. plant/m ²	
3	No. of missing plants/m ²	
4	No. of seedlings damaged/m ²	

Machine settings to obtain desired forward speed and seedling feed rate of developed finger millet transplanter at 200 rev/min output speed of gearbox are given in Appendix IX.

Procedure for evaluation of developed transplanting system with different age seedlings is as follows.

1. The mechanical transplanting system was jack-up so that ground wheels could be rotated freely with the help of engine.
2. Using throttle, engine was run at the desired speed as per experimental plan.

3. The ground wheel, number of cups on carousel and the sprocket combinations, as per Appendix VI and VII, of the transplanting system were selected to get the desired forward speed and seedling feed rate at fixed engine speed.
4. The transplanting system was evaluated with 25, 30, 35 40, 45 and 50 DAS seedlings, considering normal age of seedling adopted for manual transplanting is 25 to 35 DAS. The experiment was repeated four times for each factor combination. The 25 to 50 DAS seedlings were evaluated with developed mechanical transplanter to know suitability for better performance.
5. The seedlings feeding performance was evaluated considering the 50 to 100 m row length covered in 10 min, where 200 to 400 plants per row can be transplanted. Trial run for 10 min with one and two operators separately (Fig. 3.58) was conducted. Seedling fed, missed seedlings and damaged seedlings by single and two operators was determined for predetermined seedling feed rate.

Number of seedlings conveyed *i.e.* number of cups to be fed in 10 min run of transplanter as per seedling feed rate and forward speed is given in Table 3.7.

Table 3.7 Transplanter operating parameters for laboratory evaluation

Speed, km/h	0.3			0.5			0.7		
Seedling feed rate, seedlings/min	24	31	38	24	31	38	24	31	38
Seedlings per min, No	24.6	30.6	38.2	24.6	30.4	36.8	24.8	30.0	30.4
Seedlings to be conveyed per meter	4.4	5.6	6.9	2.9	3.7	4.6	2.1	2.7	3.3

The percentage of conveyed, missed and damaged seedlings (Satpathy and Garg, 2008) was determined as below.

Percentage of conveyed seedlings =

$$\frac{\text{Actual No. of seedlings conveyed in 10 min}}{\text{Theoretical No. of seedlings to be conveyed in 10 min}} \times 100$$

Percentage of missed seedlings =

$$\frac{\left(\text{Theoretical No. of seedlings to be conveyed in 10 min} \right) - \text{Actual No. of seedlings conveyed in 10 min}}{\text{Theoretical No. of seedlings conveyed in 10 min}} \times 100$$

Percentage of damaged seedlings =

$$\frac{\text{No. of seedlings damaged in 10 min}}{\text{Actual No. of seedlings conveyed in 10 min}} \times 100$$

3.6.2 Evaluation of transplanting system on plain land

Evaluation in jack-up condition showed that single operator could not properly feed seedlings in both carousels. Therefore, employed and trained two operators on plain land for seedling feeding operation while moving (Fig. 3.59). The 25 to 50 DAS seedlings were used to find out its proper stage suitable for transplanting mechanism. Seedlings conveyed on plain land were recorded (Fig. 3.60). This performance test helped to standardize a proper stage of seedling suitable for developed transplanting system for efficient transplanting. Observations were recorded (Annexure XI) for seedlings/m, hill to hill distance, plants/m², missed hills/m² and seedling damage/m².



a. By single operator



b. By two operators
laboratory

Fig 3.58 Seedling feeding test in



Fig 3.59 Evaluation of transplanting system on plain land



Fig 3.60 Seedlings conveyed by transplanter on plain land

3.6.3 Field evaluation of transplanting system

Based on results of laboratory and plain land performance tests, the field evaluation of developed semiautomatic self-propelled gravity fed transplanting system was carried out at Gavtale Block, CRS, Gavtale farm of Dr. B.S.K.K.V, Dapoli Dist: Ratnagiri in lateritic soil with well-drained and flat field condition. The field was divided in 12 m × 4 m size plots for each trial. The field was prepared with two passes of rotavator to obtained fine tilth. The trials were conducted in the month of March. The field was irrigated before conducting trials and allowed to drain to meet the desired 18 – 20 % soil moisture content. The field condition maintained to this limit as soil sticks to the drive wheels and wheel slippage occurs at higher soil moisture content in the field (Fig. 3.61). Experimental plan and parameters of finger millet transplanting system for field evaluation is given in Table 3.8.



Fig 3.61 Effect of higher soil moisture content (more than 20 %)

Based on laboratory and plain land trials, experimental plan as given in Table 3.8 was followed using the seedlings of 35, 40 and 45 DAS only for the field evaluation of the transplanting system. The trials were replicated four times. The following observations were recorded at four randomly selected different locations in each replication and average of the observations was considered for further calculations.

Table 3.8 Experimental plan and parameters of finger millet transplanting system for field evaluation

Sr. No	Parameters	Levels
Independent parameters		
1	Age of the seedlings, DAS	6 (25, 30, 35, 40, 45 and 50)
2	Speed of operation, km/h	3 (0.3, 0.5 and 0.7)
3	Seedling feed rate, seedlings/min	3 (24, 31, 38)
4	Replication	4
Dependent parameters		
1	Hill to hill distance, mm	
2	No. plants per m ²	
3	No. of missing plants per m ²	
4	No. of seedlings damaged per m ²	
5	Depth of operation, mm	

a. Number of seedlings/m

The seedlings conveyed per 10 m distance were measured to know the average number of seedlings/m for predetermined seedling feed rate and forward speed with two operators employed.

b. Hill to hill distance (Narang *et al.*, 2011)

Hill to hill distance between the transplanted seedlings or plant spacing was measured. The average plant spacing was calculated. It was used to find the plant missing and plant doubling.

c. Number of plants/m²

Based on number of plants/m length of operation, plants/m² was determined.

d. Number of missing plants/m²

The missed hills result in wide spacing between consecutive transplanted seedlings. Number of seedlings missed while transplanting in 10 m length of operation was determined and was expressed as per cent missed hills. Per cent missed hills was calculated using formula (Pandirwar *et al.*, 2019)

$$\text{Per cent missed hills} = \frac{S_m}{S_f + S_m} \times 100 \quad \dots(\text{Eqn 3.33})$$

S_m = Number of seedlings missed while transplanting in particular length

S_f = Number of seedlings to be transplanted for the length

e. Mechanical seedlings damaged

The injury on stem or roots of seedlings in terms of cutting of stem or roots completely or partially by transplanting mechanism is termed as mechanical seedling damage (Chaudhary and Varshney, 2003).

f. Number of seedling damaged/m²

Number of seedlings damaged in a 10 m meter length was measured. It was counted from randomly selected four locations in field in each replication. An average of it was used to find number of plants damaged in 10 m length and per square meter.

g. Depth of operation

The depth of operation was measured along the length of operation at four different locations in the field at different operating speeds. The average of the reading was considered as the depth of the operation for the particular speed.

h. The statistical analysis

Data was analyzed statistically using ‘Design Expert 10’ to determine effect of seedling age, operating speed and seedling feed rate on plant spacing (mm), plants/m² (No.), missing plants/m² (No.), seedlings damaged/m² (No.), depth of operation (mm).

RSM with second order polynomial equation in Box–Behnken Design (BBD) was used to analyse data obtained during field experiments (Table 3.8) (Myres *et al.* 2009; Verma *et al.* 2014). BBD has better prediction precision in center of factor space based on construction of balanced incomplete block design (Myers *et al.* 2009). Optimization of operational parameters of developed finger millet transplanter was done using 3-factor-3-level BBD with four replicates at center point. Three independent variable viz. forward speed (km/h), seedling feed rate (seedlings/min) and seedling age (DAS) were designated as A, B, and C and converted into coded variables x_1 , x_2 and x_3 by using Eqn 3.34 for optimizing dependent variables *i.e.* seedlings/m (No.), plant to plant distance (mm), seedlings/m² (No.), seedlings damaged/m² (No.), seedlings missed/m² (No.) (Pasma *et al.* 2013). Codes assigned for respective variables were – 1, 0 and 1 for low, intermediate and high value, respectively. Table 3.9 and Table 3.10 shows Box-Benkh design build information and levels and coded variables selected for the BBD. Table 3.11 presents nomenclature used for analysis purpose. Equations in coded factors, which are useful for identifying relative impact of factors by comparing factor coefficients, were made using this software. These equations can be used to make predictions about response for given levels of each factor.

$$x_i = \frac{X_i - X_0}{\Delta X} \quad i = 1, 2, 3 \quad \dots(\text{Eqn 3.34})$$

Nonlinear second-order regression equations Eqn 3.35 and Eqn 3.36 were developed to optimize the response *i.e.* seedlings/m (No.), hill to hill distance (mm),

seedlings/m² (No.), seedlings damaged/m² (No.), seedlings missed/m² (No.) as coded values functions of the independent parameters of developed finger millet transplanter (Khuri and Cornell,1996).

$$Y = b_0 + \sum_{i=1}^3 b_i x_i + \sum_{i=1}^3 b_{ii} x_{ii}^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 b_{ij} x_i x_j \quad \dots(\text{Eqn 3.35})$$

Table 3.9 Box-Benkhn design build information for study of effect of independent parameters on dependent parameters

File Version	10.0		
Study Type	Response Surface	Subtype	Randomized
Design Type	Box-Behnken	Runs	17.00
Design Model	Quadratic	Blocks	No Blocks

Table 3.10 Factors used for the analysis for study of effect of independent parameters on dependent parameters

Factor	A	B	C
Name	Forward speed	Feed rate	Seedling age
Units	km/h	seedlings/min	DAS
Type	Numeric	Numeric	Numeric
Subtype	Continuous	Continuous	Continuous
Minimum	0.3	24	35
Maximum	0.7	38	45
Coded Low	-1 ↔ 0.30	-1 ↔ 24.00	-1 ↔ 35.00
Coded High	+1 ↔ 0.70	+1 ↔ 38.00	+1 ↔ 45.00
Mean	0.5000	31.00	40.00
Std. Dev.	0.1414	4.95	3.54

Table 3.11 Nomenclature used for the analysis

b_0	Constant	B	Seedling feed rate, seedlings/min
b_i	linear regression coefficient	C	Seedling age, DAS
b_{ii}	quadratic regression coefficient	X_i	actual value of the i^{th} variable
b_{ij}	interaction regression coefficient	X_o	actual value of an independent variable at centre point
BBD	Box-Behnken Design	ΔX	step change value of an independent variable
F_{loc}	F-value for lack of fit	x_1	coded value of A
K	number of independent variables considered for optimization	x_2	coded value of B
N	total number of experiments	x_3	coded value of C
n_c	number of central experiments	x_i	coded value of the i^{th} variable
RSM	response surface methodology	Y_{ai}	experimental value of the i^{th} response
A	forward speed, km/h	Y_{ci}	calculated value of the i^{th} response
		Y_{av}	average of actual values of responses

The goodness of fit of the developed nonlinear equations was tested by F-value for lack of fit (F_{lof}). The value of F_{lof} was calculated by Eqn 3.36.

$$F_{lof} = \frac{\sum_{i=1}^N (Y_{ai} - Y_{ci})^2 - \sum_{i=1}^{n_c} (Y_{ai} - Y_{av})^2}{N - \text{no. of coefficients in regression equation} - N_c + 1} \dots (\text{Eqn 3.36})$$

The experimental and predicted values of responses were compared by the values of errors and correlation coefficients. The validation of the model was done by the Root Mean Square Error (RMSE), Mean Absolute Error (MAE), cross-validated correlation coefficient (q^2) and correlation coefficient (r^2). The Mean Absolute Error (MAE) is a quantity used to measure how close predicted values to the experimental values. The respective values represented an average value of the absolute error. The values MSE, MAE and q^2 were found by Eqn 3.37, 3.38, 3.39 and 3.40, respectively (Savic *et al.*, 2015; Savic *et al.*, 2016).

$$\text{RMSE} = \sqrt{\frac{\sum (y_i^p - y_i^m)^2}{N}} \dots (\text{Eqn 3.37})$$

$$\text{MSE} = \frac{\sum (y_i^p - y_i^m)^2}{N} \dots (\text{Eqn 3.38})$$

$$\text{MAE} = \frac{|(y_i^p - y_i^m)|}{N} \dots (\text{Eqn 3.39})$$

$$q^2 = 1 - \frac{\sum_{i=1}^n (y_i^p - y_i^m)^2}{\sum (y_i^m - \bar{y}^m)^2} \dots (\text{Eqn 3.40})$$

The independent variables were fixed at three levels as per the BBD and a total number of 17 experiments were carried out as evident from Table 3.7. The experiments were conducted in a random order. To calculate the error sum of squares and the lack of fit of the developed regression equation between responses and independent variables, four replicated experiments were conducted at central points of coded variables (Myres *et al.*, 2009). The effect of operational parameters viz. speed of operation, seedling feed rate and seedling age was studied on individual response parameters viz. seedlings/m (No.), hill to hill distance (mm), seedlings per square meter (No.), seedlings damaged/sq.m (No.), seedlings missed/m² (No.).

i. Optimization of operational and response parameters

The optimisation of operational parameters for developed finger millet transplanter was carried out using miscellaneous method for 3-levels factorial design. The experiments were conducted in a randomized order. The numerical optimization for the obtained data (Annexure XII) was carried out for obtaining optimized values of independent parameters by using response surface method. The operational

parameters viz. speed, seedling feed rate and seedling age was set within range of 0.3 to 0.7 km/h, 24 to 38 seedlings/min and 35 to 45 DAS respectively. The goal was to achieve operating parameters within the limits and the responses as desired to get the optimum plant population in the field. It was decided to evaluate the performance of the transplanting system in the field at the optimized parameters. All the response parameters *i.e.* viz. seedlings/m (No.), hill to hill distance (mm), seedlings/m² (No.), seedlings damaged/m² (No.) and seedlings missed/m² (No.) were set as 4.5 to 7, 220 to 330 mm, 24 to 36, 0.75 to 2 and 0.75 to 2 respectively. The performance of the developed two row transplanter was evaluated at the optimized operating parameter and compared with manual method of transplanting finger millet. The methodology for measurement of field performance parameters and seedling mortality is given below. A control plot of 12 m × 4 m was transplanted manually by peg (*Thomba*) method using seedlings grown in same batch. Two male and two female labours were employed for this transplanting. Number of seedlings per m², seedling mortality of seedlings transplanted, field capacity, transplanting efficiency, man-h required, plant mortality and cost of operation for both developed transplanter and manual method of finger millet transplanting were determined.

3.6.4 Performance evaluation of mechanical transplanting system in field

The observations related to the preparations required for operation of the machine, feeding of seedlings and transportation of machine from one field to another were considered. The parameters studied for evaluating field performance of the developed transplanter are explained below.

a. Transplanting efficiency

The transplanting efficiency was determined by the ratio of number of vertical transplanted seedlings with proper soil compaction around roots to the total number of seedlings transplanted (Gaikwad, 2010).

$$TE = \frac{S_{st}}{S_{total}} \times 100 \quad \dots(\text{Eqn 3.41})$$

where,

TE=Transplanting efficiency, %

S_{st} = number of vertical transplanted seedlings with proper soil compaction

S_{total} = Total number of seedlings transplanted

b. Total time required for operation (T_t)

Time required for transplanting operation, turning, feeding seedlings on tray, repair and adjustment etc. were taken as total time required for operation.

c. Unproductive time (T_u)

The time lost in turning, feeding the seedlings on tray, repair and adjustment of machine etc. were considered as unproductive time.

d. Speed of operation (S)

The transplanting speed was obtained by recording the time (t) required for the transplanter to travel a 12 m distance (D) in the field (Anonymous, 2010b). The speed of transplanting was computed using the following equation.

$$S = \frac{D}{t} \times 3.6 \quad \dots \text{(Eqn 3.42)}$$

where,

S = Transplanting speed, km/h;

D = Distance, m; and

t = Time required to cover the distance D, s.

e. Actual field capacity

It is the actual area covered per unit time (includes the time loss in turning, feeding the seedlings on tray, repair and adjustment) (Anonymous, 2010b). It was calculated as

$$AFC = \frac{A}{T_t} \quad \dots \text{(Eqn 3.43)}$$

where,

AFC = Actual field capacity, ha/h;

A = Total transplanted area, ha; and

T_t = Total operating time required for transplanting, h.

f. Theoretical field capacity

It is the theoretical area covered per unit time eliminating the time loss in turning, feeding the seedlings on tray, repair and adjustment. It is the function of speed and the width of operation expressed in ha/h (Anonymous, 2010b) and it was calculated by the following equation

$$TFC = \frac{W \times S}{10} \quad \dots \text{(Eqn 3.44)}$$

where,

TFC = Theoretical field capacity, ha/h;

W = Operating width of the transplanter, m; and

S = Transplanting speed, km/h.

g. Field efficiency

It is the ratio of the actual field capacity and theoretical field capacity expressed in percentage (Anonymous, 2010b). The field efficiency was calculated using following formula.

$$FE = \frac{AFC}{TFC} \times 100 \quad \dots(\text{Eqn 3.45})$$

where,

FE = Field efficiency, %;

AFC = Actual field capacity, ha/h; and

TFC = Theoretical field capacity, ha/h.

h. Number of plants/m²

Based on the number of plants/m length of operation, *i.e.* plant spacing, the number of plants per square meter was determined.

i. Seedling mortality

To assess the damage to seedlings during mechanical transplanting, a control plot of 12 m × 4 m was transplanted manually with seedlings grown in same batch. Observations for mortality of seedlings occurring within three days after transplanting was recorded for both manually and mechanically transplanted seedlings. The seedling mortality was calculated considering equal number of seedlings transplanted in both manual and mechanical method as follows (Gaikwad, 2010):

$$M = \frac{S_{\text{manual}} - S_{\text{mechanical}}}{S_{\text{total}}} \times 100 \quad \dots(\text{Eqn 3.46})$$

where ,

M = Seedling mortality, %

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

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

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

As there was missing and damage seedling in manual transplanting method, assuming plant spacing 120 mm × 120 mm, the transplanting efficiency was calculated as

$$\text{Transplanting efficiency of manual method} = \frac{\text{Actual No. of seedlings transplanted}}{\text{Theoretical No. of seedlings to be transplanted}} \times 100$$

j. Fuel consumption

Before starting the field operation, the fuel tank of engine was filled (top up) to full capacity. Then the field operation was carried out and the total operating time was recorded. After the completion of field operation, the fuel tank of engine was refilled (top up) to previous level and the amount of fuel required for refill was noted (Anonymous, 2010b). Fuel consumption per unit time was calculated by equation:

$$F = \frac{F_t}{T_t} \quad \dots \text{(Eqn 3.47)}$$

where,

F = Fuel consumption, l/h;

F_t = Fuel used during operation, l; and

T_t = Total time needed for operation, h.

3.6.5 Cost analysis of newly developed mechanical transplanting system

Cost of fabrication for power-operated finger millet transplanting system was determined as per material required (Appendix XII). The operating cost of newly developed transplanter was determined using IS-9164-1979 test code. Cost analysis was done based on fixed cost and variable cost for transplanter. The detailed cost analysis is given in Appendix XIII. The transplanting cost by manual method was also determined (Appendix XIV) for comparing with operating cost of mechanical method. The results of the evaluation of the developed finger millet transplanter are presented and discussed in the next chapter.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the analysis and interpretation of experimental results under the following heads.

- 4.1 Study of existing method of nursery raising and manual transplanting of finger millet.
- 4.2 Standardizing the nursery raising method and seedling stage (age, height) required for mechanical transplanting system through laboratory trials.
- 4.3 Selection of seedling feed rate for developed finger millet transplanter
- 4.4 Performance evaluation of developed mechanical transplanting system in field.
- 4.5 Cost analysis of newly developed mechanical transplanting system.

4.1 Study of existing method of nursery raising and manual transplanting of finger millet

a. Conventional finger millet nursery raising method

The University method and farmers' method for finger millet nursery raising was studied as mentioned in Section 3.1.1. In both the methods, the sowing is carried out in well tilled and dry field on the 1/10th of the area to be transplanted. These methods are discussed below.

- i. University sowing method:** In this method, a raised bed of 100 to 150 mm height, 1 m width and of desired length is prepared in dry and well-tilled soil. The furrows, spaced at 100 mm are opened with the pickaxe or any hand tool across the length of the bed. The granular fertilizer (granular urea and SSP), at the rate of 1 g/m² (Anonymous 2017b), is applied in the furrows and seeds are sown manually in it at a shallow depth of about 20 mm (Fig. 4.1). Then soil is covered with the help of plank or bamboo stick over the seeds sown. The 25 to 30 days old seedlings raised by this method are manually transplanted in the main field (Anonymous, 2017a). The non-uniform spacing of seeds and fertilizer grains observed in manual sowing for nursery raising is given in Fig. 4.2. The densely populated seedlings of finger millet obtained by manual sowing method followed in University is given in Fig. 4.3.



Fig 4.1. University method of finger millet sowing



Fig 4.2. Non-uniform spacing of seeds and fertilizer grains observed in manual sowing for nursery raising



Fig 4.3. Densely population seedlings of finger millet by manual sowing in University sowing method

- ii. **Farmers' method:** The farmers of this region use to burn agricultural waste over the field where the seedling nursery is to be raised. Usually, the farmers broadcast

(Fig. 4.4) finger millet seeds in $1/10^{\text{th}}$ area of field to be transplanted. The farmers follow same seed rate as recommended by University. Few farmers mix in very small quantity of other seeds like *Okra*, *Pavta*, *Vari*, *Maka*, *Jwari*, *Chavali*, *Til* or any local leafy vegetable with finger millet seeds while broadcasting (Fig. 4.5).



Fig 4.4. Finger millet sowing by broadcasting method on farmer's field



a. Finger millet broadcasted with seeds of other crops



b. Finger millet broadcasted without seeds of other crops

Fig 4.5. Finger millet nursery raised by manual broadcasting method

The observations were recorded for the manual sowing of the finger millet seeds on the Experimental Farm, Department of Agronomy, DBSKKV, Dapoli and farmer's field (Table 4.1).

Table 4.1 Observations recorded during manual sowing of finger millet

Location	Experimental field, Department of Agronomy, DBSKKV, Dapoli	Farmer's field, Kumbhave, Dapoli
Soil type	Red lateritic	Red lateritic
Date of sowing	25/06/2018	15/06/2018
Method of sowing	Line sowing	Broadcasting
Fertilizer	Line sown	Broadcasted
No. of labours required	2 F + 1 M	2 F + 2 M
Area covered, ha	0.027	0.050
Quantity of seed sown, kg	1.75	3.5
Time required, min (man-days/ha)	80 (24.69)	90 (20)
Seedling density, no./m ²	850	1020
Height of seedlings (25 DAS), mm	250	220
No. of leaves	5	5
Stem width, mm	1	0.7
Stem thickness, mm	0.4	0.3
Time required for uprooting 100 seedlings, s	206	214
Seedling damage while uprooting, per cent	10	15

The time required for sowing operation in farmers' field was observed less than University method of sowing as sowing was done in rows whereas farmer's field it was broadcasted. In University method of sowing, the labour has to work in bending position (Fig. 4.1) which is tedious and time consuming.

It was observed that while sowing, the seed rate and fertilizer application rate is very much dependent on the experience and skill of the person doing this job. Normally, for better assurance, the person tends to sow the seeds and apply fertilizers in the dense manner *i.e.* in excess quantity than recommended (Fig. 4.2), which leads to the uneven seedling growth. It may due to uneven seed and fertilizer application (Fig. 4.3). Many of them are unhealthy that need to be discarded from transplanting.

Height of seedlings observed higher in University sowing method. The seedling density may be affecting the growth (Duryea and Landis, 2012, Adhikari *et al.*, 2013). The stem thickness and width of the seedlings grown with University method of sowing observed better compared to farmer's method with marginal difference. Seedling density was not uniform in the farmer's method (Fig 4.5 a and b). It indicates the non-uniform crop cover in this method (Anonymous, 2016c).

b. Conventional finger millet transplanting

The conventional methods of finger millet transplanting were studied to know its advantages and limitations. In the rain fed crop, the finger millet transplanting is done on the wet field which is prepared or cultivated either by rota-tilling using power tiller, bullock drawn plough or hand tools like pickaxe and spade for small land patch prior to transplanting.

The four methods of finger millet transplanting were studied

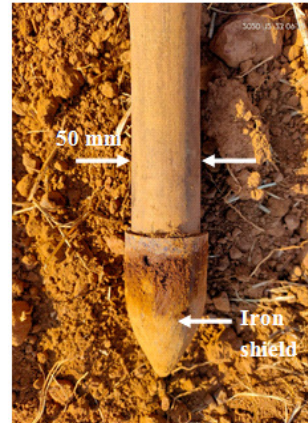
- i. Random transplanting using peg (*Thomba*)
- ii. Line transplanting using peg (*Thomba*)
- iii. Line transplanting with thumb press
- iv. Transplanting in water ponded condition (summer crop)

i. Random transplanting using peg (*Thomba*)

The field is prepared using bullock drawn desi plough (Fig. 4.6). Conventionally, a person randomly makes holes about 30 mm deep in wet field with the help of bamboo peg (*Thomba*) of about 30 to 50 mm diameter (Fig. 4.7). The distance between the holes is not maintained (Fig. 4.8). Another person drops the approximate quantity of granular fertilizer (SSP) in each hole in bending posture (Fig. 4.9). Later, the third person place 20 to 25 days old seedlings in the respective hole and cover soil over the roots by toe (Fig. 4.10). This method relieves the person of pressing the seedling roots in the soil by thumb. The fertilizer application and the transplanting need be done in the bending posture by the labour though the holes are made in the field in the standing position.



Fig 4.6. Land preparation using bullock drawn *desi* plough for finger millet transplanting



a. *Thomba* (Peg)

b. Pointed front end of *Thomba*

Fig 4.7. *Thomba* (peg) used for making holes in the wet field for manual finger millet transplanting



Fig 4.8. Manual method of making holes in the field using bamboo (*Thomba*)



Fig 4.9. Manual placement of fertilizer in the holes made in the field for transplanting



Fig 4.10. Manual transplanting of seedling in the holes and covering the soil over the roots of the transplanted seedling

ii. Line transplanting using peg (*Thomba*)

This method is mostly followed for the research work. The seedlings are transplanted in the wet soil with the help of line transplanting method. A rope with markings *i.e.* small wooden piece or ribbon tied at the recommended distance is held in the field in stretched condition by two male or female persons. A male person makes the holes at the point of markings on the rope. A female person puts the fertilizer in the holes made in the field and another female person transplant seedlings in these holes and cover soil over the seedling root by hand (Fig. 4.11). Once the transplanting of a row is done, the rope is shifted parallel to another measured position and the transplanting is repeated as mentioned above.



Fig 4.11. Line transplanting of finger millet using peg (*Thomba*)

iii. Line transplanting with thumb press

This method is similar to method discussed above but without using peg and fertilizer. The marked ropes are used in similar way as mentioned earlier. Persons press seedlings by thumb in wet soil at the point of markings on rope. (Fig. 4.12). Line transplanting permits use of interculturing tools if spacing is kept accordingly.



Fig 4.12. Manual line transplanting in wet soil using line rope without making holes in the field *i.e.* by thumb pressing

iv. Transplanting in water ponded condition (summer crop)

The summer crop of finger millet is grown in the regions where the irrigation facility is available. In this method, the check basins are made in the tilled field for the ponding of water up to 60 to 70 mm depth. The seedling nursery is needed to be prepared off the main field for the transplanting in the main field. The transplanting of the seedlings is done similar to manual paddy transplanting method (Fig. 4.13).



Fig 4.13. Manual transplanting of summer finger millet crop

The information related to manual finger millet transplanting *i.e.* method, area, labour requirement, population density, fertilizer applied *etc.* are recorded as per method given in 3.1.2 and the results of the study are presented in Appendix I. It was

observed that the finger millet is cultivated on small patches of field. The 5 – 6 g mixture of Urea and SSP fertilizer is applied at each hill. Seedling density varied from 25 to 70 seedlings/m². Few farmers use to place three seedlings per hill when the seedling density is kept less. The actual time required for transplanting that includes personal time of labour was measured. It varied too much within the cases studied as time lost due to rains, seedling uprooting and bringing it to field was also considered. Only one farmer adopted line transplanting method amongst cases studied.

