DESIGN, DEVELOPMENT AND TESTING OF A TRACTOR DRAWN SEMI-AUTOMATIC RHIZOME PLANTER FOR GINGER AND TURMERIC

By

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TAVANUR - 679 573

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(2014 - 18 - 111)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

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IN

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(Farm Power Machinery and Energy)

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ABSTRACT OF THE THESIS

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Dedication

This thesis is dedicated to my Mother, Father and Brother, who sacrificed much to bring me up to this level and to my lovely sisters, brothers and their families for the devotion they made to make my life successful.

DECLARATION

I hereby declare that this thesis entitles **"Design, Development and Testing of a Tractor Drawn Semi-Automatic Rhizome Planter for Ginger and Turmeric"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Place: Tavanur **MADHUKUMARA D M**

Date : 20/03/2017 **(2014-18-111)**

CERTIFICATE

Certified that this thesis entitled **"Design, Development and Testing of a Tractor Drawn Semi-Automatic Rhizome Planter for Ginger and Turmeric"** is a record of research work done independently by **MADHUKUMARA D M (2014-18-111)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Place: Tavanur

Date : 20/03/2017

Dr. Manoj Mathew

(Chairman, Advisory Committee)
Professor (FPME),
Rice Research Station,
Moncompu, Alappuzha

CERTIFICATE

We, the undersigned members of the advisory committee of **Mr. MADHUKUMARA D M,** a candidate for the degree of Master of Technology in Agricultural Engineering with major in Farm Power, Machinery and Energy, agree that the thesis entitled **"Design, Development and Testing of a Tractor Drawn Semi-Automatic Rhizome Planter for Ginger and Turmeric"** may be submitted by **Mr. MADHUKUMARA D M** in partial fulfillment of the requirement for the degree.

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(Name and Address)

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MADHUKUMARA D M

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SYMBOLS AND ABBREVIATIONS

Symbols		Abbreviations
<	:	Less than
>	:	Greater than
%	:	Per cent
±	:	Plus or minus
×	:	Multiplication
÷	:	Division
≤	:	Less than or equal to
≥	:	Greater than or equal to
°	:	Degree
°C	:	Degree centigrade
ANOVA	:	Analysis of variance
ASAE	:	American society of agricultural engineers
cm	:	Centimeter
cm^2	:	Square centimeter
cm^3	:	Cubic centimeter
CV	:	Coefficient of variation
DAP	:	Days after planting
db	:	dry basis
et al.	:	and others
etc.	:	et cetera
Fig.	:	Figure
g	:	Gram
$g\ cm^{-3}$	:	Gram per cubic centimeter
ha	:	Hectare
$ha\ h^{-1}$	:	Hectare per hour
hp	:	Horse power
hr	:	Hour

hr ha^{-1}	:	Hour per hectare
I_{fq}	:	Quality of feed index
I_{miss}	:	Missing index
I_{mult}	:	Multiple index
I_p	:	Precision index
IS	:	Indian standards
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji college of agricultural engineering and technology
kg	:	Kilogram
kg cm	:	Kilogram centimeter
kg cm^{-2}	:	Kilogram per square centimeter
kg ha^{-1}	:	Kilogram per hectare
kg m	:	Kilogram meter
kg m^{-3}	:	Kilogram per cubic meter
kg mm^2	:	Kilogram per square millimeter
kgf	:	Kilogram force
km h^{-1}	:	Kilometer per hour
l hr^{-1}	:	Liter per hour
m	:	Meter
m min^{-1}	:	Meter per minute
m s^{-1}	:	meters per second
m^2	:	Square meter
m^3	:	Cubic meter
mm	:	Millimeter
mm^2	:	Square millimeter
MS	:	Mild steel
N	:	Newton
N cm^{-2}	:	Newton per square centimeter
N m^{-1}	:	Newton per meter

pH	:	Potential of hydrogen
PVC	:	Polyvinyl chloride
q	:	Quintal
RNAM	:	Regional Network of Agricultural Machinery
rpm	:	Revolutions per minute
Rs	:	Rupees
Rs ha^{-1}	:	Rupees per hectare
Rs h^{-1}	:	Rupees per hour
SD	:	Standard deviation
Sl. No.	:	Serial Number
t	:	Tons
viz.	:	Namely
wb	:	Wet basis
α	:	Alpha
θ	:	Theta
μ	:	mue
π	:	Pi
ρ	:	Rho
σ	:	Sigma

CHAPTER I

INTRODUCTION

Ginger (*Zingiber officinale Roscoe*) is a tropical monocotyledon and herbaceous perennial species belonging to the family *Zingiberaceae*. It is the oldest rhizome widely cultivated as a spice and is popular for its distinct sharp and hot flavour due to an oily substance called gingerol. Ginger is a medicinal plant and plays an important role in Indian Ayurvedic medicine as a folk remedy to promote cleaning of the body through perspiration, to calm nausea, to stimulate appetite and also it is used in food and chemical industries.

Turmeric (*Curcuma longa* L.) plant is a perennial herb belonging to the ginger family *Zingiberaceae*, has primary and secondary rhizomes of different forms, from spherical to slightly conical, hemispherical and cylindrical. The most active component of turmeric is curcumin, which constitutes 2 to 5% of the spice. Turmeric is valued for its underground orange coloured rhizome which is used as a natural colouring agent for food, cosmetics and dye. Curcuminoids the active principles in turmeric rhizomes is to known have some medicinal properties and has been used efficiently in the treatment of circulatory problems, liver diseases, dermatological disorders and blood purification (Olojede *et al.,* 2009). The turmeric powder is highly valued as a base material for curry production in confectionery industries for food seasoning and in the international markets as a functional food due to its health-promoting properties. It is used as a food additive (spice), preservative and colouring agent in all Asian countries, including China and South East Asia.

Most of the spices are native to our country hence, India is known as the land of spice crops and also the largest producer, consumer and exporter of spices crops. India contributes around 30.27 % to the world production of ginger. There is an increase from 110.6 thousand ha area and 391.2 thousand tonnes production in 2005-06 to 155.1 thousand ha area and 755.6 thousand tonnes production in 2011-12 and it is decreased to 136.3 thousand ha area and 682.6 thousand tonnes production in 2012-13. The productivity has increased from 3537 kg ha^{-1} in 2005-

06 to 5010 kg ha^{-1} in 2012-13. The main ginger growing states are Kerala, Karnataka, Sikkim, Meghalaya, Himachal Pradesh, West Bengal, Assam and other Northeastern states (Indiastat, 2013).

Turmeric occupies about 6% of the total area under spices and condiments in India. There is an increase from 172.0 thousand ha area, 851.7 thousand tonnes production and 4952 kg ha^{-1} productivity in 2005-06 to 218.6 thousand ha area, 755.6 thousand tonnes production and 5337 kg ha^{-1} productivity in 2011-12 and it is decreased to 194.2 thousand ha area, 971.1 thousand tonnes production and 5000 kg ha^{-1} in 2012-13. Indian turmeric is considered as the best in the world and it is named as "Indian saffron". The main turmeric growing states are Andhra Pradesh, Karnataka, Orissa, Tamil Nadu, West Bengal, Gujarat and North Eastern states.

In Kerala area under cultivation of ginger is about 4.51 thousand ha and turmeric is 2.63 thousand ha. The production of ginger is about 22.06 thousand tonnes and turmeric is 6.90 thousand tonnes and productivity of ginger is about 4900 kg ha^{1} and turmeric is 2590 kg ha^{-1} in 2013-14 (Indiastat, 2013)

India is the largest exporter of ginger and exports important varieties like Suruchi, Ernad, Wynadkuruppampadi, Himgiri, etc. The export of ginger during 2010-11 was 15,750 tonnes valued at Rs.12131.25 lakhs compared to 9,411 tonnes valued at Rs. 4295.52 lakhs in 2005-06. The major importers of turmeric from India are Srilanka, UAE, Bangladesh, China, Malaysia, etc.

India is the largest exporter of turmeric and exports important varieties like Alleppey finger, Rajapuri, Erode variety etc. The export of turmeric during 2010-11 was 49,250 tonnes valued at Rs. 70285.15 lakhs compared to 46,405 tonnes valued at Rs. 15286.02 lakhs in 2005-06. The major importers of turmeric from India are Bangladesh, UAE, USA, Australia, Japan, etc.

Ginger is a perennial plant usually grown as an annual for harvesting as a spice. Ginger requires a warm and humid climate. It is cultivated from almost sea level to an altitude of 1500 m above mean sea level either under heavy rainfall conditions (150-300 cm $year^{-1}$) or under irrigation. The ginger grows well in sandy or clayey loam, red loam or laterite loam soils having good drainage and humus content. Ginger is propagated vegetatively through rhizomes. The size of the planting material varies from place to place and variety to variety. Ginger planting is manually done by digging the soil and placing the rhizome into it then it is covered with soil by using hands. The bits are made from mother rhizomes having 3-5 cm in length 15-20 g weight (15 g is optimum) and at least one or two buds. A seed rate of about 1500-2000 kg ha^{-1} is considered to be optimum for planting. The spacing for the planting of ginger should be kept 25-45 cm between rows and 20-25 cm between plants.

Turmeric can be grown in diverse tropical conditions from sea level to 1500 m above mean sea level, at a temperature range of 20-35°C with an annual rainfall of (1500 mm or more), under rainfed or irrigated conditions. Though it can be grown on different types of soils, it thrives best in well-drained sandy or clay loam soils with a pH range of 4.5-7.5 with good organic status. In turmeric, there are mainly two types of rhizome *viz.,* mother and fingers. Fingers are further classified as primary, secondary or tertiary. In general, planting mother rhizome gives better yield. Mother rhizome alone may not sufficient to cover a large area, hence, in addition to mothers; primary fingers are also used as seed due to high seed rate of 2000-2500 kg ha^{-1}. The optimum spacing in furrows and ridges is 45-60 cm between the rows and 25 cm between the plants. Turmeric planting is manually done by placing the seed rhizomes of 6-7 cm length with at least one or two sound buds in the ridges (Jayashree *et al*., 2014).

Nowadays, spices crops are having more market value as compared to other horticultural crops. Spices crops provide excellent opportunities in raising the income of the farmers even in the dry tracts. Present study is focusing on ginger and turmeric since these crops provides higher unit productivity and offers great scope for value addition. Higher productivity can be achieved by speedy and timely farm operations. So, for the specific and speedy farm operations should have appropriate farm machines. Nowadays, the labour availability in rural areas is low due to labour migration. Hence, to increase the productivity of ginger and turmeric cultivation and mechanize the farm operations, development of suitable machines are essential (Kandiannan *et al*., 2008).

In the recent years, no machinery was developed for planting ginger and turmeric rhizomes. These are close spacing crops and requires about 200-250 man-hr ha^{-1} which increase cultivation cost (Mathanker and Mathew, 2002). Also, the rhizome planting coincides with field operations of other crops at the onset of monsoon rains in Kharif seasons. Delays in planting due to labour shortages and rains adversely affect yield and production of ginger and turmeric.

At present, it is observed that the farmers in the state had faced problems in ginger and turmeric planting due to lack of labour shortage. Therefore, it is essential to develop a rhizome planter for mechanizing planting of ginger and turmeric. The ginger and turmeric are planted in beds or ridges. Mechanizing planting operation results in uniform plant spacing, depth and aids further mechanization of intercultural operations that will reduce the total production cost and increase yield and productivity.

Under this circumstances, a project entitled "**Design, Development and Testing of a Tractor Drawn Semi-Automatic Rhizome Planter for Ginger and Turmeric**" was undertaken at Kelappaji College of Agricultural Engineering and Technology (KCAET), Tavanur, Kerala with the following objectives.

1. To study the characteristics of ginger and turmeric rhizomes related to planter design.
2. To design and develop of a tractor drawn semi-automatic rhizome metering mechanism and components of ginger and turmeric planter.
3. Field testing and evaluation of planter.

CHAPTER II

REVIEW OF LITERATURE

This chapter gives a comprehensive review of the research work done by various research workers related to the cultivation methods of ginger and turmeric, physical and engineering properties of ginger and turmeric, development of planters for crops *viz.,* onion, garlic, potato and peanut, different types of seed metering mechanisms used in various planters and planter design and operational parameters that affects the planter performance.

2.1. CULTIVATION METHODS OF GINGER AND TURMERIC

Islam *et al.* (2002) conducted experiments to find out the optimum plant spacing for maximizing the yield of turmeric. The highest average yield of 17.87 t ha^{-1} was obtained from 45 cm x 10 cm plant spacing which was closely followed average yield of 16.77 t ha^{-1} by 45 cm x 20 cm plant spacing. The lowest average yield of 13.42 t ha^{-1} was recorded from 60 cm x 30 cm. They concluded that planting geometry of 45 cm x 10 cm is suitable agronomically, but also a spacing geometry of 45 cm x 20 cm is economically viable for turmeric production.

Amzad Hossain *et al*. (2005) stated that the required weight of seed rhizome is about 50 g of mother rhizome which must include secondary and tertiary rhizomes that develop, to mature plants to give comparable yield. Other than weight, size of seed rhizome is an important factor for the selection of good rhizome seeds of turmeric. Finally the turmeric seed rhizome should be the part of mother or primary rhizome with large diameter. It should have weight within 30-40 g. The secondary and tertiary daughter rhizomes should be removed from the seed rhizomes used for planting.

Kandiannan and Chandaragiri (2008**)** conducted experiments to study the effect of variety, planting time, and spacing on turmeric yield. They concluded that the variety BSR-2 performed better than BSR-1 in terms of growth and yield. The plant geometry 30 cm x 15 cm recorded significantly higher growth, nutrient uptake and yield than 45 cm x 15 cm and 60 cm x 15 cm spacing.

Monnaf *et al*. (2010) conducted a field experiment to study the effect of planting method and rhizome size on the growth and yield of ginger. The study comprised two factors *viz.,* planting method and rhizome size. The main effects and the combined effects of three planting methods namely ridge method, furrow method and flat method with five rhizome sizes *viz.,* 10-15 g, 15-20 g, 20-25 g, 25-30 g and 30-35 g were evaluated. Planting methods and rhizome size and their combined effects showed significant influence on the yield and yield components of ginger. They reported that the highest yield (18.78 t ha^{-1}) was obtained from ridge method of planting followed by furrow (14.56 t ha^{-1}) and flat method (11.06 t ha^{-1}). The highest yield (19.64 t ha^{-1}) was recorded from 30-35 g of rhizome size and the lowest (11.30 t ha^{-1}) was from 10-15 g of rhizome size. The most satisfactory yield (22.78 t ha^{-1}) was found from the treatment combination of ridge method with 30-35 g of rhizome size; while the poorest yield (8.34 t ha^{-1}) was obtained from the treatment combination of flat method with 10-15 g of rhizome size.

Kumar and Gill (2010) conducted an experiment to evaluate the effect of planting method, plant density and planting material on growth, yield and quality of turmeric (*Curcuma longa*). The experiment consisted of two planting methods (flat and ridge), three plant densities (1,66,667; 1,11,111 and 83,333 plants ha^{-1}) and three types of planting material (mother, primary and secondary rhizomes). Fresh rhizome resulted in an yield of 164.8 and 160.3 q ha^{-1} was produced in flat and ridge method of planting but the differences were non-significant. Whereas, planting of mother rhizomes produced highest yield (207.7 q ha^{-1}), turmeric yield compared to primary and secondary rhizomes and it decreased significantly with decrease in seed size.

Mahender *et al*, (2013) conducted experiment to study the effect of seed rhizome size and plant spacing on growth, yield and quality of ginger with three seed rhizome sizes *viz.,* 20 g, 30 g and 40 g and five plant spacing *viz.,* 25 cm × 15 cm, 25 cm × 25 cm, 30 cm × 20 cm, 30 cm × 30 cm and 40 cm × 20 cm. They reported that the rhizome size of 40 g took least number of days to first sprouting of rhizome (12.73) followed by 30 g. Similarly plant height at harvest 67.87 cm, number of tillers per plant 11.51 and leaf area index 3.59, yield 27.41 t ha^{-1}, essential oil content 1.83% and starch content 30.27% were recorded maximum with 40 g seed rhizome size. Regarding plant spacing highest plant height 65.07 cm, leaf area index 5.25 and yield 26.40 t ha^{-1} was recorded from closest plant spacing of 25 cm × 15 cm. The most satisfactory rhizome yield 38.06 t ha^{-1} was found from the treatment combination of 40 g seed rhizome size with 25 cm × 15 cm plant spacing.

Singh and Kaur (2015) carried out study on different methods of turmeric planting to evaluate the growth and yield of turmeric. The mean length of turmeric rhizomes for T1 (planting of turmeric manually at 30 cm × 20 cm spacing), T2 (planting of turmeric manually at 45 cm × 15 cm spacing) and T3 (planting of turmeric with semi-automatic potato planter at a spacing of 60 cm × 15 cm). They reported that after uprooting the mean length of turmeric rhizomes was 7.85 cm, 7.91 cm and 8.20 cm, and mean diameter was 3.05 cm, 2.64 cm and 3.45 cm, respectively. The number of rhizomes per kg for T1, T2 and T3 were 34, 30 and 24, respectively. The yield of turmeric rhizome was highest (130.0 q $acre^{-1}$) in T3 which was 17.65% and 8.33% more as compared to T2 and T1, respectively because the rhizomes were grown on ridges and the overall size of rhizomes was bigger.

2.2 ENGINEERING PROPERTIES OF GINGER AND TURMERIC

2.2.1 Physical properties

Physical properties are important parameters for the design of a particular equipment or determining the behavior of a product, during its handling and processing, in different machines (Sahay and Singh, 1994). The physical properties such as moisture content, size, shape, and bulk density of turmeric, as reported by different researchers are reviewed and presented here.

2.2.1.1 Moisture content

Athmaselvi and Varadharaju (2002) reported the moisture content of the turmeric varieties. The average moisture content of the variety BSR-1 and Erode local was 82% (wb) and the moisture content of BSR-2 was 86% (wb) immediately after harvest.

2.2.1.2 Size

Size and shape are two inseparable physical properties and both are generally necessary for satisfactorily describing shape of any solid object. Seeds, grains, fruits and vegetables are irregular in shape and a complete specification of their form theoretically requires an infinite number of measurements in mutually perpendicular axis. Size, generally refers to the characteristic of an object which determines space requirement within the limit. Several researchers described the size of many biological materials satisfactorily by measuring their dimensions in three principal mutually perpendicular axis as length, width and thickness.

Mathanker and Mathew (2002) studied the design characteristics of seed rhizomes for designing the critical dimensions of metering devices. They reported that the average length, width, thickness and angle of repose of seed rhizome was 72.35 mm, 49.28 mm, 19.23 mm and 38 to 41.5° respectively, whereas average weight of rhizome by manual preparation was 26.75 g.

Jayashree (2009) reported the size of the ginger rhizomes, which has the shape like turmeric. The average length, width and thickness of fresh ginger rhizome at the moisture content of 81.70% (wb) were found to be 14.99, 8.17 and 4.49 cm respectively.

Mishra and Kulkarni (2009) identified some engineering properties of turmeric (variety-Sangli), *viz.*, the average length, width and thickness of turmeric as 42.77, 10.85, and 9.51 mm respectively at 12.4% moisture content (db).

Ajav and Ogunlade (2014) studied some physical properties of ginger rhizomes and they reported the average values of major, minor and intermediate diameters, geometric mean, sphere city, bulk volume and surface area are 112 mm, 38.3 mm, 72.3 mm, 67.6 mm, 0.61, 832.5 cm^3 and 147 cm^2.

Subhashini *et al.* (2015) studied the physical properties of turmeric rhizomes were determined at different moisture contents such as 8, 12 and 16%. They reported that the bulk density and true density of turmeric rhizome at 12%

moisture content were 647.5 kg m^{-3} and 1303.3 kg m^{-3} respectively. The porosity of turmeric rhizomes was found to be 67.3%.

2.2.1.3 Bulk density

The mass per unit bulk volume of a substance under some specified conditions such as temperature, moisture content etc., is called bulk density.

Athmaselvi and Varadharaju (2002) reported the relationship between moisture content and bulk density for turmeric varieties. The bulk density of BSR-1 was in the range of 779 to 809 kg m^{-3}, 693 to 853 kg m^{-3} for BSR-2, 753 to 801 kg m^{-3} for Erode local at the moisture range of 40 to 70% (wb), respectively. It was stated that bulk density increased with increase in moisture content.

Jayashree (2009) found out the average bulk density of ginger rhizomes. The average bulk density of fresh ginger rhizome at 81.70% (wb) moisture content was 471.49 kg m^{-3}.

Mishra and Kulkarni (2009) found out the bulk density of turmeric rhizomes (variety-Sangli). The average bulk density of fresh turmeric rhizome at 12.4% (db) moisture content was 622.33 kg m^{-3}.

Ajav and Ogunlade (2014) found out the average bulk density of ginger rhizomes. The average bulk density of fresh ginger rhizome at 10.9% and 51.6% (db) moisture content was 0.92 g cm^{-3}.

2.2.2 Frictional properties

The frictional properties such as coefficient of friction and angle of repose are important in the design of hoppers, conveying system, threshers etc. (Sahay and Singh, 1994). Frictional properties help to understand the behavior of the given material motion on different surfaces.

2.2.2.1 Angle of repose

The angle of repose is the angle between the base and the slope of the cone formed on a free vertical fall of granular materials over a horizontal plane. The size, shape, moisture content and orientation of the grains affect the angle of repose (Sahay and Singh, 1994).

Mishra and Kulkarni (2009) identified the angle of repose of fresh turmeric rhizome, by using a bottomless cylinder placed on a flat surface and filled it with turmeric rhizomes. The cylinder was raised slowly allowing the rhizomes to flow and assume a natural slope in the form of cone. The diameter and height of cone was measured and angle of repose calculated. The angle of repose for fresh turmeric rhizome was 33°.

Ajav and Ogunlade (2014) reported that the angle of repose of fresh ginger rhizomes measured by using a specially constructed topless and bottomless box made of plywood, with a removable front panel was 48°.

2.2.2.2 Coefficient of friction

The coefficient of friction between granular materials is equal to the tangent of the angle of internal friction for the material. The frictional coefficient depends on grain shape, surface characteristics and moisture content.

Athmaselvi and Varadharaju (2002) studied the static coefficient of friction of turmeric rhizomes of BSR -1, BSR-2 and Erode varieties with respect to moisture content on four metallic surfaces *viz.*, aluminum, mild steel, galvanized iron and stainless steel. The static coefficient of friction increased with increase in moisture content of rhizomes in all metal surfaces.