Studies of conventional finger millet transplanting lead to observations as

1. Finger millet cultivation is generally done on small patches of land having irregular shape and slope.
2. The fields are tilled before transplanting either using power tiller or bullock drawn *desi* plough.
3. The seedling height at the transplanting time varied from 300 to 400 mm.
4. Transplanting is done randomly in the main field where least attention is given to maintain the plant spacing that hinders the interculturing operation.
5. Fertilizer is applied at the time of transplanting in the method where holes are made for placing seedling.
6. The field capacity of manual line transplanting method was observed lesser compared to the random method of transplanting.
7. In manual finger millet transplanting methods, labour works in bending posture.
8. The manual transplanting method is time and labour consuming.

The study of manual methods of finger millet transplanting indicated that transplanting of finger millet is done in wet field prepared prior to transplanting. Fields are small in size having sloppy terrain. Seedlings with 300 to 400 mm height *i.e.* of 20 to 25 days old and exceptionally older are transplanted. The labour works in bending posture for placing fertilizer and seedling in field which is time consuming.

4.2 Standardizing the nursery raising method and seedling stage (age, height) required for mechanical transplanting system through laboratory trials for millets

4.2.1 Evaluation of manually operated finger millet drum seeder cum fertilizer applicator

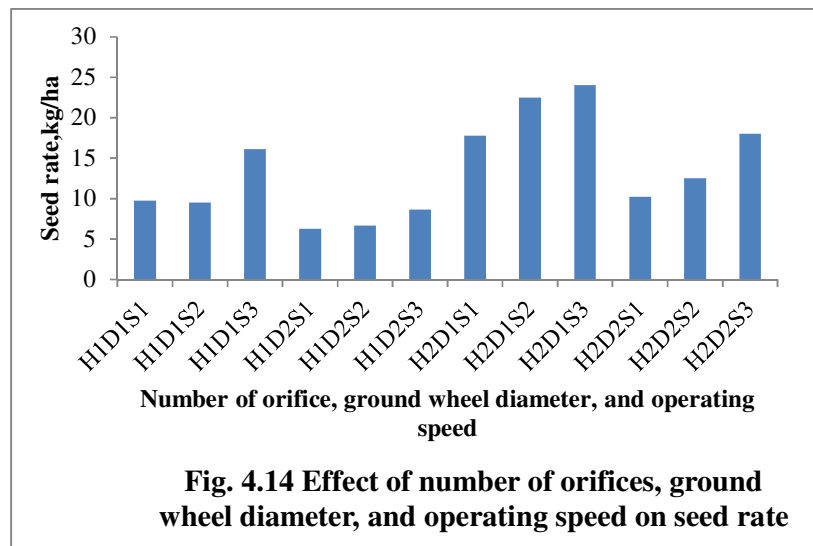
A finger millet seeder cum fertilizer applicator was developed for finger millet nursery raising to standardize nursery raising method. It was designed, developed, and evaluated in laboratory at Department of Farm Machinery and Power, CAET, Dapoli

and on farm at Research Plot of Department of Agronomy, DBSKKV, Dapoli. The results obtained are discussed below.

4.2.1.1 Laboratory tests of manually operated finger millet drum seeder cum fertilizer applicator

The actual seed rate of the seed drill was determined as per the predetermined operating parameters and its levels as per the procedure mentioned in the Section 3.2.10.1. The results obtained are presented in Appendix II and in Fig. 4.14.

The seed rate observed to increase with the forward speed of seeder. It also increases with increase in diameter of ground wheel. This may be due to the centrifugal force that forces seed outside through the orifice at higher rotational speed (Ratnayake and Balasoriya, 2013). This may also be due to seed roundness and higher vibrations which occurred at higher speed. In general, factors such as orifice size, spacing between the orifices on the drum, percentage fill of drum, and speed of operation significantly affected the flow rate of seeds through the orifices.



4.2.1.2 Laboratory tests of manually operated finger millet drum seeder cum fertilizer applicator on sticky plate

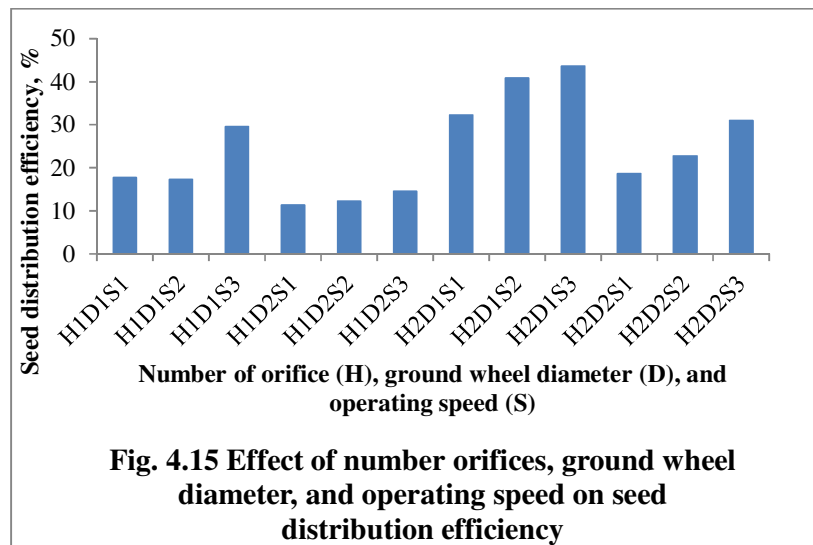
The trial of the seed drill was conducted on the sticky plate as per section 3.2.10.2. The results of the sticky plate tests are discussed here.

a. Effect of number of orifices on drum, diameter of ground wheel and speed of operation on seed distribution efficiency

The seed distribution efficiency of drum seeder was determined as per the predetermined operating parameters and its levels as per the procedure mentioned in the Section 3.2.10.1 and the trials were conducted on sticky plate. The results obtained are presented in Appendix III and graphically in Fig. 4.15.

The seed distribution efficiency was observed to be maximum with H₂D₁S₃ (24 orifices, 160 mm wheel diameter, 2 km/h forward speed) combination. In drum seeder, the seed distribution efficiency observed to be increased with the increase in forward speed of the seeder and ground wheel diameter.

As per the recommended seed rate and row spacing of 100 mm for raising the finger millet nursery seedling, the quantity and number of seeds to be dropped per meter per row was 0.55 g and 220, respectively. Accordingly, the seed spacing was 4.5 mm. The seed distribution refers to the planting of seeds according to a predetermined pattern (Soza *et al.*, 2004). The maximum seed distribution efficiency of 43.64 % was observed with H₂D₁S₃ followed by 40.91 % with H₂D₁S₂ operating conditions. The least seed distribution efficiency of 11.27 % was observed at H₁D₂S₂ operating combination. The lower distribution efficiency may be due to the free flowing, small size, round shape of seeds and vibrations on the uneven field condition. The similar results on seed distribution in row were also observed for paddy seeds through orifices by Sivakumar *et al.*, 2003 and Sivakumar *et al.*, 2005.

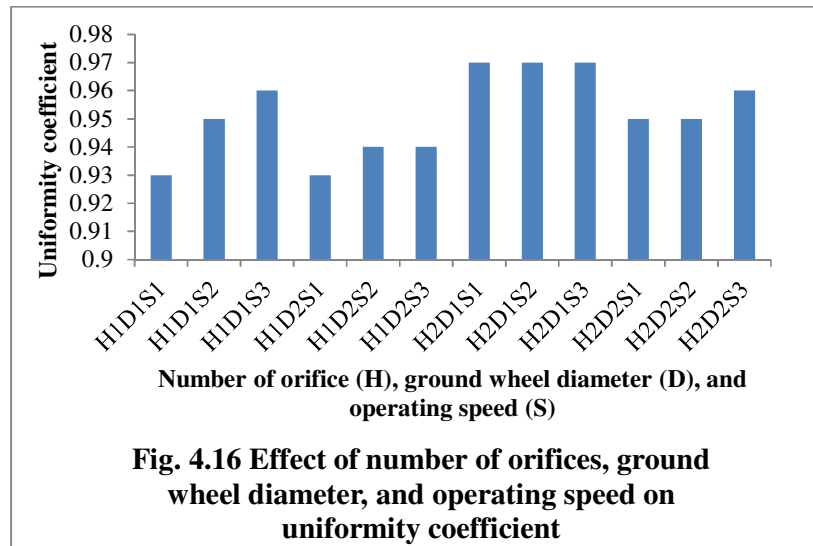


b. Effect of number of orifices, ground wheel diameter, and operating speed on seed uniformity coefficient

The seed uniformity coefficient of the seed drill was determined as per the predetermined operating parameters and its levels as per the procedure mentioned in the Section 3.2.10.2 and the trials were conducted on sticky plate. The results obtained are presented graphically in Fig. 4.16.

The uniformity coefficient was observed to be more than 0.9 for all the trials. It was maximum 0.97 for H₂D₁S₁, H₂D₁S₂ and H₂D₁S₃ followed by 0.96 for H₁D₁S₃

and $H_2D_2S_3$ operating conditions. It indicates that uniformity coefficient is higher for 24 orifices than 12 orifices. It was also observed that uniformity coefficient increased with forward speed for all combination of operating parameters. The falling of seeds on grease plate was affected due to point from which the seeds were leaving orifice. This affects the falling of the seed on the grease plate and affects the seed spacing in line and uniformity in metering of seed in line. (Asl *et al.*, 2019). The uniformity coefficient up to 0.97 was recorded by Rahmati and Hajiahmad, 2008 for Paddy.



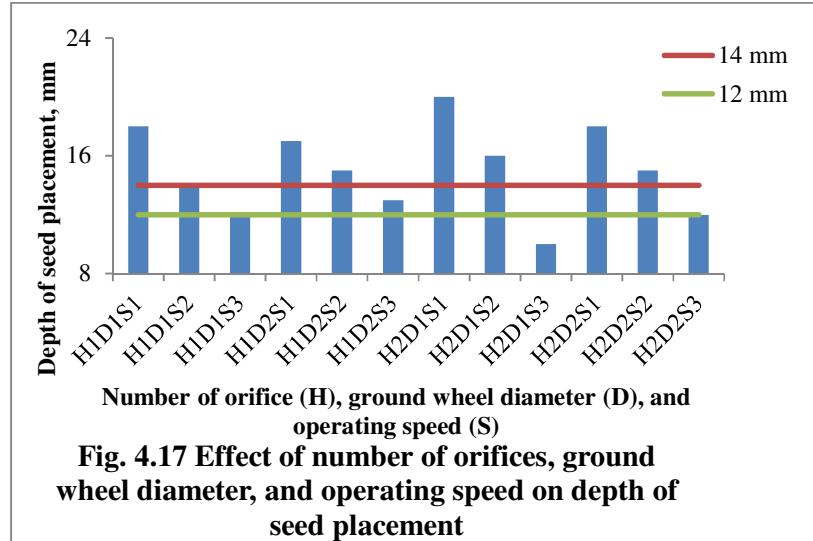
4.2.1.3 Field tests of the manually operated finger millet drum seeder cum fertilizer applicator for nursery raising

The drum seeder was tested in the field as per the procedure mentioned in Section 3.2.10.3 with predetermined operating parameters and its levels. The depth of seed placement and plants/m² were determined. Results obtained are discussed below.

a. Effect of number of orifices, ground wheel diameter, and operating speed on depth of seed placement

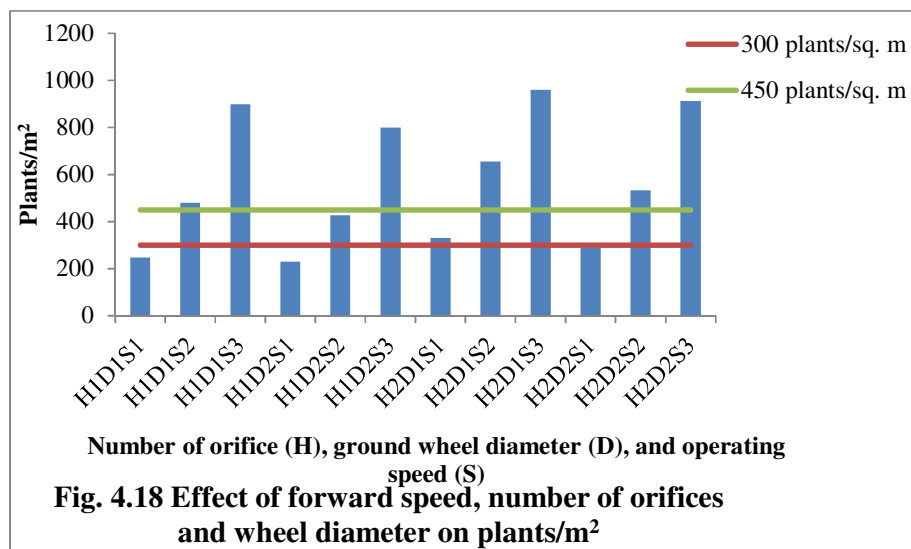
The depth of seed placement was studied at the predetermined operating parameters as per Section 3.2.10.3.a. The results obtained are presented graphically in the Fig. 4.17. The depth of seed placement was observed to vary between 10 to 20 mm, which is required for such small size seeds. The desired depth of placement of seed is 12 to 13 mm for proper germination and growth (Anonymous, 2017d). The minimum and maximum depth was occurred at $H_2D_1S_3$ and $H_2D_1S_1$ respectively. The operating parameters $H_1D_1S_2$, $H_1D_1S_3$, $H_1D_2S_3$ and $H_2D_2S_3$ showed the desired depth of seed placement. The depth of operation was observed to be decreased with the increase in the speed of operation. Casão Junior *et al.*, 2000 Mahl *et al.*, 2004 and

Silveira *et al.*, 2011 also reported deeper furrows at lower speeds. This may be due to pulling forces acting horizontally more at higher speed than vertically downward forces of drum seeder weight at lower speed. Condition of soil prepared, *i.e.* tilth of soil, moisture content and type of soil might have affected the depth of operation.



b. Effect of forward speed, number of orifices and wheel diameter on plants/m²

No. of plants/m² was studied at predetermined operating parameters as per Section 3.2.10.3.b. Results obtained are presented graphically in Fig. 4.18. It was observed that number of plants/m² increases with increase in speed of operation and number of orifices on drum whereas decreases with ground wheel diameter (Sarkar *et al.*, 2019). This may be due to lesser number of revolutions of drum due to larger wheel to cover same distance created less opportunity for seeds to fall through orifices. Plant density was very high as the seeds were falling from orifices. As per recommended seed rate and area under nursery, 300 to 450 plants/m² are expected. Hence, seedling population obtained within this range can be considered satisfactory because it could satisfy the need of quantity of seedlings required. H₂D₁S₂, H₁D₂S₂, H₂D₁S₁ and H₂D₂S₁ were operating parameters that met this criterion. Other operating parameters showed either higher or lower plant population than required. Seedling population less than recommended can be accepted if seedlings obtained are healthier. Gravity fed mechanical transplanting system requires either plug or paper pot seedlings or healthy and heavy seedlings with stiff stem to facilitate seedlings to easily pass under gravity through gravity fed metering mechanism. It helps seedlings to stand erect in furrow opened by furrow opener (Satpathy and Garg, 2008). Seedling population in nursery can be compromised to get required seedling quality.



4.2.1.4 Cost of operation

The cost of seeding to raise nursery on one hectare area is ₹ 1083.33. As the seedlings nursery is raised on 1/10th of the area to be transplanted, the cost seeding to raise seedlings for transplanting on one hectare area is ₹ 108.33 (Appendix IV).

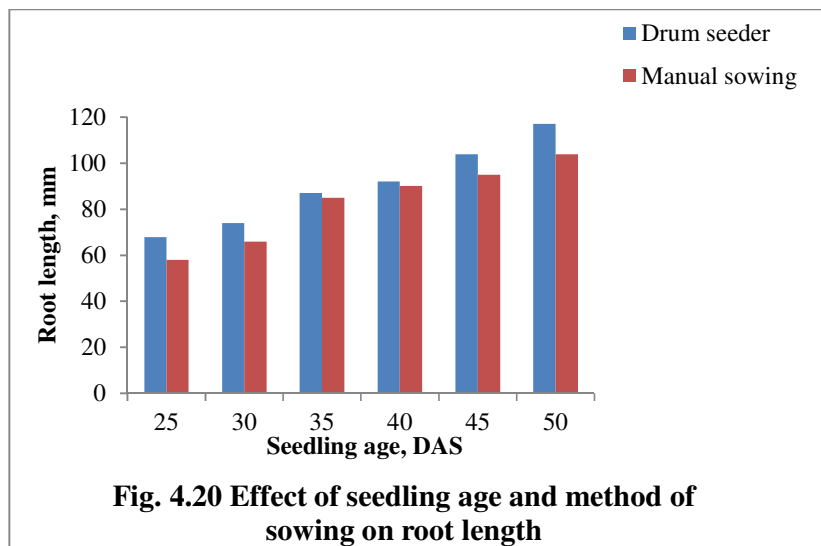
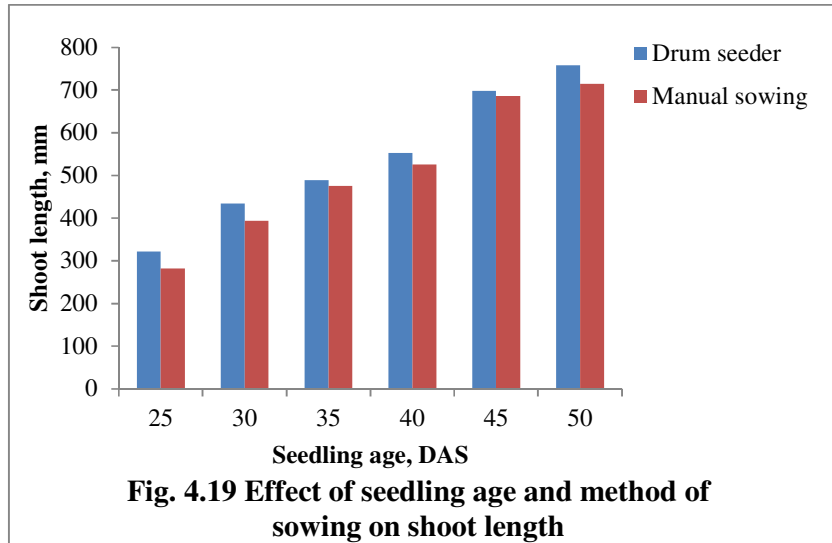
4.2.2 Standardization of nursery raising method suitable for mechanical transplanting of finger millet

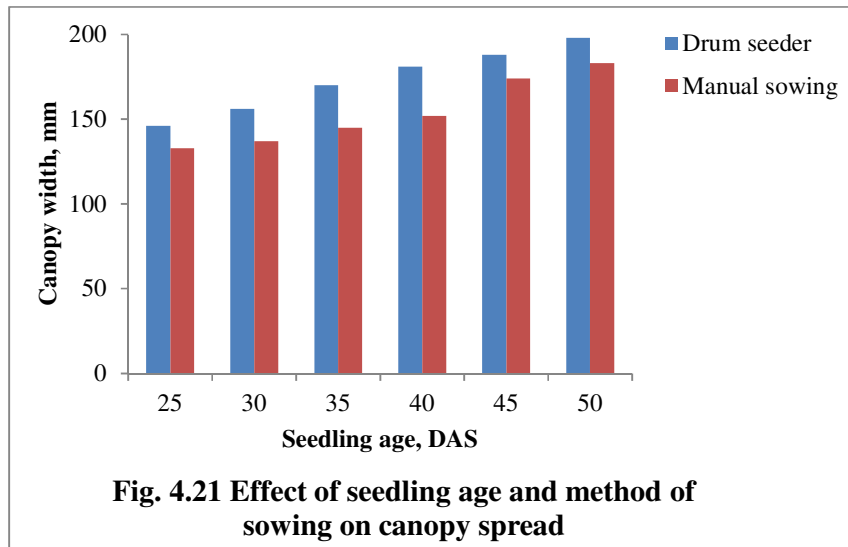
The standardization of nursery raising method suitable for mechanical transplanting of finger millet was done as per Section 3.2.11. The physical parameters of seedlings like shoot length (mm), root length (mm), canopy spread (mm), stem thickness (mm), stem width (mm), No. of leaves and seedling weight (g) were recorded on 25 to 50 days after sowing (DAS) at every five days of interval. The observations of the seedlings physical parameters are given in the Appendix V and presented graphically below in Fig. 4.19 to Fig. 4.21.

a. Effect of seedling age and method of sowing on seedling shoot length, root length and canopy spread

The effect of seedling age and method of sowing on seedling shoot length, root length and canopy spread are presented graphically in Fig. 4.19, Fig. 4.20 and Fig. 4.21. The seedlings of manually sown method found marginally inferior in terms of shoot length, root length and canopy spread compared to the seedlings sown by drum seeder. This may be due to higher seed density by manual sowing method compared to drum seeder sowing method. In overall field, the distribution of the seeds was uniform due to the use of drum seeder. The seed-to-seed distance was properly maintained and facilitates the supply of nutrient and water for healthy growth. This

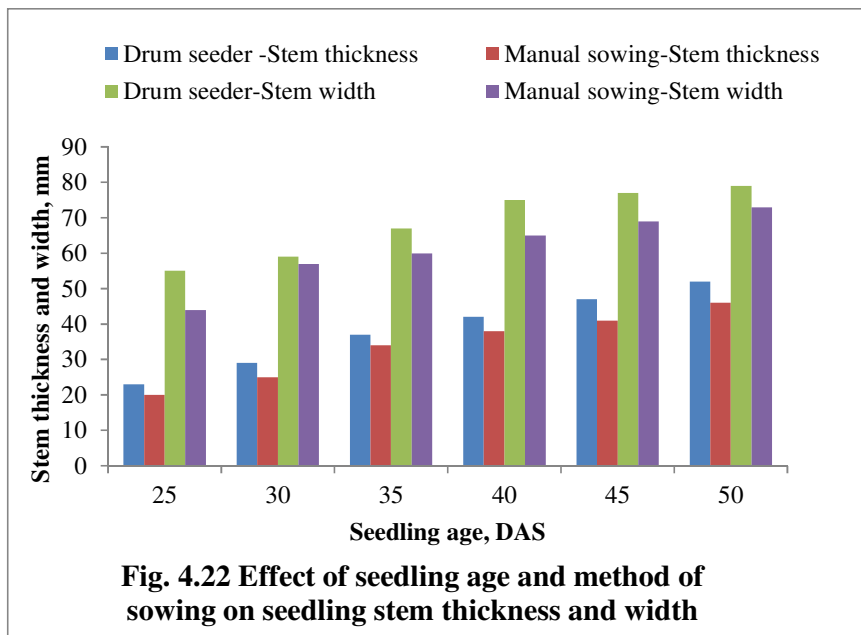
might have resulted in higher growth of shoot length, root length and canopy spread of finger millet seedlings. Similar results were reported by Robinson *et al.*, 1981, Duryea and Landis, 2012, Kurmi and Sarmah, 1993, Lal and Roy, 1996, Paroda and Siddiq, 1996, Wopereis *et al.*, 2009, Bitew and Asargew, 2014.





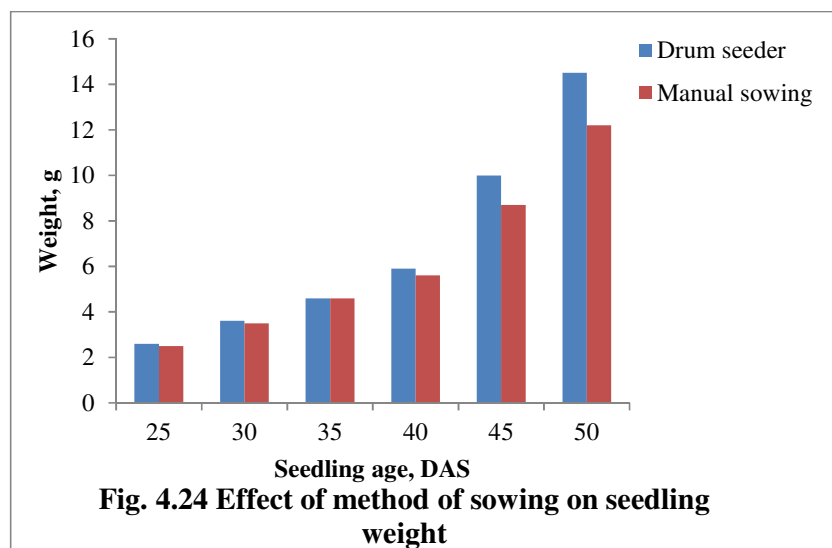
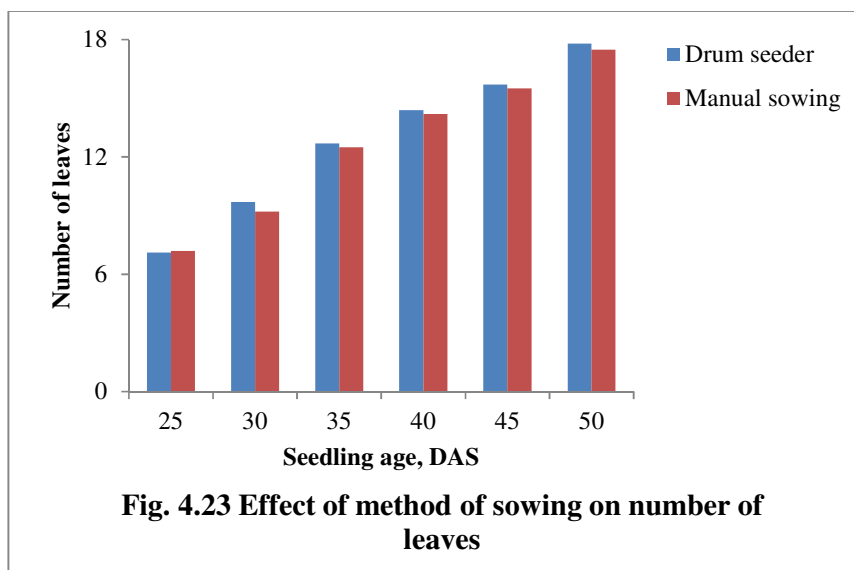
b. Effect of seedling age and method of sowing on seedling stem thickness and width

The effect of seedling age and method of sowing on seedling stem thickness and width was studied and is presented graphically in Fig. 4.22. The seedling stem thickness and width observed to increase with age. The seedling stem thickness and width of drum seeder sown method were observed marginally superior compared to manually sown method. This might be because the seeds had placed more uniformly and at proper depth using drum seeder. Seedling density affects the seedling physical parameters (Mughal *et al.*, 2014, Duryea and Landis, 2012).



c. Effect of seedling age and method of sowing on number of leaves and weight of seedlings

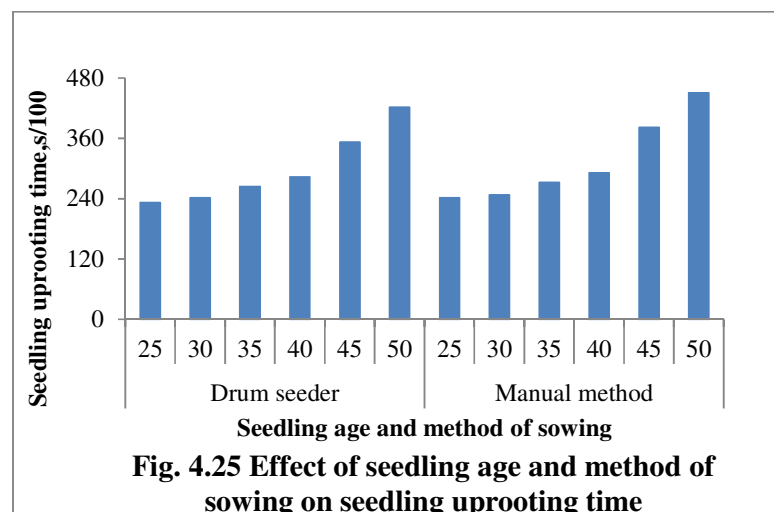
The effect of seedling age and method of sowing on number of leaves and weight of seedlings was studied. The results are reported graphically in Fig. 4.23 and Fig. 4.24. The numbers of leaves and weight of seedlings in case of drum seeder sown seedlings were observed higher than manually sown seedlings. This may be due to the proper seedling density obtained in drum seeder sown method. Similar results were reported by Thapa *et al.*, 2019. The variation in number of leaves and weight of seedlings was observed in both the methods of sowing. This might be due to the availability of nutrient and water to the seedling during its growth.

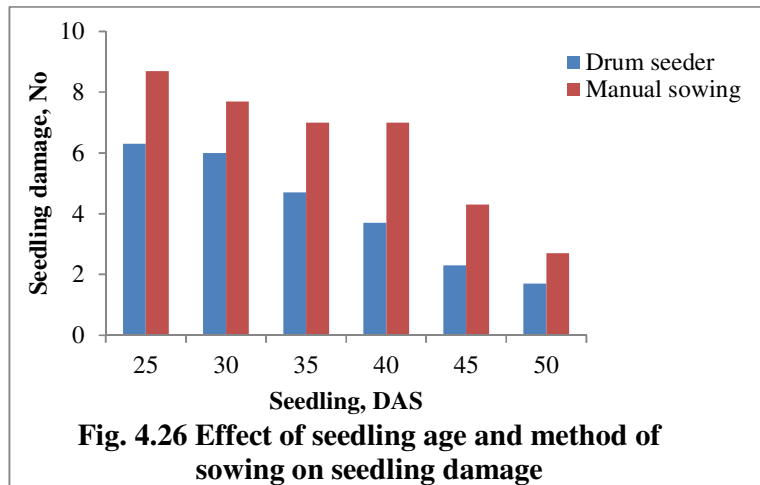


d. Effect of seedling age and method of sowing on seedling uprooting time and seedling damage

The effect of seedling age and method of sowing on seedling uprooting time and seedling damage was studied. The results obtained are depicted graphically in Fig. 4.25 and Fig. 4.26. The seedling uprooting time increased with respect to its age. This may be due to growth of root length that increased the force required and hence time required for the uprooting. It was observed that the moisture content of the soil affected the seedling uprooting time. Higher the moisture content of soil, lesser the time required for uprooting. At lower soil moisture content, the soil remained attached to the roots after uprooting. At lower soil moisture content, it was observed that the younger seedlings roots and stem were damaged while uprooting due to higher uprooting force applied. The seedling damage was observed to decrease with increase in age of seedlings in both methods of sowing.

The growth of seedlings increases with age, which results in stronger seedlings. The higher strength of seedlings results in lower damage during uprooting. While uprooting, the drum seeder sown seedlings were observed to have lesser damage compared to manually sown seedlings. This may be due to sparsely and uniformly sown seeds by drum seeder method. The drum seeder sown seedlings could be uprooted easily. The seedling damage of drum seeder sown seeds was observed to be lesser compared to manually sown seeds (Fig. 4.26). Entangling of the roots of closely grown seedlings may be the reason for more damage in manually sown seedlings. This satisfies the statement that seedling strength decreases with the increase of seed rate (Hossen *et al.*, 2018). It is also due to less competition and better plant nutrition availability with low seeding density (Adhikari *et al.*, 2013).





The laboratory and field studies indicated that the developed drum seeder can be a tool for raising the seedling nursery for finger millet. The experiment on method of raising seedling revealed that developed drum seeder sow the finger millet seeds spaciously and uniformly as compared to manual method which resulted into healthy growth of seedling in nursery. The results are presented in Table 4.2 to 4.3 and graphically in Fig. 4.27 to Fig. 4.31. Table 4.3 represents the percentage variation of physical parameters of seedling grown by drum seeder as compared to seedlings grown by manual method. The healthy seedling further after transplanting establishes well in field and gives higher yield. The similar results that planting healthy and vigorous seedlings can have more productive tillers and higher yield per unit area were reported by Singh *et al.*, 1987. Panda *et al.*, 1991 and Tekrony and Egli 1991. Selecting proper seeding density of finger millet for getting healthy seedlings is the part of further research. The maximum seedling thickness and seedling width obtained were for 24 orifices, 165 diameter wheel and 1 km/h speed ($H_2D_1S_1$) operating combination of drum seeder. Hence, this operating combination of the developed drum seeder was selected for raising seedlings for performance evaluation of the developed transplanting system.

Table 4.2 Effect of forward speed, number of orifices and wheel diameter on physical parameters of seedling at different seedling age

Seedling age, DAS	Physical parameters	Drum seeder operating parameters											
		H ₁ D ₁ S ₁	H ₁ D ₁ S ₂	H ₁ D ₁ S ₃	H ₁ D ₂ S ₁	H ₁ D ₂ S ₂	H ₁ D ₂ S ₃	H ₂ D ₁ S ₁	H ₂ D ₁ S ₂	H ₂ D ₁ S ₃	H ₂ D ₂ S ₁	H ₂ D ₂ S ₂	H ₂ D ₂ S ₃
25	SL	330	290	275	322	289	284	337	300	269	335	285	270
	RL	65	76	81	81	77	77	81	73	68	65	77	75
	SW	5	5	4.5	4.9	5.1	5.3	5.8	5.1	5.2	5	4.8	5.1
	ST	4	4	4.1	4	4.3	4.1	4.4	4	4	4.2	4.4	4
	SWT	7.2	7.3	7	6.8	7.2	7	7.5	6.9	7.2	8	7.3	7.2
30	SL	445	418	400	434	419	410	468	425	385	450	400	401
	RL	73	79	80	83	85	78	90	76	74	71	80	80
	SW	5.3	5.9	5.3	5.2	5.6	6	6.5	6	6.1	5.9	5.6	6.2
	ST	4.5	4.5	4.5	4.3	4.6	4.3	4.7	4.2	4.2	4.4	4.6	4.2
	SWT	8.7	8.2	7.8	7.9	8.6	7.9	9	8.1	8.3	8.9	8.9	8.3
35	SL	499	450	423	489	460	428	510	441	415	495	427	415
	RL	85	96	100	103	92	85	104	93	87	86	100	103
	SW	5.7	7.3	5.9	6.8	6.4	7.2	7.6	7.3	7.2	6.8	7	7.5
	ST	4.9	4.8	5	4.8	4.9	4.8	5	4.7	4.8	4.8	4.8	4.9
	SWT	10	9.9	8.9	9.2	9.9	9.1	10.2	9.2	9.5	9.5	9.7	10.5

Contd...

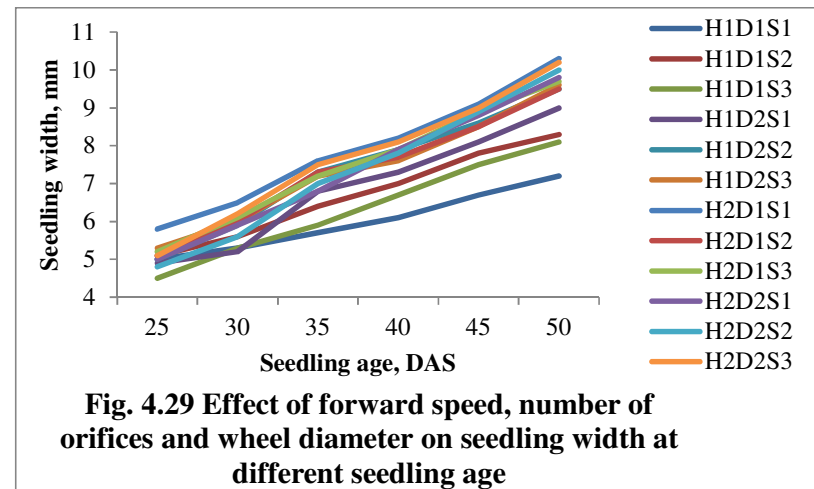
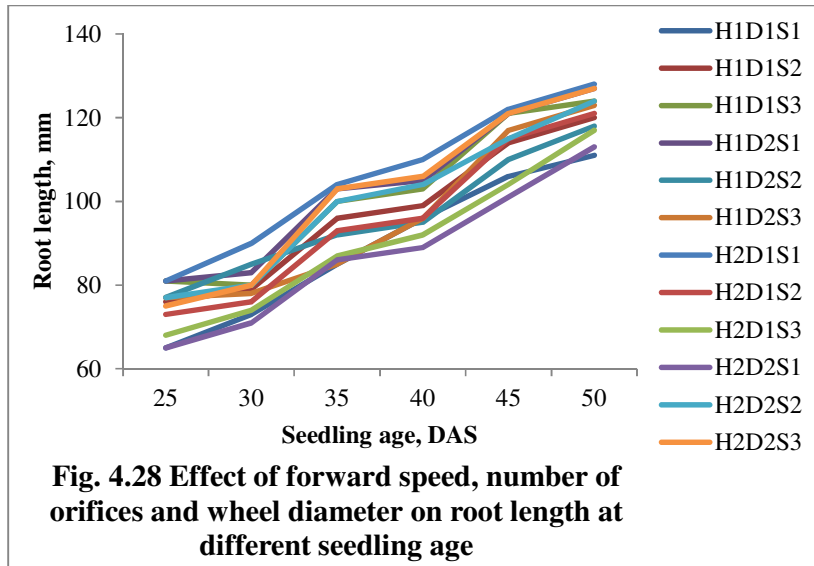
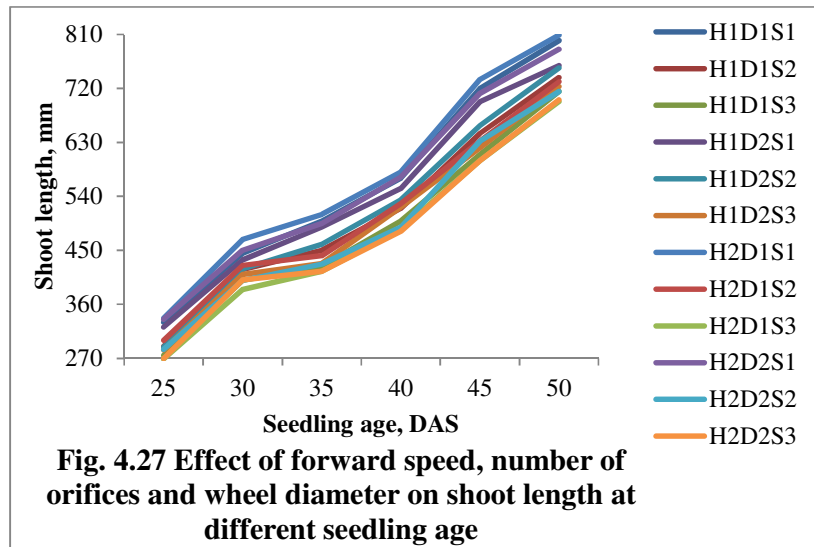
Seedling age, DAS	Physical parameters	Drum seeder operating parameters											
		H ₁ D ₁ S ₁	H ₁ D ₁ S ₂	H ₁ D ₁ S ₃	H ₁ D ₂ S ₁	H ₁ D ₂ S ₂	H ₁ D ₂ S ₃	H ₂ D ₁ S ₁	H ₂ D ₁ S ₂	H ₂ D ₁ S ₃	H ₂ D ₂ S ₁	H ₂ D ₂ S ₂	H ₂ D ₂ S ₃
40	SL	570	520	499	553	534	522	580	528	485	572	489	482
	RL	96	99	103	105	95	96	110	96	92	89	104	106
	SW	6.1	7.9	6.7	7.3	7	7.6	8.2	7.7	7.9	7.9	7.8	8.1
	ST	5.3	5.2	5.6	5.4	5.3	5.3	5.5	5.4	5.3	5.4	5.4	5.3
	SWT	11.2	11	10.2	11.3	11.5	11.2	11.5	10.5	11.4	11.6	10.9	11.7
45	SL	720	645	610	698	658	621	735	632	600	712	632	600
	RL	106	114	121	121	110	117	122	115	104	101	115	121
	SW	6.7	8.6	7.5	8.1	7.8	8.5	9.1	8.5	8.9	8.8	8.9	9
	ST	5.9	5.8	6	5.6	5.8	5.8	6.1	5.6	5.6	5.8	5.7	5.5
	SWT	12.6	11.9	12	12.7	12.9	13.9	14.1	13.1	13.2	13.8	13.9	13.3
50	SL	800	738	715	758	754	723	809	731	698	785	715	701
	RL	111	120	124	127	118	123	128	121	117	113	124	127
	SW	7.2	9.5	8.1	9	8.3	9.6	10.3	9.5	9.7	9.8	10	10.2
	ST	6.7	6.5	6.4	6	6.5	6	6.9	6	6.1	6.5	6.2	6.3
	SWT	14	13.8	12.9	13.9	14	15.7	15.8	14.9	15	15.7	15.6	15.4

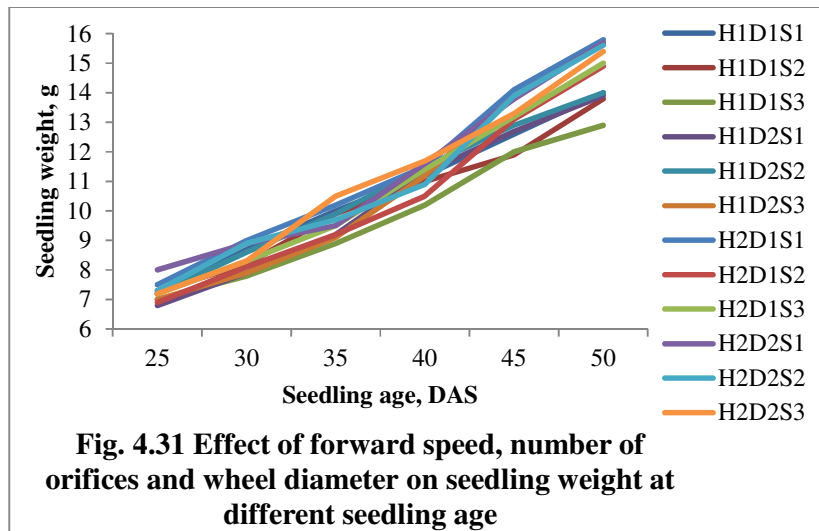
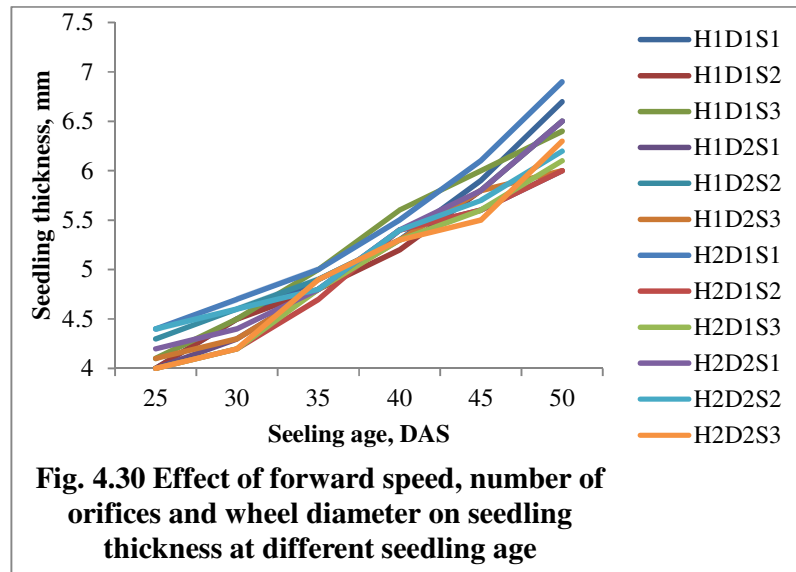
SL–Seedling length (mm), RL–Root length (mm), SW–Seedling width (mm), ST–Seedling thickness (mm), SWT–Seedling weight (g)

H₁ and H₂ – No of orifices (12 and 24), D₁ and D₂ - Diameter of ground wheel (165 and 230 mm); S₁, S₂ and S₃ – Forward speeds (1, 1.5 and 2 km/h)

Table 4.3 Variation of physical parameters of seedling grown by drum seeder as compared to seedlings grown by manual method.

Particulars	Drum seeder						Manually sown						Variation (+/-)					
	25	30	35	40	45	50	25	30	35	40	45	50	25	30	35	40	45	50
Seedling age, DAS	25	30	35	40	45	50	25	30	35	40	45	50	25	30	35	40	45	50
Shoot length, mm	322	434	489	553	698	758	282	394	476	526	686	714	40	40	13	27	12	44
Root length, mm	68	74	87	92	104	117	58	66	85	90	95	104	10	8	2	2	9	13
Canopy width, mm	146	156	170	181	188	198	133	137	145	152	174	183	13	19	25	29	14	15
Stem thickness, mm	23	29	37	42	47	52	20	25	34	38	41	46	3	4	3	4	6	6
Stem width, mm	55	59	67	75	77	79	44	57	60	65	69	73	11	2	7	10	8	6
No. of leaves	7.1	9.7	12.7	14.4	15.7	17.8	7.2	9.2	12.5	14.2	15.5	17.5	-0.1	0.5	0.2	0.2	0.2	0.3
Weight, g	2.6	3.6	4.6	5.9	10	14.5	2.5	3.5	4.6	5.6	8.7	12.2	0.1	0.1	0	0.3	1.3	2.3
Uprooting time / 100 seedlings, sec	231.7	241.7	264.3	283	352.3	421.7	241.3	247.3	272.3	291.3	381.7	450.7	-9.6	-5.6	-8	-8.3	-29.4	-29
Seedling damage /100 seedling uprooted, No	6.3	6	4.7	3.7	2.3	1.7	8.7	7.7	7	7	4.3	2.7	-2.4	-1.7	-2.3	-3.3	-2	-1





4.3 Selection of seedling feed rate for developed finger millet transplanter

To get the required plant spacing and population it was estimated as per Section 3.3. To obtain 0.3, 0.5 and 0.7 km/h transplanter operating speed and 24, 31 and 38 seedling/min feed rate were selected for further study.

4.4 Evaluation of the developed mechanical transplanting system

The developed transplanting system was evaluated in laboratory as per Section 3.6 for seedling feed rate and to verify requirement of one or two operators for seedling feeding to developed transplanter. The results of trials are discussed further.

4.4.1 Evaluation of metering mechanism of transplanter in laboratory

The transplanter was evaluated in laboratory as per Section 3.6.1. The results obtained are presented graphically in Fig. 4.32 to 4.40. It was observed that the seedlings conveyed per 10 min increases with increase in seedling feed rate. Also it

was observed that 95 to 98 % of estimated seedlings were conveyed. The number of seedlings fed by single operator conveyed to furrow increases with increase in seedling age from 25 to 35 DAS. This may be because of the seedling size. Kumar and Tripathi, 2016 also reported that small seedlings are difficult for separating individual seedling while feeding. The 25 and 30 DAS seedlings were getting damaged in the gap between stationery seedlings metering plate and revolving seedling feed cup. This was happened because these seedlings could not be placed properly in seedling feed cup. The 50 DAS seedlings were getting oriented horizontal at the entry point of the seedling feed tube that further blocking the path. It was also observed that in case of 40 and 45 DAS seedlings, around 5 % get trapped in gap between the stationery seedlings metering plate and revolving seedling feed cup. This increases the seedling miss. Similar trends were observed at all forward speeds (Fig. 4.32 to 4.34). Narang *et al.*, (2011) reported that 2.2 to 4.4 % missed plantings for a revolving magazine type or rotary cup type metering device which indicates the plants that are damaged or not able to feed by metering unit into furrow (missed planting).

It was observed that operators did not miss to feed seedlings as operator was comfortable in seedling feeding to cup. However, number of seedlings missed increases with increase in speed of operation with seedling fed by single operator to both carousels. Singh (1994) reported that feed rate and duration of work had a linear relationship with physiological parameters and the number of missing and doubles. Suggs (1979) found that one operator could plant 79.2 tobacco plants per minute with missing of 2.3 % in a conventional transplanter with single loading finger. Kavitha *et al.* (2007) also reported that an increase in per cent plant missing from 0 % to 12.33 % with increase in speed of operation from 0.6 km/h to 1.8 km/h in plug-type metering mechanism developed for wide-spaced crops like brinjal, chilli and tomato.

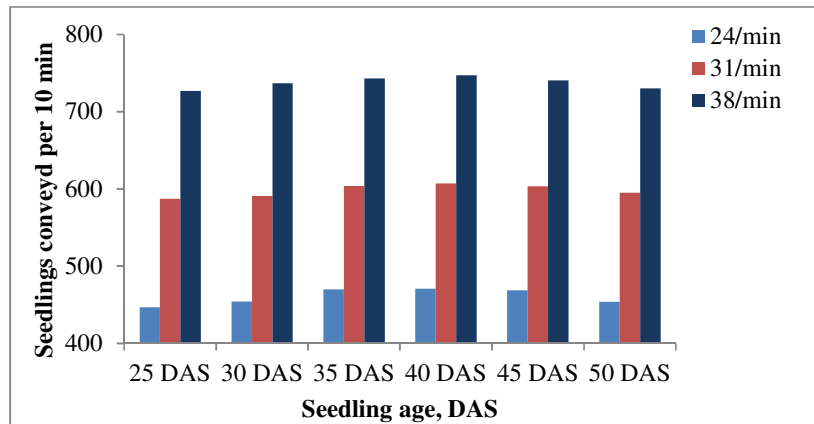


Fig. 4.32 Effect of seedling age and seedling feed rate on seedlings conveyed per 10 min by single operator at 0.3 km/h speed

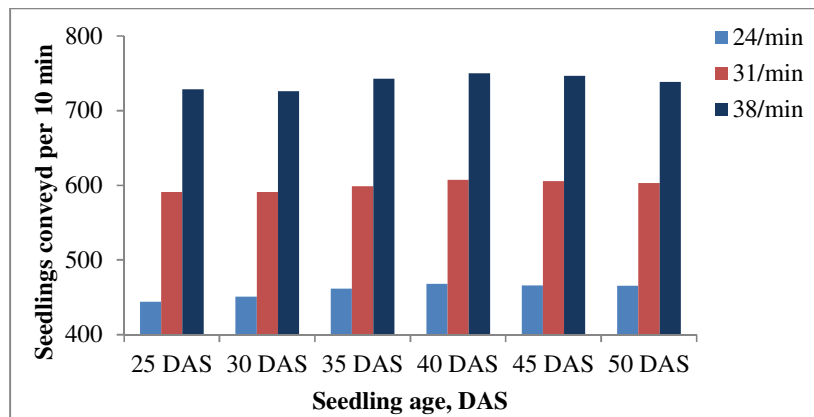


Fig. 4.33 Effect of seedling age and seedling feed rate on seedlings conveyed per 10 min by single operator at 0.5 km/h speed

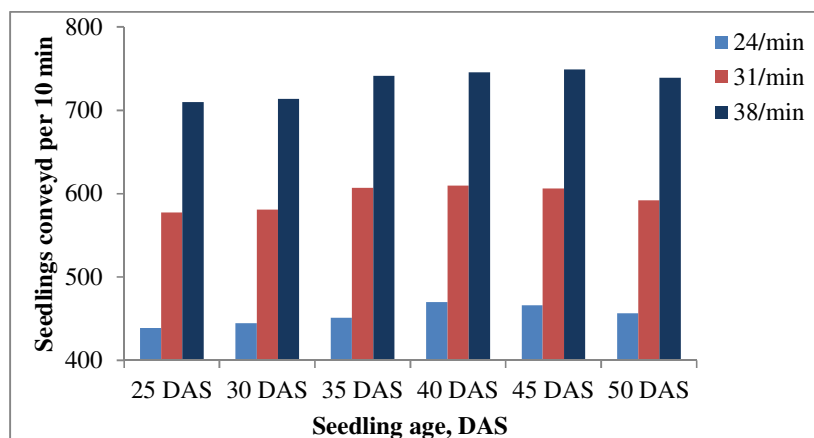
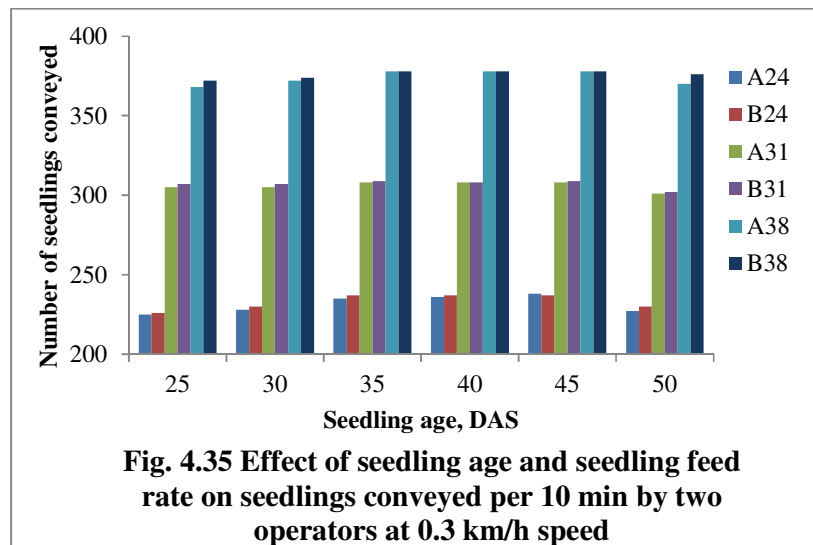
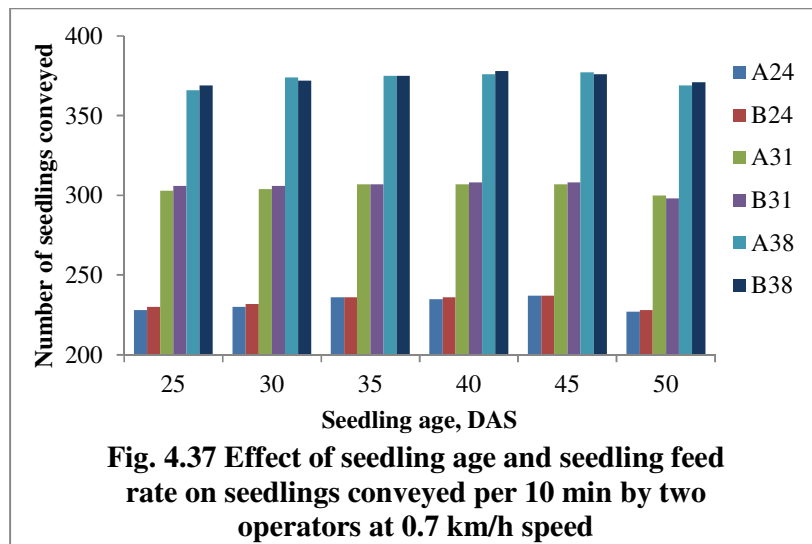
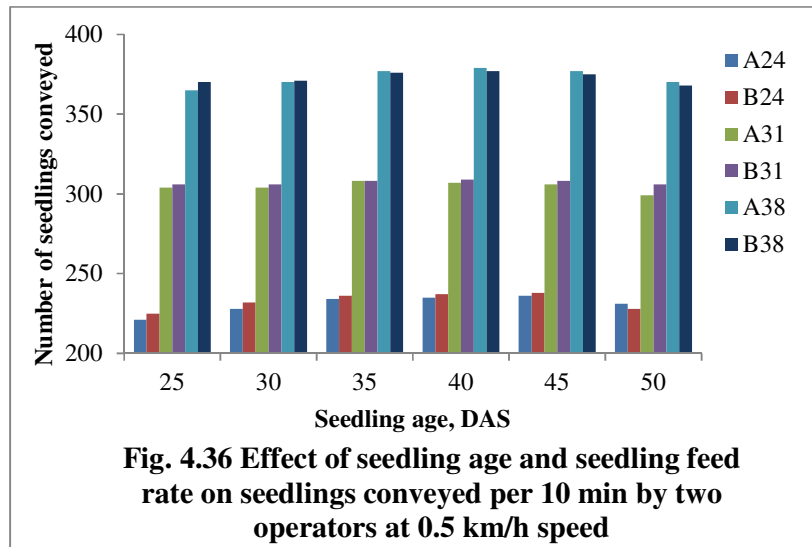


Fig. 4.34 Effect of seedling age and seedling feed rate on seedlings conveyed per 10 min by single operator at 0.7 km/h speed

It was also observed that when an operator fed the seedling for one row *i.e.* two operators for feeding seedling to two row transplanter, around 4 % seedlings were missed which is within acceptable limit. The seedling metering and conveying performance in laboratory of the two row transplanter with two operators to feed seedling are presented graphically in Fig. 4.35 to Fig. 4.37. Where ‘A’ indicates operator for carousal one (row one) and ‘B’ indicates operator for carousal two (row two). Khadatkar *et al.*, (2018), Rasool Kamal *et al.* (2020) reported the similar results. Mori, 1975 reported that the per cent plant missing within the permissible limit of 5 %. The missed seedlings were observed to increase with the seedling feed rate that may be because operator has to feed seedlings more cautiously at higher seedling feed rate and hence tends to commit errors while feeding. Similar results were reported for feed rate by Bhambota *et al.*, (2018) and for forward speed by Hassen and Almubarak, (2019) and Dhupal and Sahu (2020). Anonymous (2004) and Satpathy and Garg, (2008) found that two persons per planting unit (carousel) or per row decreases the per cent of missing.