Jayashree (2009) reported the coefficient of friction of ginger rhizomes. The coefficient of friction of fresh ginger rhizomes at a moisture content of 81.70% (wb) against plywood, stainless steel, aluminum, galvanized iron and mild steel surfaces was 0.53, 0.57, 0.68, 0.72 and 0.74, respectively.

Mishra and Kulkarni (2009) found out the co-efficient of friction of turmeric rhizomes (variety-Sangli). The static coefficient of friction on four metal surfaces namely, mild steel (0.51 to 0.66), galvanized iron (0.47 to 0.64), aluminum (0.40 to 0.56) and stainless steel (0.37 to 0.54) with increase in moisture range from 12.40 to 21.85% (db).

Ajav and Ogunlade (2014) reported the coefficient of friction of ginger rhizomes. The coefficient of friction was obtained on three different structural materials the values obtained are 0.40 on glass, 0.49 on stainless steel and 0.55 on wood.

2.3 DEVELOPMENT OF VARIOUS PLANTERS

Sadhu (1982) designed and developed a tractor operated two row onion set planter. The metering mechanism used was horizontal plate type. The onion set hopper was a vertical, cylindrical shell mounted coaxially above the metering mechanism. The hopper consisted of an outer shell fitted around the outside at the bottom. This left an annular space between the two cylinders. The annular space was utilized as a passage to guide the onion-sets into the drop chute during operation. There were two guide plates in the annular space, fixed to the inner cylinder, adjacent to the outlet openings, so that the flow of onions was diverted into the drop chutes.

Odigdoh and Akubuo (1991) designed and tested a two-row automatic minisett yam planter and it has a special two-row ridger which makes small, 50 cm ridges at 90 cm row spacing. The prototype can operate at up to 7 km h^{-1} and makes ridges and automatically meters and plants the yam minisetts in the ridges at a spacing of about 24 cm within the row and at a planting depth of 4 cm.

Sahoo and Srivastava (2000) developed a three-row ridger planter for planting soaked okra seed on ridges. The seed metering mechanism in the planter is of inclined plate type. The power is transmitted from ground wheel to metering system through chain and sprockets. The machine has four ridger bottoms with runner type furrow opener for making ridges. The seed is placed in these ridges at desired depth. The ridge size and depth of placement of seed are adjustable. The implement is operated by a 35 hp tractor. The field capacity of the machine was 0.2 ha r^{-1} at an average operating speed of 2.27 km h^{-1}. The field efficiency of the planter was 66.5%.

Singh (2004) stated that potato planting in large parts of eastern Uttar Pradesh is done manually and manual operation results in varying and non-uniform plant stand and requires large labour force in field preparation as well as planting operations. To overcome the shortage of labours, timeliness in operation and planting problems, a two-row tractor operated potato planter ridger was tested. Necessary modifications were made in the machine based on the test results and it was introduced to the farmers. The modified potato planter was widely accepted among the potato growers in eastern Uttar Pradesh.

Kazmeinkhah, *et al*, (2007) designed a semi-automatic transplanter machine, in order to cultivate sugar beet seedling. This machine was able to cultivate seedling with the row distance of 65 cm, seedling distance of 50.3 cm and 13cm depth. Standard deviation in comparison to the desired position was 4.5% along the cultivation row line and 3.6% perpendicular to the cultivation row line.

Bakhtiari and Loghavi (2009) designed and developed a tractor-mounted, ground-wheel driven, three row precision planter for garlic cloves on raised bed. The metering drums and sweepers were driven by two ground wheels through a chain drive system. The test performance parameters evaluated were seeding mass rate, seeding depth, seed spacing, miss index, multiple index and seed damage. The tests results showed that the new machine was capable of planting 2,20,000 plants ha^{-1} at a seeding depth and spacing of 12.3 and 22.7 cm, respectively. Also, miss index, multiple index and seed damage measured were 12.23, 2.43 and 1.41% respectively.

Jiraporn *et al*. (2010) designed and developed a tractor operated 10-row garlic planter. The metering mechanism was buckets mounted on a disc. They reported that the buckets had maximum scoop efficiency for one clove was 90.42% at a disk revolution of 40 rpm at a forward speed 1.67 km h^{-1}. The seed was delivered above 30 cm from the ground level. The furrow opener was a shoe type, placed in two lines with spacing of 250 mm between the lines.

A tractor-operated garlic planter developed at MPUAT, was provided with star wheel type seed and fertilizer metering mechanism. The two-row paired hopper and adjustable seed rate are the main features of 12-row unit which has minimum row spacing of 150 mm. The observed seed rate during testing varied from 500 to 700 kg ha^{-1} mainly dependent on size of garlic cloves. The spacing of garlic cloves ranged from 50 to 100 mm. The field capacity, field efficiency and cost of planting were 0.35 ha h^{-1}, 70% and 1300 Rs ha^{-1}, respectively Anon. (2010).

Kumari (2011) developed a tractor operated onion set planter. The developed onion set planter consisted of inclined plate seed metering unit, seed hopper and furrow opener. The onion set planter was evaluated in the laboratory for its performance. The performance indices *viz.,* multiple index, miss index, quality of feed index, precision, mean and standard deviation of onion set planter were 0.05,0.18, 0.77, 0.27, 11.71 cm and 5.22 cm, respectively. The field capacity of the onion set planter was 0.09 ha ha^{-1} at a forward speed of 0.6 km h^{-1}.

Turbatmath *et al.* (2011) developed and evaluated a tractor operated onion transplanter. The engineering physical properties like height, weight, diameter, moisture content and compressive strength etc. were determined for VI^{th}, VII^{th}, and $VIII^{th}$ week old onion seedlings. Two metering mechanism, finger type and plug type were tested in laboratory with three different travel speeds of 0.75 km h^{-1}, 1 km h^{-1} and 1.25 km h^{-1} for different days old onion seedlings. It was observed that plug type metering mechanism at speed of 0.75 km h^{-1} with VII^{th} week age seedling was more suitable for transplanting. The field trials of semi-automatic transplanter with the plug type metering mechanism resulted a row to row spacing of 20.4 to 21.2 cm, plant to plant spacing of 11 to 11.6 and depth of placement was observed 2.8 to 4 cm. The missing was 9 to 10.9%. The capacity of the machine was 0.1088 to 0.1174 ha h^{-1} with field efficiency of 70.49 to 71.6%. The draft of machine was in the range of 450 to 469.8 kgf. The saving in cost of operation over manual transplanting was 40.17%.

Vasuki (2012) designed and developed a tractor operated turmeric planter and it consist of ridger bottom, rhizome hopper, cup feed rhizome metering mechanism, main frame, shoe type furrow opener, ground wheel and chain sprocket power transmission drive. The turmeric rhizome planter was evaluated in the laboratory for its performance. The performance indices viz., singles, doubles, triples and missing index of turmeric planter were 67.9, 12.55, 3.52, and 15.95% respectively. The mean and standard deviation of rhizome spacing in the laboratory tests were 28.95 cm and 9.73 cm, respectively. The tractor operated turmeric planter was tested in the field for performance at an optimized speed of 1.5 km h^{-1}. The average plant to plant spacing was 22.68 cm after 30 DAP. The field capacity of the turmeric planter was 0.27 ha h^{-1}. The total time required for the planting operation was 5.78 hr ha^{-1} with a field efficiency of 64.28%. The seed rate was reduced to 1027 kg ha^{-1} by the developed planter.

Zamani (2014) designed and constructed a fully automatic tomato transplanter. This machine include a main chassis, seedling trays transfer mechanism to pick up arm position, the seedling pick up arm mechanism of the tray, crash tube, furrower and control system. The transplanter was evaluated in the field to find its performance. Tests were conducted at three levels of forward speeds of 1, 1.5 and 2 km h^{-1} and two levels of cultivation depths of 5 and 10 cm. The performance indices *viz.,* mechanical damage, establishment angle from the vertical line and distance on the row of seedlings was investigated. The results showed that forward speed and cultivation depth on distance between planted seedlings, seedling establishment angle and damage to seedlings at the level 5% has been effective with a forward speed of 1 km h^{-1}. The theoretical capacity of the single-row machine was 0.06 ha h^{-1}.

2.4 PLANTER DESIGN FACTORS

2.4.1 Seed metering mechanisms for planters

The metering mechanisms must work effectively in order to continuously meter seeds at a uniform rate and spacing with respect to the ground surface at travelling speed. Besides, the metering mechanism should meter the seeds with minimum damage. However, the metering mechanism parameters that affect the performance are discussed in the subsequent sections.

Wanjura and Hudspeth (1969) recommended that the metering device on a seeder should be located as low as possible so that seed should fall freely to the bottom of soil trench.

Kepner *et al.* (1987) reported that metering of tuber and seed flow has two aspects. The first is the metering rate, which refers to the number of seeds that are released from the hopper per unit time. Metering rate is an important parameter for any planter to achieve desired plant population. The second is that, seeds must be dropped through the seed tubes to achieve a uniform spacing of seed placement in each row.

Kepner *et al.* (1987) reported automatic potato planters have vertical, rotating picker wheels with devices to either pierce or grip individual seed pieces and then drop them into the furrow. The picker pin type is the most common type of mechanism. Each arm or head of the picker wheel had two sharp picking pins that pierce a seed piece in the picking chamber carry it over to the front, and then release it above the furrow. The position of the picker pins on each head is adjustable to accommodate various sizes of seed pieces. The spacing of seed pieces in the row is controlled by the speed ratio between the ground wheels and the picker wheels.

Kachman and Smith (1995) reported that the spacing of the seeds are affected where the mechanism fails to select or drop a seed resulting in large spacing between seeds; or because the mechanism selects and drops multiple seeds causing small spacing between seeds. To achieve accurate seed spacing, different parameters that affect the placement need to be optimized for a specific size of seed *viz.*, shape of the seed hole on the disc for singulation of seed, speed of the disc to regulate seed spacing and vacuum pressure required to hold, transport and drop the seed.

Mathanker and Mathew (2002) stated that picker wheel type and horizontal disk cell type metering mechanisms perform well under suitable working conditions. The planting mechanisms were tested at various linear (peripheral) speeds. The percentage of cell filled varies from 128 to 143%, physical damage from 6.5 to 16% and missing cells percentage from 12 to 14.2% as the linear speed varied from 5.5 to 18.1 m min^{-1} respectively for the picker wheel type metering mechanism. For the horizontal disc cell type metering mechanism percent cell filled varies from 80 to 99% and percentage of physical damage from 1 to 3% as the linear speed varied from 5.1 to 21.7 m min^{-1} respectively. Hence, picking wheel mechanism was found suitable for automatic ginger planters with optimum linear speed in the range of 10 to 12 m min^{-1} and horizontal disc cell mechanism was found suitable for semi-automatic ginger planters with optimum linear speed range of 5 to 8 m min^{-1}.

Jayan and Kumar (2004) investigated the design of planter in relation to the physical properties of seeds. They reported that in the absence of devices for the positive removal of seeds from the cells of the plate, seeds drop by gravity and as the peanut seeds are non-spherical, they move slowly leading to the variation in seed spacing. In order to achieve the uniformity in seed spacing and accuracy in seed rate, it is essential to use the metering plate with size of cells matching the size of seeds.

Sahoo and Srivastava (2008) investigated the seed pattern characteristics of soaked okra seed with different metering systems *viz.,* vertical roller, horizontal plate, horizontal plate (edge drop), inclined plate, cell size *viz.*, maximum seed dimension, 10% more than maximum seed dimension, 25% more than maximum seed dimension and cell speed *viz.,* 10,14,18, 24 rpm. They concluded that the average spacing was close to theoretical spacing for vertical roller, horizontal plate, horizontal plate (edge drop) with cell size 10% more than the maximum seed dimensions. But in case of inclined plate the average spacing was close to theoretical spacing with the cell size equal to maximum seed dimensions. The quality of feed index was influenced highly by the metering systems, cell size and cell speed. The quality of feed index decreased with increase in speed. However, with increase in cell speed to 14 rpm only 5% decrease of quality of feed index was observed. The cell speed mostly influenced the multiple index, miss index and degree of variation. The metering system influenced the seed damage the most followed by cell speed. Incline plate metering system was found the best for planting soaked okra seed.

2.4.2 Furrow openers for planters

Dransfield *et al.* (1964) reported that rake angle of a furrow opener was proportional to the force on it. They reported that both the horizontal and vertical forces are increased with increase in rake angles.

Shaaf *et al.* (1981) evaluated different types of opener *viz.*, shoe type, hoe type and disc type. They concluded that the hoe opener tends to penetrate more easily than the disc opener for loamy soil.

Dubey and Srivastava (1985) evaluated different types of furrow openers of bullock-operated seed cum fertilizer drill in the black soils. The study was conducted on the basis of penetration ability of furrow openers, non-clogging of seed and fertilizer in boots, also on the amount of soil disturbance and draft. It was reported that the shoe type furrow opener gives the best performance.

Collins and Fowler (1996) reported that draft forces increased significantly from 1,700 to 4,300 N m^{-1} for all furrow openers when seeding depth was increased from 1 to 5 cm. Further, they stated that the average increase in draft for all furrow openers was 4% for each km h^{-1} increase in speed when seeding depth measured from 1 to 5 cm.

Verma and Dewangan. (2007) reported the mechanical consideration for the design of furrow openers of the seed cum fertilizer drill. They had identified the shoe, shovel, inverted-T furrow openers for the study. The potential of furrow openers were compared on the basis of draft requirement, soil disturbances and seed emergence. They had concluded that the draft requirements of the inverted-T type furrow opener was the lowest of 32.12 kgf, minimum soil disturbances (4 to 5 cm) and minimum clogging frequency as compared to the shovel and shoe type furrow opener. Also soil disturbance was less in the case of inverted-T furrow opener as compared to shoe and shovel type furrow opener. This was due to smaller boot width.

Marakoglu and Carman (2009) conducted study on effects of parameters of a cultivator share on draft force and soil loosening in a soil bin. The test tool variables included rake angle to the horizontal of 12.5^o, 17.5^o and 22.50^o working depths of 70, 110, and 150 mm and forward speed of 1.08, 1.55 and 2.08 m s^{-1}. The results indicated that the draft force was increased from 420 to 2025 N. The greatest distributed area occurred at rake angle of 22.5^o, forward speed of 2.08 m s^{-1} and depth of 150 mm.

Jiraporn *et al.* (2010) conducted experiments to study the performance of three types of furrow openers *viz.,* shoe, shovel and hoe for a tractor operated 10 row garlic planter in terms of depth of the clove placement, clove space disturbance, draft requirements and extension of soil disturbance occurring during their operation. As the depth of operation increased, soil disturbance and back flow increased. The shovel type opener showed the maximum germination percentage of 83.3% with a draft force of 1.067 kgf per opener, which was 27% higher than the hoe type opener.

Chaudhuri (2011) evaluated the performance evaluation of various types of furrow openers for seed drill. The results stated that increase in rake angle increased the draught and vertical force acting on the furrow opener. The values of the rake angle for the lowest draught are usually around 25^o to 30^o. Increase in the width of furrow opener increases draught and reduces the amount of soil covering the seed in the furrow. Disc type furrow openers are generally satisfactory for conventional tillage due to lower draught, less soil disturbance and less variation in depth. Hoe-type furrow openers place seed close to the furrow bottom and create more soil disturbance which increase the soil moisture loss from the furrow. The best performance under zero tillage condition was given by the chisel, winged chisel, inverted-T and winged type furrow openers. Runner type furrow openers are suitable for sowing under conventional tillage system only for shallow sowing under irrigated conditions. Winged, inverted-T and hoe-type furrow openers are suitable for seed cum fertilizer drills.

2.4.3 Ridger type furrow openers

The ridge planting is a practice that eliminates conventional seed bed preparation or which combines with planting operation (Raghavendra *et al.,* 2013). The ridges and furrows can be simultaneously formed by using tractor drawn semi-automatic rhizome planter. The ridges were formed by the wings of the ridger and the seeds were placed while the formation of ridges. The main function of ridge forming is to ensure weed control, infiltration and storage of runoff water in order to conserve moisture.

Mathur and Pandey (1992) reported that the minimum specific draft for lateritic sandy clay loam soil was recorded at a rake angle 28^o of the furrow opener.

Zhang and Araya (2001) reported that the draft force of a mould board plough had increased steeply when rake angle was more than 30^o.

Abd El-Tawwab *et al*. (2007) reported that the design parameters of the furrow opener such as the share rake angle and wing shape and angle strongly affect the shape of the ridge profile. In addition, one of the most important parameters strongly affect the required draft force is the share rake angle. For better penetration of soil, the rake angle of the share should be $\geq 25^o$ to the ground.

Marey (2015) studied the impact of design parameters of the ridger furrow opener and planting methods on sugar beet yield and water use efficiency. The field experiments are conducted to (i) investigate the effects of share rake angles (20^o, 25^o and 30^o), opener wing angles (35^o and 45^o) and wing shape configurations (straight and curved) on the furrow profile characteristics, transverse scattering, draft force, and (ii) evaluate planting methods (*i.e.,* ridges with 50 cm rows spacing and pair of rows on bed with 30, 35 and 40 cm rows spacing), the wing shape and angles on the emergence, sugar percentage, root and sugar yield, applied water and water use efficiency. The results indicated that the curved shape and the wing angle of 45^o produced wider furrows than those produced by the straight shape and 35^o wing angle. Minimum transverse scattering is associated with the curved wing, wing angle of 35^o and share rake angle of 20^o. Increasing the share rake and wing angles increased the required draft force. The highest average values of root and sugar yields have been achieved at beet planting in beds with 30 cm rows spacing flowed by beds with 35 and 40 cm rows spacing, respectively. The lowest value of the water use efficiency is achieved at planting on ridges compared to the other planting methods. The maximum emergence percentage, root and sugar yields, sugar percentage and water use efficiency are associated with a wing angle of 45^o and the curved wing shape.

2.5 DESIGN FACTORS AFFECTING THE PLANTER PERFORMANCE

Buitenwerf *et al.* (2006) reported that the accuracy of planting (distance in the seeding furrow) is influenced for a large part by the cup-belt unit of the potato planter. A more regular shape (lower shape factor) does not automatically result in a higher accuracy. A sphere (golf ball) in most cases was deposited with a lower accuracy than a potato. This was caused by the shapes of the guiding duct and cups.

Jiraporn *et al.* (2010) conducted experiments to optimize the height of seed delivery tube above ground level for 10 row tractor operated garlic planter. They observed that the height of the seed delivery tube at 30 cm above ground level provides the lowest variation of 25 mm, from the line of motion at a forward speed 1.67 km h^{-1}.

Kocher *et al.* (2011) studied the variation in corn seed spacing from a John Deere MaxEmerge and Vacumeter planter was evaluated in a laboratory setting for two seed tube conditions (new or worn) with two examples of corn seed shape (round or flat). They had measured the seed spacing uniformity by using three seed spacing uniformity parameters: i) Coefficient of Precision (CP), ii) multiples index, and iii) miss index. Differences were perceived in all three seed spacing uniformity parameters due to the seed tube condition. The new seed tubes had better seed spacing uniformity than the worn seed tubes, within each example of the seed shapes (round or flat). For the seed used in this experiment, is the round corn seed which had better seed spacing uniformity, for each of the seed tube conditions (new or worn).

2.5.1 Operational speed parameters

Bjerkan (1947) reported that slippage on ground wheels, too high planting speeds and non-uniform seed size were the causes of irregular planting. An average slippage value of 5% for rubber tyres and 15% for steel wheels was suggested.

Chhinnan *et al.* (1975) showed the effect of planting speed on metering and seed accuracy. Then they reported that higher planting speeds resulted in more skips, higher seed placement error, and higher average spacing.

Hamad and Banna (1980) and Amin (1983) showed that the length of feeding –wheel mechanism speed and transmission rotor has positive effect on the amount of sowing rate. There is also a good deal of variation between different machines in the accuracy of spacing, depending on whether there is appreciable wheel slip and on whether the potatoes are allowed to role in the furrow bottom. Generally, the forward speed of this type of machinery is not over 3.2 km h^{-1}.

Ismail (1989) stated that the operational speed of manual filling of buckets of metering mechanism in planting machine at is very low and in the range from 1.5 to 1.6 km h^{-1} (0.4 to 0.44 m sec^{-1}). He stated that the time span necessary for the operation of taking out potato seed from the box and placing it into the bucket amounts to approximately 0.75 seconds.

2.5.2 Seed box parameters

Kual and Egbo (1985) said that the seed box or hopper in planters should be trapezoidal, rectangular or oval in shape. The capacity of the box also varies depending on the size of machines. Trapezoidal shape of seed box helps to ensure a free flow of seed.

Awady and El-Said (1985) developed a simple planter whose hopper is built from iron sheeting with 45^o slopping bottom.

Bosai *et al.* (1987) reported that the hopper must have an optimum capacity which ensures the uniformity of feed seeds and continuous motion to the seeds metering mechanism, independent of the direction of motion of the swing unit.

2.6 PERFORMANCE EVALUATION OF PLANTERS

Misener (1979) evaluated the cup and pick type potato planters. Co-efficient of variation in spacing, number of seeds fill and number of seed piece skips were determined for each planter. In general, the pick type planter was slightly more effective than the cup type planter. The co-efficient of variation of spacing for the cup and pick type planters ranged from 59.2 to 87.1 and from 55.3 to 68.7, respectively. The average number of doubles per 30.5 m of row length ranged from 5 (6.2% of seed pieces) to 65 (33.6%) for the cup type and from 5 (6.8%) to 52 (29.0%) for the pick type planter over various forward speeds and nominal spacings. The range of skips for the cup planter was 3 (3.2%) to 22 (14.7%) and for the pick type planter, varied from 3 (3.0%) to 19 (12.1%) per 30.5 m of row length.

Griepentrog (1998) reported mean spacing (X), standard deviation of the spacing between plants (SD) and coefficient of variation (CV) for describing seed spacing uniformity. The mean spacing was influenced by seed or plant density and longitudinal distribution. For common grain drills, a CV of 20% was an acceptable accuracy achieved by mechanical and pneumatic machines when they were performing well.

Panning *et al.* (2000) evaluated sugar beet planting performance for a precision planter designed for shallow planting of small seeds, a general purpose planter designed for row crops, and a vacuum metering general purpose planter designed for row crops that was equipped with three seed tube designs. In their field study, the most uniform seed spacing for each planter configuration occurred at the lowest speed of 3.2 km h^{-1}. For all planter configurations, the seed spacing uniformity decreased as the forward speed increased from 3.2 to 8.0 km h^{-1}. Seed spacing uniformity determined in laboratory tests was greater than, or equal to, seed spacing uniformity determined in field test.