The comparative laboratory study of operation of two row transplanter with seedling fed by single operator and two operators indicates that the percentage of missed seedlings was of 7.9 % with 25 DAS at 0.5 km/h speed while it was 0.3 % with seedlings of 40 to 45 DAS at 0.3 and 0.5 km/h. Higher seedling miss was observed with single operator for all seedling ages and at all forward speeds. Though two operators were feeding the seedling in feed cup, the 25 to 35 DAS seedling showed near about same trend of seedling missing *i.e.* seedling damage due to crushing at metering mechanism. The 40 and 45 DAS seedlings showed lower percentage of damage (0.3 to 1.7 %) as compare to seedlings of other ages (Fig. 4.38 to Fig. 4.40). The 45 DAS seedlings showed the least damage. It was observed that the percentage of missed seedlings was more for seedlings of 50 DAS. It may be due to the horizontal orientation of seedling while conveying through seedling feed tube.

No particular trend was observed for the missed seedlings with respect to seedling age. The percentage of missed seedling observed to decrease with increase in seedling feed rate. At higher rotary speed of carousel, the seedling might have got lesser chances of getting trapped in the gap between seedling metering plate and seedling feed cup. It was observed that miss seedlings do not vary much with change in speed of operation. The variation may be due to exceptional circumstances at the time of trial. As the missed seedlings were acceptable with two operators, it was decided to conduct the trials on plain land and field with two operators.

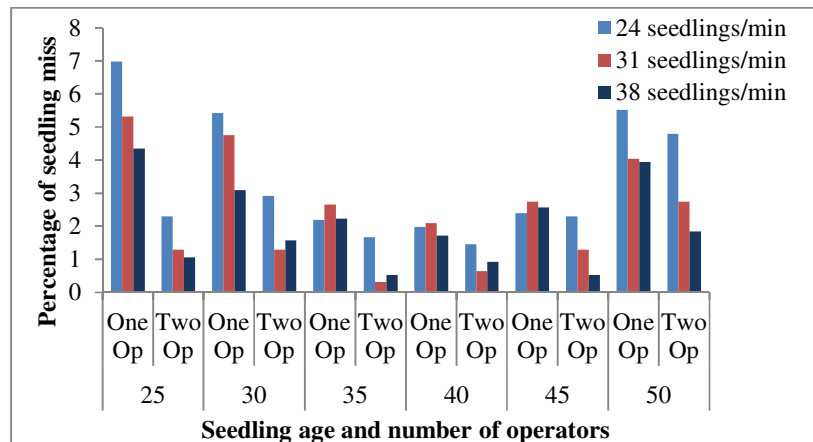


Fig. 4.38 Comparison of percentage of seedling miss by one and two operators at 0.3 km/h speed

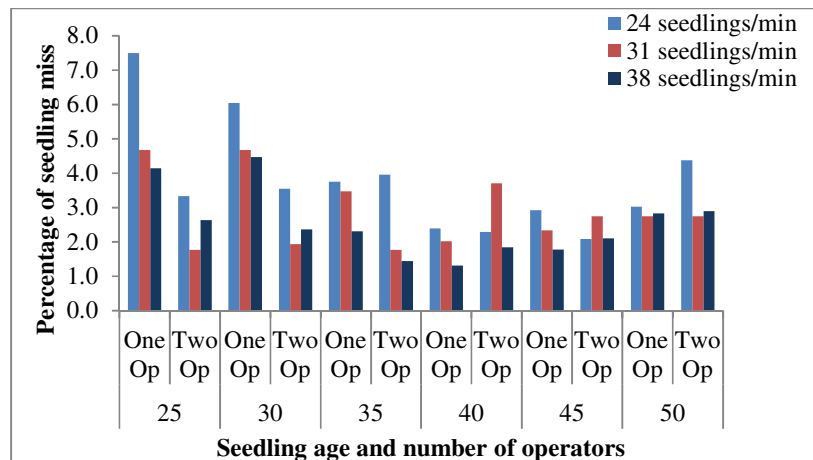
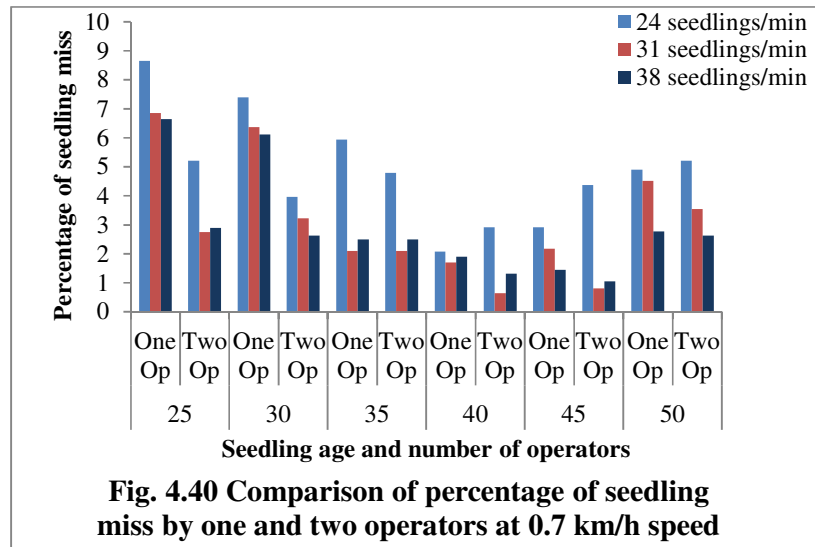


Fig. 4.39 Comparison of percentage of seedling miss by one and two operators at 0.5 km/h speed



The metering mechanism of the transplanting system was evaluated in the jack-up condition in laboratory as per the experimental plan given in Table 3.5. The 25, 30, 35, 40, 45 and 50 DAS seedling were used to know the performance of the metering mechanism at different seedling age and seedling feed rate. The experiment was for check the suitable stage of seedlings for the designed metering mechanism. The trial was also conducted to decide whether one or two operators to be used for seedling feeding. It was observed that the 25 and 30 DAS seedlings were getting damaged in the gap between the stationery seedlings metering plate and revolving seedling feed cup. This may be due to lower height and weight of seedlings could not be placed properly in the seedling feed cup. The number of seedlings conveyed per 10 min were varied in the range of 447 to 729 with the variation in the forward speed and feed rate. The seedlings conveyed per minute were increased *i.e.* 469 to 750 seedlings/10 min for seedlings older than 30 DAS. The 50 DAS seedlings during conveying oriented horizontally at the entry point of the seedling feed tube. The less numbers *i.e.* 453 to 739 of 50 DAS seedlings were conveyed per 10 min. The seedlings of 35, 40 and 45 DAS showed proper metering and conveying through transplanter mechanism than 25, 30 and 50 DAS seedlings (Fig. 4.32 to Fig. 4.34).

The jack-up trials also indicated that two operators are needed to properly feed seedlings to the carousels of metering mechanism. The missed seedlings were observed as reduced with the two operators compared to single operator.

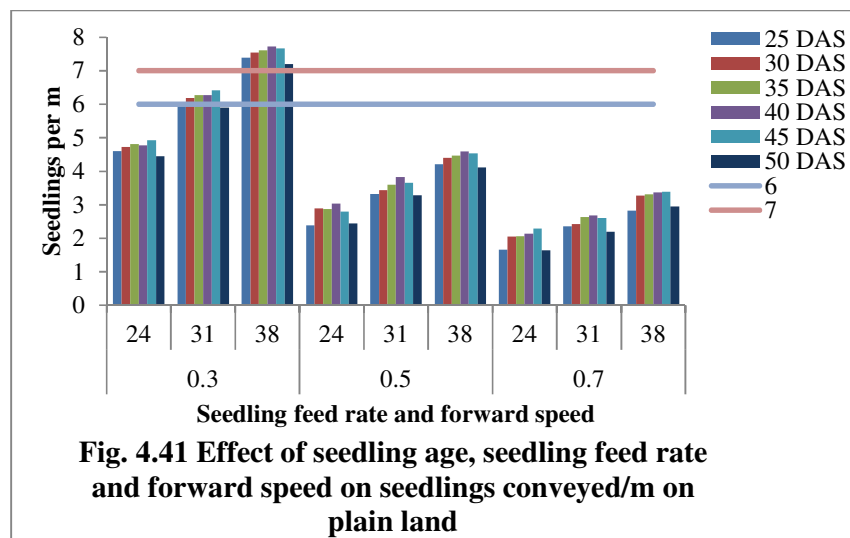
4.4.2 Evaluation of transplanting system on plain land

After the evaluation of metering mechanism of transplanter in laboratory in jack-up condition, the transplanting system was evaluated as per Section 3.6.2 using

seedlings of different ages on the plain land with two operators *i.e.* one operator to feed one carousel. The ANOVA was done using SAS 6.3 version. The results obtained are presented in Appendix X and are discussed below.

a. Seedlings/m

The results for the number of seedlings/m distance are presented graphically in Fig. 4.41. It indicates that with the increase in speed of operation for each seedling feed rate, the distance between the consecutive seedlings increases and hence, the number of seedlings/m decreases. It was observed that irrespective of speed of operation, the increase in feed rate increase the number of seedling conveyed/m distance. The seedlings/m observed to be influenced by seedling age, forward speed and feed rate. The seedling growth that changes with the seedling age might have affected seedlings/m. The 25 to 35 DAS seedlings affected its placement in the seedling feed cup may be due to its lower height. The 40 to 50 DAS seedlings get clogged in the seedling feed tube due to its more height and larger canopy spread. It creates hurdle to the conveyance of the further seedling. Considering the desired plant population, the plant spacing of 250 × 150 mm is required. Accordingly, 6 to 7 seedlings are required per meter. Such desired plants/m were obtained at 0.3 km/h forward speed using seedlings of all ages under study at 31 seedlings/min feed rate only. At 38 seedlings/min feed rate, number of plants/m was higher than desired one. In rest of operating cases, it was less than desired plants/m.



The statistical analysis was done using Design Expert 10 to evaluate the effect of different operating parameters on the performance of transplanter. The ANOVA at

1 % level of significance (Table 4.4) showed that number of seedlings conveyed per 10 m on plain land was influenced by seedling age, forward speed and feed rate. Row and feed rate do not significantly influence seedlings conveyed per 10 m length. The combined effect of forward speed and feed rate *i.e.* the interaction of forward speed × feed rate also observed the significant effect at 1 % level of significance. Seedling age significantly influenced seedling conveyed per 10 m. It may be due to conveyance of seedlings getting affected by seedling growth with respect to age as discussed above.

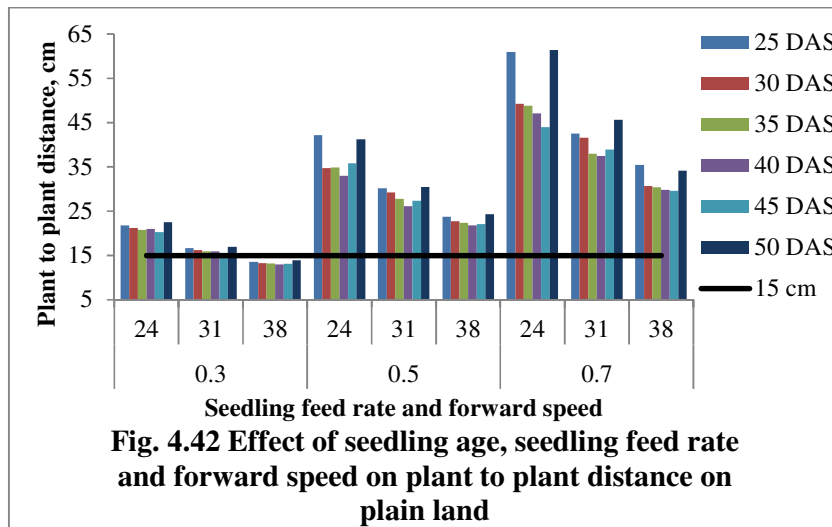
Table 4.4 ANOVA showing the effect of seedling age, seedling feed rate and forward speed on seedlings conveyed per 10 m on plain land

Source	DF	Type I SS	Mean Square	F Value	Pr > F	SE	CD
Rep	3	14.16	4.72	1.25	0.29		
Seedling age	5	1435.36	287.07	76.02	<.0001	0.23	0.64*
Forward speed	2	98928.88	49464.44	13098.30	<.0001	0.16	0.45*
Row	1	3.34	3.34	0.89	0.35	0.13	NS
Feed Rate	2	25770.50	12885.25	3412.05	<.0001	0.23	0.64*
Seedling age × Forward speed	10	62.10	6.21	1.64	0.09	0.40	NS
Seedling age × Row	5	12.21	2.44	0.65	0.66	0.32	NS
Seedling age × Feed rate	10	37.72	3.77	1.00	0.44	0.56	NS
Forward speed × Row	2	1.87	0.93	0.25	0.78	0.23	NS
Forward speed × Feed rate	4	3319.00	829.75	219.72	<.0001	0.40	1.10*
Row × Feed rate	2	9.02	4.51	1.19	0.30	0.32	NS
Seedling age × Forward speed × Row	10	32.33	3.23	0.86	0.57	0.56	NS
Seedling age × Forward speed × Feed rate	20	85.44	4.27	1.13	0.32	0.97	NS
Seedling age × Row × Feed rate	10	39.09	3.91	1.04	0.41	0.56	NS
Forward speed × Row × Feed rate	4	26.48	6.62	1.75	0.14	1.12	NS
Error	341	1287.75	3.78				
Corrected Total	431	131065.25					
Model	90	129777.50	1441.97	381.84	<.0001		

* Significant at 1 % level

b. Plant to plant distance

The results for plant to plant distance are presented graphically in Fig. 4.42. Plant to plant distance observed to increase with forward speed at same seedling feed rate. It decreased with increase in seedling feed rate for same forward speed. Higher than estimated spacing (150 mm) between consecutive plants was observed in case of 25 and 50 DAS seedlings. It may be due to seedlings not conveyed properly through seedling metering mechanism as it trapped in seedling metering mechanism or clogged in seedling feed tube. Plant to plant distance was almost near to desired *i.e.* 150 mm using seedlings of all ages at 0.3 km/h speed at 31 and 38 seedlings/min feed rate. In rest of the operating conditions, it was more than desired spacing due to which plant population cannot be maintained. Similar observations were reported by Dhupal and Sahu (2020) that by increasing forward speed of transplanter missing percentage, plant spacing, planting depth, row spacing and no. of seedlings per hill increases and effective field capacity, theoretical field capacity and field efficiency decreases.



The ANOVA at Table 4.5 indicates that seedling age, forward speed and feed rate influences plant to plant distance. Row (among two rows) does not significantly influence plant to plant distance. The interactions of seedling age \times forward speed, seedling age \times feed rate, forward speed \times feed rate and Seedling age \times forward speed \times feed rate had significant effect on plant to plant distance on plain land at 1 % level of significance.

Table 4.5 ANOVA showing the effect of seedling age, seedling feed rate and forward speed on plant to plant distance on plain land

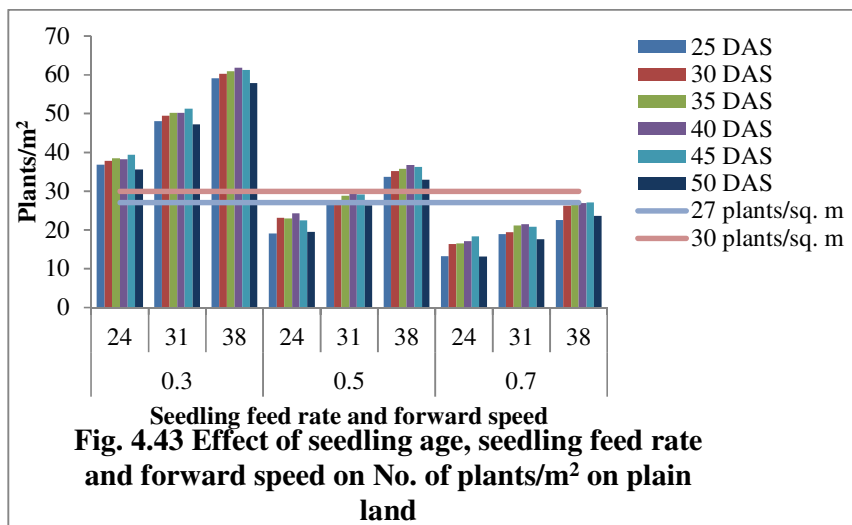
Source	DF	Type I SS	Mean Square	F Value	Pr > F	SE	CD
Rep	3	2.23	0.74	0.12	0.9		
Seedling age	5	1850.66	370.13	59.03	<.0001	0.30	0.82*
Forward speed	2	43345.18	21672.59	3456.65	<.0001	0.21	0.58*
Row	1	3.17	3.17	0.51	0.5	0.17	NS
Feed rate	2	14322.17	7161.08	1142.15	<.0001	0.30	0.82*
Seedling age × Forward speed	10	895.51	89.55	14.28	<.0001	0.51	1.42*
Seedling age × Row	5	28.23	5.65	0.90	0.5	0.42	NS
Seedling age × Feed rate	10	587.11	58.71	9.36	<.0001	0.72	2.01*
Forward speed × Row	2	4.73	2.36	0.38	0.7	0.30	NS
Forward speed × Feed rate	4	1914.69	478.67	76.35	<.0001	0.51	1.42*
Row × Feed rate	2	11.80	5.90	0.94	0.4	0.42	NS
Seedling age × Forward speed × Row	10	74.58	7.46	1.19	0.3	0.72	NS
Seedling age × Forward speed × Feed rate	20	420.28	21.01	3.35	<.0001	1.25	3.48*
Seedling age × Row × Feed rate	10	51.09	5.11	0.81	0.6	0.72	NS
Forward speed × Row × Feed rate	4	18.04	4.51	0.72	0.6	1.45	NS
Error	341	2138.01	6.27				
Corrected Total	431	65667.48					
Model	90	63529.47	705.8829	112.58	<.0001		

* Significant at 1 % level

c. Number of plants/m²

The data for plants/m² is presented graphically in Fig. 4.43. While transplanting with the developed transplanter, single seedling was transplanted at a spot. The required number of plants/m² is 27 to 30 considering single seedling per hill

and plant spacing 250×150 mm. Plants/m² were higher than required at lowest speed of 0.3 km/h. It ranged between 36 to 62 plants/m². While at highest speed of 0.7 km/h it was lower than required. It ranged between 13 to 27 plants/m². At 0.5 km/h speed and 31 seedlings/min feed rate, plant population obtained was near to required (27 to 32 seedlings/m²). At 0.5 km/h speed with 24 and 38 seedlings/min feed rate, seedling population obtained was respectively lower and higher than required plant population. Plants/m decreases using seedlings of 45 and 50 DAS, (Fig. 4.43). Bigger size of seedling of 45 and 50 DAS created clogging in seedling path. Seedling age, forward speed of transplanting unit and seedling feed rate affected number of plants/m² as it does in case of seedlings/m.



The ANOVA indicated that the seedling age, forward speed and feed rate individually influenced plants/m² at 1 % level of significance. The interaction of Forward speed \times Feed rate also influenced plants/m² on plain land (Table 4.6). Plants/m² might have got influenced by similar reasons that affected the seedlings/m.

Table 4.6 ANOVA showing the effect of seedling age, seedling feed rate and forward speed on No. of plants/m² on plain land

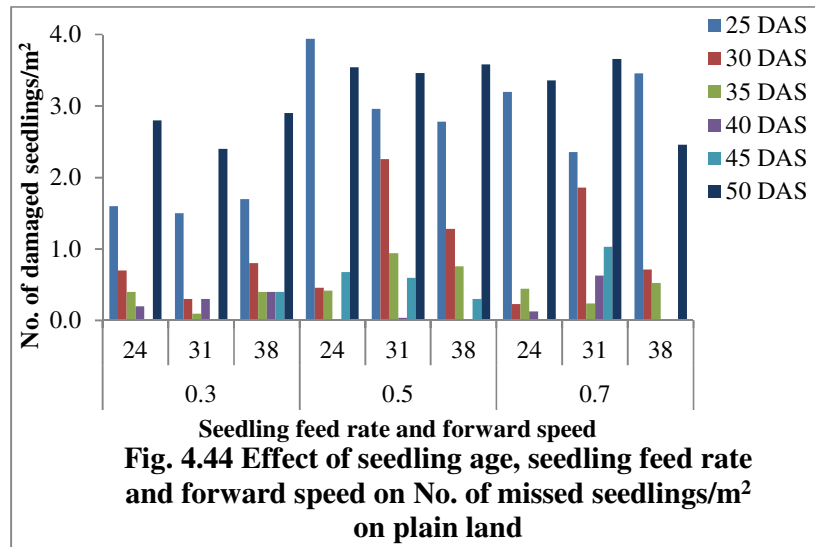
Source	DF	Type I SS	Mean Square	F Value	Pr > F	SE	CD
Rep	3	5.46	1.82	1.26	0.2895		
Seedling age	5	440.71	88.14	61.12	<.0001	0.20	0.56*
Forward speed	2	31707.00	15853.50	10993.5	<.0001	0.14	0.40*
Feed rate	2	8313.44	4156.72	2882.44	<.0001	0.14	0.40*
Seedling age \times Forward speed	10	26.17	2.62	1.81	0.0619	0.20	NS
Seedling age \times Feed rate	10	17.06	1.71	1.18	0.3062	0.35	NS

Forward speed × Feed rate	4	1084.22	271.06	187.96	<.0001	0.35	0.97*
Seedling age × Forward speed × Feed rate	20	33.28	1.66	1.15	0.3017	0.49	NS
Error	159	229.29	1.44				
Corrected Total	215	41856.63					
Model	56	41627.33	743.35	515.47	<.0001		

* Significant at 1 % level

d. Number of seedlings missed/m²

The observations for the seedlings or plants missed/m² were recorded and presented graphically in Fig. 4.44. It was observed that the operator did not missed seedling to feed to the metering mechanism. The seedlings or plants missed were occurred due to the improper conveyance of the seedlings from seedling metering mechanism to opened furrow. The seedlings of 25 DAS missed/m² were ranged between 2 to 4. It ranged between 3 to 4 missed seedlings/m² when seedlings of 50 DAS were used. It indicated that the more number of missed seedlings were observed using the seedlings of 25 DAS and 50 DAS. The placement of 25 DAS seedlings in the seedling feed cup might have affected due to its lower height. It gets trapped in the metering mechanism. Whereas, when the 50 DAS seedling falls through the seedling cup in to the seedling conveying tube, due its root length and height, the seedling sometimes gets placed horizontally at the entrance of this tube and it get clogged between the metering plate and the seedling conveying tube. It creates the hindrance for the further seedlings to convey. The missed seedlings for seedlings of 45 DAS ranged 0 to 1/m², which were minimum compared to other seedling ages. It was observed that missed seedlings increased with the increase in the forward speed of transplanter. The seedlings those were trapped in the seedling metering mechanism were failed to get conveyed in the open furrow. Hence, it creates the missed hill. The missed seedling may be due to operator or seedling clogging while conveying.



The ANOVA for the missed seedlings showed that the seedling age and forward speed influenced the seedling damage. Seedling growth was the major reason for the seedling trapped in the seedling conveying system. The trapped seedlings create gaps in the consecutive seedlings conveying in the row. The higher missed seedlings increases with the increase in the forward speed (Table 4.7). The missed seedlings observed high with 25 and 50 DAS seedlings. No other operating parameter significantly affected the seedling missed.

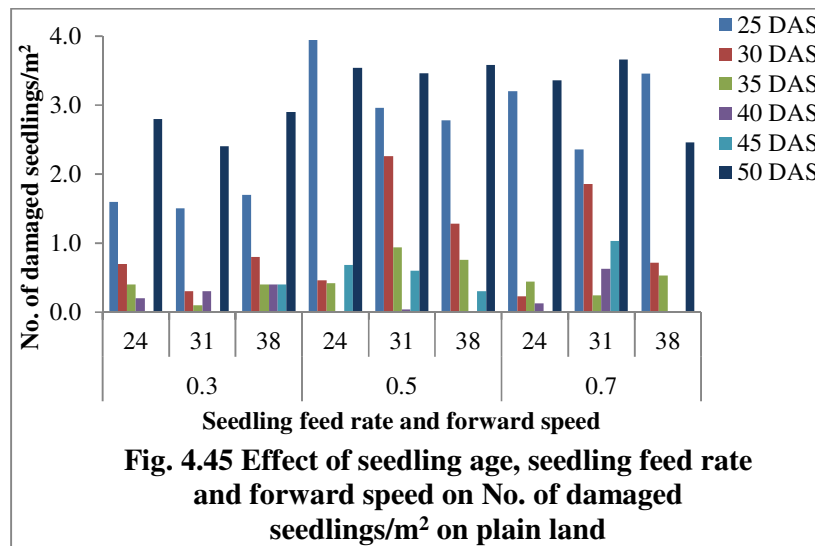
Table 4.7 ANOVA showing the effect of seedling age, seedling feed rate and forward speed on No. of missed seedlings/m² on plain land

Source	DF	Type I SS	Mean Square	F Value	Pr > F	SE	CD
Rep	3	0.24	0.08	0.09	0.9658		
Seedling age	5	307.22	61.44	68.43	<.0001	0.16	0.44*
Forward speed	2	13.00	6.50	7.24	0.001	0.11	0.31*
Feed rate	2	1.19	0.60	0.67	0.5156	0.11	NS
Seedling age × Forward speed	10	14.61	1.46	1.63	0.1032	0.16	NS
Seedling age × Feed rate	10	8.25	0.83	0.92	0.5174	0.27	NS
Forward speed × Feed rate	4	3.39	0.85	0.94	0.4404	0.27	NS
Seedling age × Forward speed × Feed rate	20	17.83	0.89	0.99	0.4734	0.39	NS
Error	159	142.76	0.90				
Corrected Total	215	508.50					
Model	56	365.74	6.53	7.27	<.0001		

* Significant at 1 % level

e. Number of seedlings damaged/m²

The data for number of seedlings damaged was recorded and is presented graphically in Fig. 4.45. The seedlings those were trapped in seedling metering mechanism were failed to get conveyed in open furrow. These trapped seedlings were damaged in metering mechanism due to crushing. These seedlings were counted as seedling damaged. The more number of damaged seedlings were observed using seedlings of 25 DAS and 50 DAS. Placement of 25 DAS seedlings in seedling feed cup may be affected due to its lower height. It gets trapped in metering mechanism. Whereas, when larger seedling falls through seedling cup in to seedling conveying tube, due its roots and height, seedling sometimes gets placed horizontally at entrance of this tube. These were also getting crushed in metering mechanism. Number of damage seedlings increases with forward speed of transplanting unit. It is observed that seedlings are damaged in metering and conveyance mechanism only.



The ANOVA for the number of damaged seedlings showed that the seedling age and forward speed influenced the seedling damage at 1 % level of significance. Seedling growth was the major reason for the seedling trapped in the seedling conveying system (Table 4.8). The number of damaged seedlings observed more in case of 25 and 50 DAS seedlings at all speeds. Where as in case of 30 DAS seedlings, it was more at higher forward speed.

Table 4.8 ANOVA showing the effect of seedling age, seedling feed rate and forward speed on No. of damaged seedlings/m²

Source	DF	Type I SS	Mean Square	F Value	Pr > F	SE	CD
Rep	3	0.24	0.08	0.09	0.9658		
Seedling age	5	307.22	61.44	68.43	<.0001	0.16	0.44*
Forward speed	2	13.00	6.50	7.24	0.001	0.11	0.31*
Feed rate	2	1.19	0.60	0.67	0.5156	0.11	NS
Seedling age × Forward speed	10	14.61	1.46	1.63	0.1032	0.16	NS
Seedling age × Feed rate	10	8.25	0.83	0.92	0.5174	0.27	NS
Forward speed × Feed rate	4	3.39	0.85	0.94	0.4404	0.27	NS
Seedling age × Forward speed × Feed rate	20	17.83	0.89	0.99	0.4734	0.39	NS
Error	159	142.76	0.90				
Corrected Total	215	508.50					
Model	56	365.74	6.53	7.27	<.0001		

* Significant at 1 % level

It was planned to evaluate the transplanting system for seedlings conveyance on the plain land. The operators were trained to feed seedlings before field trials. As combination of ground wheel diameter, speed of operation, gear ratio, chain ratio and number of cup on carousel varied to get desired feed rate. The operator has to practice to feed single seedling in cup of carousel. The seedlings of 25, 30, 35, 40, 45 and 50 DAS were used for trials. It was observed that at 0.3 km/h speed and 31 seedlings/min feed rate, the 35 to 45 DAS seedlings properly conveyed from metering mechanism and is acceptable. At 0.3 km/h forward speed and 24 seedlings/min feed rate, and at 0.5 and 0.7 km/h forward speeds and for all the seedling feed rate, the seedlings conveyed/m were lower than the required. Similar observations were recorded for the plant to plant distance for these operating parameters. The numbers of plants/m² were observed within the acceptable limits *i.e.* 27 to 30 at 0.5 km/h forward speed and 31 seedlings/min feed rate. At 0.3 km/h, these values were higher while at 0.7 km/h speed these values were lower. This may be due to seedlings damage and missed at these operating parameters. The missed seedlings were 1.5 to 3.5/m² for 25 DAS, 0.2 to 2.2/m² for 30 DAS and 2.4 to 3.7/m² for 50 DAS at different speeds of operation. The seedling growth stage and the seedlings feed rate affected the missed and damaged seedlings. With the increase in the forward speed, the seedlings/m and

plants/m² were observed to be reduced. It was also observed that at 0.3 km/h speed and 31 seedlings/min feed rate, the 35 to 45 DAS seedlings conveyed from metering mechanism was in acceptable limits.

4.4.3 Field evaluation of transplanting system

The seedling metering mechanism of the designed transplanting method was tested in the laboratory under jack-up conditions. The transplanting system was also tested on plain land. The tests were conducted as per the experimental plan given in Table 3.7 and Section 3.6.1 and 3.6.2. Based on the results of these experimentations, the transplanting system was evaluated in field as per experimental plan given on Table 3.5 and section 3.6.3. The seedlings of 35, 40, and 45 DAS only were used for the field trials as the seedlings of 25, 30 and 50 DAS had more missing and damage percentage in the laboratory testing of the transplanter. The results obtained were analysed and optimized statistically by RSM method using 'Design Expert 10'. The results obtained are given in Appendix XI and are discussed below.

a. Number of seedlings/m

The data for seedlings conveyed in 10 m length of travel was recorded. The average values of seedlings/m length were determined and are presented graphically in Fig. 4.46 and 4.47. The required numbers of seedlings/m are 6 – 7 considering 150 mm plant spacing. The seedling feed rate of 38 seedlings/min conveyed 8, 5 and 3 seedlings of 40 DAS at 0.3, 0.5 and 0.7 km/h forward speed. It was observed that at 0.3 km/h speed, the numbers of seedlings conveyed/m were near to the required value for all seedling feed rates. In the experiment, average 1.7 to 4.7 seedlings/m, which is less than required value, were observed with 35 DAS and 45 DAS seedlings. It was observed that the seedlings/m length decreases with increase in the forward speed for each seedling feed rate. Srivastava *et al.*, 2006, Pandirwar *et al.*, 2018 reported that the forward speed and seeding feed rate have significant effect on the number of seedlings/m length of travel.

Fig 4.47 (a) indicates that the seedlings/m length increases with the reduction in the speed of travel for seedlings of all ages used for the test. Fig. 4.47 (b) shows the seedlings/m length increases with the increase in the seedlings feed rate for seedlings of all the ages. Fig. 4.47 (c) indicates with reduction in speed and increase in seedling feed rate, the number of seedlings/m observed to increase. It was highest at least speed and maximum seedling feed rate used for the trial. The effect on the seedlings/m while seedling feed rate and speed of travel affects it.

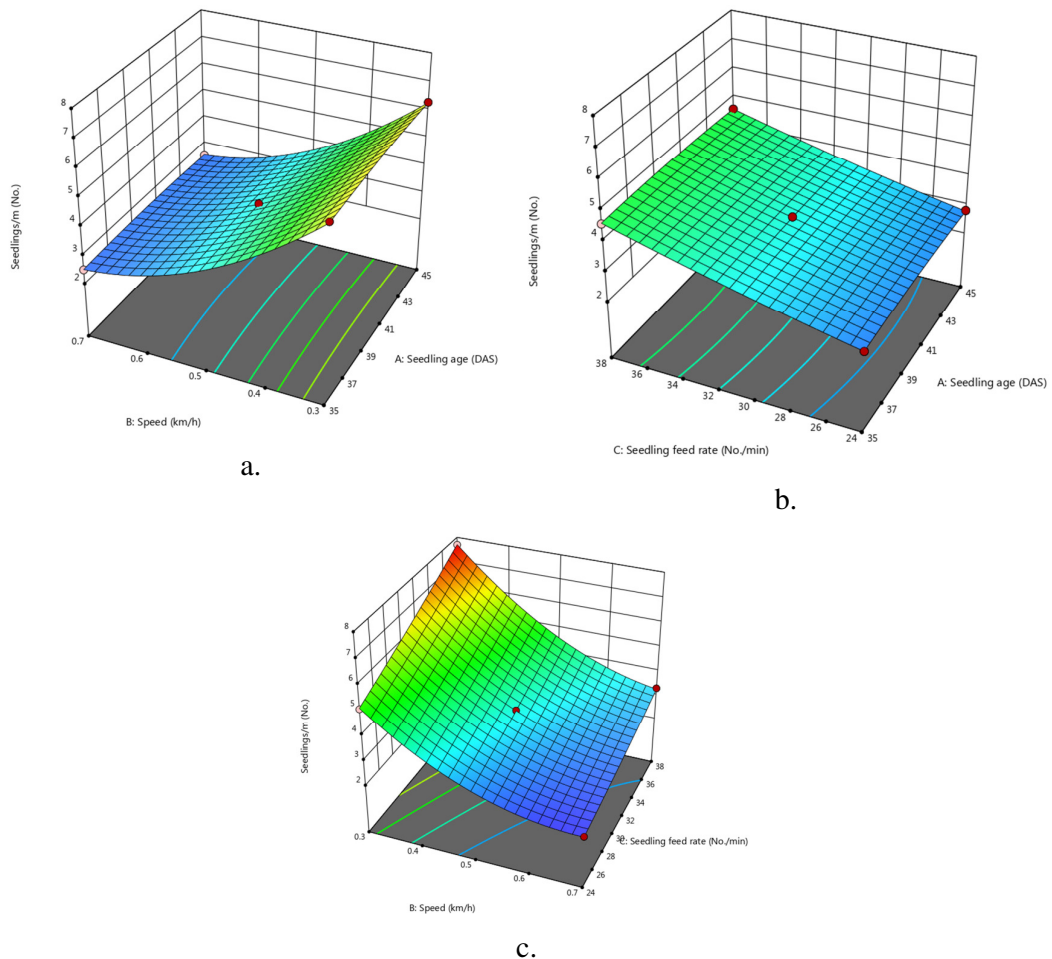
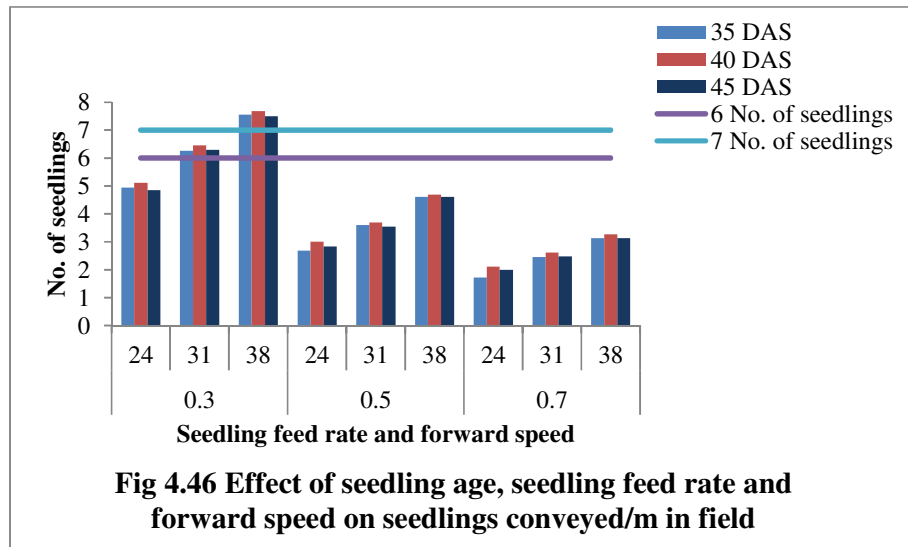


Fig. 4.47 Effect of independent parameters on seedlings conveyed/m in field

The ANOVA (Table 4.9) indicates seedling age, forward speed and seedling feed rate individually influenced the seedlings per 10 m distance at 1 % level of

significance. The interaction of Forward speed \times Feed rate indicated its influence on seedlings per 10 m. The other parameters and its interactions didn't show such effect.

Table 4.9 ANOVA for Quadratic model showing effect of seedling age, seedling feed rate and forward speed on seedlings per 10 m distance in field

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	38.39	9	4.27	1926.22	< 0.0001	Significant
A-Seedling age	0.0012	1	0.0012	0.5645	0.4769	
B-Speed	28.12	1	28.12	12701.61	< 0.0001	*
C-Seedling feed rate	7.03	1	7.03	3175.40	< 0.0001	*
AB	0.0000	1	0.0000	0.0000	1.0000	
AC	0.0025	1	0.0025	1.13	0.3233	
BC	0.4900	1	0.4900	221.29	< 0.0001	*
A ²	0.0253	1	0.0253	11.42	0.0118	
B ²	2.68	1	2.68	1209.38	< 0.0001	*
C ²	0.0221	1	0.0221	9.99	0.0159	
Residual	0.0155	7	0.0022			
Lack of Fit	0.0075	3	0.0025	1.25	0.4028	not significant
Pure Error	0.0080	4	0.0020			
Cor Total	38.40	16				
Std. Dev.	0.0471			R²	0.9996	
Mean	4.05			Adjusted R²	0.9991	
C.V. %	1.16			Predicted R²	0.9965	
				Adeq Precision	155.8584	

* Significant at 1 % level

The **Model F-value** of 1926.22 implies the model is significant. There is only a 0.01 % chance that an F-value this large could occur due to noise.

P-values less than 0.0500 indicate model terms are significant. In this case B, C, BC, and B² are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve model.

The **Lack of Fit F-value** of 1.25 implies the Lack of Fit is not significant relative to the pure error. There is a 40.28 % chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

The **Predicted R²** of 0.9965 is in reasonable agreement with the **Adjusted R²** of 0.9991; *i.e.* the difference is less than 0.2.

Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 155.858 indicates an adequate signal. This model can be used to navigate the design space.

Final equation in terms of actual factors

$$\begin{aligned} \text{Seedlings/m} = & + 0.801263 + 0.272643 * A - 21.56250 * B + 0.195765 * C - 9.37333E-16 \\ & * A * B - 0.000714 * B * C - 0.25 * A * C - 0.003100 * A^2 + 19.93750 * B^2 \\ & + 0.001480 C^2 \end{aligned} \quad \dots(\text{Eqn 4.1})$$

$R^2 = 0.9965$

Where,

A = Seedling age, DAS

B = Speed, km/h

C = Seedling feed rate, seedlings/min

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Comparison of actual and predicted values of seedlings/m as per Eqn 4.1 is shown in Fig 4.48. Actual values are much close to predicted values ($R^2 = 0.9344$).

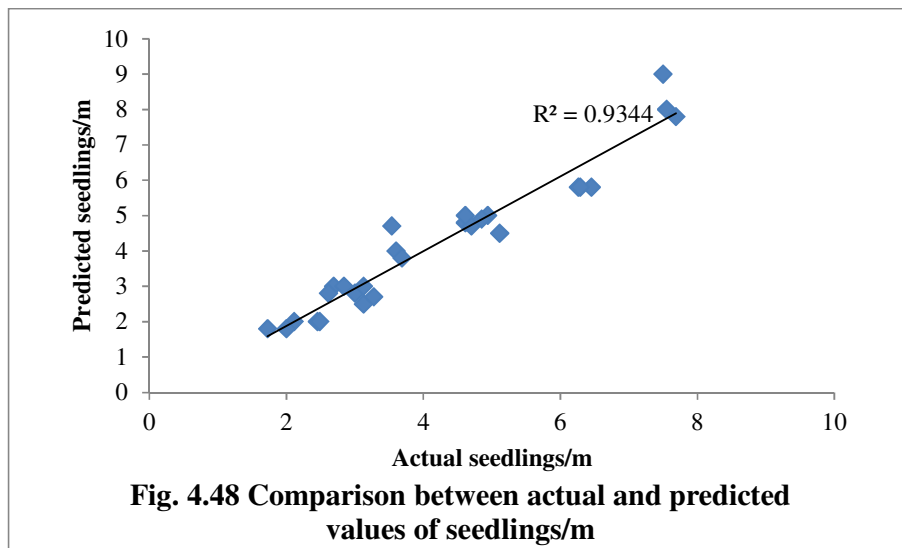


Fig. 4.48 Comparison between actual and predicted values of seedlings/m

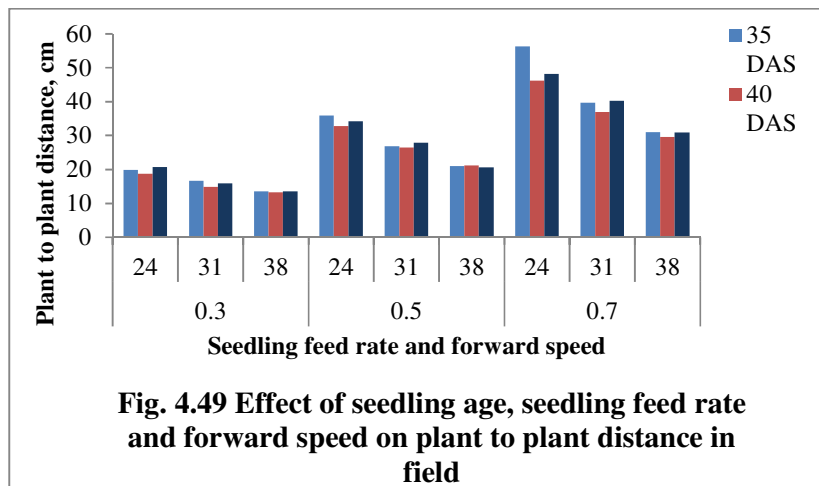
b. Plant to plant distance

The experimental findings of trials for the plant to plant distance are presented graphically in Fig. 4.49 and 4.50. The required plant to plant distance is 150 mm. It was observed that at 0.3 km/h speed and 31 seedlings/min feed rate, the plant to plant distance for 35, 40 and 45 DAS seedlings was 150 to 170 mm which is acceptable.

The plant to plant distance was observed to be increased with increase in the speed of operation. It ranged between 210 to 610 mm for 0.5 and 0.7 km/h speeds. Similar results were reported by Pandirwar *et al.*, 2018 that the change in forward speed and feed rate affects the plant to plant distance.

The forward speed of the transplanter could not be maintained due to the field undulations, soil moisture content and difference in the soil condition. This might have caused the variation in the plant to plant distance. The negative slippage of transplanter conveyed the seedlings at short distance while its positive slippage conveyed seedlings at longer distance. The plant to plant distance might have varied due to improper conveyance of the seedlings and stage of seedling age.

Fig. 4.50 (a) indicates that plant to plant distance increases with the increase in the speed of travel for all the ages of the seedlings used for the trial. Fig. 4.50 (b) indicates that plant to plant distance decreases with increase in seedling feed rate for all ages of seedlings used for trials. Seedling age do not have any effect on plant to plant distance while seedling feed rate and speed of travel affects it. Fig. 4.50 (c) indicates cumulative effect of seeding feed rate and speed of travel on plant to plant distance. It was observed to increase with speed and decrease in seedling feed rate.



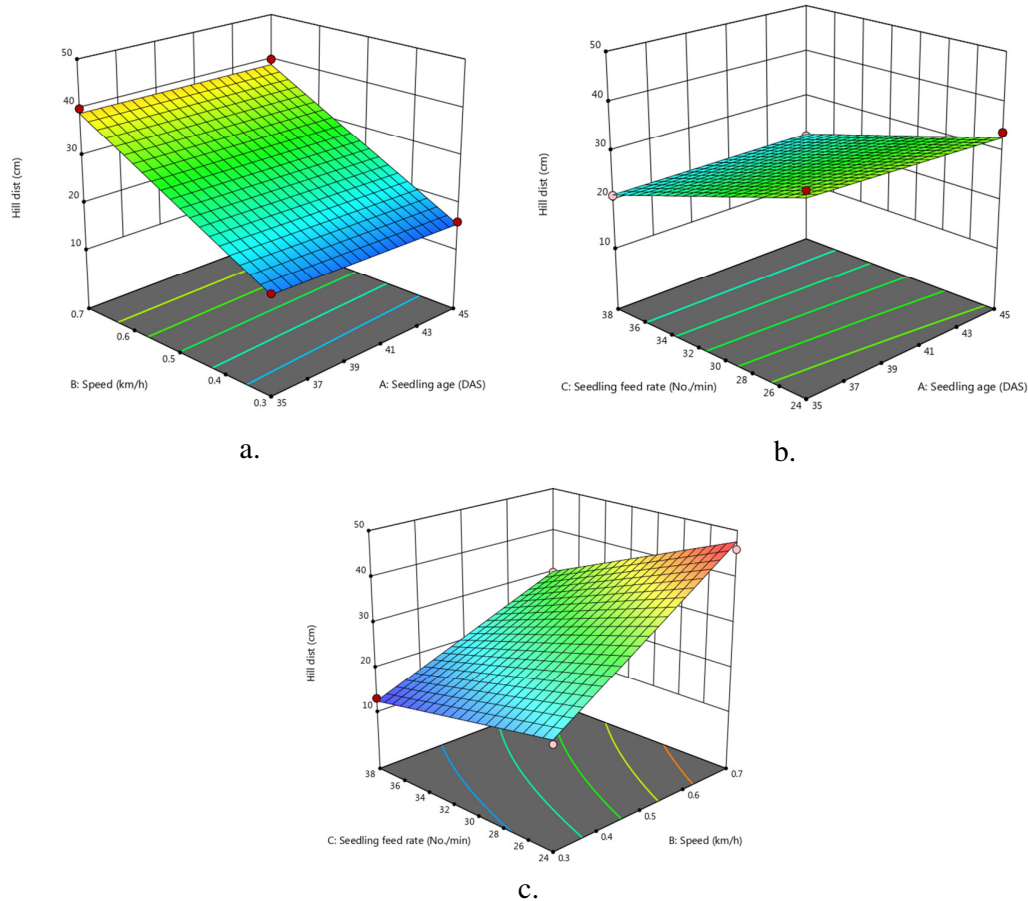


Fig. 4.50 Effect of independent parameters on plant to plant distance in field

The ANOVA for plant to plant distance indicates that seedling age, forward speed and seedling feed rate have effect on plant to plant distance at 1 % level of significance. The interactions of Seedling age \times Forward speed, Seedling age \times Feed rate, Forward speed \times Feed rate, Seedling age \times Forward speed \times Feed rate also showed the significant effect on the plant to plant to distance (Table 4.10). The plant to plant distance depends on the number of seedlings conveyed/m. It is affected by seedling age, forward speed and seedling feed rate.

Table 4.10 ANOVA for 2FI model showing effect of seedling age, seedling feed rate and forward speed on plant to plant distance in field

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	1375.00	6	229.17	203.97	< 0.0001	significant
A-Seedling age	1.13	1	1.13	1.00	0.3406	
B-Speed	1035.12	1	1035.12	921.32	< 0.0001	*
C-Seedling feed rate	312.50	1	312.50	278.14	< 0.0001	*
AB	0.2500	1	0.2500	0.2225	0.6473	

AC	1.0000	1	1.0000	0.8901	0.3677	
BC	25.00	1	25.00	22.25	0.0008	*
Residual	11.24	10	1.12			
Lack of Fit	11.24	6	1.87			Non-significant
Pure Error	0.0000	4	0.0000			
Cor Total	1386.24	16				
Std. Dev.	1.06			R²	0.9919	
Mean	27.53			Adjusted R²	0.9870	
C.V. %	3.85			Predicted R²	0.9624	
				Adeq Precision	51.8254	

* Significant at 1 % level

The **Model F-value** of 203.97 implies the model is significant. There is only a 0.01 % chance that an F-value this large could occur due to noise.

P-values less than 0.0500 indicate model terms are significant. In this case B, C, BC are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model.

The **Lack of Fit F-value** of 0.0349 implies the Lack of Fit is not significant relative to the pure error. There is a 99.95 % chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

The **Predicted R²** of 0.9624 is in reasonable agreement with the **Adjusted R²** of 0.9870; *i.e.* the difference is less than 0.2.

Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 51.825 indicates an adequate signal. This model can be used to navigate the design space.

The regression equation (Eqn 4.2) representing variation of plant to plant distance, mm with different independent parameters were fitted in polynomial is

Final Equation in Terms of Coded Factors

$$\text{Hill dist.} = 24.80620 - 0.642857*A + 102.23214*B - 0.571429*C + 0.25*A*B + 0.014286*A*C - 1.78571*B * C \quad \dots(\text{Eqn 4.2})$$

$$R^2 = 0.9624$$

Where,

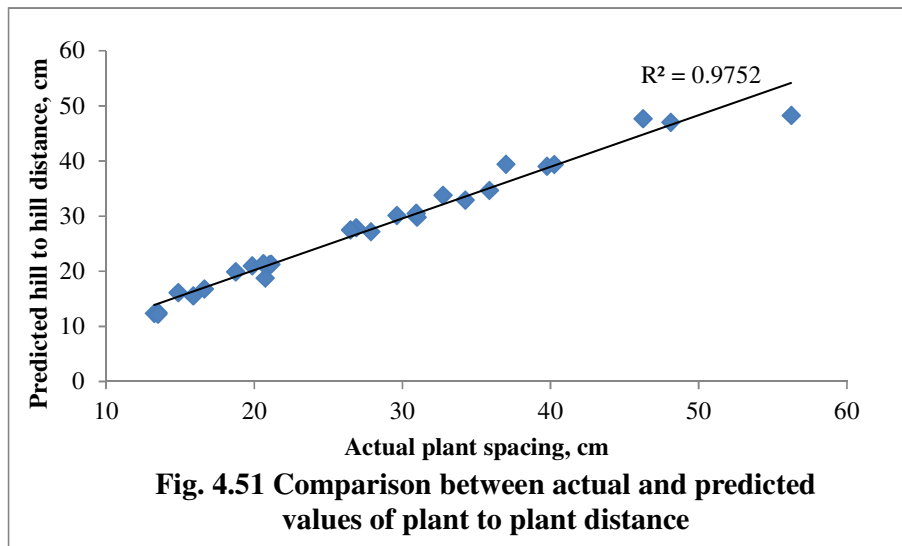
A = Seedling age, DAS

B = Speed, km/h

C = Seedling feed rate, seedlings/min

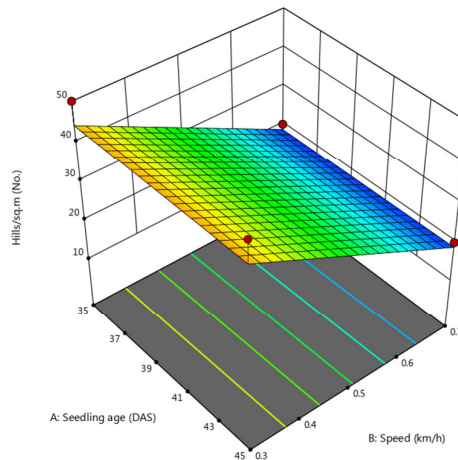
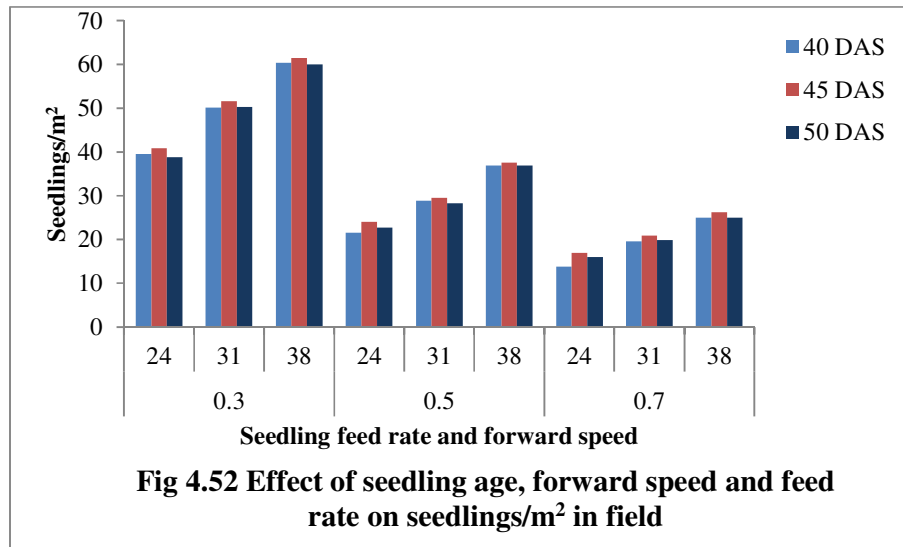
The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

The comparison of actual and predicted values of hill-to-hill distance as per the Eqn 4.2 is shown in Fig 4.51. The R^2 value indicates that the actual values are much close to the predicted values.



c. Number of plants/m²

The numbers of plants/m² were measured and the data is presented graphically in Fig. 4.52 and 4.53. The plants/m² for seedlings of 40 DAS obtained were more than 35 and 45 DAS. It was also observed that the required number of plants/m² was obtained with 31 seedlings/min feed rate at 0.5 km/h forward speed with 40 DAS seedlings. The variation in plants/m² was observed may be due seedling feed rate and growth stage of seedling (DAS). The plants/m² was observed to increase with increase in seedling feed rate and. At every feed rate, the plants/m² decreased with increase in speed of operation for all the ages of seedlings used in trial (Fig. 4.53).



The ANOVA (Table 4.11) revealed that the seedling age, forward speed and feed rate influences the plants/m² at 1 % level of significance. The plants/m length gets affected directly with seedling feed rate. It inversely affected with forward speed of the machine. The interactions of Forward speed × Feed rate also affects the number of plants/m. It indicated that the causes for the variation in plants/m² might be same as that for the seedlings conveyed/m. The conveyance of number of seedlings/m² depends on number of missed as well as damaged seedlings. This might have affected the number of plants/m².

Table 4.11 ANOVA for Linear model showing effect of seedling age, seedling feed rate and forward speed on plants/m² in field

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	1545.83	3	515.28	42.39	< 0.0001	significant
A-Seedling age	0.1250	1	0.1250	0.0103	0.9208	
B-Forward Speed	1320.98	1	1320.98	108.66	< 0.0001	*
C-Seedling feed rate	224.72	1	224.72	18.49	0.0009	*
Residual	158.03	13	12.16			
Lack of Fit	158.03	9	17.56			Significant
Pure Error	0.0000	4	0.0000			
Cor Total	1703.86	16				
Std. Dev.	3.49			R²	0.9072	
Mean	31.50			Adjusted R²	0.8858	
C.V. %	11.07			Predicted R²	0.8172	
				Adeq Precision	21.4633	

* Significant at 1 % level

The **Model F-value** of 42.39 implies the model is significant. There is only a 0.01 % chance that an F-value this large could occur due to noise.