Mari *et al.* (2002) carried out an experiment to evaluate the performance of potato planter. The planter was powered by Fiat-480 diesel tractor at low 3rd gear speed. The performance of tractor planter determined were moisture content of

15.73%, fuel consumption was 24.04 *l* h^{-1}, the travel reduction was 5.04%, field efficiency was 67.47%, field capacity was 0.80 ha h^{-1}.

Celik et al. (2007) evaluated four different type seeders for seed spacing, depth uniformity, and plant emergence at three forward speeds (3.6, 5.4, and 7.2 km h^{-1}). The planter types were: no-till planter, precision vacuum planter, universal planter, and semi-automatic potato planter. The sowing uniformity of the horizontal distribution of seeds was described by using the multiple index, the miss index, the quality of feed index, and the precision in addition to the means and standard deviations of the sample methods.

Satpathy and Garg (2008) conducted studies on a 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 and planting depth for two vegetable crops *viz.*, tomato and chilli. They reported that best results were obtained at 10% soil moisture content with 5-week seedlings in tomato and 17 to 19 weeks seedlings in chilli crop. The average field capacity of the machine was 0.09 ha h^{-1} and 0.12 ha $^{-1}$ with corresponding field efficiencies of 71.5% and 67.2% at an operating speed of 1.0 km h^{-1} and 1.2 km h^{-1} respectively. The missing was 3 to 4% and the average depth of planting varied from 2.33 to 5.32 cm in tomato crop and 2.31 to 5.16 cm in chilli crop. The labour and time saving were 70 to 75% and 75 to 78% was obtained with the machine over manual transplanting.

Al-Gaadi and Marey (2011) evaluated the effect of forward speed and tuber characteristics on tuber spacing for a cup belt potato planter. They had selected the three level of forward speeds (1.8, 2.25 and 3 km h^{-1}) and three tuber sizes (35 to 45, 45 to 55 and 55 to 65 mm) the performance of the planter was evaluated in terms of mean tuber spacing (M), the coefficient of variation (CV), the multiple index (MULTI), the miss index (MISI). Tuber sizes of 35 to 45 mm resulted better tuber spacing uniformity than other tested tuber sizes. Forward speed of 2.25 km h^{-1} had maximum efficiency and does not affect the seed tuber uniformity.

Al-Gaadi (2011) investigated the performance of an auto feed cup-belt potato planter under different operating conditions with different tuber shapes for whole and cut tubers. He concluded that the coefficient of variation and missing index were proportional to the forward speed, and inversely proportional to the gate height and speed ratio. The highest CV (coefficient of variation) and MISI(missing index) values were 68.4% and 16.42% respectively for cut tubers at 3 km h^{-1} travel speed at a speed ratio of 1.22 and 80 mm gate height. The lower multi index values were observed in the cut tubers and the maximum MULTI value of 7.76% was observed in the whole tubers.

Dixit *et al.* (2015) conducted the performance evaluation of tractor mounted vertical belt type paired row potato planter for planting potato variety Kufri Jyoti on beds in controlled traffic. The field capacity of the paired row planter was 0.24 ha h^{-1} at an average forward speed of 2.5 km h^{-1}. Missing, multiples and seed damage for paired row planter was 3.3, 1.5 and 1.5%, respectively, whereas in case of automatic planter, it was 5.0, 1.8 and 10.0%, respectively. Performance evaluation of vertical belt of paired row potato planter was also conducted at farmer's field covering approximately 117 ha. The results obtained were of similar pattern. Overall planting performance of the machine and potato crop stand was found to be satisfactory for the belt type paired row planter.

CHAPTER III

MATERIALS AND METHODS

In this chapter, methods of rhizome planting, the conceptual design of horizontal plate rhizome planter, selection of functional planter's components of for planting ginger and turmeric, their design requirements along with the constructional details and tests procedure adopted are discussed in the following sections.

3.1 DESIGN OF HORIZONTAL PLATE RHIZOME PLANTER

For the design of a suitable horizontal plate planter for rhizomes, the crop and machine parameters have to be considered. A number of planting material and planter factors are to be considered and these parameters affects the rhizome planter performance.

3.1.1 Crop parameters related to rhizome planter design

The rhizome setts and crop parameters play a vital role in the design of planters. The rhizome crop parameters considered for the design of horizontal plate rhizome planter are furnished below.

i. Row to row spacing, m
ii. Plant to plant spacing, m
iii. Rhizome used for planting
iv. Recommended rhizome rate, kg ha^{-1}
v. Seed bed configuration
vi. Depth of placement of rhizome, m

Ginger and Turmeric planting is manually done by digging the soil and placing rhizomes into it, then it is covered with soil by using hands. The rhizome bits are prepared from mother rhizomes having 3-5 cm in length 15-20 g weight (15 g is optimum) and have at least one or two buds. The rhizome sett rate of ginger and turmeric is about 1500-2000 and 2000-2500 kg ha^{-1} respectively for optimum planting. The planting space of ginger and turmeric should be kept 25-60 cm between rows and 20-30 cm between plants.

The recommended values of the crop parameters for ginger and turmeric rhizome are furnished in Table 3.1.

Table 3.1 Crop Parameters

Sl. No.	Crop Parameters	Ginger	Turmeric
1	Row to row spacing, cm	45	45
2	Plant to plant spacing, cm	15 - 20	15 - 20
3	Rhizome used for planting	Primary	Primary
4	Rhizome rate, kg ha^{-1}	1500-1800	2000-2500
5	Seed bed configuration	Ridge type	Ridge type
6	Depth of placement of rhizome, cm	4 - 10	4 - 10

Source: Package & Practices (KAU, 2011),

3.2 ENGINEERING PROPERTIES OF GINGER AND TURMERIC RHIZOME

The engineering properties of rhizome, especially physical and mechanical properties are important factors to determine the design parameters of an efficient mechanical planters.

3.2.1 Physical properties of rhizomes

The physical properties that affect the design of a rhizome planter are weight of rhizome, moisture, size dimensions, bulk density, and true density, which are directly related to the design of metering mechanism and other major components of the planter are determined in the present study (Sahay and Singh, 1994). The methods followed to determine these properties are discussed below.

3.2.1.1 Weight of rhizomes

Three samples each weighing 1 kg were randomly selected from the bulk. The weight of seed rhizomes was determined by using an electronic balance to an accuracy of 0.01 g and the mean value was obtained.

3.2.1.2 Moisture content of rhizomes

The moisture content of the ginger and turmeric rhizomes was obtained according to ASAE Standard S358.2 (1993). The sample was dried in an electric oven at a temperature of 105°C for 24 hours and weighed using a weighing balance at every 6 hours interval to obtain four different levels of moisture content. The moisture content of the sample in percent dry basis was determined by the following formula.

$$MC(\%) = \frac{Wi - Wd}{Wi} \times 100 \qquad \text{... (3.1)}$$

Where,

W_i is initial weight of the rhizomes, g

W_d is dry weight of the rhizomes, g

3.2.1.3 Size of rhizomes

The size of rhizomes pertaining to its major axis (x), intermediate axis (y) and minor axis (z) of a ginger and turmeric rhizome were measured with help of a digital vernier caliper as shown in Fig. 3.1. The major and minor axis of randomly selected twenty five rhizome of predominant crops of ginger and turmeric was measured. When the rhizome metering disc rotates inside the casing, each rhizome may position itself with respect to major or minor axis. The configuration of the cell should accommodate the rhizome in any position without causing external injury.

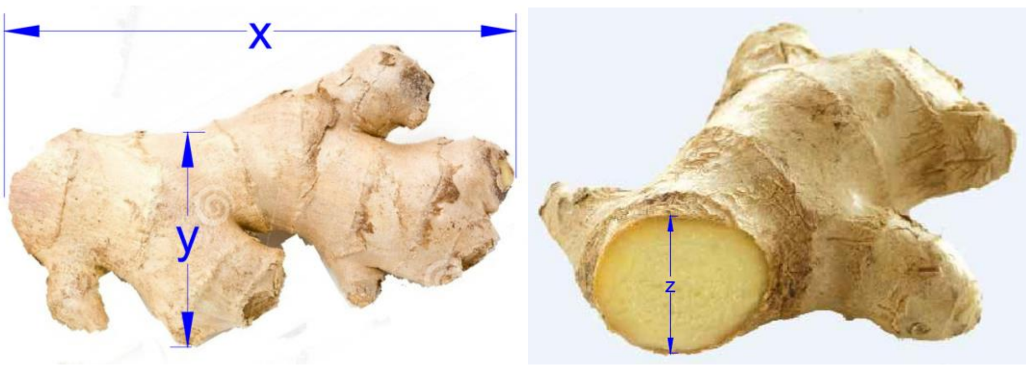


Fig. 3.1 Measurement of major (x), intermediate (y) and minor axis (z) of a ginger rhizome

3.2.1.4 Determination of bulk density

The bulk density was measured by standard method. A cubical container was filled by ginger or turmeric primary rhizome setts and the weight of rhizomes were measured and experiment was replicated 5 times. The bulk density was determined by the following formula.

$$\text{Bulk density,(kg m}^{-3}) = \frac{\text{Weight of rhizomes, (kg)}}{\text{Volume of container, (m}^3)} \quad \text{... (3.2)}$$

3.2.1.5 Determination of true density

The true density of ginger and turmeric rhizomes was determined by platform scale method (Mohsenin, 1986). The sample of rhizomes was first weighed on a precision electronic balance having a least count of 0.01 g and then immersed in water in a container. The mass of displaced water was recorded and used in the following expression to determine the true volume. True density of the turmeric primary seed rhizomes were determined by taking 5 replications.

$$\text{True volume, (m}^3) = \frac{\text{Mass of displaced water, (kg)}}{\text{Density of water, (kg m}^{-3})} \quad \text{... (3.3)}$$

By knowing the mass of the ginger and turmeric rhizomes in air and the true volume, the true density was obtained as the ratio between the mass to its true volume.

$$\rho_t = \frac{M_a}{V_t} \quad \text{... (3.4)}$$

Where,

ρ_t = True density of rhizomes, kg m^{-3}

M_a = Mass of rhizomes in air, kg

V_t = True volume of rhizomes, m^3

3.2.2 Frictional properties

Frictional properties such as angle of repose and coefficient of friction of ginger and turmeric rhizomes on selected surfaces were studied to understand the ease with which the rhizomes move or slide over selected surfaces. This is necessary to identify the materials suitable for making planting equipment's containers or tanks. The methods adopted for estimating these properties are detailed below.

3.2.2.1 Angle of repose

The angle of repose is the angle made by the material with the horizontal surface when piled from a known height. The angle of repose was measured by using bottomless cylinder placed on a flat surface and filled it with ginger and turmeric rhizomes. The cylinder was raised slowly allowing the rhizomes to flow and assume a natural slope in the form of cone (Mishra and Kulkarni 2009). The angle of repose was calculated by following expression.

$$\theta = \tan^{-1}\left(\frac{H}{r}\right) \qquad \text{... (3.5)}$$

Where,

θ = Angle of repose, degree

H = Height of the heap, mm

r = Radius of the heap, mm

3.2.2.2 Coefficient of friction

The experimental apparatus used in the frictional studies consisted of a frictionless pulley fitted on a frame, a bottomless cylindrical container (94 mm diameter and 98 mm height), loading pan and test surfaces. The bottomless container was placed first on the test surface and filled with known quantity of rhizomes and weights were added to the loading pan until the container began to slide. The mass of rhizomes and the added weights represent the normal force and frictional force, respectively. The co-efficient of static friction was calculated as the ratio of frictional force to the normal force as,

$$\text{Coefficient of friction}, \mu = \frac{\text{Frictional force (kg)}}{\text{Normal force (kg)}} \qquad \text{... (3.6)}$$

The experiment was performed on test surfaces like galvanised iron, mild steel, aluminium, wooden board and stainless steel. Experiments were replicated three times by emptying and refilling the container with different samples every time and the average value was determined and recorded as the average static coefficient of friction.

3.3 THEORETICAL CONSIDERATION

Based on literature review and laboratory studies the following theoretical design considerations have been considered and discussed under following sub-sections.

i. Design considerations of rhizome planter design
ii. Design of functional components rhizome planter

3.3.1 Design considerations for the development of rhizome planter

The following design requirements were envisaged for the development of proposed rhizome planter.

i. The developed planter will have a semi-automatic metering mechanism for controlling the seed rate.
ii. It should open seedbed to make furrows, meter and drop rhizomes in the furrows and cover with soil in single pass.
iii. The rhizome dropped in the furrows should be covered with soil and compacted.
iv. The total power requirement should not exceed the power available from currently available 60 hp tractor.
v. The row to row spacing should be 45 – 60 cm
vi. The plant to plant spacing should be at 15 – 20 cm.
vii. The depth of placement of rhizomes should be at 4 – 10 cm.
viii. The operating width of the implement should cover the wheel track of the tractor.
ix. The implement should not cause soil compaction which inhibit plant growth.
x. The implement should be simple in operation and ease to manufacture at cheap cost.

3.3.2 Functional design of rhizome planter components

The detailed design of the functional components and mechanisms were calculated to obtain strength design of planter. The design calculations of functional components of rhizome planter are given below.

3.3.2.1 Design of rhizome box and vermicompost box

a) Design of rhizome box

The rhizome box made of MS sheet. The length of box is given by

Length of seed box (L) = Working width of planter - 2b

Where, b = distance between the rhizome box wall to outer end of frame (10 cm)

So, Working width of planter = Number of rows × Row spacing

= 4 × 45= 180 cm

Therefore, length of rhizome box (L) = 180 – 2 (10) = 160 cm

Now, the maximum seed rate of ginger = 1800 kg ha^{-1}

Let us assume, speed of the planter is 2 km h^{-1} and field capacity be 60%

Actual field capacity of planter

$$= \frac{\text{Speed(km hr}^{-1}) \times \text{Working width of planter, m} \times \text{Field capacity}}{10} \quad \text{... (3.7)}$$

$$= \frac{2 \times 1.8 \times 0.6}{10}$$

$$= 0.21 \text{ ha h}^{-1}$$

Let us design a rhizome box for such a capacity, assuming that it requires refilling of rhizomes after 0.5 hour.

Therefore,

Weight of rhizomes to be used in 0.5 hour = Seed rate (kg ha^{-1}) × Area covered per hr × time (hr)

= 1500×0.21×0.5

= 157.5 kg

$$\text{Volume of rhizome box} = \frac{\text{Weight of rhizome (kg)}}{\text{Bulk density (kg m}^{-3})}$$

Bulk density of ginger = 470 kg m^{-3}

Therefore, Volume of rhizome box $= \frac{157.5}{470} = 0.33\,m^3$

Volume of seed box (V_s) = 0.33 m^3

Volume of seed box = Area x Length of seed box

Now from Fig. 3.2, Total area = Area 1+ Area 2+ Area 3

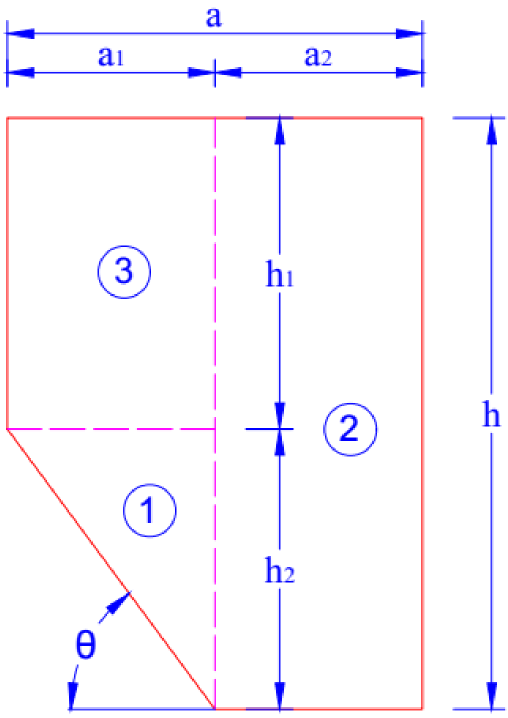


Fig. 3.2 Cross sectional view of rhizome box

So, Total Area = $0.5 \times a_1 \times h_2 + bh + a_1h_1$

$= a_1 \times (0.5h_2 + h_1) + bh$

Where, $h = h_1 + h_2$. Therefore, $h_1 = h - h_2$

So, Area = $a_1 \times (0.5h_2 + h - h_2) + bh$

Area = $a_1 \times (h - 0.5h_2) + bh$

From Fig. 3.2, $\frac{h_2}{a_1} = \tan\theta$

So, $h_2 = a_1 \times \tan\theta$

Now the equation become,

Area = $a_1 \times (h - 0.5(a_1 \times \tan\theta)) + bh$

Area = $a_1h - 0.5a_1^2 \times \tan\theta + bh$

So, Volume of seed box = $(a_1h - 0.5a_1^2 \times \tan\theta + bh) \times L$

Now, assume the value of $a_1 = 0.20$ m and $a_2 = b = 0.20$ m and also take the value of $\theta = 49°$

Therefore,

$$0.33 = (0.20h - 0.5 \times (0.20)^2 \times \tan 49 + 0.20h) \times 1.6$$

$$0.33 = 0.64h - 0.036$$

$$0.64h = 0.366$$

$$h = 0.57 \text{ m}$$

We know that, $\frac{h_2}{a_1} = \tan\theta$

So, $h_2 = a_1 \times \tan\theta = 0.2 \times \tan 49$

$h_2 = 0.23$ m

Therefore, $h_1 = h - h_2 = 0.57 - 0.23 = 0.34$ m

The specifications of rhizome seed box are,

Length of the rhizome box = 160 cm

Top width of the rhizome box = 40 cm

Bottom width of the rhizome box = 20 cm

Height of the rhizome box = 57 cm

Angle of repose = 49°

b) Design of Vermicompost box

Let the length of the vermicompost box is same as the length of the rhizome box

So, length of the vermicompost box = 160 cm

Field capacity of the machine = 0.21 ha h^{-1}

Let us design a vermicompost box for such a capacity, that it requires refilling of vermicompost after 0.5 hour.

Therefore,

Weight of vermicompost to be used in 0.5 hour = Vermicompost rate (kg ha^{-1}) × Area covered per hr × time (hr)

= 3000 x 0.21 x 0.5

= 315 kg

$$\text{Volume of manure box} = \frac{\text{Weight of vermicompost (kg)}}{\text{Bulk density (kg m}^{-3})}$$

$$= \frac{315}{750} = 0.42\ m^3$$

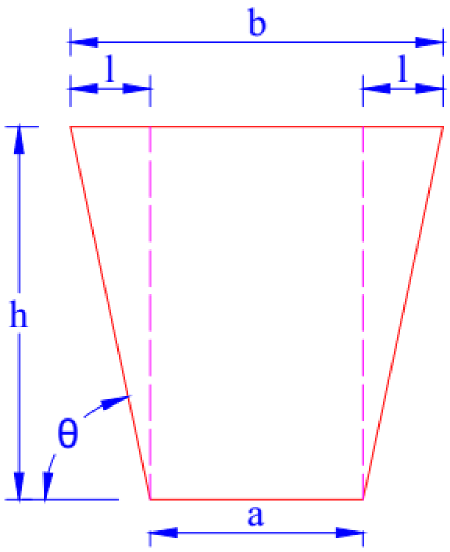


Fig. 3.3 Cross sectional view of vermicompost box

Now from the Fig. 3.3,

Volume of vermicompost box is given by,

$$V = \frac{(a+b)}{2} \times a \times L \qquad \text{... (3.8)}$$

Where,

a = Bottom width of the box

b = Top width of the box

h = height of the box

From Fig. 3.3, b = 2l + a

$$\text{Therefore, } V = \frac{(a+2l+a)}{2} \times h \times L$$

$$V = \frac{(2a+2l)}{2} \times h \times L$$

Now from the (Fig. 3.3), $\frac{h}{l} = \tan\theta$

So, $l = h \cot\theta$

Now the above equation become,

$$V = (a + h \cot \theta) \times h \times L \qquad \text{... (3.9)}$$

Where, θ = angle of repose, it's considered as 35° for vermicompost

Assume the value of a = 0.2 m

Now, V = (0.2 + h cot 35) × h × 1.6

$0.4 = 0.32h + 2.28\ h^2$

$2.28h^2 + 0.32h - 0.4 = 0$

This quadratic equation is in the form of $Ah^2 + Bh + C = 0$

Where, A = 2.28, B = 0.32, C= -0.4

Now, we can solve for 'h' by using following formula

$$h = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

$$h = \frac{-0.32 \pm \sqrt{0.32^2 - 4 \times 2.28 \times (-0.4)}}{2 \times 2.28}$$

$$h = \frac{-0.32 \pm 1.93}{4.56}$$

$$h = \frac{1.61}{4.56}$$

h = 0.35 m

The top width of the vermicompost box is same as the height of the box for easy flow of vermicompost

So, b = 0.35 m

Design specifications of vermicompost box are,

Length of box = 160 cm

Top width of the box = 35 cm

Bottom width of the box = 20 cm

Height of the box = 35 cm

Angle of repose = 35°

3.3.2.2 Design of rhizome metering disc

The assumed diameter of the ground wheel was selected as 570 mm. The slippage of the ground wheel was assumed as one third of recommended slippage of 15% (Bjerkan 1947). The diameter of the metering disc was assumed as 300 mm.

$$\text{Slippage of ground wheel} = \frac{1}{3} \times 15 = 5\%$$

Distance travelled per revolution of ground wheel = π ×Diameter of ground wheel

= π × 0.57 m

= 1.79 m

Because of the slippage,

The actual distance travelled by the unit per revolution of ground wheel

= 1.79 + (1.79 × 0.05)

= 1.88 m

Recommended spacing between rhizomes = 0.20 m

$$\text{Number of cells per disc} = \frac{\text{Distance travelled per revolution, m}}{\text{Spacing between rhizomes, m}} \quad \text{... (3.10)}$$

$$= \frac{1.88}{0.20}$$

= 9.4 ≈ 10 cups.

In order to provide the guide plate the peripheral distance between two cups should be at least 9.25 cm.

$$\text{So, Diameter of metering disc} = \frac{10 \times 9.25}{\pi} = 29.44 \approx 300 \text{ mm}$$

a) Speed ratio

Distance covered by a ground wheel per one revolution = π × D ... (3.11)

= 3.14× 0.57

= 1.789 m.

Distance covered by a rhizome metering disc per revolution = π × D

= π × 0.30

= 0.942

$$\text{Speed ratio} = \frac{1.789}{0.942}$$

= 1: 1.9 ≈ 1: 2.