P-values less than 0.0500 indicate model terms are significant. In this case B, C are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model.

The **Lack of Fit F-value** of 17.56 implies the Lack of Fit is significant relative to the pure error. Significant lack of fit is good -- we want the model to fit.

The **Predicted R²** of 0.8172 is in reasonable agreement with the **Adjusted R²** of 0.8858; *i.e.* the difference is less than 0.2.

Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 21.463 indicates an adequate signal. This model can be used to navigate the design space.

The regression equation (Eqn 4.3) representing variation of No. of plants/m² with different independent parameters were fitted in polynomial form is

Final Equation in Terms of Coded Factors

$$\text{Plants/m}^2 = +39.15357 + 0.025 * A - 64.25000 B + 0.757143 * C$$

...(Eqn 4.3)

$$\mathbf{R^2 = 0.8172}$$

Where,

A = Seedling age, DAS

B = Speed, km/h

C = Seedling feed rate, seedlings/min

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Comparison of actual and predicted values of seedlings/mas per the Eqn 4.3 is shown in Fig 4.54. Actual values are much close to predicted values ($R^2 = 0.9369$).

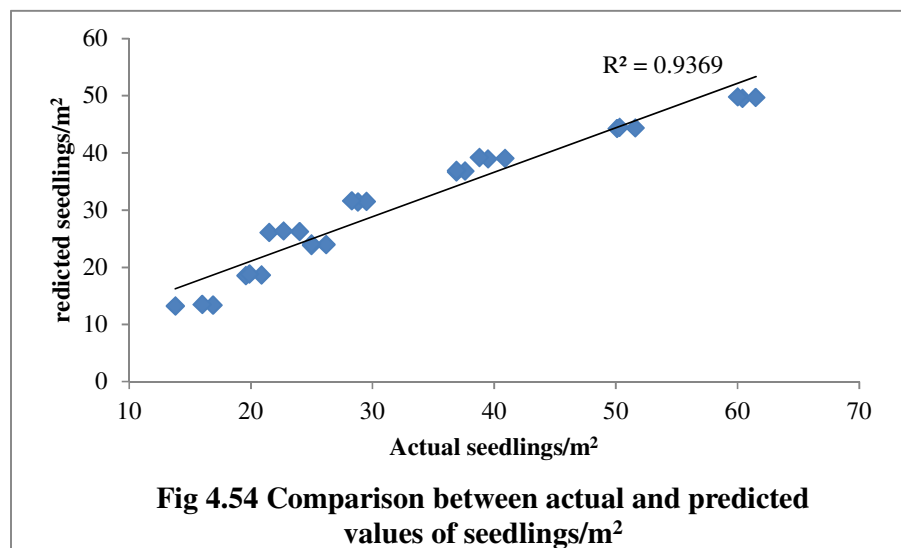


Fig 4.54 Comparison between actual and predicted values of seedlings/m²

d. No. of missed and damaged seedlings/m²

In the developed transplanting mechanism, it was observed that the seedlings were damaged only when they got trapped between seedling cup and seedling metering plate of the seedling metering mechanism as shown in Fig. 4.55. The seedlings entangled in seedlings metering mechanism could not reach to the opened furrow. Numbers of missed seedlings with different operating parameters are depicted in Fig. 4.56 and 4.57. During conduct of trials, average 2.5 seedlings/m² were missed at 0.5 km/h forward speed with 31 seedlings/min feed rate of 45 DAS seedlings. Missed seedling was observed the least i.e. 0.5 seedlings/m² for 0.7 km/h forward speed at 38 seedlings/min with 35 DAS seedlings. It indicates that at higher forward speed and higher seedling feed rate, seedling damage was less. This may be due to the high peripheral speed of the carousel that made the seedling to stay for lesser time in

the seedling feed cup. It reduced the chances of seedling to get trapped in metering mechanism. The percentage of missed seedlings varied between 2 to 11 %. The higher percentage (11 %) of missed seedlings was observed at 0.7 km/h speed with 45 DAS of seedling. Missed seedlings were due to improper conveyance of seedling through metering mechanism of machine. Missed planting rates of 2.9 – 9.3 %, 3 – 4 % and 2.9 – 3.5 % have been reported by Manes *et al.* (2010), and Satpathy and Garg (2008), respectively for semi-automatic vegetable transplanters that used bare-root seedlings. In semi-automatic vegetable transplanters, missed plantings occurred when labourer failed to feed metering unit with seedling due to higher speed of operation.

Fig. 4.56 (a) indicates that missed seedlings were minimum at the lowest and highest speeds. It was more for 35 and 45 DAS seedlings compared to 30 DAS. Fig. 4.56 (b) indicates that at the highest seedling feed rate, missed seedlings were the highest. It increases with seedling age at lower seedling feed rate. A reverse trend was observed at highest feed rate where missed seedlings reduced with increase in age of seedlings though seedling feed rate got increased. Fig. 4.56 (c) indicates missed seedlings initially increased with forward speed and seedling feed rate but later on it decreased. It clearly indicate that seedling age, speed and seedling feed rate do not have any relation with missed seedlings (predicted R^2 value is -0.2660).



Fig. 4.55 Seedlings trapped between seedling feed cup and metering plate

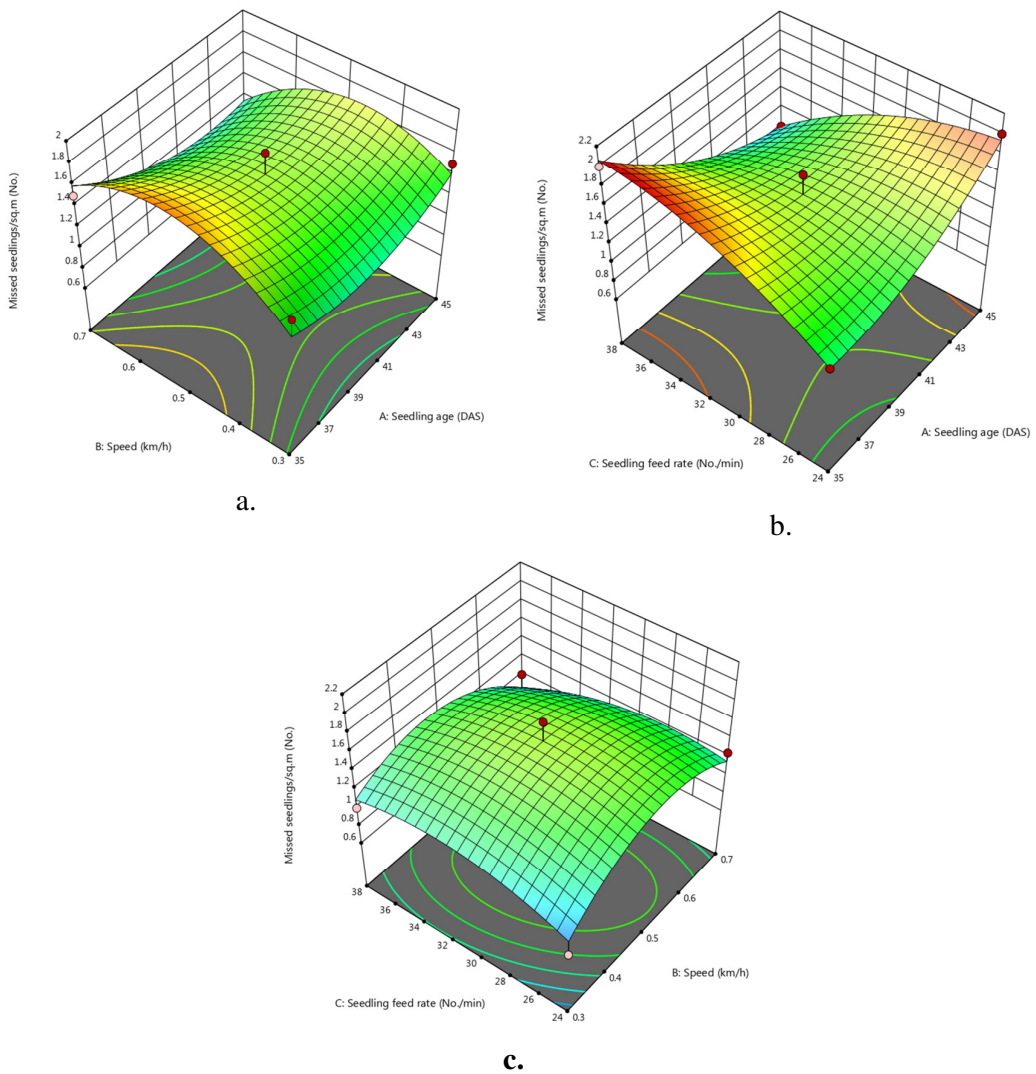
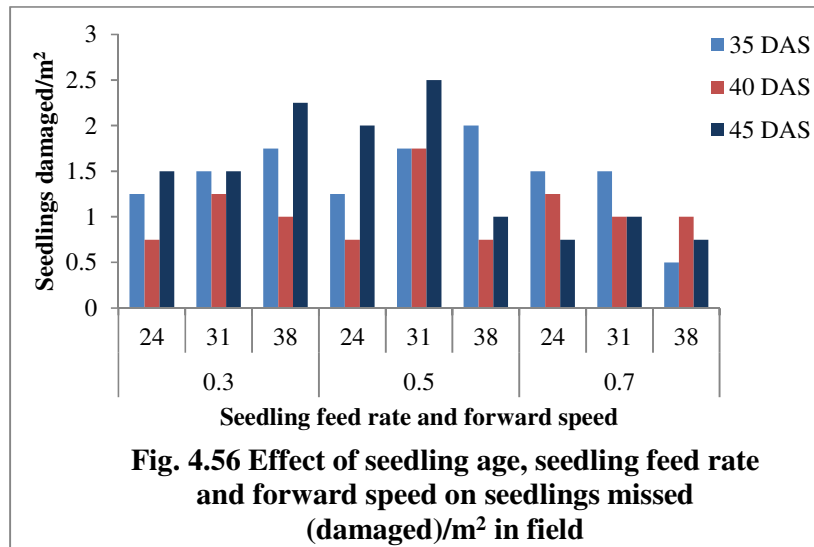


Fig. 4.57 Effect of seedling age, seedling feed rate and forward speed on seedlings missed(damaged)/m² in field

ANOVA indicates that none of the independent parameters affected the missed seedlings at 1 % level of significance (Table 4.12).

Table 4.12 ANOVA for Quadratic model showing effect of seedling age, seedling feed rate and forward speed on missed (damaged) seedlings/m² in field

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	1.82	9	0.2027	1.51	0.3008	not significant
A-Seedling age	0.0703	1	0.0703	0.5233	0.4929	
B-Speed	2.220E-16	1	2.220E-16	1.652E-15	1.0000	
C-Seedling feed rate	0.0078	1	0.0078	0.0581	0.8164	
AB	0.0625	1	0.0625	0.4651	0.5172	
AC	0.7656	1	0.7656	5.70	0.0484	
BC	0.0625	1	0.0625	0.4651	0.5172	
A ²	0.1581	1	0.1581	1.18	0.3141	
B ²	0.5725	1	0.5725	4.26	0.0779	
C ²	0.1383	1	0.1383	1.03	0.3441	
Residual	0.9406	7	0.1344			
Lack of Fit	0.1406	3	0.0469	0.2344	0.8684	not significant
Pure Error	0.8000	4	0.2000			
Cor Total	2.76	16				
Std. Dev.	0.3666					
Mean	1.38					
C.V. %	26.52					

The **Model F-value** of 1.51 implies the model is not significant relative to the noise. There is a 30.08 % chance that an F-value this large could occur due to noise.

P-values less than 0.0500 indicate model terms are significant. In this case AC is a significant model term. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model.

The **Lack of Fit F-value** of 0.23 implies the Lack of Fit is not significant relative to the pure error. There is 86.84 % chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 4.335 indicates an adequate signal. This model can be used to navigate the design space.

Final equation in terms of coded factors

$$\text{Missed seedlings/m}^2 = -10.40494 - 0.188750 * A + 16.98661 * B + 0.769515 * C - 0.125000 * A * B - 0.012500 * A * C - 0.089286 B * C + 0.007750 A^2 - 9.21875 B^2 - 0.003699 C^2 \dots(\text{Eqn 4.4})$$

Where,

A = Seedling age, DAS

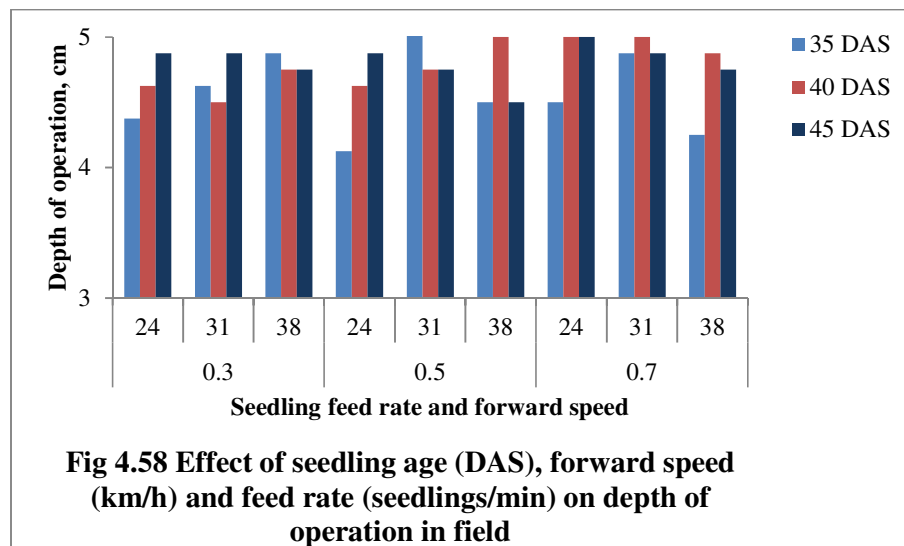
B = Speed, km/h

C = Seedling feed rate, seedlings/min

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

e. Depth of operation

The observations for the depth of operation are depicted graphically in Fig. 4.58. The depth of operation was observed in the range of 30 to 50 mm. It varies with to row. It might be because the soil condition occurred below the wheel while its forward motion. More depth of operation was recorded in the row when the soil condition was lose below wheel. Seedling age, seedling feed rate and forward speed had not directly affected depth of operation. It might be varied due to the soil, soil moisture content and undulations of the field. The soil moisture content higher than the 18 – 20 % creates the negative slippage of the wheels. The undulations in the field vary the depth of operation for both the furrow openers.



The depth of operation was more at lower forward speeds compared to at higher speeds (Fig. 4.59 (a) and (c)). There was no effect of seedling age and seedling feed rate over the depth of operation (Fig. 4.61 (b)).

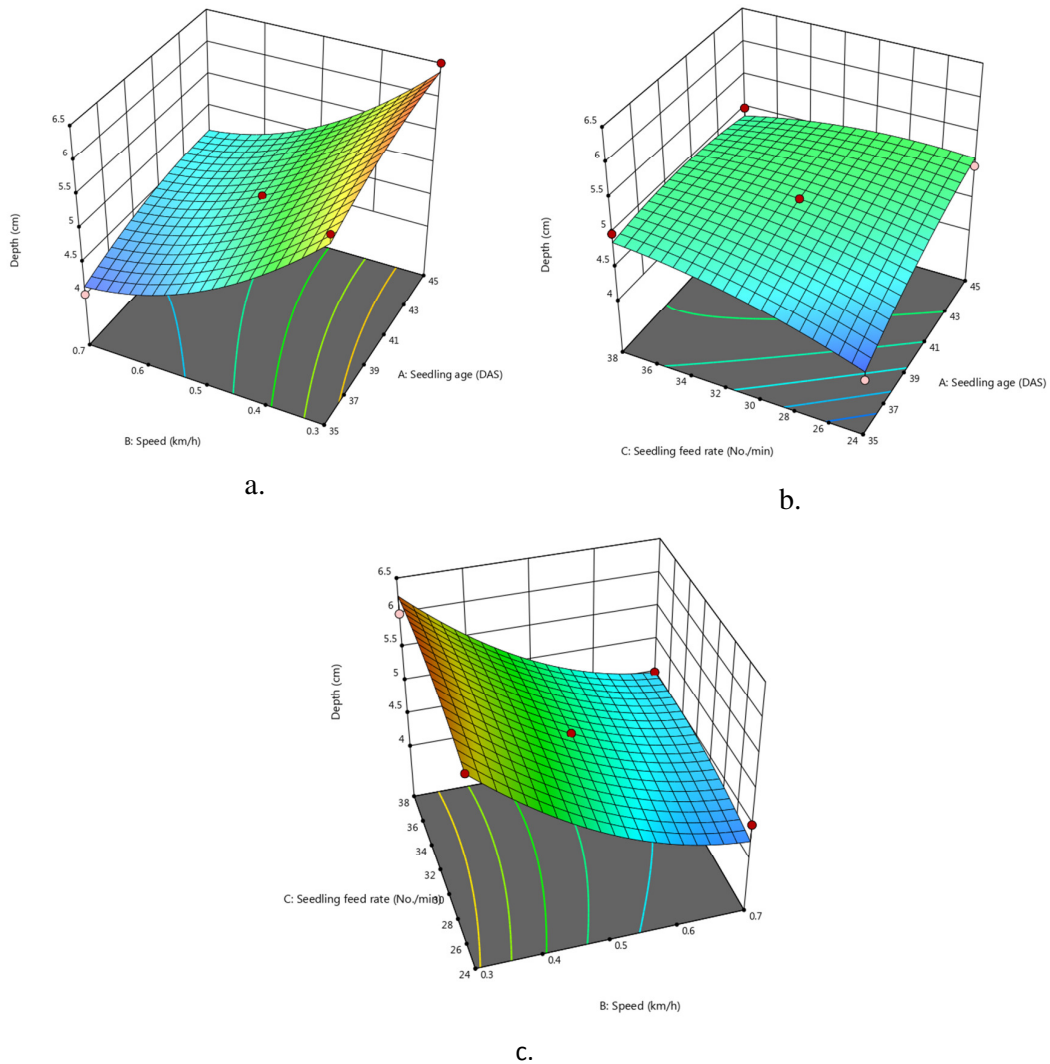


Fig. 4.59 Effect of seedling feed rate and forward speed on depth of operation in field

The ANOVA (Table 4.13) indicates that there was no effect of seedling age and seedling feed rate over the depth of operation however speed of operation affected it at 1 % level of significance.

Table 4.13 ANOVA for Quadratic model showing effect of seedling age, seedling feed rate and forward speed on depth of operation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	7.69	9	0.8546	23.93	0.0002	significant
A-Seedling age	0.5000	1	0.5000	14.00	0.0072	
B-Speed	6.13	1	6.13	171.50	< 0.0001	*
C-Seedling feed rate	0.1250	1	0.1250	3.50	0.1036	
AB	0.0000	1	0.0000	0.0000	1.0000	
AC	0.2500	1	0.2500	7.00	0.0331	
BC	0.0000	1	0.0000	0.0000	1.0000	
A ²	0.0658	1	0.0658	1.84	0.2168	
B ²	0.5921	1	0.5921	16.58	0.0047	
C ²	0.0658	1	0.0658	1.84	0.2168	
Residual	0.2500	7	0.0357			
Lack of Fit	0.2500	3	0.0833			
Pure Error	0.0000	4	0.0000			
Cor Total	7.94	16				
Std. Dev.	0.1890		R²		0.9685	
Mean	5.06					
C.V. %	3.74					

* Significant at 1 % level of significance.

The **Model F-value** of 23.93 implies the model is significant. There is only a 0.02 % chance that an F-value this large could occur due to noise.

P-values less than 0.0500 indicate model terms are significant. In this case A, B, AC, B² are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model.

Adeq Precision measures signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 15.523 indicates an adequate signal. This model can be used to navigate the design space.

Final equation in terms of coded factors

$$\text{Depth, mm} = -12.33099 + 0.671429 * A - 13.75000 * B + 0.461735 * C + 2.17988E-15 A * B - 0.007143 A * C - 2.21517E-16 B * C - 0.005000 A^2 + 9.37500 B^2 - 0.002551 C^2 \quad \dots(\text{Eqn 4.5})$$

Where,

A = Seedling age, DAS

B = Forward speed, km/h

C = Seedling feed rate, seedlings/min

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

f. Briquette spacing

The linear placement of the briquettes was measured by keeping the furrow openers in the lifted condition such that the briquettes should not be covered under soil. The spacing of briquettes metered through the metering mechanism was observed to vary between 176 to 329 mm for different forward speed and seedling feed rate (Fig. 4.60). Briquette spacing was increased with the forward speed of operation. In fact seedling feed rate as such had no effect on the briquette spacing but vibrations created in machine might have affected briquette metering. It was expected to have increase in the briquette spacing with respect to forward speed. But at higher forward speed, the briquette metering might have not occurred properly due to machine vibrations. The variation in briquette spacing was observed between the rows. The briquette spacing obtained was close to plant spacing in row (Fig. 4.61).

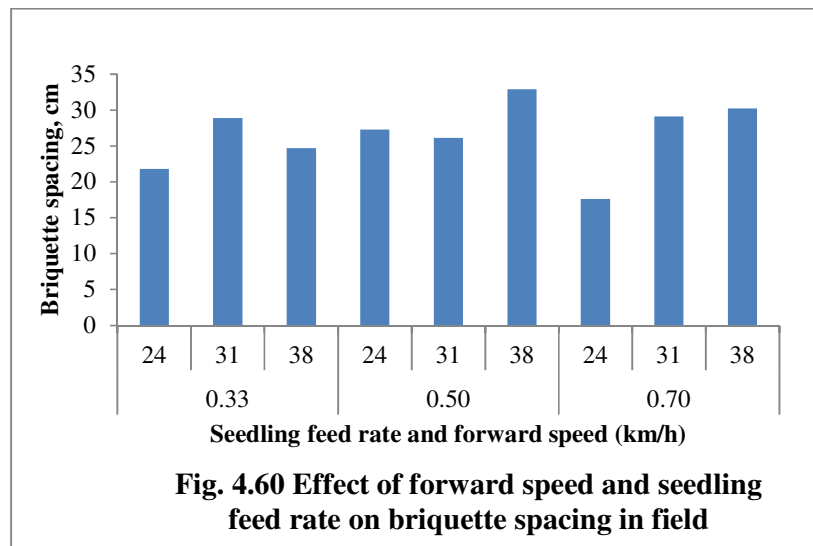


Table 4.14 ANOVA showing effect of forward speed and seedling feed rate on briquette spacing in field

Source	DF	Type I SS	Mean Square	F Value	Pr > F	SE	CD
Rep	3	835.38	278.46	1.80	0.16		
Forward speed	2	185.25	92.63	0.60	0.55	2.54	NS
Row	1	820.13	820.13	5.30	0.03	2.07	5.89*

Feed rate	2	669.00	334.50	2.16	0.13	2.54	NS
Forward speed × Row	2	125.08	62.54	0.40	0.67	2.54	NS
Forward speed × Feed rate	4	516.50	129.13	0.83	0.51	3.59	NS
Row × Feed rate	2	170.33	85.17	0.55	0.58	4.40	NS
Forward speed × Row × Feed rate	4	327.33	81.83	0.53	0.72	4.40	NS
Error	51	7894.88	154.80				
Corrected Total	71	11543.88					
Model	20	3649.00	182.45	1.18	0.31		

* Significant at 5 % level of significance

ANOVA indicated that only row is the factor that affected the briquette metering. This might be due to the variation in the briquettes conveyed per row.



Fig. 4.61 Urea briquettes dropped in field through metering mechanism

4.4.4 Optimization of seedling parameters and operating parameters of developed mechanical transplanting system for its performance

As more number of seedlings damaged with 25, 30 and 50 DAS seedlings at all the operating parameters, the 35, 40 and 45 DAS seedlings were used for the field trials of the transplanting system. In the field trials, it was observed that at 0.3 km/h for all three seedling ages, the number of seedlings conveyed/m were (6.3 to 6.5) within the desired limits *i.e.* 6 to 7 seedlings/m at 31 seedlings/min feed rate. At the forward speeds of 0.5 and 0.7 km/h, the seedlings conveyed/m were lower than the required for all seedling feed rates and all seedlings ages. The field trials revealed that the plant to plant distance were maintained near to desired *i.e.* 150 mm at 0.3 km/h speed only for all seedling ages tested at 24 and 31 seedlings/min feed rate. The plant to plant distance and plants/m² were higher *i.e.* 206 – 663 mm than required 150 mm and 39 – 62 plants/m² than required 27 to 30 plants/m² respectively at 0.5 and 0.7 km/h speeds at all the seedling feed rate and seedling ages tested. The seedling age

affected number of missed and damaged seedlings. Whereas, at 0.5 km/h forward speed using 31 seedlings/min feed rate with 35, 40 and 45 DAS seedlings, it was 28 to 30 plants/m². The required number of plants/m² is 27 to 30. The number of missed seedlings/m² was 1.8 for 35 and 40 DAS seedlings and 2.5 for 45 DAS seedlings at 31 seedlings/min feed rate at 0.5 km/h speed.

The recommended plant population, plant to plant spacing and number of seedlings per hill should be maintained during the transplanting operation. The plants/m² is one of the parameters for performance evaluation of the transplanting system along with the number of seedlings/m. The number of seedlings/m, plant to plant distance and hill/m² observed were 3.5 to 3.7, 265 to 279 mm and 28 to 30 plants respectively against required 6 to 7, 150 mm and 27 to 30 plants. The plants/m² is the criterion that maintains required plant population. Hence, the ‘Design Expert 10’ software was used to optimize the operating parameters with the constraints of the desired responses. The factors (Table 4.15) are the independent parameters while the responses (Table 4.16) are the dependent parameters for which the data according to the field trials was fed to the software. The design of experiment for transplanting system performance with three independent and five dependent parameters as per software is given in Table 4.17. It gave 17 runs of the dependent parameters. This experimental data was used for the optimization with the numerical optimization of the RSM tool. The optimization yielded a solution. The optimal values of corresponding parameters (Fig 4.62) for this solution being used for field testing. According to this approach, the optimal speed (km/h), seedling feed rate (seedlings/min), and seedling age (DAS) were 0.5, 29.2, and 41.3 respectively.