3.3.2.3 Design of Ground wheel

Diameter of wheel = 57 cm = 0.57 m

Circumference of ground wheel = $\pi \times D = 3.14 \times 0.57 = 1.79$ m

Area covered for one revolution = Circumference of ground wheel × width of planter

= 0.57 × 1.8

= 1.02 m^2

$$\text{Number of turns covered, ha}^{-1} = \frac{10000}{1.02} = 9804 \text{ turns}$$

Rhizome to rhizome spacing = 20 cm = 0.2 m

Since, the speed ratio is 1:2 so,

Number of rhizomes per 2 revolution of ground wheel

$$= \frac{\text{Circumference of ground wheel, m}}{\text{Spacing between rhizomes, m}}$$

$$= \frac{1.79}{0.20} = 8.95 \approx 10$$

3.3.2.4 Kinematics of chain drive

From the Fig. 3.4 as shown below, Let,

N_1 = Speed of the driver at ground wheel shaft in rpm

N_2 = Speed of the driven at ground wheel shaft in rpm

N_3 = Speed of the driver at ground wheel shaft (linked to vermicompost metering screw) in rpm

N_4 = Speed of the driven at vermicompost metering screw shaft in rpm

N_5 = Speed of the driver at ground wheel shaft (linked to rhizome metering shaft) in rpm

N_6 = Speed of the driven at rhizome metering shaft in rpm

T_1 = Number of teeth on the driver at ground wheel shaft

T_2 = Number of teeth on the driven at ground wheel shaft

T_3= Number of teeth on the driver at ground wheel shaft (linked to vermicompost metering screw)

T_4 = Number of teeth on the driven at vermicompost metering screw shaft

T_5 = Number of teeth on the driver at ground wheel shaft (linked to rhizome metering shaft)

T_6 = Number of teeth on the driven at rhizome metering shaft

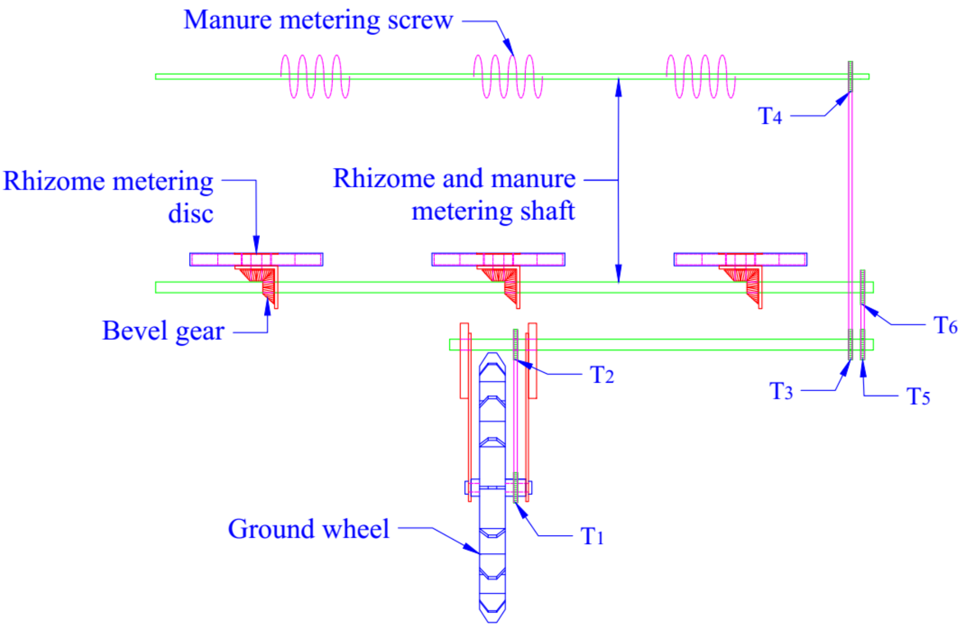


Fig. 3.4 Design of power transmission

a) At ground wheel shaft,

$T_1 = 18$, $T_2 = 18$

Velocity ratio,

$$\frac{N_1}{N_2} = \frac{T_2}{T_1} = \frac{18}{18} = 1$$

Therefore, $N_1 = N_2$

b) At vermicompost metering shaft,

$T_3 = 18$, $T_4 = 18$

Velocity ratio,

$$\frac{N_3}{N_4} = \frac{T_4}{T_3} = \frac{18}{18} = 1$$

Therefore, $N_1 = N_2 = N_3 = N_4$

c) At rhizome metering shaft

i. For 1:1 gear ratio,

$T_5 = 18$, $T_6 = 18$

Velocity ratio,

$$\frac{N_5}{N_6} = \frac{T_6}{T_5} = \frac{18}{18} = 1$$

Therefore, $N_5 = N_6 = N_3 = N_4 = N_1 = N_2$

ii. For 1:1.25 gear ratio,

$T_5 = 7.6$ cm, $T_6 = 22$ cm

Velocity ratio,

$$\frac{N_5}{N_6} = \frac{T_6}{T_5} = \frac{22}{18} = 1.22$$

Therefore, $N_5 = 1.22\ N_6$

iii. For 1:1.5 gear ratio,

$T_5 = 18$, $T_6 = 27$

Velocity ratio,

$$\frac{N_5}{N_6} = \frac{T_6}{T_5} = \frac{27}{18} = 1.5$$

Therefore, $N_5 = 1.5\ N_6$

3.3.2.5 Design of ridger bottom

The details of ridger type bottom, its tyne and various dimensions are listed below (Sharma and Mukesh, 2008).

R = Radius of curvature of bent portion of tyne (generally = 120 mm)

Also, $$R = \frac{(h - l \sin \alpha)}{\cos \alpha} \quad \text{... (3.12)}$$

Where

d = Maximum operating depth of ridger bottom, mm

l = Breast length of shovel, mm

α = Rake angle, degrees

b x t = Cross section of tyne, mm^2

b = Width of tyne, mm

a) The draft load on ridger bottom tyne (D_f)

The force exerted on the ridger bottom is calculated as given below.

$D_f = k_s \times W_f \times d_o$ ... (3.13)

Where,

D_f = Draft on ridger bottom, kg or N

K_s = Specific soil resistance, kg cm^{-2} or N cm^{-2}

W_f = Width of furrow opener, cm

D_o = depth of operation, cm

The furrow slice cut by ridger bottom will make the trapezoidal shaped furrow as shown in Fig. 3.5 below,

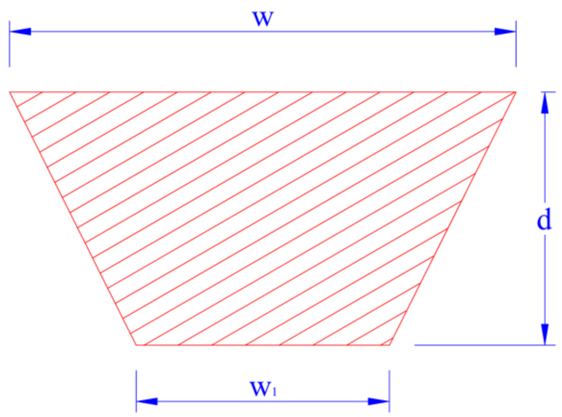


Fig. 3.5 Cross sectional view of furrow

Now, the depth of operation of the ridger bottom of the furrow opened

Assume,

w = 50 cm

w_1 = 25 cm

d = 25 cm

k = 0.41 kg cm^{-2} (Kepner *et al.*, 1987)

Therefore, putting above design values in equation (3.13)

$$D_f = 0.41 \times \left[\frac{(50+25)}{2}\right] \times 25$$

D_f = 384.37 kgf

Then, for mild steel tynes we can take factor of safety of 2

Therefore, the soil resistance encountered by ridger bottom is,

= D_f x factor of safety

= 384.37 x 2

= 768.75 kgf

b) Design of ridger bottom tyne standard

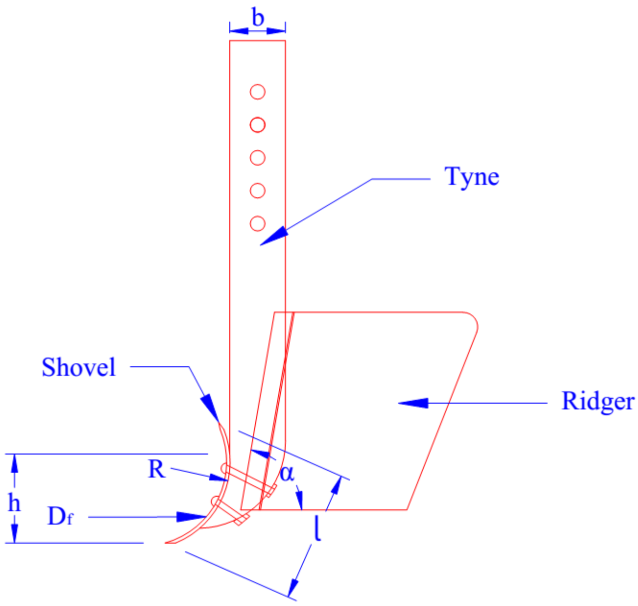


Fig. 3.6 Ridger bottom

By referring the Fig. 3.6 based on the findings the values considered are,

h = 170 mm,

l = 130 mm,

α = 42°

Therefore, putting values in equation (3.12), we get

$$R = \frac{[170 - 130\sin(42)]}{(\cos 42)} = 111.70 \text{ mm, which is less than 120 mm}$$

Now, considering the ridger bottom tyne as a cantilever beam of 530 mm size fixed to the frame at one end (Krutz *et al.* 1984).

Then, the maximum bending moment in the tyne is given by,

M = Design draft (kg) x Beam span (cm)

= 768.75 × 53

= 40743.75 kg-cm

Now, the section modulus of the tyne 'Z' is calculated as

σ_b is the bending stress in tine, kg cm^{-2}. We can take bending stress in mild steel flat as 1000 kg cm^{-2} (Sengar, 2002).

Then, for rectangular sections,

$$Z = \frac{t \times b^2}{6} \quad \text{... (3.14)}$$

The ratio between the thickness to width (t: b) can be taken from 1: 3 to 1: 4, (Sharma and Mukesh, 2008)

So, t : b = 1: 3

b = 3 x t

Therefore, $$Z = \frac{t \times (4t)^2}{6} = \frac{16t^3}{6}$$

Also, $$Z = \frac{M}{\sigma_b}$$

$$Z = \frac{40743.75}{1000} = 40.75$$

So, $$40.75 = \frac{16t^3}{6}$$

t = 2.48 cm = 24.8 mm

b = 4 × 24.8 = 74.4 mm

Therefore, cross section of the tyne = 24.8 × 74.4 mm

So, we may take MS flat of 25 × 76 mm for the section size for the standard ridger support of the planter.

3.3.2.6 Design of shoe type furrow opener

The details of shoe type furrow opener, its tyne and various dimensions are listed below.

a) The draft load on furrow opener (D_f)

Now, the depth of rhizome planting in the bottom of furrow

Assume,

w = 30 cm

w_1 = 15 cm

d = 10 cm

$k = 0.41$ kg cm^{-2} (Kepner *et al.*, 1987)

Therefore, putting values in equation (3.13), we get

$$D_f = 0.41 \times \left[\frac{(30+15)}{2} \right] \times 10$$

D_f = 92.25 kgf

Then, for mild steel tynes we can take factor of safety of 2

Therefore, design draft of furrow opener would be

= D_f x factor of safety

= 92.25 × 2

= 184.5 kgf

b) Design of shoe type furrow bottom tyne standard

Now, considering the furrow opener cantilever tine as a cantilever beam of 650mm size fixed to the frame at one end (Krutz *et al*. 1984).

Then, the maximum bending moment in the tine is given by,

M = Design draft (kg) x Beam span (cm)

= 184.5 × 65

= 11992.5 kg-cm

Now, the section modulus of the tyne 'Z' is calculated as

σ_b is the bending stress in tine, kg cm^{-2}. We can take bending stress in mild steel flat as 1000 kg cm^{-2} (Sengar, 2002).

Then, for rectangular sections,

$$Z = \frac{t \times b^2}{6}$$

The ratio between the thickness to width (t: b) can be taken from 1: 3 to 1: 4, (Sharma and Mukesh, 2008)

So, t: b = 1: 3

b = 3 × t

Therefore,

$$Z = \frac{t \times (4t)^2}{6} = \frac{16t^3}{6}$$

Also, $Z = \frac{M}{\sigma_b}$

$$Z = \frac{11992.5}{1000} = 11.99$$

So, $11.99 = \frac{16t^3}{6}$

t = 1.65 cm = 16.5 mm

b = 3 × 16.5 = 49.5 mm

Therefore, cross section of the tyne = 16.5 × 49.5 mm

So, we may take MS flat of 19 × 50 mm for the construction of furrow opener standard of rhizome planter.

3.3.2.7 Design of frame for rhizome planter

Let the furrow is 50 cm wide and 25 cm deep

Soil resistance is 0.41 kg cm^{-2}

Draft = 0.41 × 50 × 25 = 512.5 kg

Torque produced on frame (T) = 0.41 × 50 × 25 × 0.42 × 4 = 861 kg-m

= 86100 kg-cm

The maximum bending moment at the centre is,

M = 3.5P × 2.5z - 3Pz - 2Pz - Pz

M = 8.75Pz - 6Pz

M = 2.75Pz

M = 2.75 × 512.5 × 50 = 70468.75 kg-cm

So, $T_e = (M^2 + T^2)^{1/2}$

$= (70468.75^2 + 86100^2)^{1/2}$

= 111261.2 kg-cm

The maximum shear stress developed at the centre of the tool bar is given by,

$$\frac{Ss}{y} = \frac{Te}{I} \qquad \text{... (3.15)}$$

Where,

Ss = Shear stress at section

Y = Distance from outermost fibre from neutral axis

Te = Equivalent torque

I = Moment of inertia ($bd^{1/2}$ for rectangular section and for square section b = d)

Let assume, Ss = 2000 kg cm^{-2}

$$I = \frac{b \times d^3}{12}$$

$$= \frac{d^4}{12}$$

$$\frac{I}{y} = \frac{d^4/12}{d/2} = \frac{d^3}{6}$$

$$d^3 = \frac{6Te}{Ss}$$

$$= \frac{(6 \times 111261.2)}{2000}$$

d = 6.93 cm

So, the size of the frame is 7.6 × 7.6 cm.

3.4 DEVELOPMENT OF A RHIZOME PLANTER

A prototype of rhizome planter was designed and developed with optimized levels of variables. The constructional details of the rhizome planter are presented below.

3.4.1 Constructional details of rhizome planter

The prototype planter consisted of main frame, metering mechanisms, rhizome and fertilizer hoppers, ground wheel, power transmission system, seating unit, ridger bottom and furrow openers. The different components of the planter was designed for the structural strength for the selected materials and the dimensions were obtained.

3.4.1.1 Main frame

The main frame of the planter that supports all other components of the planter. In this design, mild steel tubular section of 76 mm × 76 mm × 6 mm was used to give the required strength and rigidity, so that it can withstand all types of load during operation. Three point hitch assembly is provided in the front position of the main frame so as to hitch the planter to the tractor.

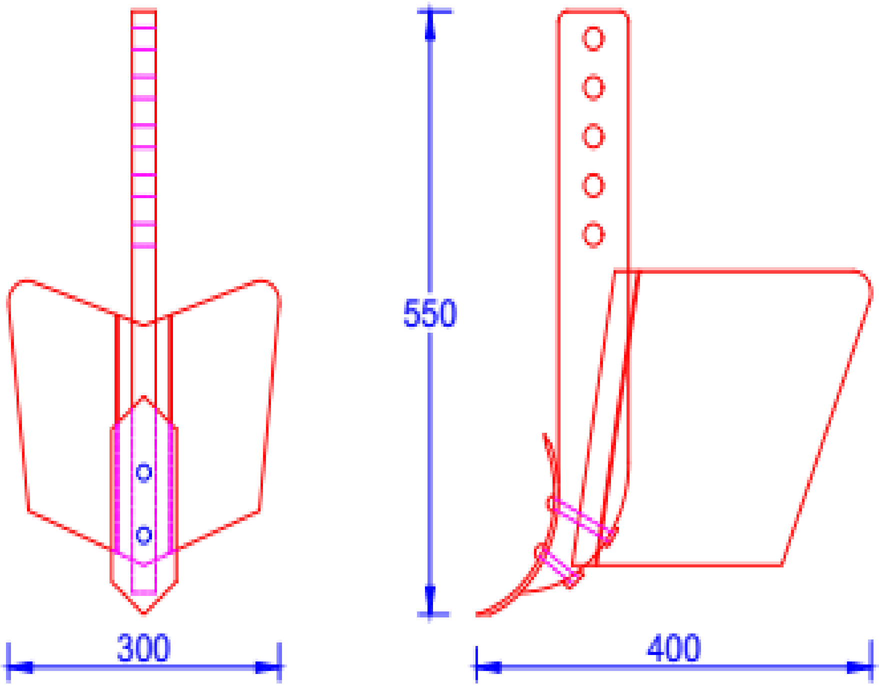
Connections between the frame and other component parts of the planter were made using appropriate sizes of square clamps, bolts and nuts. During the design and fabrication of the frame, provisions were made to vary or change row to row spacing as required and positions of furrow openers too. The design dimensions of the frame was based on the design loads of components to be mounted on it.

3.4.1.2 Ridger bottom

The ridger bottom was attached to the rhizome planter frame to make uniform sized ridges after planting of ginger and turmeric rhizome seeds at one pass of the machine. The ridger bottom was provided with adjustable curved wings of mould board shape. The wings were hinged to the shank by clamp. The shank was a fabricated from 76 mm × 25 mm and having a height of 650 mm mild steel flat bar to which wings were hinged and tyne was fixed by plough bolts as shown in Fig. 3.7. The wings of ridger bottom was made of 6 mm M.S. plate and was forged to provide the curvature towards the wings. The overall dimension of the ridger bottom was 400 mm × 300 mm × 550 mm.

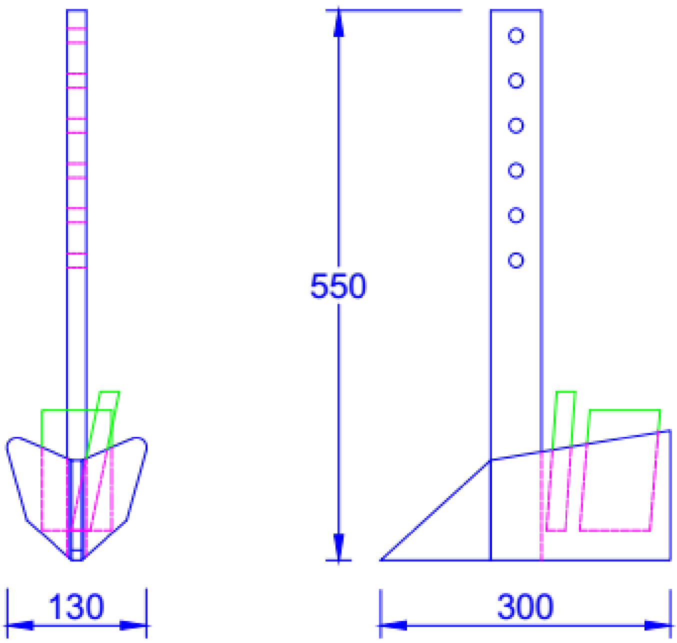
3.4.1.3 Shoe type furrow opener

A shoe type furrow opener with wings was fitted to the main frame under the rhizome hopper and it was fixed at a distance of 40 cm from the share point of ridger. The shoe was made out of 10 mm thick plate of triangular shape with sides of 110, 100, and 150 mm were welded to a shank. The shanks of the furrow openers were fabricated from 50 mm × 19 mm and having a height of 500 mm mild steel flat bar while the wing was made from 4 mm thick mild steel sheet metal as shown in Fig. 3.8. The wings were welded to the mild steel shank that was fixed to frame of the planter with suitable clamps, bolts and nuts, so that furrows are opened and rhizome seeds is dropped at the bottom of furrow.



Front view **Side view**

Fig. 3.7 Schematic orthographic view of ridger bottom



Front view **Side view**

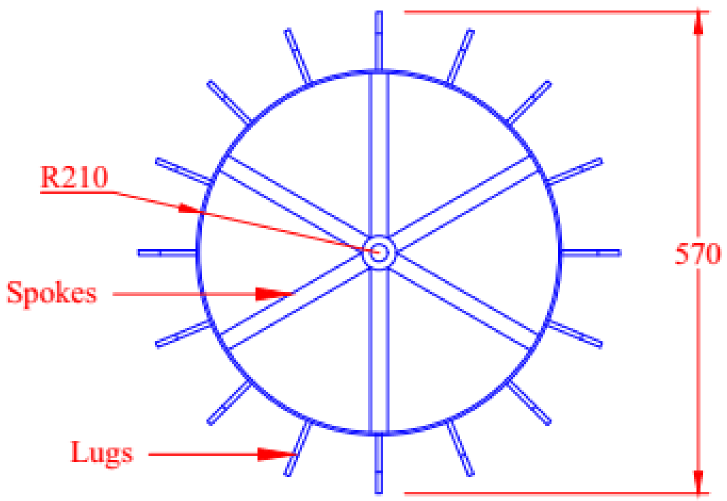
Fig. 3.8 Schematic orthographic view of shoe type furrow opener

3.4.1.4 Rhizome and vermicompost covering devices

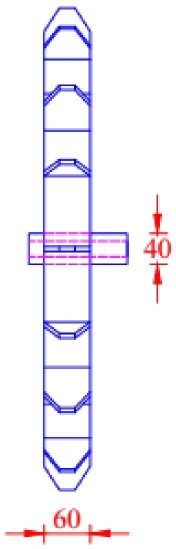
There is no need of separate rhizome and vermicompost covering device for covering the dropped rhizome and vermicompost, as the soil lifted and thrown by the wings of the ridgers at the rear will cover the dropped rhizome and vermicompost.

3.4.1.5 Ground wheel

A spike lugged ground wheel of diameter 570 mm was fabricated using 63 mm mild steel flat as shown in Fig. 3.9. The wheel rim is made of mild steel sheet flat of size 63 mm wide and 6 mm thick. 16 numbers of lugs were provided. The lug size of 6 mm thickness MS flat welded at equidistant on the round rim of the ground wheel to drive the metering drives of rhizome and vermicompost without slippage during forward travel. Wheel had 6 spokes made from mild steel rods with diameter of 20 mm and length of 560 mm, and were welded to the rim and hub at the center of the wheel that served as bushing or shaft bearing, at equal interval. The ground wheel was attached to the mainframe with necessary supporting frame works.



Front view



Side view

Fig. 3.9 Ground wheel

3.4.1.6 Power transmission system

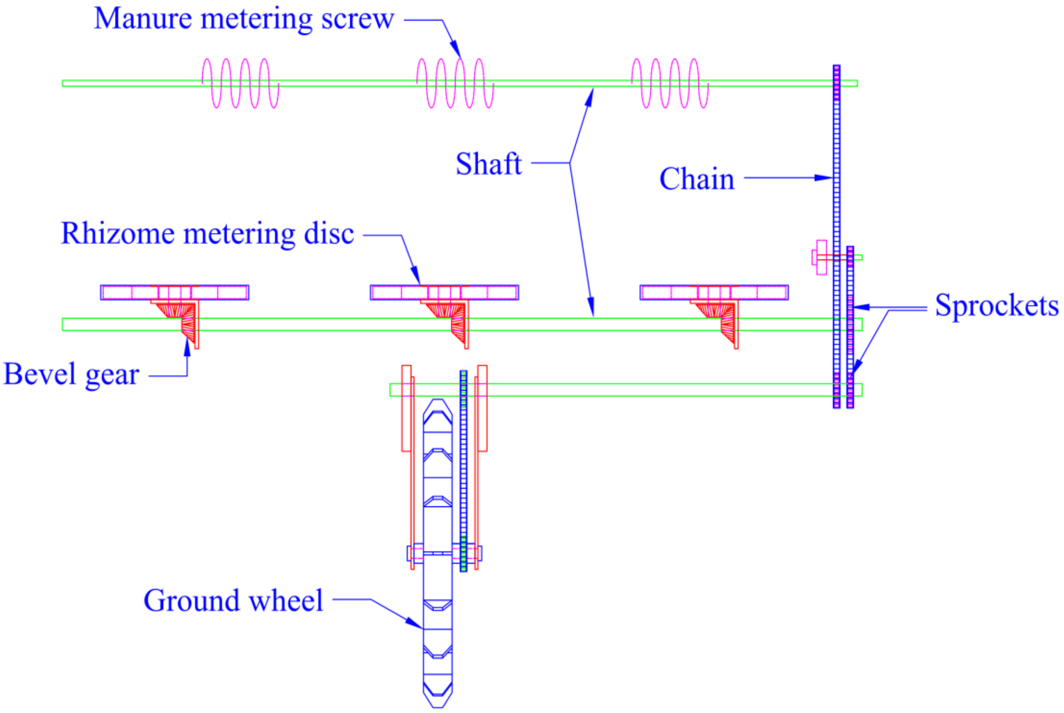
The power is transmitted from the ground wheel shaft to an intermediate shaft fitted above the main frame through chain and sprocket transmission with speed ratio 1:1 as sown in Fig. 3.10. The intermediate drive shaft gets its support from the main frame with necessary support arms. From the intermediate shaft, the drive is transmitted to the rhizome metering disc shaft and vermicompost metering shaft through chain and sprocket. The rhizome metering disc shaft rests on solid bearing at the ends and vermicompost metering shaft rests on grooves at the ends of vermicompost box. From the rhizome metering disc shaft fitted on the main frame, the drive is transmitted to the bevel gears fitted on the cross shaft of the rhizome metering units with a gear ratio 1:1 and the vermicompost metering shaft driven by intermediate shaft through chain and sprocket. The bevel gear fitted on the rhizome metering shaft drives the metering disc.

3.4.1.7 Metering mechanisms

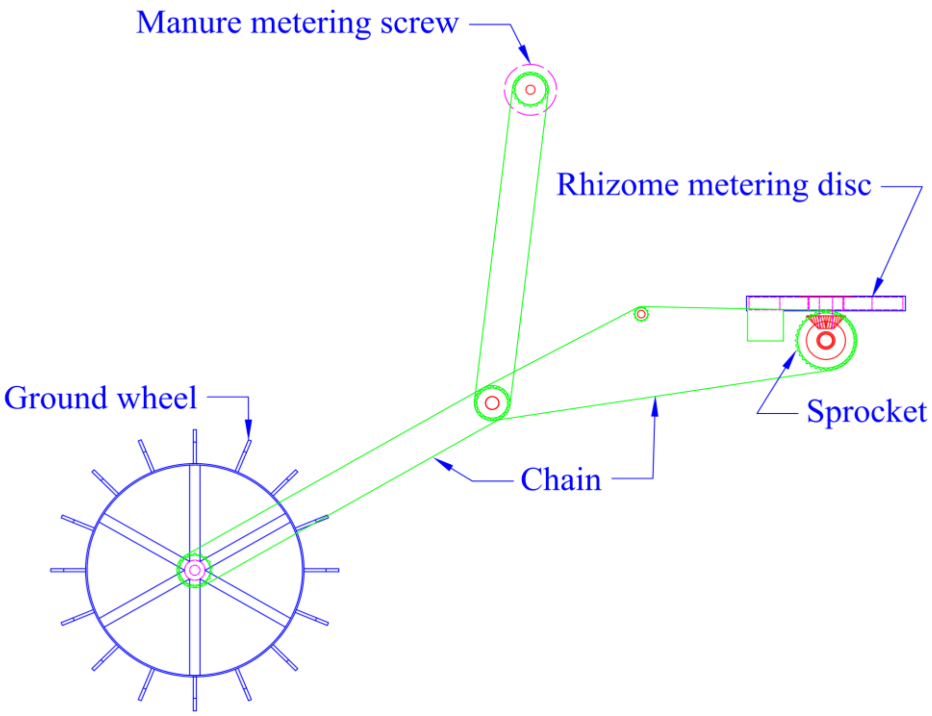
a) Rhizome metering mechanism

A horizontal disc type metering disc was designed and fabricated for ginger and turmeric rhizome seeds. The rhizome metering disc was fabricated using 25 mm thickness and 300 mm diameter plane wooden plank having ten oval shaped cells shown in Fig. 3.11. The metering disc was mounted and rotated horizontally.

The major dimensions of the oval shaped cell was 60 mm. The width of the cell at the outer perfectly was 40 mm and decreases to 30 mm towards the centre. The cells were equally spaced along the periphery of metering disc. The horizontally mounted metering disc is rotated in a casing with a bottom chute to deliver the rhizome seeds. The horizontal metering disc was mounted over a set of bevel gear. The horizontal disc type metering unit is an operator assisted metering device with manual feeding. The brush type was provided to prevent multiples and for rhizome seed fit the cell.

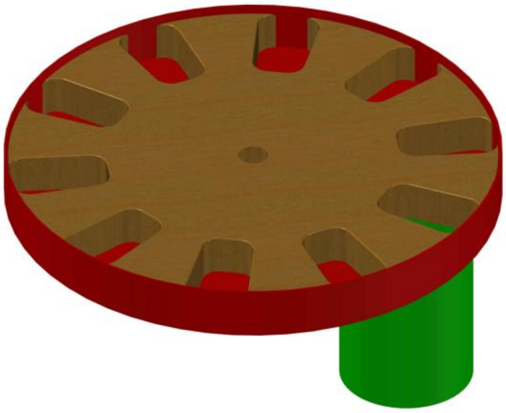


a) Front view



b) Side view

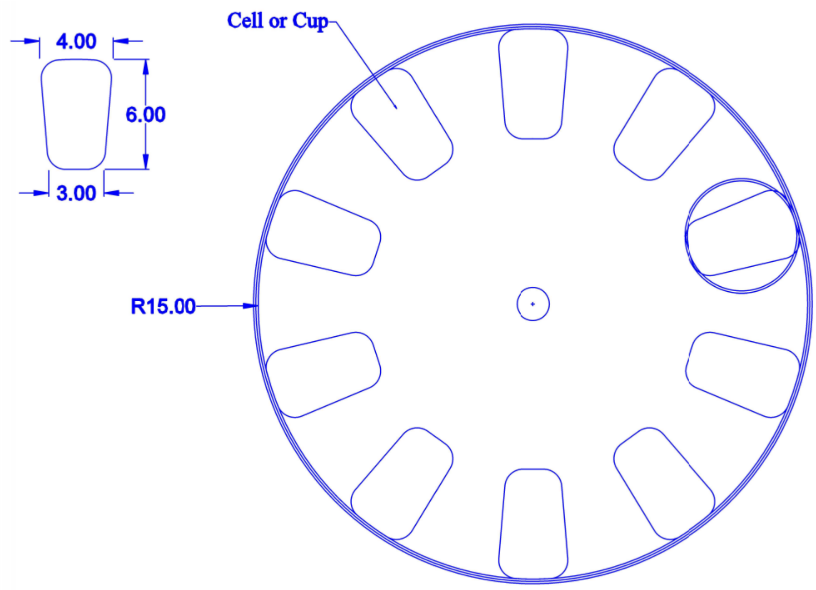
Fig. 3.10 Schematic view of power transmission



Isometric view

Top view

Side view



Plan of metering disc

Fig. 3.11 Rhizome metering mechanism

b) Vermicompost metering mechanism

A screw type metering unit was fabricated for applying vermicompost for ginger and turmeric rhizome seeds. The vermicompost metering unit was fabricated using 4 mm thickness MS sheet and 100 mm outer diameter screw. The metering unit was mounted on a horizontal shaft of 18 mm diameter. The three metering screw were equally spaced along the shaft at a distance of 360 mm. The screw type metering unit is rotated in a vermicompost box with a bottom chute to deliver the vermicompost. The vermicompost metering unit is operated by ground wheel through sprocket and chain.

3.4.1.8 Rhizome and vermicompost hoppers

a) Rhizome hopper

The rhizome hopper should have capacity to store sufficient quantity of rhizomes to avoid frequent filling during operation. The hopper was also designed for feeding the rhizome to metering devices. The hopper is constructed with MS sheet metal of thickness one mm. It was fabricated considering the volumetric capacity required, angle of repose and bulk density of ginger and turmeric rhizomes. The hopper has trapezoidal shape vertically having 350 mm rectangular width at top and 1600 mm length. The height of rhizome hopper is 570 mm as shown in Fig. 3.12. In this case, slope of 49° to the horizontal was selected to ensure free flow of all rhizomes. A rectangular opening of 70 mm length and 140 mm width with sliding door was made at the back side wall of hopper to feed and control the rhizomes to the metering mechanism.

b) Vermicompost hopper

The vermicompost hopper is constructed with MS sheet metal of thickness one mm. The hopper is made a single container common for the 3 rows. The hopper has a trapezoidal shape with rectangular bottom 1600 mm × 200 mm having a height of 350 mm and rectangular top 1600 mm × 350 mm is shown in Fig.3.13. The recommended side slopes of 35° is provided for hopper, for gravity discharge for vermicompost. In this case, side slope of 35° to the horizontal was selected to ensure free flow of vermicompost.

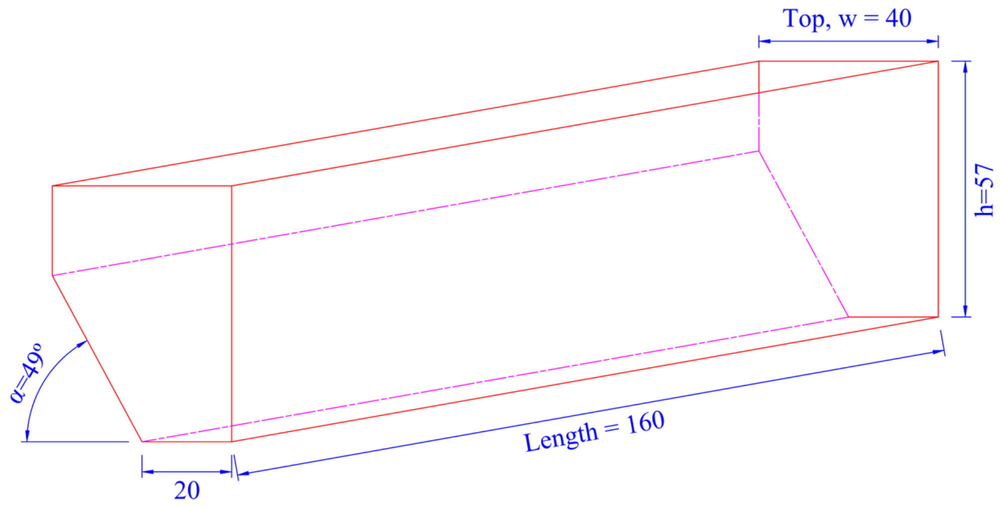


Fig. 3.12 Schematic view of rhizome box

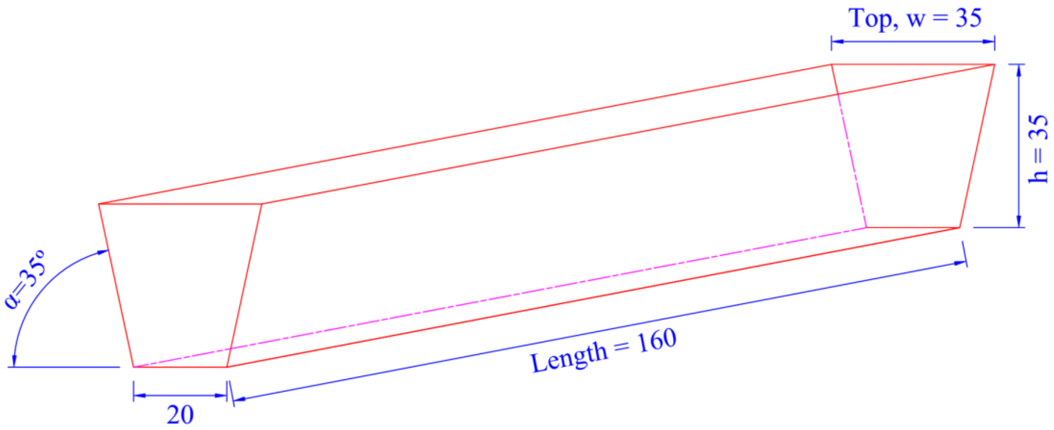


Fig. 3.13 Schematic view of vermicompost box

3.4.1.9 Rhizome and vermicompost delivery components

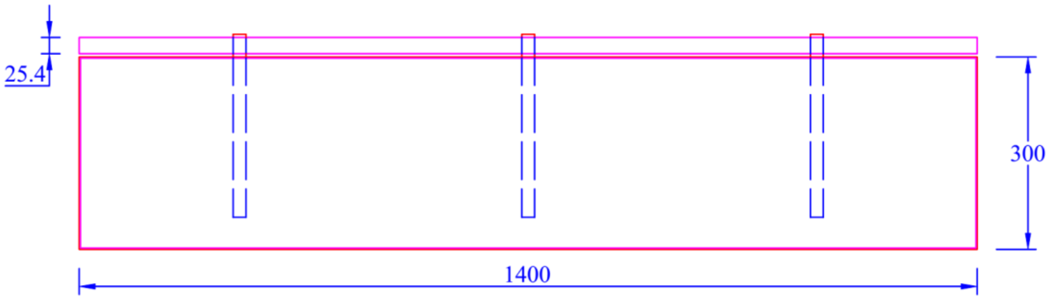
Rhizomes and vermicompost metered by metering devices, have to be transported to furrow boot for dropping into the furrow bottom. Chute sizes having 80 mm and 38 mm diameter were provided at the bottom of the rhizome and vermicompost metering unit for guiding the metered rhizomes and vermicompost to the other parts of placement device. The depth of placement of rhizome can be varied by adjusting the height furrow opener shank upwards or downwards. On the lower side of the chute, a flexible PVC hose of diameter (80 mm and 38 mm) is connected for conveying rhizome and vermicompost from metering mechanism to the furrow bottom (Wanjura and Hudsspeth, 1986), through the furrow boot.

3.4.1.10 Operator seat

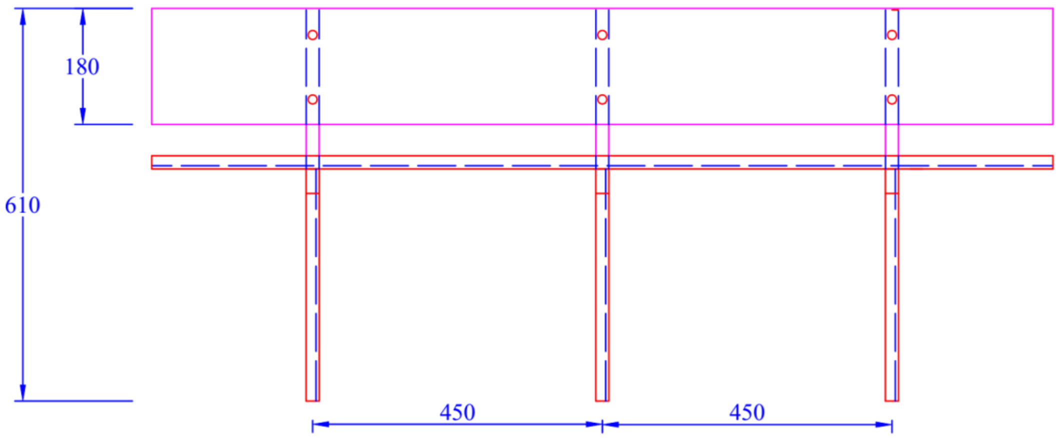
The seating bench is provided for operators to feed the rhizomes into the metering mechanism with ginger and turmeric rhizomes was developed at the rear end of the machine. The two or three operators will sit on the seating bench. The seating bench has dimensions of 1400 mm × 300 mm. The seat frame was made up of MS angle of size 25 mm × 5 mm and to this a rectangular wooden plank of 19 mm thickness was fixed. The seat is shown in Fig. 3.14 has a seat height of 360 mm above the main frame with the help of MS angle clamp of size of 25 mm × 5 mm. A back support was provided to the seat as a back support and for safety. Back support was also made of plane wooden plank of 19 mm thickness and fixed by a height of 25 mm for the entire seat length. Seat bench is fixed equidistantly over the main frame.

3.4.1.11 Complete assembly of rhizome planter

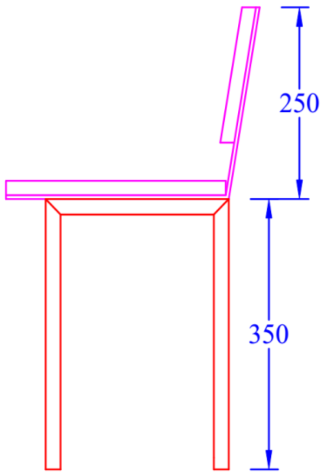
This is a semi-automatic rhizome planter having has an overall dimensions of 1850 mm, 2140 mm and 1530 mm with respect to length, width and height respectively. The developed rhizome planter (Plate 3.1) is shown in (Fig. 3.15 and 3.16) and working of rhizome planter in field is shown in Plate 3.2.