Table 4.15 Factors of experimental design

Factor	A	B	C
Name	Seedling age	Speed	Seedling feed rate
Units	DAS	km/h	No./min
Minimum	35	0.3	24
Maximum	45	0.7	38
Coded Low	-1 ↔ 35.00	-1 ↔ 0.30	-1 ↔ 24.00
Coded High	+1 ↔ 45.00	+1 ↔ 0.70	+1 ↔ 38.00
Mean	40.00	0.5000	31.00
Std. Dev.	3.54	0.1414	4.95

Table 4.16 Responses of experimental design

Name	Seedling s/m, No.	Plant dist., mm	Depth, mm	Seedlings / m ² , No.	Missed seedlings/m ² , No.	Damaged seedlings / m ² , No.
Observations	17	170	170	17	17	17
Minimum	2.1	130	40	16.9	0.75	0.75
Maximum	7.7	460	65	50	2	2
Mean	4.05	275.3	50.6	31.5	1.38	1.38
Std. Dev.	1.55	93.1	7.045	10.32	0.4157	0.4157
Ratio	3.67	3.54	1.63	2.96	2.67	2.67

Table 4.17 Experimental design used to evaluate the effect of operational parameters on performance by RSM

Std	Run	Seedling age, DAS	Speed, km/h	Seedling feed rate	Seedlings/m, No	Plant Dist., mm	Depth, mm	Seedlings/m ² , No.	Missed seedlings/m ² , No.	Damaged seedlings/m ² , No.
17	1	40	0.5	31	3.7	270	50	29.5	1.75	1.75
4	2	45	0.7	31	2.5	400	45	20	1	1
3	3	35	0.7	31	2.5	400	40	20	1.5	1.5
5	4	35	0.5	24	2.7	360	40	22	1.25	1.25
10	5	40	0.7	24	2.1	460	45	16.9	1.25	1.25
14	6	40	0.5	31	3.7	270	50	29.5	1.75	1.75
9	7	40	0.3	24	5.1	190	60	40.9	0.75	0.75
1	8	35	0.3	31	6.3	170	60	50	1.5	1.5
15	9	40	0.5	31	3.7	270	50	29.5	1.75	1.75
13	10	40	0.5	31	3.6	270	50	29.5	1.75	1.75
6	11	45	0.5	24	2.8	340	50	23	2	2
12	12	40	0.7	38	3.3	300	45	26.2	1	1
11	13	40	0.3	38	7.7	130	60	45	1	1
7	14	35	0.5	38	4.6	210	50	37	2	2
2	15	45	0.3	31	6.3	160	65	50	1.5	1.5
8	16	45	0.5	38	4.6	210	50	37	1	1
16	17	40	0.5	31	3.7	270	50	29.5	0.75	0.75

Table 4.18 Solution of numerical optimization obtained using RSM

Parameter	Optimized value
Seedling age, DAS	41.3
Forward speed, km/h	0.5
Seedling feed rate, seedlings/min	29.2
Seedlings/m, No.	4.50
Plant to plant dist., mm	255.3
Depth, mm	52.00
Seedlings/m ² , No.	36.00
Missed seedlings/m ² , No.	1.50
Damaged seedlings/m ² , No.	1.50
Desirability	1

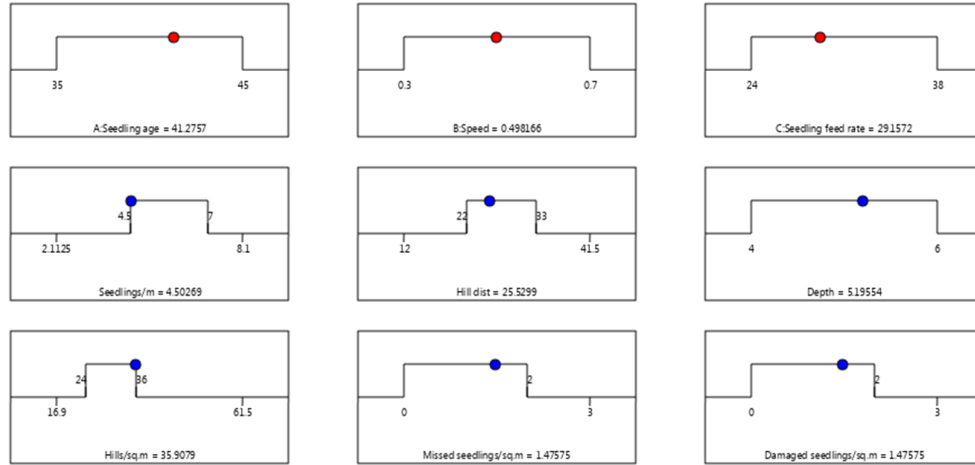


Fig. 4.62 Optimized values of respective parameters

4.4.5 Validation of optimized operating parameters

The values optimized by Design Expert were quite close to the actual operating parameters that the designed transplanting system could achieve. As a result, the performance of the transplanting system was assessed using 40 DAS seedlings at a speed of 0.5 km/h and a feed rate of 31 seedlings/min. The predicted values for seedlings/m (No.), plant to plant distance (mm), seedlings/m² (No.), seedlings damaged/m² (No.), and seedlings missed/m² (No.) were 4.5, 222 mm, 36, 1.6, and 1.6 respectively. The predicted and experimental values for the performance of the transplanting system using the optimized operating parameters along with difference in these values are given in Table 4.19. It was observed that except seedlings/m and depth of operation, all the other parameters observed less than the predicted values. As the variation observed was minimal, the optimized operating parameters can be adopted to get the desired results.

Table 4.19 Variation in optimized and actual values of independent and dependent variables according to optimization

Sr. No.	Particulars	Optimized	Actual	Variation (Actual - Optimized)
A	Independent parameters			
1	Speed, km/h	0.5	0.5	0.00
2	Feed rate, seedlings/min	29.2	31	1.8
3	Seedling age, DAS	41.3	40	-1.3
B	Dependent parameters			
1	Seedlings/m (No.)	4.5	4.25	-0.253
2	Plant to plant distance (mm)	255.3	237.5	-17.8
3	Seedlings/m ² (No.)	36.0	36.25	0.25

4	Seedlings damaged/m ² (No.)	1.5	1.75	0.25
5	Seedlings missed/m ² (No.)	1.5	1.75	0.25
6	Depth of operation (mm)	52.0	42.5	-09.5

The variation observed between the optimized and actual values was very minor. Hence, the optimized values were selected for the performance evaluation of mechanical transplanting system in field.

4.4.6 Performance evaluation of mechanical transplanting system in field

The operational parameters were optimized based on the findings of the laboratory and field studies using Design Expert 10. With the optimized operating settings, the transplanting system was examined in the field. The seedlings grown with the developed drum seeder using 24 orifice drum, 165 mm diameter wheel operated at 1 km/h speed (H₂D₁S₁) (Table 4.2) demonstrated the best physical growth and were used for the performance evaluation of the proposed transplanting system as well as manual transplanting. Field details for sowing operation are given in Table 4.20. The manual and mechanical transplanting field trials were conducted on similar 12 m × 4 m fields. The field was prepared as per Section 3.6.3. Both experiments were carried on four times each. The parameters studied were transplanting efficiency, total time required for operation (T_t), unproductive time (T_u), speed of operation (S), field capacities (ha/h), field efficiency (%), plants transplanted (No./m²), seedling mortality (%) and fuel consumption (l/h). Parameters of finger millet seedling grown with developed drum seeder are presented in Table 4.21. The field details for manual and mechanical transplanting are given in Table 4.22.



Fig. 4.63 Observations recording during field trials

Table 4.20 Field details of sowing operation done with developed drum seeder

Location	Gavtale Block, CRS, Gavtale Farm, Dr. B.S.K.K.V, Dapoli Dist.: Ratnagiri
Soil type	Well drained lateritic soil
Tillage operation	Two passes of rotavator
Depth of tillage	200 to 250 mm
Method of seed sowing and fertilizer application	Line sowing with developed drum seeder
Plot size	4 m × 1 m

Table 4.21 Parameters of finger millet seedling grown with developed drum seeder with 24 orifices, 165 mm diameter wheel and 1 km/h speed

Sr. No.	Parameter	Observations
1	Variety of seedling	Dapoli -1
2	Age of seedling, days	40
3	Number of leaves	14
4	Seedling length, mm	580
5	Root length, mm	110
6	Seedling width, mm	8.2
7	Seedling thickness, mm	5.5
8	Seedling weight, g	11.5

Table 4.22 Details of field used for transplanting operation

Location	Gavtale Block, CRS, Gavtale Farm, Dr. B.S.K.K.V, Dapoli Dist.: Ratnagiri
Soil type	Well drained lateritic soil
Tillage operation	Two passes of rotavator
Depth of tillage	200 to 250 mm
<i>A. Manual Transplanting</i>	
Plot size	12 m × 4 m
No. of plots	4
Soil moisture content	18 – 20 % (with irrigation)
<i>B. Mechanical Transplanting</i>	
Plot size	12 m × 4 m
Soil moisture content	18 – 20 % range (with irrigation)

Observations recorded during manual and mechanical transplanting are discussed below.

a. Manual transplanting

Finger millet seedling transplanting was done manually to evaluate its performance. In manual transplanting, the time required to cover 12 × 4 m² area was 75.25 min. The area covered by manual method observed to be 38.3 m²/h. The manual transplanting was studied to determine the number of seedlings transplanted/m². It was observed that about on an average 70.5 plants/m² were transplanted randomly in

manual transplanting method (Table 4.23). The spacing between hills is not maintained properly (Fig. 4.64). The approximate plant spacing was observed to be 200 – 250 mm. The manually transplanted seedlings were observed to be inclined more than 60° with vertical. Such inclined seedlings were also considered under transplanted seedlings. The finger millet crop stands vertical when its sets in the field. The seedling mortality in manual transplanting was observed to be nil. This might be due to the proper placement of seedlings by the labour.



Fig. 4.64 Manually transplanted finger millet

Table 4.23 Transplanting of finger millet by manual method

Sr. No.	Particulars	R ₁	R ₂	R ₃	R ₄	Average
1	Time required to cover 12 × 4 m ² area, min	72	79	76	74	75.25
2	Field capacity, m ² /h	40	36.5	37.9	38.9	38.3
3	No. hills/m ² manual transplanting	72	69	71	70	70.50
4	Seedling mortality of manual transplanting, %	0	0	0	0	0

b. Mechanical transplanting

The performance of the developed transplanting system was evaluated in the field by following the method given in Section 3.6.3. The results obtained are presented in Table 4.24 and discussed below.

Table 4.24 Performance evaluation of mechanical transplanting system in field

Sr. No.	Particulars	R ₁	R ₂	R ₃	R ₄	Average
1	Seedlings/m (No.)	4	5	5	5	4.75
2	Plant to plant distance (mm)	230	270	240	250	247.5
3	Seedlings/m ² (No.)	38	34	36	37	36.25
4	Seedlings damaged/m ² (No.)	2	2	1	2	1.75
5	Seedlings missed/m ² (No.)	2	2	1	2	1.75
	Depth of operation (mm)	40	50	40	40	42.5

6	No. of vertical transplanted seedlings/10 m	55	65	50	67	59.25
7	Total transplanted seedlings/10 m	78	86	70	88	80.50
8	Transplanting efficiency, %	70.5	75.6	71.4	76.1	73.4
9	Time required to cover 12 × 4 m ² area, min	14.8	14.6	14.7	14.5	14.65
10	Unproductive time, min	7.0	7.5	7.0	7.8	7.33
11	Total time required for operation, h/ha	75.7	76.7	75.3	77.4	76.30
12	Speed of operation, km/h	0.39	0.39	0.39	0.40	0.39
13	Actual field capacity, m ² /h	97.3	98.6	98.0	99.3	98.3
14	Theoretical field capacity, m ² /h	125	125	125	125	125
15	Field efficiency, %	77.8	78.9	78.4	79.4	78.64
16	Fuel consumption, l/h	0.75	0.78	0.75	0.79	0.77
17	No. of plants/ m ²	45	42	48	44	44.75
18	Seedling mortality, %	2.2	2.4	0	0	1.15
19	Briquette spacing, mm	230	180	280	300	250

i. Transplanting efficiency

The transplanting efficiency was determined by the ratio of number of vertical transplanted seedlings with proper soil compaction around roots to the total number of seedlings transplanted (Gaikwad, 2010). It was determined as per Eqn 3.15. The maximum and minimum transplanting efficiency observed to be 76.1 and 70.5 % while the average transplanting efficiency observed was 73.4 %. The variation in the transplanting efficiency may be due to seedling growth stage and the soil condition available under the furrow closure to place soil around the seedling roots. It might be affected due to the soil moisture content. The seedlings those were not placed straight were not laid over the soil but were tilted in the forward direction. Similar results were reported by Gaikwad, 2013. Kumawat *et al.*, 2020 recorded the maximum transplanting efficiency as 72.39 % at 3.5 km/h operational working speed. Durga *et al.*, 2020 recorded transplanting efficiency as 83.3 %.

ii. Total time required for operation (T_t)

Time required for transplanting operation, turning, placing seedlings on tray, repair and adjustment were taken as total time required for operation. The time required to cover 12 × 4 m² area was determined. It was observed that the actual time required for transplanting operation including unproductive time ranged between 13 to 14 min with average 13.4 min. The total time required for operation ranged between 45.1 to 48.6 h/ha.

iii. Unproductive time (T_u)

The time lost in turning, feeding the seedlings on tray, repair and adjustment of machine were considered as unproductive time. The time lost in turning at headland was about 3 to 4 s per turn. For the $12 \times 4 \text{ m}^2$ area covered, it ranged 30 to 60 s with average 44 s. The variation in the turning time may be due to the field condition at the headland and the skill of the operator to maneuver the transplanting system. Time lost in machine adjustments, removal of chocked seedlings, furrow opener cleaning and placing seedlings on tray was considered. Total unproductive time varied between 7 to 7.8 min for the operation in $12 \times 4 \text{ m}^2$ area (Table 4.24).

iv. Field capacity, ha/h

Theoretical field capacity of developed transplanting system at 0.5 km/h forward speed and 0.25 m width of operating was found to be $125 \text{ m}^2/\text{h}$. Average actual field capacity was $98.3 \text{ m}^2/\text{h}$. The variation in forward speed and time lost in turning at headland, machine adjustments and placing seedlings on tray might have affected actual field capacity.

v. Field efficiency, %

Field efficiency of transplanter ranged between 77.8 to 79.4 % with an average of 78.6 %. It indicated that unproductive time and variation in forward speed affected field efficiency. Gaikwad observed the field efficiency near to this (73 to 75 %), 2013 for tractor operated two row semiautomatic vegetable transplanter. A field efficiency of 78 to 80 % was recorded by Dixit and Khan, 2011 for eight row paddy transplanter.

vi. Plants transplanted/ m^2

In case of the transplanting done by the developed finger millet transplanter, the row to row distance was maintained with some variation in plant to plant distance. The average numbers of plants/ m^2 were observed to be 44.8. The average plant to plant distance was observed to be 90 mm in the row (Fig. 4.65).



Fig. 4.65 Views of mechanically transplanted finger millet

vii. Seedling mortality

Average mortality was observed to be 1.2 % only. This might be due to improper seedling placement or laid over the soil surface or might be due to transplanting shock to bare root seedlings. The seedling mortality was within the acceptable limits. Narang *et al.*, 2011 observed mortality of 3.3 to 4 % was for a 2-row vegetable transplanter with revolving magazine type metering mechanism. Sahoo and Mahapatra, 2018 observed seedling mortality of 21.66 to 25.66 % for single row bullock drawn vegetable transplanter whereas Gaikwad, 2013 observed nil mortality.

viii. Fuel consumption

The fuel consumption for transplanting operation varied between 0.75 to 0.79 l/h with an average of 0.77 l/h.

ix. Briquette spacing

Linear placement of fertilizer briquettes was measured during transplanting operation. The spacing of briquettes metered through metering mechanism varied between 180 to 300 mm. It was average 250 mm. Briquette spacing observed to vary between the rows and within the row also.

x. Comparison of manual and mechanical transplanting method

The comparative performance of manual and mechanical transplanting is given in Table 4.25. Plant spacing was not maintained uniform in case of manual transplanting. In mechanical transplanting, plant spacing in row ranged between 23.9 to 29.5 % with average variation 26.6 %. It was due to the seedling missing and wheel slippage. Plant spacing in case of manual transplanting was 200 – 250 mm while in case of mechanical it was average 90 mm. In manual transplanting method, 70.5 seedlings/m² observed compared to 44.8 seedlings/m² by mechanical transplanting. In manual method, plants/m² might be varied due to skill of labour that makes holes in field using *Thomba*. In mechanical method it may due to seedling metering variation. Mortality was nil in case of manual transplanting method that might be due to proper placement of seedlings in soil by hand. In mechanical transplanting method, seedling mortality was 1.2 %. In case of mechanical transplanting method, seedlings are made to vertically land in open furrow under gravity. Disorientation of seedlings while landing may lay seedling over soil that may create mortality. In mechanical method, field capacity was 98.3 m²/h. Field efficiency of mechanical method was observed to

be 78.64 % considering time loss. Transplanting cost of mechanical transplanting method was ₹ 19,278/ha compared to ₹ 29,700 for manual transplanting.

Table 4.25 Comparative performance of manual and mechanical transplanting

Sr. No.	Transplanting	Manual	Mechanical
1	Speed, km/h	--	0.45
2	Plant spacing, mm	Random (approx. 120)	90
3	Plants/m ²	70.5	44.8
4	Percentage miss, %	--	2
5	Percentage mortality, %	--	1.2
6	Avg. transplanting rate, seedlings/min/person	43	31
7	Transplanting efficiency, %	100	93.27
8	Field capacity, m ² /h	38.3	98.3
9	Field efficiency, %	--	78.64
10	Transplanting cost, ₹ /ha	29,700	19,278
11	Transplanting cost, ₹ /1000 seedlings	42.6	48.4

4.4.7 Cost analysis of newly developed mechanical transplanting system

Field capacity of manual transplanting was observed to be 0.0038 ha/h. Hence, the time required to cover one hectare was 263.15 h *i.e.* 32.89 say 33 days (assuming 8 working hours per day). Total wages assuming three labours per day @ ₹ 300/day/person (33 × 300 × 3) was found as ₹ 29,700/ha.

Cost of fabrication for power operated finger millet transplanting system was ₹ 41900/- as per the material required given in Appendix XII. It includes the cost of engine. The operating cost of newly developed transplanter was determined using IS-9164-1979 test code. The annual fixed and variable cost of transplanter was calculated to be ₹ 7,250 and ₹ 40,000 respectively. Total cost of operation was found to be ₹ 19,278/ha. The operating cost of developed transplanter was observed to be lower than the manual method of transplanting. The developed transplanting system could save transplanting cost by 35.10 % over the manual transplanting operation.

CHAPTER V

SUMMARY AND CONCLUSIONS

Finger millet (*Eleusine coracana* (L.) Gaertn) is a staple food crop produced by subsistence farmers in more than 25 countries spanning Asia and Africa's semi-arid tropics due to its ease of cultivation, drought tolerance, and high nutritional content (Thilakarathna and Raizada, 2015). It is mostly farmed in Karnataka, Tamil Nadu, Andhra Pradesh, Jharkhand, Orissa, Maharashtra, Chattisgarh, Gujarat, and Uttarakhand in India.

Broadcasting, line sowing, or transplanting can all be used to establish finger millet crop. High labour requirement, particularly for weeding, are a key restraint in the broadcasting approach (Thilakarathna and Raizada, 2015). Under rain-fed circumstances, transplanting outperformed broadcasting and line sowing in terms of yield attributes and yield. Weed control becomes simple using the transplanted and line-sown methods. Under transplanting, the weed infestation and dry matter were observed to be at their lowest levels (Pradhan *et al.*, 2014).

Direct sowing (broadcasting or line sowing) or transplanting are indeed options for growing finger millet crop. Seed broadcasting or line sowing is not viable in high rainfall areas like Konkan, since the broadcasted seeds may be swept away in torrential rainstorm. Hence, nursery is traditionally grown on 1/10th of area to be transplanted. Seed broadcasting is the preferred method of sowing. For nursery raising, Dr BSSKKV, Dapoli recommends line sowing across raised beds of 1 m width and 20 – 30 cm height (for good drainage) and of suitable length, in furrows (2 – 3 cm deep) at 10 cm spacing. Fertilizers and seeds are sowed by hand. Recommended seed rate for growing nursery is 5–6 kg/ha and fertilizer rate 10 kg/ha urea over 1/10th of area to be transplanted. Seedlings are nurtured for 25 to 30 days (Anonymous, 2017) and later only healthy seedlings are transplanted manually in main field. In manual sowing, the rate of fertilizer administration and seed rate are entirely reliant on individual's ability that affects uniformity of seedling density and nutrient in field. It influences crop output and growth. The transplanted finger millet yields higher than both broadcasted and direct seeded crop. However, for one hectare area, manual transplanting requires around 4,44,444 seedling or plants with 2 – 3 seedlings, assuming an average plant spacing of 15 × 15 cm. In case of irrigated or summer-season finger millet, transplanting is done in ponded water, similar to rice planting. The labourers have to work in bending position during transplanting, which

can cause backache and knee pain. The row and plant spacing are not maintained during hand transplanting that obstructs intercultural activities. Manual transplanting is labor-intensive, time-consuming, expensive, and exhausting (Kumar and Tripathi, 2016). For ergonomic reasons, it is not recommended to work in bending posture (Gaikwad, 2010). It results in more fatigue and reduced working capacity. The most significant obstacles in finger millet production are labour scarcity and timely availability, followed by high labour wage rates, a lack of high yielding varieties, and a lack of adoption of contemporary technologies. A delay in transplanting owing to a lack of labour, results in a low yield (Kamble, 2016).

It is necessary to mechanize finger millet transplanting in order to make it more effective and speedier while also reducing drudgery. Rain-fed finger millet seedlings are transplanted manually into wet soil. Hence, finger millet transplanter is to be designed and developed considering wet field condition. As a result, the following objectives are being pursued in order to grow the uniform seedlings suitable for mechanical transplanting system and to develop a self-propelled mechanical transplanting system for finger millet that is suited for small land holdings and wet soils with sloped terrain of Konkan region.

1. To standardize nursery raising method suitable for mechanical transplanting of finger millet.
2. To design and develop a mechanical transplanting system for finger millet seedlings.
3. To evaluate the performance of developed mechanical transplanting system for finger millet.

Mechanical transplanting requires uniform size seedling for proper metering. Manually grown seedlings may not meet this requirement of uniform seedlings. Considering size and shape of finger millet seeds and fertilizer granules, drum seeder considered as better option. A manually operated seed cum fertilizer drum seeder for nursery raising was designed and developed to maintain density of seeds, fertilizer applied, minimize labour and time required for sowing and to make available maximum number of uniform seedlings for mechanical transplanting.

The drums of seed and fertilizer were made using the PVC pipe of 75 mm diameter. The rows of 3 mm diameter orifices equally spaced in circumferential lines that are spaced 10 cm, for seed metering at 10 cm row spacing are made on drum along its circumference. Similar drums were made for fertilizer metering with bands

of three rows of orifices, spaced at 10 cm, were made for fertilizer metering. The main frame is fabricated using MS material for mounting two drums for seed, two drums for fertilizer, four furrow openers, seed covering plate and a handle. The drums were mounted on axles of unit in such a way that drums could rotate with axle of ground wheel. Front set of drums is for drilling granular fertilizer while rear one is for drilling seeds. It has a soil covering plate at its rear end to cover soil on seeds drilled in rows. The drum volume is sufficient for accommodate seed for seeding 0.1 ha area for nursery raising which is sufficient for transplanting on 1 ha area in one fill. The performance of drum seeder was tested on sticky plate for seed rate, seed distribution efficiency and seed uniformity using the drums of 12 orifices (H_1) and 24 orifices (H_2), wheels of 165 mm (D_1) and 230 mm (D_2) diameter at forward speeds of 1 (S_1), 1.5 (S_2) and 2 (S_3) km/h. Seedling physical parameters like seedling shoot length, root length, canopy spread, thickness, width and weight of seedlings obtained 25 to 50 days after the sowing (DAS) were measured. Seeds were sowed at five-day intervals using both manual and drum seeder methods, allowing physical properties of seedlings to be measured on same day. Performance of seedlings produced with drum seeder was compared to that of hand cultivated seedlings.

Seed rate obtained with different operating combinations of drum seeder ranged between 6.24 to 24.03 kg/h with seed distribution efficiency ranged between 11.36 to 43.64 % and uniformity coefficient 0.93 to 0.97. The depth of seed placement ranged between 10 to 20 mm and it observed to increase with the speed of operation. The number of plants per square meter ranged from 230 to 960 that increased with increase in forward speed. The drum seeder sows finger millet seeds sparsely and uniformly as compared to manual method which resulted into healthy growth of seedling in nursery. Seedling uprooting time was 23 s to 422 s for drum seeder sown seeds and 24 s to 450 s for manually sown seeds. Seedling quality was observed best for 24 orifices, 165 mm diameter wheels and 1 km/h speed ($H_2D_1S_1$) operating combination of drum seeder. This operational combination of developed drum seeder was chosen to raise seedlings.

The small and sloped fields of Konkan region required to have small machineries for easy maneuvering. Accordingly, a two-row semi-automatic, gravity feed walk behind type finger millet transplanter was designed and developed for 250 mm row to row spacing. The furrow opener was designed according to the theory suggested by Kostritsyn, 1956. The power required for the transplanting system was

estimated to be 2.64 kW (3.5 hp). A single cylinder, petrol engine with a rated output of 2.64 kW (3.5 hp) was chosen to meet this power demand. A reduction gearbox, chain and sprocket mechanism and two sets of two ground wheels (370 and 430 mm) were used to get the desired forward speeds and seedling feed rate. The ground wheel driven revolving carousel type seedling metering mechanism was developed as this metering mechanism gives sufficient time to operator for timely feeding and maintaining plant spacing in the field with respect to required forward speed of the machine. Two sets of carousels having 12 and 16 seedling feeding cups respectively were fabricated for getting the desired seedling feed rates 24, 31 and 38 seedlings/min at particular speed of operation. A cup feed type fertilizer metering mechanism was designed to meter urea briquettes at approximately plant spacing in the row. The transplanter was tested at forward speeds of 0.3, 0.5 and 0.7 km/h. The transplanter was fabricated in the workshop of Department of Farm Machinery and Power (FMP), CAET, Dr. BSKKV, Dapoli.

Seedling weight is the important factor in gravity fed transplanting system. To get such desired finger millet seedlings, these were standardized in laboratory in the jack-up condition for its physical parameter with respect to age at set forward speeds and seedling feed rates using seedlings of 25, 30, 35, 40, 45, and 50 DAS at 24, 31 and 38 seedlings/min feed rate. It was observed that the 25, 30 and 50 DAS seedlings were getting damaged. Seedlings of 35, 40 and 45 DAS showed proper metering and conveying through transplanter mechanism. The test was conducted to decide whether one or two operators are needed for transplanting. It indicated that two operators are needed to properly feed seedlings to the carousels of metering mechanism. Hence, two operators employed and trained on plain land for seedling feeding operation while moving. Seedlings conveyed on plain land were recorded. This performance test helped to standardize a proper stage of seedling suitable for developed transplanting system for efficient transplanting.

Based on results of laboratory and plain land tests, field evaluation of developed semiautomatic self-propelled gravity fed transplanting system was carried out at Gavtale Block, CRS, Gavtale farm of Dr. B.S.K.K.V, Dapoli Dist: Ratnagiri in lateritic soil with well-drained and flat field condition using seedlings of 35, 40 and 45 DAS. The field was prepared with two passes of rotavator to obtained fine tilth and was irrigated before conducting trials and allowed to drain to meet the desired 18 – 20 % soil moisture content. The field condition maintained to this limit as soil sticks to

the drive wheels and wheel slippage occurs at higher soil moisture content in field. The experiments were replicated for four times. Seedlings/m (No.), plant to plant distance (cm), seedlings/m² (No.), seedlings damaged/m² (No.), seedlings missed/m² (No.) were recorded for further calculations.

Plant to plant distance was maintained near to desired, *i.e.* 150 mm at 0.3 km/h speed only for all seedling ages tested at 24 and 31 seedlings/min feed rate. At 0.5 and 0.7 km/h speeds, plant to plant distance and plants/sq. m were higher, with 20.6–66.3 cm versus 150 mm and 39–62 plants/m² versus 27–30 plants/m², respectively, at all seedling feed rates and seedling ages examined. The number of missed and damaged seedlings was affected by seedling age. In comparison to the needed 6 to 7, 150 mm, and 27 to 30 plants, the number of seedlings/m, plant to plant distance, and plant/m² observed were 3.5 to 3.7, 26.5 to 280 mm, and 28 to 30 plants, respectively. The 'Design Expert 10' programme was used to optimize operational parameters Three independent (0.3, 0.5 and 0.7 km/h forward speeds, 24, 31 and 38 seedlings/min feed rate and 35, 40 and 45 DAS seedling age) and five dependent characteristics (seedlings/m, No., plant to plant distance, mm, seedlings/m², No., seedlings damaged/m², No., seedlings missed/m², No.) were used in design of experiment for transplanting system performance. The RSM tool was used to numerically optimize experimental data. The optimized operating parameters were 0.5 km/h, 29.16 seedlings/min seedling feed rate, and 41.28 DAS seedling age. These were quite close to actual operating parameters of transplanting system *i.e.* 0.5 km/h, 30 seedlings/min and 40 DAS seedling age with a variation of – 0.4 %, +5.9 % and +3.2 % respectively. The performance of the transplanting system was evaluated using 40 DAS seedlings at a feed rate of 31 seedlings/min at a speed of 0.5 km/h.

The performance of transplanting system was tested in field with optimized parameters. Seedlings grown with the developed drum seeder (H₂D₁S₁) were used to evaluate the developed transplanting and manual transplantation. The field trials were carried out on fields of 12 m × 4 m and replicated four times. Transplanting efficiency, total time required for operation (Tt), unproductive time (Tu), speed of operation (S), field capacities (ha/h), field efficiency (%), plants transplanted (No./sq. m), seedling mortality (%), and fuel consumption (l/h) were among the characteristics investigated.