a) Top view



b) Front view

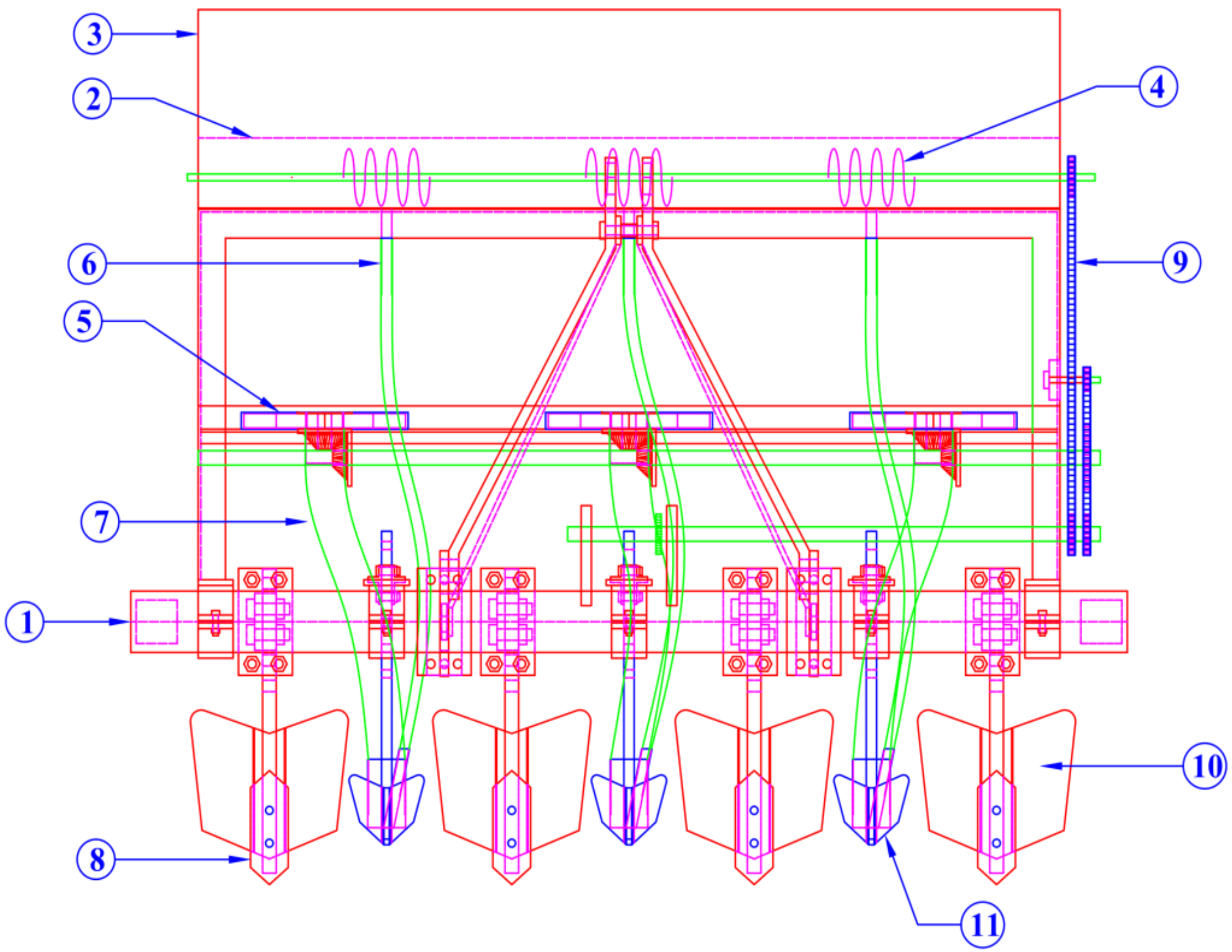


c) Side view

Fig. 3.14 Seating unit for rhizome planter for rhizome droppers

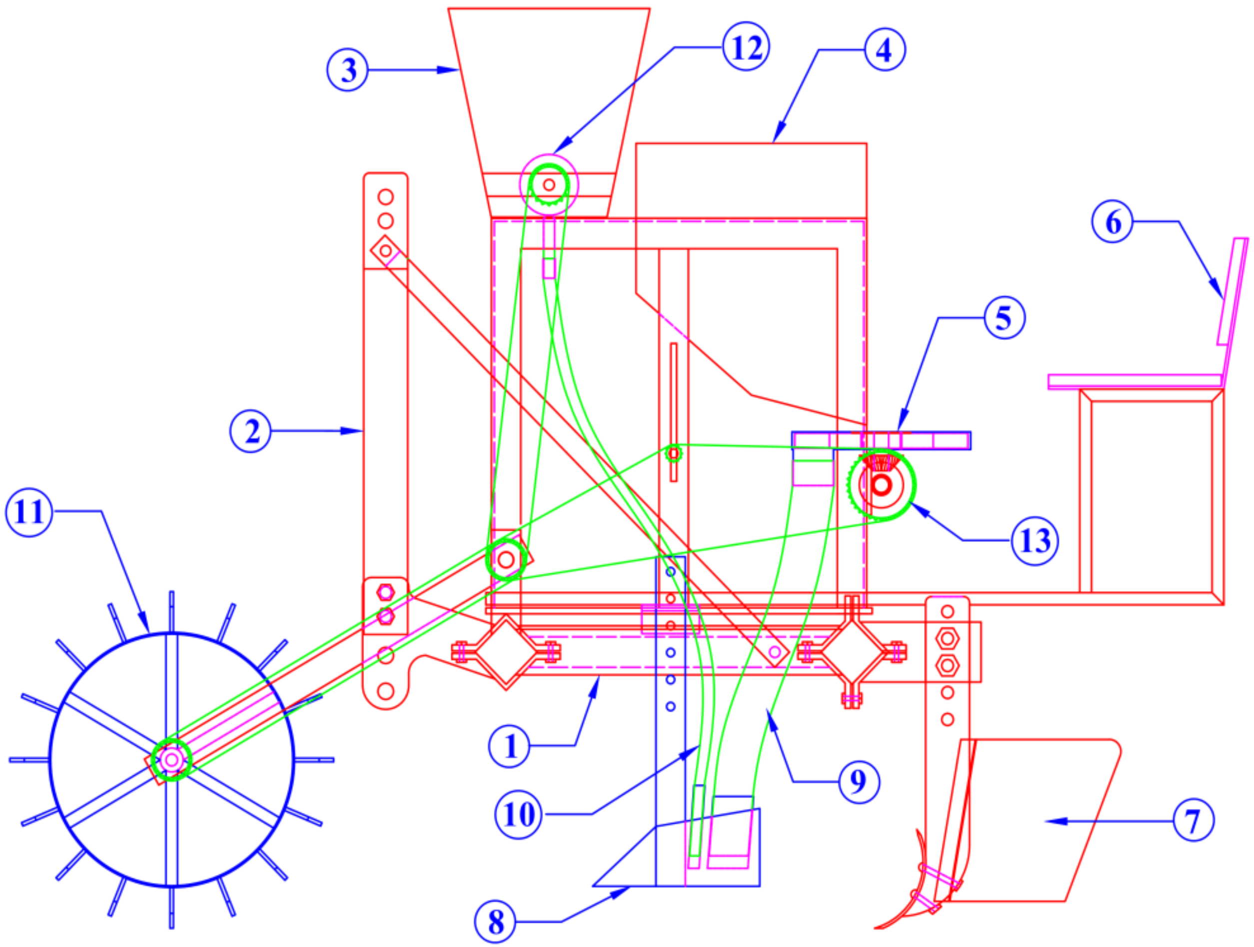
Plate 3.1 Developed rhizome planter

Plate 3.2 Working of developed rhizome planter in field



No.	Description
1	Main frame
2	Rhizome box
3	Manure box
4	Manure metering screw
5	Rhizome metering disc
6	Manure delivery tube
7	Rhizome delivery tube
8	Shovel
9	Chain
10	Ridger
11	Shoe type furrow opener

Fig. 3.15 Front view of rhizome planter



No.	Description
1	Main frame
2	Hitch
3	Manure box
4	Rhizome box
5	Rhizome metering disc
6	Seating unit
7	Ridger
8	Shoe type furrow opener
9	Rhizome placement tube
10	Manure placement tube
11	Ground wheel
12	Manure metering screw
13	Sprocket

Fig. 3.16 Side view of rhizome planter

3.5 LABORATORY TEST

Before conducting the performance evaluation of the unit in the field, laboratory test, were carried out for obtaining the correct rhizome rate and vermin compost rate.

3.5.1. Calibration of unit

The performance of the tractor operated rhizome planter was tested in the laboratory. The calibration is done to get a predetermined rhizome rate and vermin compost rate of the planter. The following procedure was followed for calibration of seed drill or planter.

1. Determine the nominal width of planter.

$$W = M \times S \qquad \text{… (3.16)}$$

Where,

M = number of furrow openers

S = spacing between the furrow openers, m.

2. Find the length of the strip (L) having nominal width W necessary to cover 1/25th of a hectare.

$$L = \frac{10000}{W} \times \frac{1}{25} \qquad \text{… (3.17)}$$

3. Determine the number of revolutions (N) the ground wheel has to make to cover the length of the strip (L).

$$\pi \times D \times N = \frac{10000}{W} \times \frac{1}{25} \qquad \text{… (3.18)}$$

Where,

D = diameter of the ground wheel. m

$$N = \frac{10000}{\pi \times D \times W} \times \frac{1}{25} \qquad \text{… (3.19)}$$

$$N = \frac{400}{\pi \times D \times W} \qquad \text{… (3.20)}$$

4. Jack up the planter so that the ground wheels rotate freely. Make a mark on the drive wheel and a corresponding mark at convenient place on the body of the planter to help in counting the revolutions of the drive wheel.
5. Put the selected two budded rhizomes in the hopper. Place a sack or a container under each boot for rhizomes and vermin compost collection.
6. Rotate the drive wheel at the speed N.

$$N = \frac{400}{\pi \times D \times W}$$

7. Weigh the quantity of rhizome dropped from each opener.
8. Calculate the rhizome dropped in kg ha^{-1}.

3.5.2. Mechanical damage of rhizomes

Mechanical damage of the rhizomes will affect the germination of rhizomes, so it is necessary to calculate the percentage of mechanical damage. For conducting this experiments injury free rhizomes were selected and used for the experiments. Take the weight of damaged rhizomes in two kg of the sample after the test and calculate the percentage of damaged rhizomes.

3.6 PERFORMANCE EVALUATION OF RHIZOME PLANTER

Performance evaluation will be conducted for 9 combinations of forward speed and transmission ratio. Experimental design with 3 forward speed and transmission ratio is given in table 3.2.

3.6.1 Selection and test performance of rhizome planer

Independent variables

i. Forward speed of tractor (S_1, S_2, and S_3)
ii. Speed ratio of metering disc (R_1, R_2, and R_3)

Dependent variables

i. Miss index, %
ii. Multiple index, %
iii. Quality of feed index, %
iv. Rhizome mean spacing, cm
v. Rhizome precision index, %

Table 3.2 Experimental design of rhizome planter testing for forward speeds and transmission ratios

Sl. No.	Experiment runs	Forward speed, km h^{-1}	Transmission ratio, np:nq
1	S_1R_1	0.97	1:1
2	S_2R_1	1.37	1:1
3	S_3R_1	1.98	1:1
4	S_1R_2	0.97	1:1.25
5	S_2R_2	1.37	1:1.25
6	S_3R_2	1.98	1:1.25
7	S_1R_3	0.97	1:1.5
8	S_2R_3	1.37	1:1.5
9	S_3R_3	1.98	1:1.5

3.6.2 Performance evaluation of rhizome planter

The performance indices of a planter namely multiple index, miss index, quality of feed index and precision along with mean and standard deviation keeping theoretical spacing as base was calculated from the measured spacing between dropped rhizomes (Kachman and Smith, 1995), (Al-Gaadi, 2011) were calculated by the following calculations.

3.6.2.1 Missing index

Miss index (I_{miss}) is an indicator of how often the rhizome seed skips the desired spacing. It is the percentage of spacing greater than 1.5 times the theoretical spacing S in mm. That is

$$I_{miss} = \frac{n_1}{N} \times 100 \qquad \text{... (3.21)}$$

Where,

n_1 = Number of spacing in the region > 1.5 S

N = Total number of observations

The rhizome misses could be due to the failure of planter to drop a rhizome seed or the failure of the seed to germinate.

3.6.2.2 Multiple index

The multiple index (I_{mult}) is an indicator of more than one seed dropped within a desired spacing. It is the percentage of spacing that are less than or equal to half of the theoretical spacing S in mm. That is

$$I_{mult} = \frac{n_2}{N} \times 100 \qquad \text{... (3.22)}$$

Where,

n_2 = Number of spacing in the region ≤ 0.5 S

N = Total number of observations

3.6.2.3 Quality of feed index

The quality of feed index (I_{fq}) is the measure of how often the spacing were close to the theoretical spacing. It is the percentage of spacing that are more than half but not more than 1.5 times the theoretical spacing S in mm. The quality of feed index is mathematically expressed as follows:

$$I_{fq} = 100 - (I_{miss} + I_{mult}) \qquad \text{... (3.23)}$$

Where,

I_{miss} - Miss index

I_{mult} - Multiple index

3.6.2.4 Precision index

Precision in spacing ($I_{p)}$ is a measure of the variability (coefficient of variation) in spacing, between rhizome seeds after accounting variability due to both multiples and misses.

$$I_p = \frac{S_d}{S} \qquad \text{... (3.24)}$$

Where,

S_d = Standard deviation of the spacing more than half but not more than 1.5 times the set spacing S in mm.

3.6.2.5 Uniformity of rhizomes spacing

The spacing between the seeds and the number of plants per hill were measured to analyze the uniformity of plant spacing (Parish *et al.,* 1991). The co-efficient of variation and standard deviation were calculated by using following expressions.

$$S.D = \sqrt{\frac{(Xi - X)^2}{n}} \qquad \text{... (3.25)}$$

$$CV = \frac{SD}{X} \qquad \text{... (3.26)}$$

Where,

SD = Standard deviation

CV = Coefficient of variation

n = Total number of seeding actions

X_i = i^{th} spacing

X = Mean spacing.

The above procedure was repeated three times and means values were taken.

3.7 FIELD TESTING OF RHIZOME PLANTER

The developed prototype of rhizome planter was tested for field performance. The tests were conducted at Kelappaji College of Agricultural Engineering and Technology, Thavanur campus. The plot was ploughed soil was prepared by rotavator operated twice in experimental plots to obtain a fine seedbed for rhizome planting. The John Deere tractor 5065E (65 hp) was used for field test. The tractor driver and two or three operators for regulating and dropping the rhizomes were employed for the test. The following parameters were observed during the field test.

3.7.1 Rhizome to rhizome spacing

During the field trial the rhizome to rhizome spacing (cm) in the 1 m length was measured with the help of steel scale. The rhizome to rhizome spacing was measured in the field at five different locations randomly (Plate 3.3).

Plate 3.3 Rhizome spacing measurement

Plate 3.4 Row to row spacing measurement

3.7.2 Row to row spacing

While conducting the field trials of the rhizome planter the spacing between two adjacent rows (cm) was measured with the help of steel tape (Plate 3.4). The row to row spacing was measured in the field at five different locations randomly.

3.7.3 Width of operation

During the field trials of the rhizome planter the width of operation (cm) of entire machine was measured with the help of steel scale. The width of operation was measured in the field at five different locations randomly.

3.7.4 Wheel slippage

The wheel slippage of tractor was measured by marking the sides of rare tyre lugs by numbers for a distance of 20 m load and in planting condition was recorded to determine wheel slip. The wheel slippage was computed in percentage and measured by using the formula,

$$\text{Wheel slippage (\%)} = \frac{N_1 - N_2}{N_1} \times 100 \qquad \text{... (3.27)}$$

Where,

N_1 = No. of rotation of rear wheel of tractor in 20 m distance at load condition.

N_2 = No. of rotation of rear wheel of tractor in 20 m distance at no load condition.

3.7.5 Fuel consumption

An external portable fuel tank was fitted on the tractor. Fuel tank was filled to full capacity before and after the field test. Amount of refueling after the test was recorded and the fuel consumption for the test was worked out. When filling up the tank, careful attention was paid to keep the tank horizontal and not to leave empty air space in the tank. The fuel consumption was expressed in l h^{-1}.

3.7.6 Draft

The load cell dynamometer was attached at the front of the tractor on which the implement was mounted (Plate 3.5). Another auxiliary tractor was used to pull the implement mounted tractor through the load cell dynamometer. The auxiliary tractor pulled the implement mounted tractor with the latter tractor in neutral gear but with implement in the operating position. The pull was recorded in the dial gauge of load cell dynamometer. The draft in the measured distance of 20 m shall be read and recorded. On the same field, the draft in the same distance shall be read and recorded while the implement is lifted above the ground. The difference gives the draft of the implement.

Plate 3.5 Draft measurement in field

3.7.7 Theoretical field capacity

Theoretical field capacity was measured by considering the width of operation and travel speed of the tractor. The theoretical field capacity was expressed in ha h^{-1} and measured by using the formula,

$$\text{Theoretical field capacity} = \frac{\text{Width of operation (m)} \times \text{Travel speed (km hr}^{-1}\text{)}}{10}$$

... (3.28)

3.7.8 Effective field capacity

During field tests, time losses for every event *viz,*. refilling of rhizomes and vermicompost in the planter, and turning losses were recorded. However in calculating the effective field capacity (ha h^{-1}), the time consumed for effective work and the time losses for other activities such as turning, refilling of rhizome and vermicompost were recorded.

$$M = \frac{A}{T_p + T_n} \qquad \text{... (3.29)}$$

Where,

M = Effective field capacity, ha h^{-1}

A = Area covered, ha

T_p = Productive time, hr

T_n = Non-productive time, hr

3.7.9 Field efficiency

Field efficiency (E_f) was expressed as percentage and measured by using below formula,

$$\text{Field efficiency} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100 \qquad \text{... (3.30)}$$

$$E_f = \frac{W_e \times V_e \times T_p}{W_t \times V_t \times (T_p + T_n)} \times 100 \qquad \text{... (3.31)}$$

Where,

W_e = Effective working width, m

W_t = Theoretical working width, m

V_e = Effective operating speed, m s^{-1}

V_t = Theoretical operating speed, m s^{-1}

T_p = Productive time, s

Tn = Non-productive time, s

3.7.10 Ridge and furrow profile measurement

The furrow profile meter consist of a frame plotting board, measuring pins, pin holding and releasing mechanism and paper feeding arrangements. The furrow profile meter was placed across the ridges and furrows and the measuring pins were released by operating the release lever. The furrow profile was recorded on graph sheet by drawing a line over the top of all measuring pins. The measurements were taken at three different locations and the mean value is taken.

3.7.11 Depth of rhizome placement

The depth of rhizome placement was measured by removing the soil formed on rhizome by ridger and measure the depth at which the rhizome was placed.

3.8 STATISTICAL ANALYSIS

The data obtained were statistically analyzed by 2 Factorial Completely Randomized Design (FCRD) using Design Expert (v 10) software. The analysis of variance (ANOVA) and mean table for different parameters were tabulated and the level of significance was reported.

3.9 COST OF OPERATION

Based on the material used and labour requirement for the fabrication of the rhizome planter, fixed cost and variable cost of the unit was calculated as per the procedure described by IS: 9164-1979. From the field capacity of the planter, the cost of operation per hectare was calculated.

CHAPTER IV

RESULTS AND DISCUSSION

The study was undertaken to design, develop and test rhizome planter performance for ginger and turmeric planting at desired spacing and depth. Engineering and physical properties of rhizome setts were investigated for designing the rhizome planter components. The rhizome planter was tested for rhizome missing index (I_{miss}), rhizome multiple index (I_{multi}), quality of feed index (I_{qf}), precision index (I_p) and rhizome spacing (I_s) to evaluate the planting performance. The following sections gives the details about the engineering and physical properties of rhizome setts and field testing of rhizome planter.

4.1 AGRONOMIC AND ENGINEERING FACTORS RELATED TO RHIZOME PLANTER DESIGN

4.1.1 Soil type and conditions

The test field was prepared by plouging and soil was pulverized so that ridges and furrows can be easily formed during planting operation. Soil was worked at optimum soil moisture to obtain a good tilth for planting rhizomes at proper depth. Rhizome planter was tested in a field having sandy loam soil with moisture content of 13% and bulk density of 1.63 g cm^{-3}. Hence, these soil factors were considered while testing of rhizome planter.

4.1.1 Farm yard vermicompost and conditions

The farm yard vermicompost is applied into furrows during planting operation to provide the basal amount of organic nutrients for better rhizome sprouting and establishment during the early period of crop growth. The moisture content, bulk density and angle of repose of vermicompost was about 25.8%, 750.8 kg m^{-3} and 35° respectively. Hence, these farm yard vermicompost factors were considered while testing of rhizome planter.

4.2 PHYSICAL PROPERTIES OF RHIZOMES

4.2.1 Weight distribution of rhizomes

The frequency distribution of rhizome sett weight after separated from primary clump ginger and turmeric is given in Table 4.1. For ginger, it was observed that the rhizome setts weighing 10-20 g range was maximum of about 86.2% followed by rhizome setts weigh 1-10 g to about 7.5% and remaining 6.3% of rhizome setts weighed in 20-30 g range. Similarly for turmeric, rhizomes setts weighing 10-20 g contributed about 78.2% followed by 1-10 g range weighing to 17%. The turmeric rhizome setts weighing in the range of 20-30 g was minimum was minimum to about 4.8%. The weight of rhizome setts were directly proportional to their moisture content. As the moisture content increased, the average weight of rhizome setts also increased.

Table 4.1 Weight distribution of ginger and turmeric rhizome setts

Sl. No.	Range of rhizome sett weight frequency, g	Ginger	Turmeric
		Percentage of weight distribution (%)	Percentage of weight distribution (%)
1	1-10	7.8	17.00
2	10-20	86.20	78.20
3	20-30	6.30	4.80
4	Total	100	100

4.2.2 Moisture content

The moisture content of seed rhizome setts were determined as described in section 3.2.1.2. The average moisture content of ginger and turmeric rhizome sett is presented in Table 4.2. The average moisture content of rhizome setts under study was found to be 80.64±2.7%. Athmaselvi and Varadharaju (2002) reported that the moisture content of BSR-2 variety was 86% (wb) immediately after harvest. In the present study, the moisture content of rhizome setts was less due to two months storage after harvest.

Table 4.2 Moisture content of turmeric and ginger rhizome setts

Sl. No.	Type of Crop	Moisture content, Mean ± SD, % (wb)
1	Ginger	81.16 ± 1.12
2	Turmeric	80.61 ± 1.98

4.2.3 Size of ginger and turmeric rhizome setts

The ginger and turmeric rhizome setts size and shape were measured as described in section 3.2.1.3. The ginger and turmeric rhizome setts should have at least 1-2 buds with required weight. The primary and secondary were separated from rhizome clump and different size dimensions were measured (Mishra and Kulkarni, 2009). The major, intermediate and thickness dimensions of rhizome setts were measured. The average linear dimensions of two budded rhizome setts measured in natural rest position is given in Table 4.3.

Table 4.3. Linear dimensions of ginger and turmeric rhizome setts

Sl. No.	Dimensions of rhizome sett	Ginger	Turmeric
		Mean ± SD, mm	
1	Length	55.12±1.15	54.51±1.54
2	Width	25.51±0.18	23.60±0.53
3	Thickness	22.78±0.22	20.84±0.33

The mean linear dimensions of randomly two budded ginger rhizome of about 81.16% moisture content have a major axis (length) 55.12±1.15 mm; intermediate axis (width) 25.51±0.18 mm and minor axis (thickness) 22.78±0.22 mm respectively. Similarly, the linear dimensions of turmeric rhizome setts having 80.61 % moisture content have a major axis (length) 54.51±1.54 mm; intermediate axis (width) 23.60±0.53 mm and minor axis (thickness) 20.84±0.33 mm respectively. Above results indicated that rhizome setts of ginger and turmeric had irregular shape of oblong in nature. Therefore, an oblong shaped cell was selected for the metering disc with a cell length equal to the major axis and depth equal to thickness of rhizome setts. The major linear dimension selected for ginger and turmeric rhizome setts of 1-2 buds was 40-50 mm. In general the general dimensions of metering device cells depend upon the major axis and thickness of ginger and turmeric rhizome setts.

4.2.4 Bulk density

The bulk density of two budded ginger and turmeric rhizome setts were determined as explained in section 3.2.1.4 and results are given in Table 4.4. The bulk density of two budded rhizome was found to be 470.56±5.63 kg m^{-3} for ginger and 462.02±5.73 kg m^{-3} for turmeric respectively. The hopper capacity was computed using the measured values of bulk density were 0.33 m^3 and 0.34 m^3 for ginger and turmeric respectively. The storage capacity of rhizome hopper depends upon on the bulk density of rhizomes and its packing nature in the container. It was observed that increase in finger length of rhizome setts resulted decrease in bulk density of ginger and turmeric respectively.

Table 4.4 Bulk density of ginger and turmeric rhizome setts

Sl. No.	Crop type	Bulk Density , Mean ± SD (kg m^{-3})
1	Ginger	470.56±5.63
2	Turmeric	462.02±5.73

4.2.5 True density

The true density of two budded ginger and turmeric rhizome setts were determined as explained in Section 3.2.1.5 are presented in Table 4.5. The true bulk density of ginger rhizome was found to be 1031.66±6.49 kg m^{-3} and turmeric, 822.02±5.73 kg m^{-3} respectively. From the above results, it was observed that the true density decreased as the length of rhizome decreased.

Table 4.5 True density of ginger and turmeric rhizome setts

Sl. No.	Crop type	True density, Mean ± SD(kg m^{-3})
1	Ginger	1031.66±6.49
2	Turmeric	822.02±5.73

4.3 FRICTIONAL PROPERTIES

4.3.1 Angle of repose

The angle of repose of two budded ginger and turmeric rhizome setts were determined as explained in section 3.2.2.1 and results are given in Table 4.6. The angle of repose of ginger and turmeric rhizome setts was experimentally determined as 36.34°±0.98 and 34.75°±1.65 respectively. The above angle of repose values were used for the design of rhizome hopper. The bottom portion of rhizome hopper was inclined downwards at 49° which was higher than the angle of repose values experimentally to facilitate easy flow of rhizome setts towards hopper bottom outlets and to metering units.

Table 4.6 Angle of repose of ginger and turmeric rhizome setts

Sl. No.	Type of Crop	Angle of repose Mean ± SD (Degrees)
1	Ginger	36.34±0.98
2	Turmeric	34.75±1.65

4.3.2 Coefficient of friction

The coefficient of friction of two budded ginger and turmeric rhizome setts were determined as explained in section 3.2.2.2 and results are presented in Table 4.7. The coefficient of friction values of rhizome setts on wood, stainless steel, aluminum and mild steel were measured to select material for rhizome hopper. It was observed that the coefficient of friction was highest on aluminum and least on stainless steel. The strength, cost and fabrication easiness of material were main criteria for the selection. The mild steel was selected considering all these factors, being cheaper for fabrication of rhizome and vermicompost hoppers.

Table 4.7 Coefficient of friction of ginger and turmeric rhizome

Sl. No.	Material surface	Ginger	Turmeric
		Mean ± SD	
1	Wood	0.523±0.03	0.543±0.02
2	Stainless steel	0.486±0.01	0.499±0.02
3	Aluminum	0.533±0.03	0.546±0.01
4	Mild steel	0.522±0.01	0.514±0.01

4.4 DESIGN OF RHIZOME PLANTER

A tractor drawn semi-automatic rhizome planter was designed and developed for ginger and turmeric as per the general requirements explained in section 3.3.1. The planter unit was fabricated as explained in section 3.4.

4.4.1 Design features and specifications

The rhizome planter was developed to suit ginger and turmeric crops and to work in various types of soil and in their conditions. The rhizome planter performs several functions during planting operation are (1) opens the soil and forms furrows (2) manually meters rhizomes setts (4) meters and drops vermicompost (5) delivers and deposits rhizome setts and vermicomposts in the ridges and (6) covers and compacts rhizome setts and vermicompost with soil, forming a ridge in single pass.

Provisions were made to adjust or alter row to row spacing, rhizome to rhizome spacing and depth of rhizome placement to suit both ginger and turmeric crops. The row spacing was altered by changing the positions of mounting clamps along the main frame. While the depth of working of furrow opener or ridger can be adjusted by raising or lowering the standard through a rectangular hollow bracket on mounting clamp. The rhizome to rhizome spacing was varied by changing the speed of metering disc by changing sprockets size on the shafts between ground wheel and rhizome metering disc shaft. Also, this can be achieved by changing the number of cells on the rhizome metering disc. The general specifications of the rhizome planter is given in Table 4.8

Table 4.8 Specifications of rhizome planter

Sl. No.	Particulars	Values
1	Over all dimensions	
	Length × width ×height, mm	1850 × 2140 × 1530
2	Specifications of tractor	
	i. Make and model	John Deere 6510
	ii. Power source, hp	65
3	Type of implement	Mounted
4	Number of rows	3

5	Row spacing, mm	450 (Adjustable)
6	Plant spacing, mm	200 (Adjustable)
7	Nominal working width, mm	1350
8	Depth of planting, mm	70 (Adjustable)
9	Metering mechanism	
	i. Type of rhizome metering mechanism	Cell feed horizontal disc type
	ii. Type of vermicompost metering mechanism	Screw feed type
	ii. Source of power for driving metering disc	Ground wheel
	v. Number of rhizome metering disc	3
	v. Diameter of metering disc, mm	300
10	Hoppers	
	a) Rhizome hopper	
	i. Shape	Trapezoidal section
	ii. Capacity, m^3	0.33
	b) Vermicompost hopper	
	i. Shape	Trapezoidal section
	ii. Capacity, m^3	0.42
11	Ground wheel	
	i. Type	Spike toothed wheel
	ii. Effective diameter of ground wheel, mm	480
	iii. Number of spikes	16
12	Furrow openers	
	i. Number of furrow openers	3
	ii. Type of furrow openers	Shoe type
13	Ridger bottoms	
	i. Number of ridger bottoms	4
	ii. Type of ridger bottom	Wing type (Adjustable)
14	Weight of planter, kg	450
15	Power transmission	
	i. The power from ground wheel to rhizome and vermicompost metering mechanisms	Chain and sprocket
	ii. Speed ratio	1:1, 1:1.25, 1:1.5

4.5 CALIBRATION TESTS

The rhizome planter was calibrated in the laboratory to determine the rhizome sett rate, mechanical damage of rhizomes and vermicompost rate for a particular area. The calibration of rhizome planter was conducted to test and adjust the planter to obtain desired plant population and vermicompost or fertilizer application rate. The calibrations test results are discussed in the following sections.

4.5.1 Calibration of rhizome planter for ginger and turmeric rhizome rate

The rhizome sett requirement per unit area was determined by calibrating the rhizome planter in the laboratory for ginger and turmeric. The rhizome planter was calibrated to determine the rhizome sett rate per hectare as described in section 3.5.1. The ground wheel was rotated for 20 revolutions and metered rhizomes were collected from all the three furrow openers and rhizome sett rate was calculated and the results are given in Table 4.9.

Table 4.9 Calibration results of rhizome planter

Sl. No.	Description	Value
1	Number of furrow openers	3
2	Spacing between the furrow openers, m	0.45
3	Diameter of ground wheel, m	0.57
4	Number of revolutions	20
5	Ginger rhizomes collected, kg	5.3
6	Turmeric rhizomes collected, kg	4.98

The recommended rhizome sett rate of ginger per hectare is 1500-1800 kg, as per the Package of Practices (KAU, 2011; Jayashree *et al*., 2014). However, the developed rhizome planter was calibrated to achieve a rhizome sett rate of 1096.20 kg ha^{-1}, 876.95 kg ha^{-1} and 730.80 kg ha^{-1}, for different spacing of rhizome to rhizome.

In case of turmeric, the recommended rhizome sett rate per hectare is 2000-2500 kg, (KAU, 2011; Kandiannan *et al.*, 2008). However, the rhizome planter reduced the rhizome sett rate to 1030.00 kg ha^{-1}, 824.00 kg ha^{-1} and 686.67 kg ha^{-1} for rhizome spacing of 20, 25 and 30 cm respectively, since the rhizomes length has been reduced to 40 to 50 mm for mechanical planting.

4.5.2 Calibration of vermicompost metering mechanism

The quantity of vermicompost required per unit area for ginger and turmeric by the rhizome planter was tested in the laboratory. The vermicompost metering mechanism was tested and quantity of vermicompost dropped was weighed to calculate the vermicompost rate requirement as per the recommendations of Kerala Agricultural University Package & Practices (KAU, 2011) as described in section 3.5.1.

Table 4.10 Calibration results for vermicompost rate

Sl. No.	Particulars	Value
1	Number of furrow openers	3
2	Spacing between the furrow openers, m	0.45
3	Diameter of ground wheel, m	0.57
4	Number of revolutions	20
5	Vermicompost collected, kg	
	Orifice 1 of 19 mm diameter size (3 No.)	4.2
	Orifice 2 of 25 mm diameter size (3 No.)	8.1

The recommended ginger rhizome sett rate per hectare is 3 tons, as per the Package and Practices (KAU, 2011). The compost vermicompost drilled from orifice 1 and orifice 2 were 868.68 and 1675.31 kg ha^{-1} respectively. The screw type metering mechanism can drill compost vermicompost in the furrow instead of spreading all over the field. This direct application of vermicompost in the furrow will facilitate the root system to utilize the nutrients efficiently for the effective growth of plants which also saves labour, cost and time for manual spreading and also the quantity required.

4.5.3 Mechanical damage of rhizome sett

The rhizome setts were collected randomly during calibration and was observed for damaged ones from a two kg rhizome sett lot, as described in section 3.5.2. The percentage of damaged rhizome was calculated.

4.5.3.1 Ginger

Weight of damaged rhizome after test = 120 g

Rhizome rate required for 4136.58 revolutions = $\frac{120}{2000} \times 100$ = 6%

4.5.3.2 Turmeric

Weight of damaged rhizome after test = 95 g

Rhizome rate required for 4136.58 revolutions = $\frac{95}{2000} \times 100$ = 4.75%

The mechanical damage of rhizomes might be due to higher tractor forward speed and metering disc speed which leads to aggressive rubbing of rhizomes with rhizome metering disc parts with in the rhizome metering chamber.

4.6 PERFORMANCE EVALUATION OF RHIZOME PLANTER

The field testing and evaluation of rhizome planter was conducted as discussed in section 3.6. The planter was tested in a ploughed field for 20 m strip length. The field testing of rhizome planter was conducted for a combination of forward speeds and transmission ratios of planter for ginger and turmeric respectively. The field performance observations on rhizome count, missing rhizomes, multiples of rhizomes, spacing between rhizomes in rows were collected and computed for ginger and turmeric respectively.

The peripheral speed varies with respect to the changes in forward speed and transmission ratio. As the forward speed increases the peripheral speed will increases due to decrease in transmission ratio. Variation in peripheral speed with respect to forward speed and transmission ratio is give in Table 4.11.

Table 4.11 Peripheral speed of metering disc with respect to forward speed and transmission ratio

Forward speed km h^{-1}	**Transmission ratio**		
	R_1	R_2	R_3
S_1	0.50	0.37	0.30
S_2	0.66	0.56	0.47
S_3	0.96	0.81	0.64

S_1, S_2 and S_3 = Forward speeds (0.37, 1.37 and 1.98 km h^{-1})

R_1, R_2 and R_3 = Transmission ratio (1:1, 1:1.25 and 1:1.5)

4.6.1 Performance evaluation of rhizome planter for ginger

The performance of the rhizome planter for ginger planting is given in Table 4.12. The results were analyzed statistically to determine the effect of forward speed and transmission ratio on the planter performance indices for ginger planting.

Table 4.12 Effect of forward speed and transmission ratio on ginger planting performance of rhizome planter

Sl. No.	Experiment runs	Mean rhizome spacing, cm	Missing index, %	Multiple index, %	Quality of feed index, %	Precision index, %
1	S_1R_1	21.66	5.17	3.39	91.44	14.76
2	S_2R_1	22.73	11.57	3.58	84.85	17.2
3	S_3R_1	22.23	18.21	7.15	74.64	20.19
4	S_1R_2	26.3	2.21	1.73	96.06	13.2
5	S_2R_2	26.83	3.4	3.23	93.37	16.73
6	S_3R_2	27.23	10.3	4.95	84.75	18.02
7	S_1R_3	30.43	0.94	0.75	98.31	11.02
8	S_2R_3	31.76	1.77	2.37	95.86	15.74
9	S_3R_3	32.63	9.17	3.57	87.26	19.4

4.6.1.1 Effect of forward speed and transmission ratio on mean spacing of rhizomes

The effect of forward speed and transmission ration on rhizome spacing is presented in Table 4.12. From figure.4.1, it is observed that the mean spacing between rhizomes increased, with increase in forward speed and transmission ratio during planting. The mean spacing of ginger rhizomes for lowest transmission ratio (R_1) was in the range of 21.66 cm to 22.73 cm and for (R_2) it ranged from 26.30 to 27.23 cm. However, for R_3 it ranged from 30.43 to 32.63 cm for three forward speeds as given in Table 4.12.

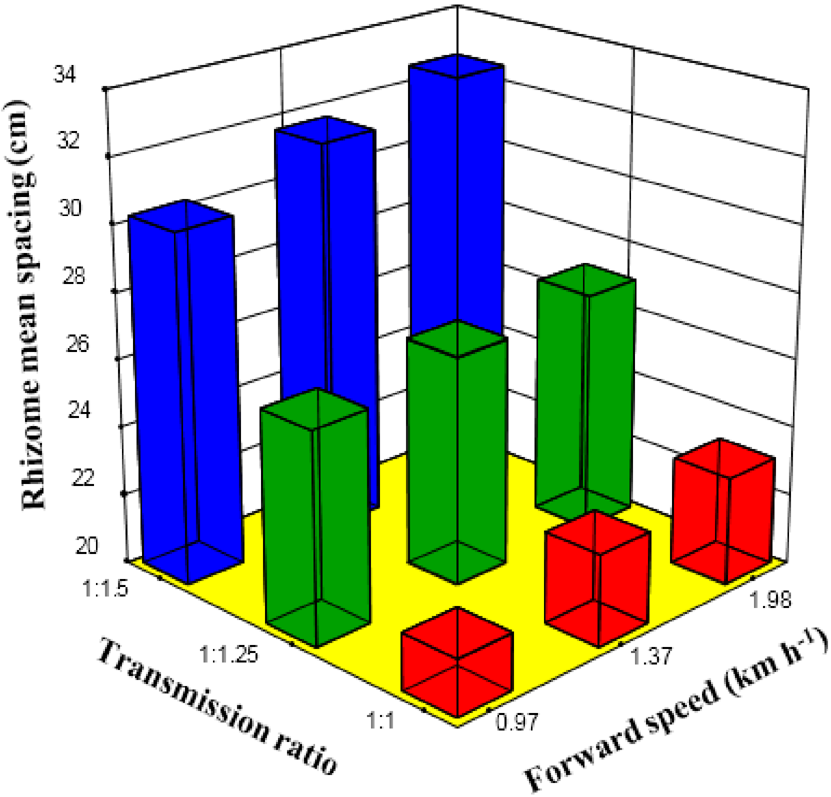


Fig. 4.1 Effect of planter forward speed and transmission ratio on mean rhizome spacing of ginger

As shown in Table 1 in Appendix III mean rhizome spacing was significant for various levels of the transmission ratio ($p<0.0001$) and forward speed ($p<0.05$). Average mean rhizome spacing was not significantly affected by interaction of transmission ratio and forward speed ($p>0.05$). As the transmission ratio and forward speed increases there was significant increase in mean spacing of rhizomes. A similar trend was observed for potato planters as reported by Gaadi and Marey (2011), for potato planting.

4.6.1.2 Effect of forward speed and transmission ratio on rhizome missing index

The effect of forward speed and transmission ratio on rhizome missing index is showed in Table 4.12.The missing index ranged from 0.94% to 18.21% for different combinations of forward speeds and transmission ratios as shown in Fig. 4.2.

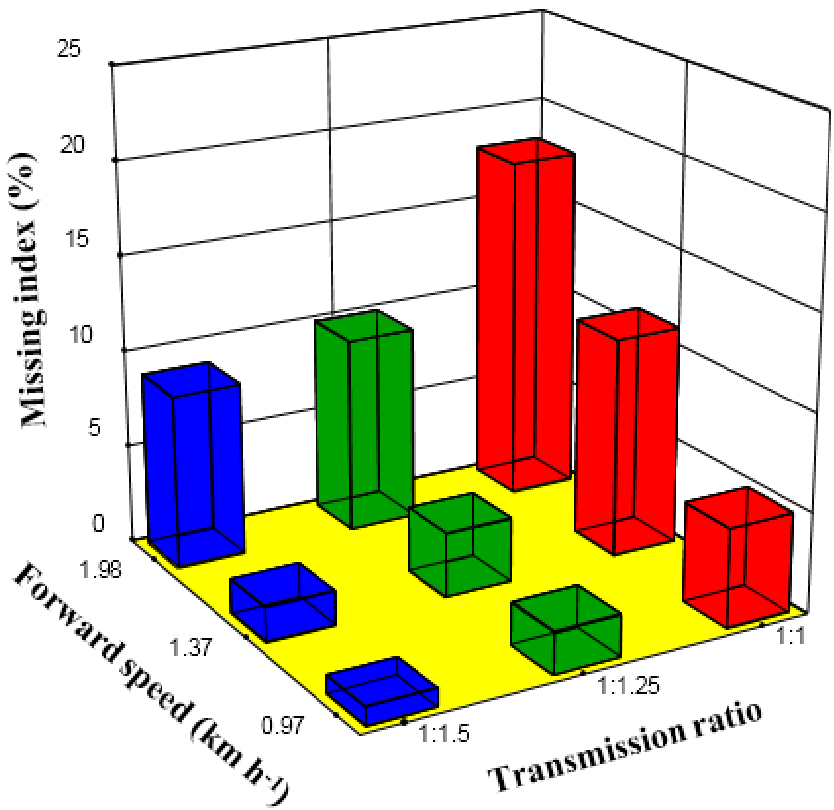


Fig. 4.2 Effect of rhizome planter forward speed and transmission ratio on ginger rhizome missing index

The highest missing index 18.21% was observed for highest forward speed (S_3) of 1.98 km h^{-1} and lowest transmission ratios (R_1) with metering disc rotating at a peripheral velocity of 0.96 m s^{-1}. The lowest missing index of 0.94% was observed with at a forward speed (S_1) of 0.97 km h^{-1} and highest transmission ratios (R_3) at which the metering disc peripheral speed is 0.30 m s^{-1}.

The analysis of variance (ANOVA) in Table 2 in Appendix III showed that the planter forward speed, transmission ratio and their interaction significant significant effect ($p < 0.0001$) on rhizome missing index. With increase in forward speed of operation and transmission ratio from 0.97 km h^{-1} to 1.98 km h^{-1} resulted an increase in percentage of rhizome missing index. This was due to the decrease in peripheral velocity of the metering disc to 0.30 m s^{-1} from 0.96 m s^{-1}.

Similar results were reported by Mathanker and Mathew (2002); Singh et al., (2005); Kachman and Smith, (1995).

4.6.1.3 Effect of forward speed and transmission ratio on multiple index

The influence of forward speed and transmission ratio on multiple index of rhizome planter performance is presented in Table 4.12. The number of rhizomes placed less than 50% spacing as per the recommended distance between spacing is indicated as multiple index of planter. The multiple index of ginger ranged from 0.75% to 7.15% for all levels of forward speeds and transmission ratios. The multiple index of ginger rhizome planting was 7.15%, for the maximum level of forward speed and lowest level of transmission ration. However, the lowest multiple index, 0.75% was for lowest level of forward speed (S_1) and highest level of transmission ratio (R_3).

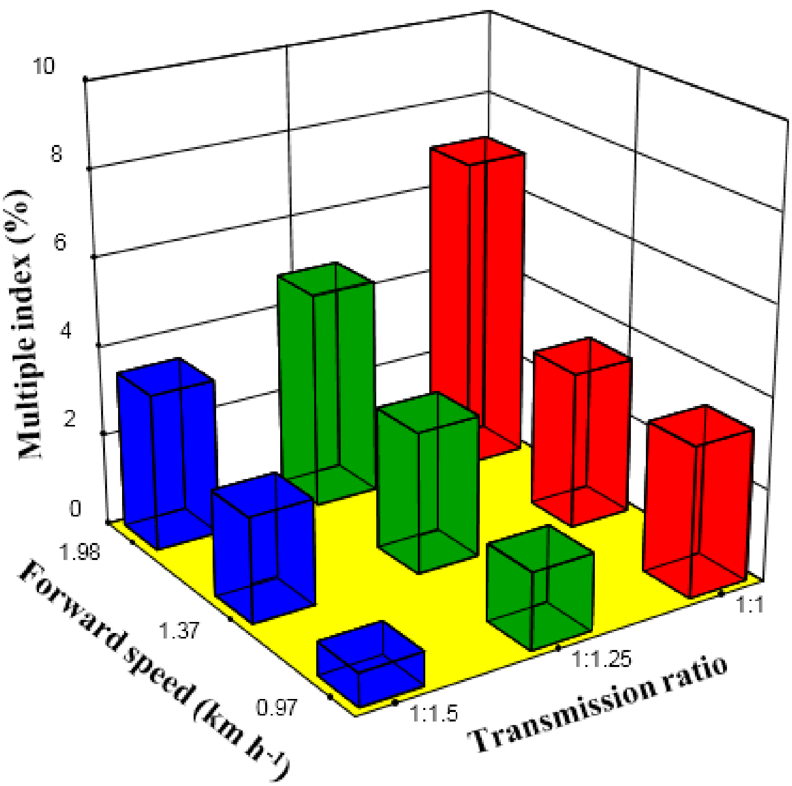


Fig. 4.3 Effect of planter forward speed and transmission ratio on multiple index of ginger

The analysis of variance (ANOVA) given in Table 3 of Appendix III revealed that the planter forward speed ($p < 0.0001$), transmission ratio ($p < 0.0001$) and the interaction between planter forward speed with transmission ratio for metering disc speed ($p < 0.05$) had significant effect on the multiple index of ginger rhizomes. The multiple index increased as peripheral velocity of metering disc increased from 0.3 to 0.96 m s^{-1} for all levels of planter forward speed. Variations in peripheral velocity with respect to forward speeds are given in Fig. 3. At higher speeds of disc, the operators were not able to control and regulate the feeding of rhizomes into the cells of metering disc which resulted in multiple rhizomes in some of the disc cells. Thus, the operators were not able to retrieve rhizomes and cells contained more than one rhizome per cell due to higher disc speeds which resulted higher multiple index with increase in peripheral speed.

4.6.1.4 Effect of forward speed and transmission ratio on quality of feed index

The results pertaining to quality of feed index is given in Table 4.12. From the Table 4.12, it is clearly observed that, the quality of feed index of ginger ranged from 74.64% to 98.31%. The highest quality of feed index (98.31%) was observed for the lowest level forward speed (S_1) and highest level of transmission ration (R_3) whereas lowest quality of feed index, 74.64% was observed for the parameter combination of highest forward speed (S_3) and lowest level of transmission ratio (R_1).

The quality of feed index decreased from 98.31% to 74.64% with increase in forward speed as shown in Fig. 4.4. It is observed that it is difficult control and regulate the feeding of rhizomes is into the disc cells as well as to remove the rhizomes from disc cells filled with multiple rhizomes at higher peripheral velocity of the metering disc (0.96 m s^{-1}). Similar result was observed for potato planter with high quality of feed index at lower forward speed as reported by Gaadi and Marey, (2011).

The analysis of variance (ANOVA) in Table 4 in Appendix III revealed that the planter forward speed and transmission ratio are significant at ($p < 0.0001$). Also, the interaction between planter forward speed and transmission ratio had significant effect on quality of feed index of ginger rhizome at ($p < 0.05$) probability.