In manual transplanting, about 705000 plants/ha transplanted randomly with an average plant spacing of 12 cm and field capacity 0.004 ha/h and zero mortality. It

varied according to skill of the labourer making holes in field. In mechanical transplanting, plant to plant spacing in the row ranged between 23 and 27 cm (average 24.8 cm) owing to seedling metering variations, variations in forward speed due to slipping wheel caused by field conditions, or seedling miss and damage. A total of 448000 plants/ha were transplanted with mortality of 1.2 %, field capacity and field efficiency of 0.01 ha/h and 78.64 % respectively at 0.5 km/h speed.

During transplanting process, linear placement of the briquettes was measured. The spacing of briquettes metered through the metering mechanism varied between 18 to 30 cm. It was average 25 cm. Fuel consumption for the transplanting operation ranged from 0.75 to 0.79 liters per hour, with an average of 0.77 liters per hour.

The study in standardization of seedling nursery raising method and performance evaluation of developed transplanter revealed that

1. The drum seeder designed for finger millet nursery growing can be used with a specific operating settings, (24 orifices, a 165 mm diameter wheel, and a speed of 1 km/h) to achieve optimum seedling spacing and healthy seedlings.
2. Seedlings of 25 to 50 DAS were tested with developed transplanter. Seedlings grown by drum seeder with 35, 40, and 45 DAS found to have lower seedling miss and damage with use of developed transplanter.
3. The 35 to 45 DAS seedlings obtained were of 580 mm shoot length, 110 mm root length, 8.2 mm width, 5.5 mm thickness and 11.7 g weight.
4. The experimental trials revealed that developed transplanting system operates effectively at 0.5 km/h operation speed, 31 seedlings/min seedling feed rate, with 40 DAS seedlings in the soils having moisture level between 18–20 %.
5. Seedling mortality, field capacity and field efficiency of the developed transplanter were observed to be 1.2 %, 0.01 ha/h and 78.64 %, respectively at forward speed of 0.5 km/h.
6. The fabrication cost of transplanter was ₹ 41,900/-. The cost of transplanting with developed system was found to be ₹ 19,278/ha, compared to ₹ 29,700/ha for manual transplanting. It could save the transplanting cost by 35.10 %.

The two row gravity fed semi-automatic transplanting system designed and developed for bare root finger millet seedlings performed satisfactorily with specific operating conditions. It is recommended to use this developed system in small and sloped land holdings in heavy rainfall zone.

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Appendix I

Table 1 Parameters of manual method of finger millet transplanting adopted in Konkan region.

Sr. No.	Location (Wadi, Village)	Area transplanted, ha	Method of transplanting	Labour required		Man-h/ha required	Time required, h/ha	Fertilizer used	No. of seedlings per sq. m	Quantity of fertilizer used per hole
				M	F					
1	Gavanwadi, Navashi	0.2	Random (Peg)	2	2	104.8	260.2	Urea and SSP	55	5 – 6 g
2	Padyalwadi, Shirshinge	0.015	Random (Peg)	1	1	56.6	281.3	Urea and SSP	29 hills (@ 3 plants per hill)	5 – 6 g
3	Padyalwadi, Shirshinge	0.02	Random (Peg)	1	1	51.8	252.9	Urea	28 hills (@ 3 plants per hill)	5 – 6 g
4	Hanumanwadi, Navshi	0.3	Random (Peg)	2	5	116.9	161.7	Urea and SSP	34	5 – 6 g
5	Durgamatawadi, Navashi	0.09	Random (Peg)	2	5	170.1	242.3	SSP	34	1 – 3 g
6	JadhavWadi, Sheravali	0.015	Random (Peg)	2	6	204	255.5	Urea and SSP	26	4 g
7	Madhaliwadi, Sheravali	0.01	15 × 20 Line transplanting (Peg)	2	6	249.6	310.2	Urea and SSP	32	4 g
8	Botany Research Field, DBSKK, Dapoli	0.198	20 × 30 Line transplanting (Pressing by thumb)	2	5	212.1	304.3	NA	25	NA
9	Tanaji Bhosale, Kudal (Summer crop)	0.2	Random in ponded condition	0	2	300	150	NA	53	NA

Appendix II

Table 2 Laboratory tests of manually operated finger millet drum seeder cum fertilizer applicator to determine seed rate with different operating conditions

S. N.	Wheel diameter, mm	Operating speed assumed, km/h	Ground wheel rotations, RPM	Seed drum with 12 orifices (H ₁)			Seed drum with 24 orifices (H ₂)		
				Seed collected, g	Seed rate, kg/ha	Seed spacing, cm	Seed collected, g	Seed rate, kg/ha	Seed spacing, cm
1	165 (D ₁)	1 (S ₁)	32.15	6.50	9.76	1.56	11.83	17.76	2.84
		1.5 (S ₂)	48.22	9.50	9.50	1.52	22.50	22.50	3.60
		2 (S ₃)	64.30	21.50	16.14	2.58	32.00	24.03	3.84
2	230 (D ₂)	1 (S ₁)	23.06	4.16	6.24	1.00	6.83	10.25	1.64
		1.5 (S ₂)	34.59	6.67	6.67	1.06	12.5	12.5	2.00
		2 (S ₃)	46.13	10.83	8.63	1.30	22.5	18.02	2.70

Appendix III

Table 3 Seed collected, g/m, seed rate deviation, % and seed distribution efficiency, % in laboratory tests of manually operated finger millet drum seeder cum fertilizer applicator

S. N.	Wheel dia., mm	Forward speed assumed, km/h	Seed drum with 12 orifices (H ₁)			Seed drum with 24 orifices (H ₂)		
			Seed, g/m,	Seed rate deviation, %	Seed distribution efficiency, %	Seed, g/m,	Seed rate deviation, %	Seed distribution efficiency, %
1	165 (D1)	1	0.39	82.27	17.73	0.71	67.73	32.27
		1.5	0.38	82.73	17.27	0.90	59.09	40.91
		2	0.65	70.45	29.55	0.96	56.36	43.64
2	230 (D2)	1	0.25	88.64	11.36	0.41	81.36	18.64
		1.5	0.27	87.73	12.27	0.50	77.27	22.73
		2	0.32	85.45	14.55	0.68	69.09	30.91

Appendix IV

Cost of operation of developed finger millet drum seeder cum fertilizer applicator

The cost of operation of finger millet drum seeder was calculated per hour as well as per hectare basis. The following assumptions were made for the calculations

1. C = The cost of the unit = ₹ 2000
2. L = Life of the unit = 10 years
3. H = Operating hours of the unit per year = 30 h (As only 1/10th of the area will be covered)
4. W = Operator' charges = ₹ 300/day
5. I = Rate of interest = 12 %
6. Repair and maintenance @ 6 % of total cost

A. Fixed cost:

i. Depreciation, ₹ /h = $\frac{C - S}{L \times H} = \frac{2000 - 200}{10 \times 30} = ₹ 6 /h$

ii. Interest: $\frac{C+S}{2} \times \frac{i}{H} = \frac{2000+200}{2} \times \frac{12}{30 \times 100} = ₹ 4.4/h$

Total fixed cost = 6 + 4.4 = ₹ 10.4 /h

B. Variable cost: In this consider following cost

i. Repair and maintenance = 6 % $\frac{C}{H} = \frac{6}{100} \times \frac{2000}{30} = ₹ 4/h$

ii. Operator's charges = $\frac{300}{8} = ₹ 37.5/h$

Total variable cost = 4 + 37.5 = ₹ 41.5/h

1. Total cost of seeding, ₹/h

Total cost = Fixed cost, ₹/h + Variable cost, ₹/h

= 10.4 + 41.5 = 51.9 ≈ ₹ 52/h

2. Total cost of seeding, ₹/ha

Assuming that the unit is operated at 1.5 km/h with 0.4 m width,

$$\text{Theoretical field capacity} = \frac{SW}{10} = \frac{1.5 \times 0.4}{10} = 0.06 \text{ ha/h}$$

If the efficiency of the operation is 80 %, the actual field capacity will be 0.048 ha/h.

Hence, Cost of seeding, ₹/ha

$$= \frac{\text{Cost of seeding, Rs/h}}{\text{Field capacity, ha/h}} = \frac{52}{0.048} = 1083.33$$

The cost of seeding for raising nursery on one hectare area is ₹ 1083.33.

Therefore, cost of seeding finger millet for raising nursery sufficient to transplant on one hectare area is equal to cost required for 1/10th of hectare area as seedlings are raised on 1/10th of area to be transplanted.

$$\frac{\text{Cost of seeding, Rs/h}}{10} = \frac{1083.33}{10} = ₹ 108.3$$

Appendix V

Table 4 Effect of sowing method and seedling age on growth of finger millet seedling for transplanting (average of 10 seedlings)

S. No.	Parameters	Method of sowing											
		Drum seeder						Manual method					
		Seedling age, DAS						Seedling age, DAS					
		25	30	35	40	45	50	25	30	35	40	45	50
1	Shoot length, mm	322	434	489	553	698	758	282	394	476	526	686	714
2	Root length, mm	68	74	87	92	104	117	58	66	85	90	95	104
3	Canopy spread, mm	146	156	170	181	188	198	133	137	145	152	174	183
4	Stem thickness, mm	2.3	2.9	3.7	4.2	4.7	5.2	2.0	2.5	3.4	3.8	4.1	4.6
5	Stem width, mm	5.5	5.9	6.7	7.5	7.7	7.9	4.4	5.7	6.0	6.5	6.9	7.3
6	No. of leaves	7.1	9.7	12.7	14.4	15.7	17.8	7.2	9.2	12.5	14.2	15.5	17.5
7	Weight, g	2.6	3.6	4.6	5.9	10.0	14.5	2.5	3.5	4.6	5.6	8.7	12.2
8	Seedling uprooting time, s/100	231.7	241.7	264.3	283.0	352.3	421.7	241.3	247.3	272.3	291.3	381.7	450.7
9	Damage seedling, %	6.3	6.0	4.7	3.7	2.3	1.7	8.7	7.7	7.0	7.0	4.3	2.7

Appendix VI

Table 5 Developed finger millet transplanter power transmission setting to get desired forward speed at 200 rpm output speed of gearbox

S.N.	Forward speed, km/h	Shaft position	No. of teeth on sprocket	Ground wheel diameter, mm
1	0.3	Shaft 1 - Gearbox output shaft	12	370
		Shaft 2 (intermediate)	44 – 12 (compound sprockets)	
		Shaft 3 (intermediate)	44 – 18 (compound sprockets)	
		Shaft 4 – Drive wheel shaft	56	
2	0.5	Shaft 1 - Gearbox output shaft	18	370
		Shaft 2 (intermediate)	44 – 18 (compound sprockets)	
		Shaft 3 (intermediate)	44 – 12 (compound sprockets)	
		Shaft 4 – Drive wheel shaft	56	
3	0.7	Shaft 1 - Gearbox output shaft	22	425
		Shaft 2 (intermediate)	44 – 18 (compound sprockets)	
		Shaft 3 (intermediate)	44 – 12 (compound sprockets)	
		Shaft 4 – Drive wheel shaft	56	

Appendix VII

Table 6 The sprocket size, drive wheel and number of seedling feed cups on carousel selected for getting desired seedling feed rate

S.N.	Forward speed, km/h	Shaft position	No. of teeth on sprocket	Ground wheel dia., mm	No. seedling cups on carousel	Seedling feed rate, seedlings/min/row
1	0.3	Shaft 1 – Gearbox output shaft	12	370	12	24
		Shaft 2 (intermediate)	44 – 12 (compound sprockets)			
		Shaft 3 (intermediate)	44 – 18 (compound sprockets)			
		Shaft 4 – Drive wheel shaft (intermediate)	56 – 12 (compound sprockets)			
		Shaft 5 (intermediate)	24 – 16 (compound bevel gear)			
		Shaft 6 – Carousel shaft	16 T bevel gear			
2	0.3	Shaft 1 – Gearbox output shaft	12	370	16	31
		Shaft 2 (intermediate)	44 – 12 (compound sprockets)			
		Shaft 3 (intermediate)	44 – 18 (compound sprockets)			
		Shaft 4 – Drive wheel shaft (intermediate)	56 – 12 (compound sprockets)			
		Shaft 5 (intermediate)	30 – 16 (compound bevel gear)			
		Shaft 6 – Carousel shaft	16 T bevel gear			
3	0.3	Shaft 1 – Gearbox output shaft	12	370	16	38
		Shaft 2 (intermediate)	44 – 12 (compound sprockets)			
		Shaft 3 (intermediate)	44 – 18 (compound sprockets)			
		Shaft 4 – Drive wheel shaft (intermediate)	56 – 12 (compound sprockets)			
		Shaft 5 (intermediate)	24 – 16 (compound bevel gear)			
		Shaft 6 – Carousel shaft	16 T bevel gear			
4	0.5	Shaft 1 – Gearbox output shaft	18	370	8	24
		Shaft 2 (intermediate)	44 – 18 (compound sprockets)			
		Shaft 3 (intermediate)	44 – 12 (compound sprockets)			
		Shaft 4 – Drive wheel shaft (intermediate)	56 – 12 (compound sprockets)			
		Shaft 5 (intermediate)	28 – 16 (compound bevel gear)			
		Shaft 6 – Carousel shaft	16 T bevel gear			

5	0.5	Shaft 1 – Gearbox output shaft	18	370	12	31
		Shaft 2 (intermediate)	44 – 18 (compound sprockets)			
		Shaft 3 (intermediate)	44 – 12 (compound sprockets)			
		Shaft 4 – Drive wheel shaft (intermediate)	56 – 12 (compound sprockets)			
		Shaft 5 (intermediate)	34 – 16 (compound bevel gear)			
		Shaft 6 – Carousel shaft	16 T bevel gear			
6	0.5	Shaft 1 – Gearbox output shaft	18	370	12	38
		Shaft 2 (intermediate)	44 – 18 (compound sprockets)			
		Shaft 3 (intermediate)	44 – 12 (compound sprockets)			
		Shaft 4 – Drive wheel shaft (intermediate)	56 – 12 (compound sprockets)			
		Shaft 5 (intermediate)	28 – 16 (compound bevel gear)			
		Shaft 6 – Carousel shaft	16 T bevel gear			
7	0.7	Shaft 1 – Gearbox output shaft	22	425	8	24
		Shaft 2 (intermediate)	44 – 18 (compound sprockets)			
		Shaft 3 (intermediate)	44 – 12 (compound sprockets)			
		Shaft 4 – Drive wheel shaft (intermediate)	56 – 12 (compound sprockets)			
		Shaft 5 (intermediate)	34 – 16 (compound bevel gear)			
		Shaft 6 – Carousel shaft	16 T bevel gear			
8	0.7	Shaft 1 – Gearbox output shaft	22	425	8	31
		Shaft 2 (intermediate)	44 – 18 (compound sprockets)			
		Shaft 3 (intermediate)	44 – 12 (compound sprockets)			
		Shaft 4 – Drive wheel shaft (intermediate)	56 – 12 (compound sprockets)			
		Shaft 5 (intermediate)	28 – 16 (compound bevel gear)			
		Shaft 6 – Carousel shaft	16 T bevel gear			
9	0.7	Shaft 1 – Gearbox output shaft	22	425	12	38
		Shaft 2 (intermediate)	44 – 18 (compound sprockets)			
		Shaft 3 (intermediate)	44 – 12 (compound sprockets)			
		Shaft 4 – Drive wheel shaft (intermediate)	56 – 12 (compound sprockets)			
		Shaft 5 (intermediate)	34 – 16 (compound bevel gear)			
		Shaft 6 – Carousel shaft	16 T bevel gear			

Appendix VIII

Table 7 Fertilizer metering shaft speed using different sprocket combination at 200-rpm gearbox output shaft

S.N.	Shaft position	No. of teeth on sprocket	Fertilizer metering shaft speed, rpm
1	Shaft 1 - Gearbox output shaft	12	22
	Shaft 2 (intermediate)	44 – 18 (compound sprockets)	
	Shaft 7 (intermediate)	42	
2	Shaft 1 - Gearbox output shaft	18	32
	Shaft 2 (intermediate)	44 – 18 (compound sprockets)	
	Shaft 7 (intermediate)	42	
3	Shaft 1 - Gearbox output shaft	22	40
	Shaft 2 (intermediate)	44 – 18 (compound sprockets)	
	Shaft 7 (intermediate)	42	

Appendix IX

Table 8 Developed finger millet transplanter operation setting to get desired speed and feed rate at 200 rpm output speed of gearbox

S. No.	Machine setting	Operational speed, km/h								
		0.3	0.3	0.3	0.5	0.5	0.5	0.7	0.7	0.7
1	Ground wheel dia., mm	370	370	370	370	370	370	425	425	425
2	Teeth of sprocket on gearbox shaft	12	12	12	18	18	18	22	22	22
3	No. of teeth on sprocket of carousel shaft	28	30	24	28	34	28	34	28	34
4	No. of cups on carousel	12	16	16	8	12	12	8	8	12
6	Seedling feed rate, seedlings/min	24	31	38	24	31	38	24	31	38

Appendix-X

Table 9 Observations of transplanting system recorded on plain land

Speed	Feed rate, No./ min	Seedling age, DAS	S-10, No.	H-dist, cm	Hills/sq m	Missed hills / sq. m, No.	Damaged / sq. m, No.	Op time, s
0.3	24	25	4.6	22	36.8	1.6	1.6	162
0.3	31	25	6.0	17	48.1	1.5	1.5	162
0.3	38	25	7.4	14	59.1	1.7	1.7	161
0.5	24	25	2.4	42	19.1	3.9	3.9	121
0.5	31	25	3.4	30	26.8	3.0	3.0	121
0.5	38	25	4.2	24	33.7	2.8	2.8	121
0.7	24	25	1.7	61	13.3	3.2	3.2	85
0.7	31	25	2.4	43	18.9	2.4	2.4	86
0.7	38	25	2.8	35	22.6	3.5	3.5	86
0.3	24	30	4.7	21	37.8	0.7	0.7	161
0.3	31	30	6.2	16	49.5	0.3	0.3	161
0.3	38	30	7.5	13	60.3	0.8	0.8	161
0.5	24	30	2.9	35	23.1	0.5	0.5	122
0.5	31	30	3.4	29	27.5	2.3	2.3	121
0.5	38	30	4.4	23	35.2	1.3	1.3	122
0.7	24	30	2.1	49	16.4	0.2	0.2	85
0.7	31	30	2.4	42	19.4	1.9	1.9	86
0.7	38	30	3.3	31	26.2	0.7	0.7	86
0.3	24	35	4.8	21	38.5	0.4	0.4	161
0.3	31	35	6.3	16	50.2	0.1	0.1	161
0.3	38	35	7.6	13	60.9	0.4	0.4	162
0.5	24	35	2.9	35	23.0	0.4	0.4	122
0.5	31	35	3.6	28	28.8	0.9	0.9	121
0.5	38	35	4.5	22	35.8	0.8	0.8	122
0.7	24	35	2.1	49	16.5	0.4	0.4	85
0.7	31	35	2.6	38	21.1	0.2	0.2	86
0.7	38	35	3.3	30	26.5	0.5	0.5	86
0.3	24	40	4.8	21	38.2	0.2	0.2	161
0.3	31	40	6.3	16	50.2	0.3	0.3	162
0.3	38	40	7.7	13	61.8	0.4	0.4	161
0.5	24	40	3.0	33	24.3	0.0	0.0	122
0.5	31	40	3.8	26	30.6	0.0	0.0	121
0.5	38	40	4.6	22	36.7	0.0	0.0	122
0.7	24	40	2.1	47	17.1	0.1	0.1	85
0.7	31	40	2.7	37	21.5	0.6	0.6	86
0.7	38	40	3.4	30	26.9	0.0	0.0	86
0.3	24	45	4.9	20	39.4	0.0	0.0	161
0.3	31	45	6.4	16	51.3	0.0	0.0	161
0.3	38	45	7.7	13	61.3	0.4	0.4	161
0.5	24	45	2.8	36	22.4	0.7	0.7	122
0.5	31	45	3.7	27	29.2	0.6	0.6	121
0.5	38	45	4.5	22	36.3	0.3	0.3	122
0.7	24	45	2.3	44	18.3	0.0	0.0	85
0.7	31	45	2.6	39	20.8	1.0	1.0	86
0.7	38	45	3.4	30	27.1	0.0	0.0	86
0.3	24	50	4.5	23	35.6	2.8	2.8	161
0.3	31	50	5.9	17	47.2	2.4	2.4	161
0.3	38	50	7.2	14	57.9	2.9	2.9	162
0.5	24	50	2.4	41	19.5	3.5	3.5	122
0.5	31	50	3.3	30	26.3	3.5	3.5	121
0.5	38	50	4.1	24	32.9	3.6	3.6	122
0.7	24	50	1.6	61	13.1	3.4	3.4	85
0.7	31	50	2.2	46	17.6	3.7	3.7	85
0.7	38	50	3.0	34	23.6	2.5	2.5	86

Appendix-XI

Table 10 Observations of transplanting system recorded during field trials

Speed	Feed rate, No./ min	Seedling age, DAS	S-10, No.	H-dist, cm	Hills/sq m	Missed hills / sq. m, No.	Damaged / sq. m, No.	Depth of operation, cm	Op time
0.3	24	35	4.9	19.9	39.5	1.25	1.25	4.4	166
0.3	31	35	6.3	16.6	50.1	1.5	1.5	4.6	167
0.3	38	35	7.6	13.5	60.4	1.75	1.75	4.9	166
0.5	24	35	2.7	35.9	21.5	1.25	1.25	4.1	125
0.5	31	35	3.6	26.9	28.8	1.75	1.75	5.1	143
0.5	38	35	4.6	21.0	36.9	2	2	4.5	126
0.7	24	35	1.7	56.3	13.8	1.5	1.5	4.5	90
0.7	31	35	2.5	39.8	19.6	1.5	1.5	4.9	91
0.7	38	35	3.1	31.0	25	0.5	0.5	4.3	92
0.3	24	40	5.1	18.8	40.9	0.75	0.75	4.6	165
0.3	31	40	6.5	14.9	51.6	1.25	1.25	4.5	168
0.3	38	40	7.7	13.3	61.5	1	1	4.8	168
0.5	24	40	3.0	32.8	24	0.75	0.75	4.6	128
0.5	31	40	3.7	26.5	29.5	1.75	1.75	4.8	128
0.5	38	40	4.7	21.1	37.6	0.75	0.75	5.0	127
0.7	24	40	2.1	46.3	16.9	1.25	1.25	5.0	90
0.7	31	40	2.6	37.0	20.9	1	1	5.0	92
0.7	38	40	3.3	29.6	26.2	1	1	4.9	91
0.3	24	45	4.9	20.8	38.8	1.5	1.5	4.9	166
0.3	31	45	6.3	15.9	50.3	1.5	1.5	4.9	165
0.3	38	45	7.5	13.5	60	2.25	2.25	4.8	168
0.5	24	45	2.8	34.3	22.7	2	2	4.9	128
0.5	31	45	3.5	27.9	28.3	2.5	2.5	4.8	128
0.5	38	45	4.6	20.6	36.9	1	1	4.5	126
0.7	24	45	2.0	48.1	16	0.75	0.75	5.0	91
0.7	31	45	2.5	40.3	19.9	1	1	4.9	88
0.7	38	45	3.1	30.9	25	0.75	0.75	4.8	92

Appendix-XII

Table 11 Cost of fabrication for power operated finger millet transplanting system

Sr. No	Particulars	Material and specification	Amount (₹)
1	Engine	CANARIS CIB5305, single cylinder, 51.5 cc, rated power 2.64 kW (3.5 hp)	10000
2	Reduction gear box	Worm and pinion type	2000
3	Transmission system	Sprockets 12 T × 3, 16 T, 18 T × 2, 22 T, 24 T, 28 T, 30 T, 32 T, 34 T, 42 T, 44 T × 2, 56 T Bevel Gears 16 T × 2 Pairs Suitable Chains	3000
4	Cage wheels	φ 320 mm × 2 φ 425 mm × 2	2000
5	Seedling metering mechanism	PVC pipe φ 75 mm × 2 MS flat-20 mm MS flat- 200 mm	700
6	Seedling metering vertical shaft	MS pipe φ 30 mm × 570 mm × 2	200
7	Wooden metering plate with sun mica lamination	φ 380 mm	1200
8	Funnel	φ 150 mm × 2	80
9	Seedling tube	φ 90 mm × 470 mm × 2	200
10	Fertilizer metering mechanism	Two seed metering cup roller	300
11	Fertilizer metering mechanism fixture frame	MS Sq. pipe 25 mm × 2400 mm	100
12	Fertilizer tubes	φ 50 mm × 1 m × 2	200
13	Seedling tray	22 guage GI sheet	300
14	Handle	MS square pipe- 25 mm	360
15	Main frame	MS Sq. pipe 40 mm	800
16	Pneumatic wheel	φ 320 mm	600
17	Furrow opener system	MS Sq. pipe 40 mm MS angle 45 × 45 × 5 mm × 600 mm GI sheet 18 guage MS flat 25 mm × 2 mm	100
18	Pedestal Bearing	P 206 × 12	360
19	Nut, Bolt, bearings		2000
20	Total Material cost, ₹		24500
21	Material cost, ₹ (excluding engine cost)		14500
22	Fabrication cost, ₹ (120 % of material cost)		17400
	Total cost of machine, ₹		41900

Appendix-XIII

Operating cost of newly developed transplanter

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

Assumptions

1. Average annual use 250 hours
2. Life of machine 10 yrs
3. Salvage value, (% of initial cost) 10 %

A. Fixed Cost

1. Cost of machine (C) = ₹ 41900/-
2. Salvage value (S) = ₹ 4190
3. Interest rate (i) = 12 per cent
4. Life of the machine (L) = 10 Years
5. Annual working hours (H) = 250
6. Depreciation (₹/h)

$$= \frac{C - S}{L \times H} = \frac{41900 - 4190}{10 \times 250} = 15.08$$

7. Interest (₹/h)

$$= \frac{C + S}{2} \times \frac{i}{H} = \frac{41900 + 4190}{2} \times \frac{12}{100 \times 250} = 11.06$$

8. Housing (₹/h) = 1.5 % of initial cost C

$$= \frac{1.5 \times 41900}{250 \times 100} = 2.5$$

Total fixed cost (₹/h) = 6 + 7 + 8

$$= 15 + 11 + 2.5 = 28.5 \cong 29$$

Annual fixed cost of transplanter (₹) = 29 × 250 = 7250

B. Variable Cost

Assumptions:

1. Two operators are required to feed seedlings in transplanter
2. Wage rate of R 300 / man / day of 8 hours

Total cost of operation of finger millet transplanter (₹/ h)

9. Fuel cost (₹/h)

$$= \text{Fuel consumed (lit/h)} \times \text{Fuel Charge (₹/lit)} = 0.77 \times 100 = 77$$

10. Operators cost (₹/h)

$$= \text{Wage of operator} / \text{Working Hours} = \frac{600}{8} = 75$$

11. Repair and maintenance (₹/h) = 5 % of initial cost

$$= \frac{5 \times 41900}{100 \times 250} = 8.38$$

Total Variable cost (₹/h) = 9 + 10 + 11

$$= 77 + 75 + 8.38$$

$$= 160.38 \cong 160$$

Annual variable cost of transplanter (₹) = 160 × 250 = 40000

The operational cost is sum of (A) Fixed cost and (B). Variable cost.

C. Operational Cost (₹/h)

$$= \text{Fixed Cost} + \text{Variable Cost}$$

$$= 29 + 160 = 189$$

Average field capacity of transplanter (ha/h) = 0.0098

Total hours required to complete transplanting one hectare are (h) = 101.72 = 102

Total cost of operation (₹/ha) = 189 × 102 = 19278.

Appendix-XIV

Cost of manual transplanting of finger millet

Field capacity manual transplanting, ha/h = 0.0038.

Time required to cover one hectare = 263.15 h = 32.89 say 33 days (assuming 8 working hours per day)

Total wages assuming three labours per day @ ₹ 300 per day per person, ₹ /ha = $33 \times 300 \times 3 = 29700/-$.