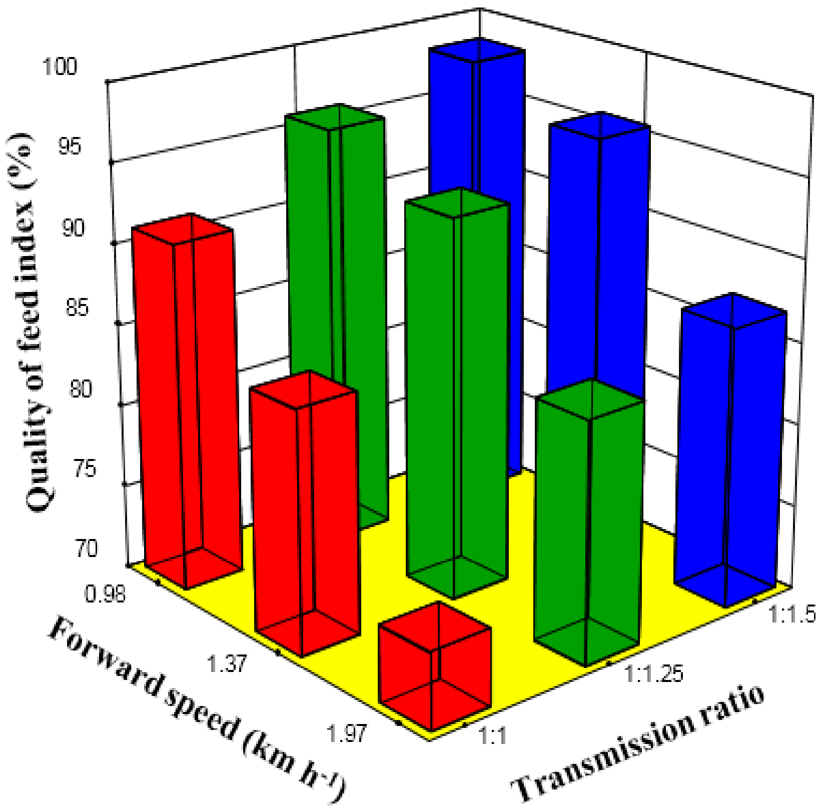


Fig. 4.4 Effect of planter forward speed and transmission ratio on quality of feed index of ginger rhizome

4.6.1.5 Effect of forward speed and transmission ratio on precision index of rhizomes

The effect of forward speed and transmission ratio on precision spacing index of planter performance is given in Table 4.12. The effect of forward speed on planter and transmission ratio for a forward speed of 0.97 km h^{-1} and transmission ratio (1.5) was 19.4 % precision index. The lowest precision index (11.02 %) was obtained at highest transmission ratio and lowest forward speed. However, the maximum precision spacing index 20.2 % was observed for lowest transmission ratio and highest level of forward speed. It is reported that lower values for the precision index indicate better performance compared to higher values of precision index (Kachman and Smith, 1995). The effect of forward speed and transmission ratio on precision index of ginger is shown in Fig. 4.5.

The precision spacing index values were not varying much for other levels of forward speed and transmission ratio values. The result obtained was similar to the findings as reported by (Tsegaye, 2015). The analysis of variance (ANOVA) is presented in Table 5 of Appendix III. The results showed that the effect of forward speed of the planter and transmission ratio on precision index was significant at probability ($p<0.05$). Also, the interaction between forward speed and transmission ratio had no significant effect on precision index at ($p>0.05$).

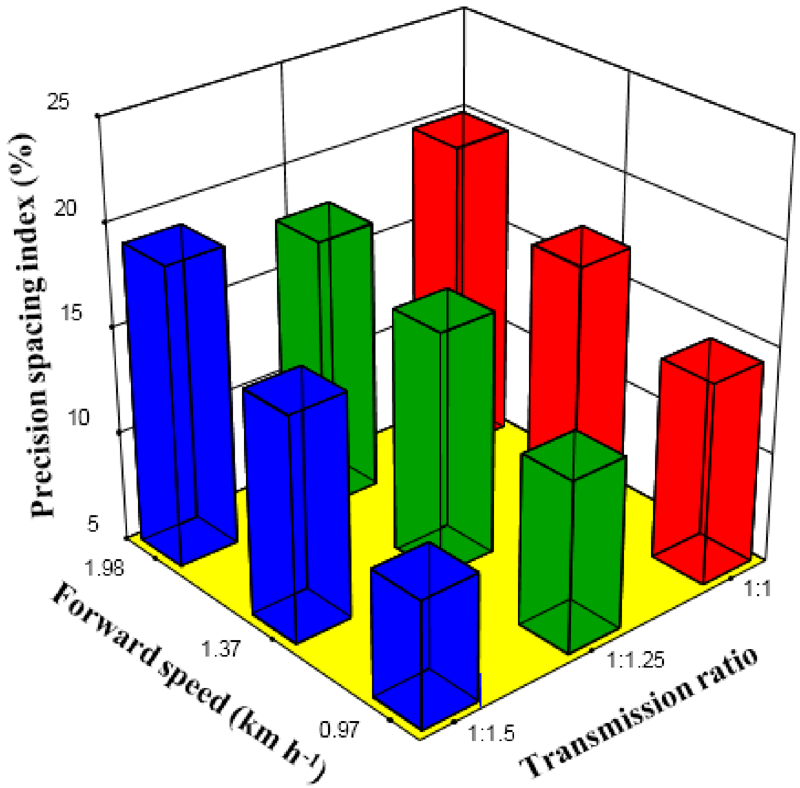


Fig. 4.5 Effect of planter forward speed and transmission ratio on precision index of ginger rhizome

4.6.2 Performance evaluation of rhizome planter for turmeric

The performance of the rhizome planter for ginger planting is given in Table 4.13. The results were statistically analyzed to determine the effect of forward speed and transmission ratio on the planter performance indices for turmeric planting.

Table.4.13 Effect of forward speed and transmission ratio on turmeric planting performance of rhizome planter

Sl. No	Experiments runs	Mean rhizome spacing, cm	Missing index, %	Multiple index, %	Quality of feed index, %	Precision index, %
1	S_1R_1	20.53	2.72	4.48	92.8	11.5
2	S_2R_1	21	6.24	7.55	86.21	14.01
3	S_3R_1	21	11.68	10.27	78.05	16.31
4	S_1R_2	24.9	2.87	2.87	94.26	10.5
5	S_2R_2	25.63	4.03	5.08	90.89	13.39
6	S_3R_2	25.73	8.26	9.5	82.24	15.63
7	S_1R_3	30.13	1.83	4.08	94.09	9.92
8	S_2R_3	31.13	3.53	4.98	91.49	12.1
9	S_3R_3	30.33	8.13	8.62	83.25	14.37

4.6.2.1 Effect of forward speed and transmission ratio on mean spacing index of rhizome

The effect of forward speed and transmission ratio on mean spacing of rhizome index for turmeric planting is given in Table 4.13. The mean spacing index of turmeric rhizomes was observed in the range of 20.53 to 21 cm for transmission ratio (1:1) and for all levels of forward speed. However, when transmission ratio was increased to (1:1.25), the mean spacing index ranged between 24.9 cm to 25.73 cm. For highest transmission ratio (1:1.5) level, the mean spacing index value ranged between 30.13 cm to 31.13 cm with increase in forward speeds. The influence of forward speed and transmission ratio on mean spacing index is shown in Fig. 4.6.

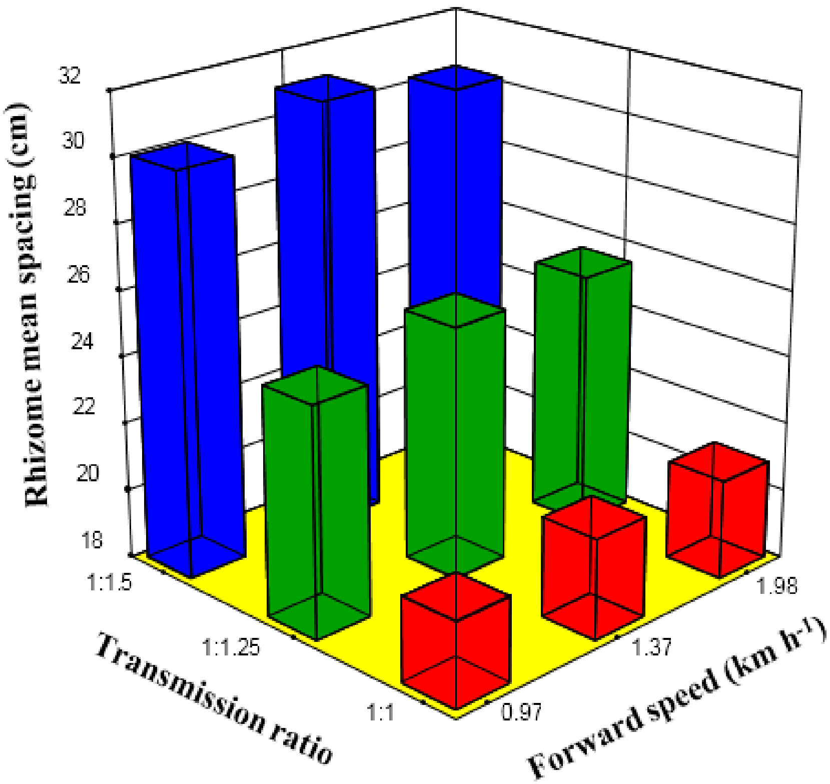


Fig. 4.6 Effect of planter forward speed and transmission ratio on mean spacing of turmeric rhizome

The effect of forward speed and transmission ratio on mean spacing index was analyzed statistically and the analysis of variance is presented in Table 1 in Appendix IV. The ANOVA revealed that the mean spacing index is highly affected by transmission ratio ($p<0.0001$) than forward speed ($p<0.05$). The mean spacing index was not significant for the interaction between transmission ratio and forward speed ($p>0.05$).

4.6.2.2 Effect of forward speed and transmission ratio on missing index of rhizome

The effect of forward speed and transmission index on turmeric rhizome missing index is given in Table 4.13. From the Table 4.13, it was observed that missing index ranged from 1.83% to 11.68%. The maximum missing index (11.68%) was observed for highest level of forward speed and lowest level of transmission ratio. However, the lowest missing index (1.83%) was observed for lowest level of transmission ratio (1:1.5). Table 4.13 showed the effect of forward speed and transmission ratio on turmeric rhizome missing index. The Fig. 4.7 showed the influence of forward speed and transmission ratio parameters on turmeric rhizome missing index. At the lowest forward speed and maximum reduction in transmission ratio resulted in decrease in peripheral speed of metering disc which indicated decrease in missing index of rhizomes.

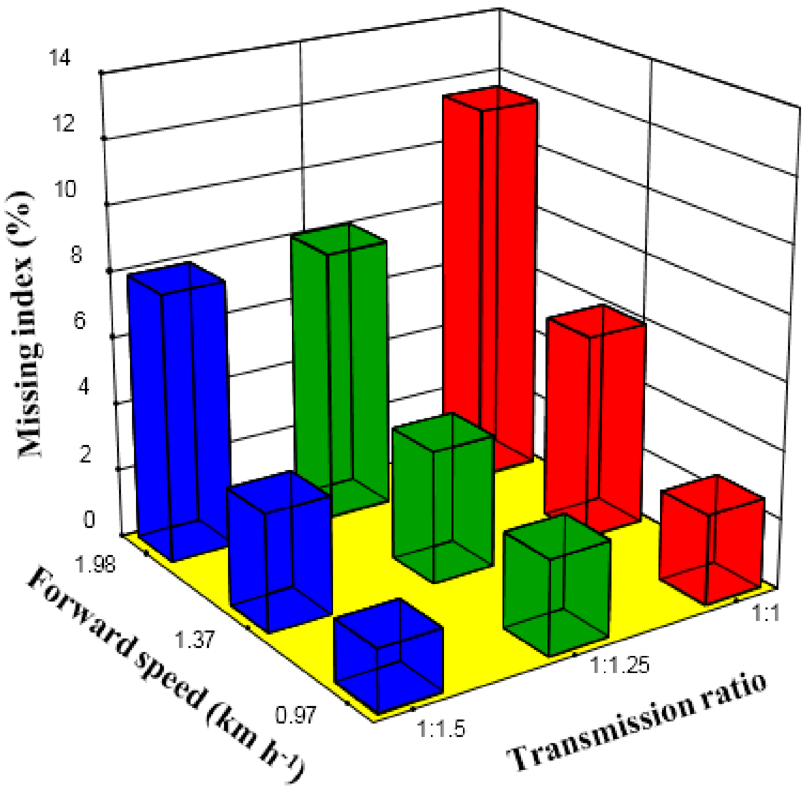


Fig. 4.7 Effect of planter forward speed and transmission ratio on missing index of turmeric rhizome

The analysis of variance (ANOVA) showed that, the planter forward speed ($p < 0.0001$) and transmission ratio ($p < 0.0001$) as well as the interaction between planter forward speed and transmission ratio ($p < 0.05$) are significant and affects rhizome missing index.

4.6.2.3 Effect of forward speed and transmission ratio on multiple index of rhizome

The influence of forward speed and transmission ratio is given Table 4.13. The turmeric rhizome multiple index was observed in the range of 2.87% to 10.27%. The maximum multiple index (10.27%) was observed for highest level of forward speed and lowest level of transmission ratio (1:1). The minimum multiple index (2.87%) was observed for maximum forward speed and at the transmission ratio (1:1.25). From Fig. 4.8 it is observed that with increase in forward speed, there was a corresponding increase in multiple index for all levels of transmission ratio. However, the multiple index % was lowest for the transmission ratio (1:1.25) compared to the other levels of transmission ratios.

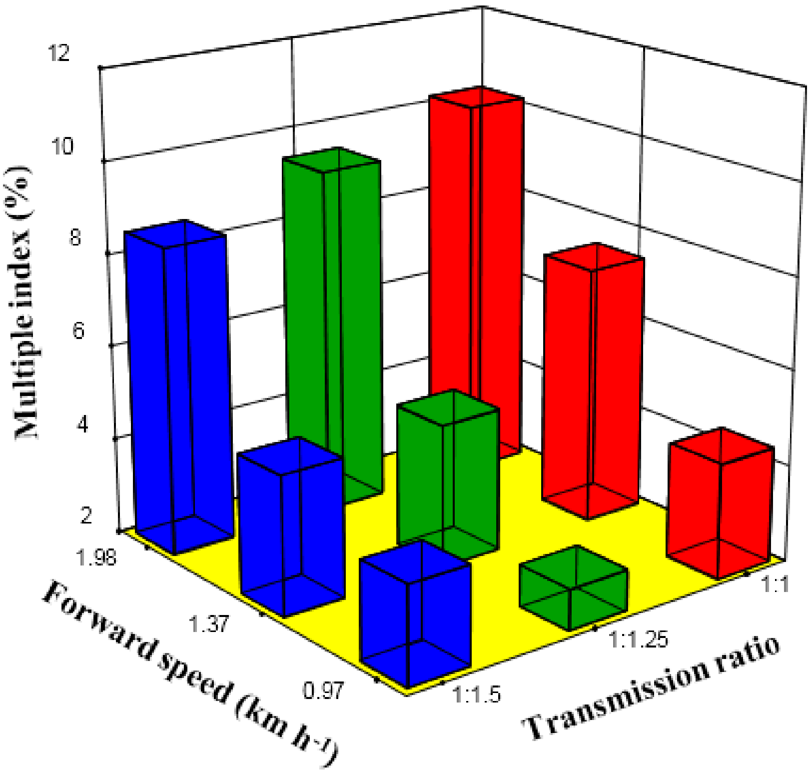


Fig. 4.8 Effect of planter forward speed and transmission ratio on multiple index of turmeric rhizome

Since the shape and size of turmeric rhizome fingers were small compared ginger rhizome which resulted in higher percentage of multiple index. As the dimensions of rhizomes decreases, more number of turmeric fingers were filled in the cells which was in agreement with results of Dixit *et al.* (2015), for the potato planter.

The analysis of variance (ANOVA) revealed that the planter forward speed ($p < 0.0001$) and transmission ratio ($p < 0.0001$) were significant on multiple index. Also, the combined effect of interaction between planter forward speed and transmission ratio was significant ($p < 0.05$) for multiple index of turmeric rhizome (Table 3 in Appendix IV).

4.6.2.4 Effect of forward speed and transmission ratio on quality of feed index of rhizome

The result of quality of feed index on turmeric rhizome is presented in Table 4.13. From Table 4.13 it is observed that the quality of feed index of turmeric rhizomes ranged between 78.05% to 94.26%. The highest quality of feed index (94.26%), was observed at a forward speed of 0.97 km h^{-1} and for a transmission ratio (1:1.25) whereas the lowest quality of feed index was observed at a forward speed of 1.98 km h^{-1} and transmission ratio (1:1).

The quality of feed index decreased from 94.26% to 78.05% with increase in forward speed from 0.97 km h^{-1} to 1.98 km h^{-1} as observed from Fig. 4.9 since it was difficult for manual feeding of rhizomes to the metering cells as result of the increased peripheral velocity of metering disc from 0.30 m s^{-1} to 0.96 m s^{-1}. Similar observations were reported by (Kachman and Smith, 1995).

The analysis of variance (ANOVA) is given in Table 4 of Appendix IV. The ANOVA analysis revealed that the planter forward speed ($p < 0.0001$) and transmission ratio ($p < 0.0001$) as well as interaction between them were significant ($p < 0.05$) which affected the quality of index of turmeric rhizome.

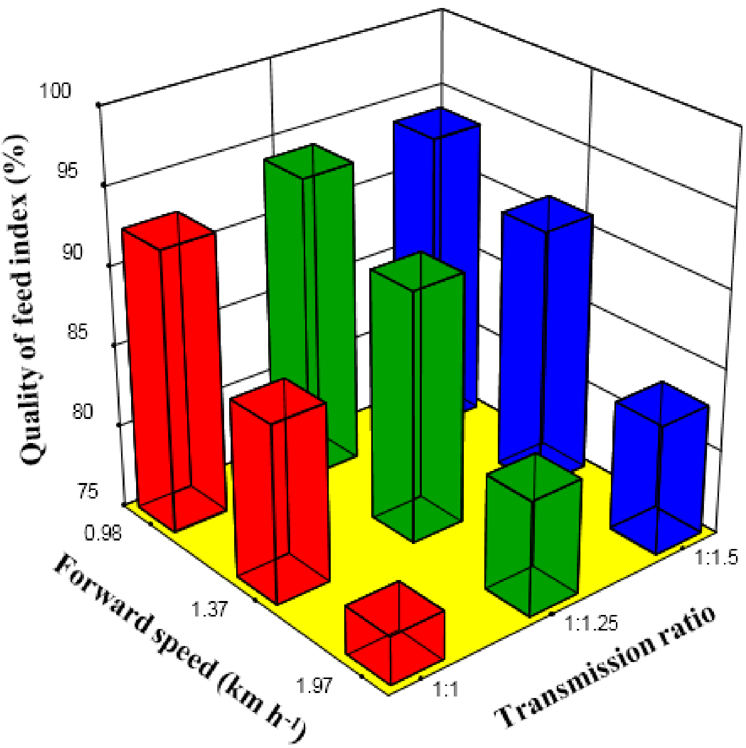


Fig. 4.9 Effect of planter forward speed and transmission ratio on quality of feed index of turmeric rhizome

4.6.2.5 Effect of forward speed and transmission ratio on precision index of rhizome

The result of precision index for different levels of forward speed and transmission ratio is presented in Table 4.13. The precision index % for all levels of forward speeds and transmission ratios ranged from were 9.92% to 16.31%. The lowest precision index (16.31 %) was for highest level of transmission ratio and lowest level of forward speed. Highest precision index (9.92%) resulted when forward speed was 1.98 km h^{-1} and transmission ratio (1:1) as observed in Fig. 4.10. The above result were in conformity with observations of Singh *et al.*, (2005). The effect of forward speed and transmission ratio on precision index of turmeric rhizome was analyzed statistically and the results of ANOVA are given in Table 5 of Appendix IV. The result indicated that the effect of forward speed of planter and transmission ratio influenced the precision index of turmeric rhizome.

The ANOVA analysis revealed that the planter forward speed had significant effect ($p<0.05$) on rhizome precision index whereas the transmission ratio and interaction between the main treatments had no significant effect ($p>0.05$) effect on precision index.

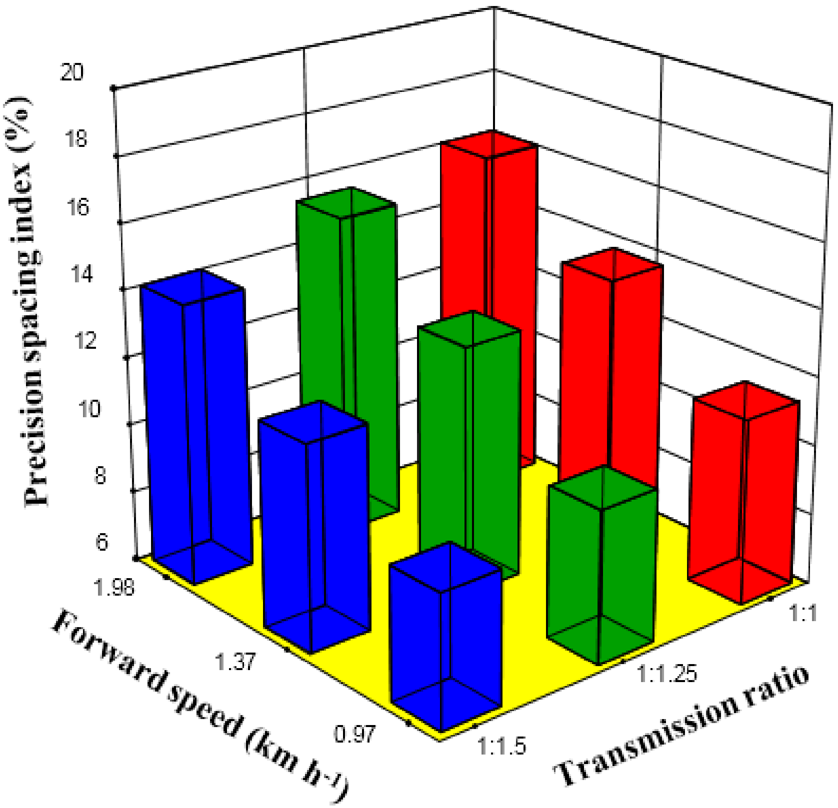


Fig. 4.10 Effect of planter forward speed and transmission ratio on precision index of turmeric rhizome

4.6.3 Optimization of test parameters for rhizome planter performance

The optimum settings of the test parameters for maximum planter performance was analyzed by desirability function. The optimum level of forward speed and transmission ratio was analyzed for maximum performance of quality of feed index and minimum performances of missing index, multiple index, precision index and mean spacing index of rhizome planting by the maximum value of the desirability. For a multi responses of ginger planting performance, the desirability value obtained was 0.819 at a forward speed of 0.97 km h^{-1} and a transmission ratio of 1:1.25. Fig. 4.11 showed the optimum values obtained for

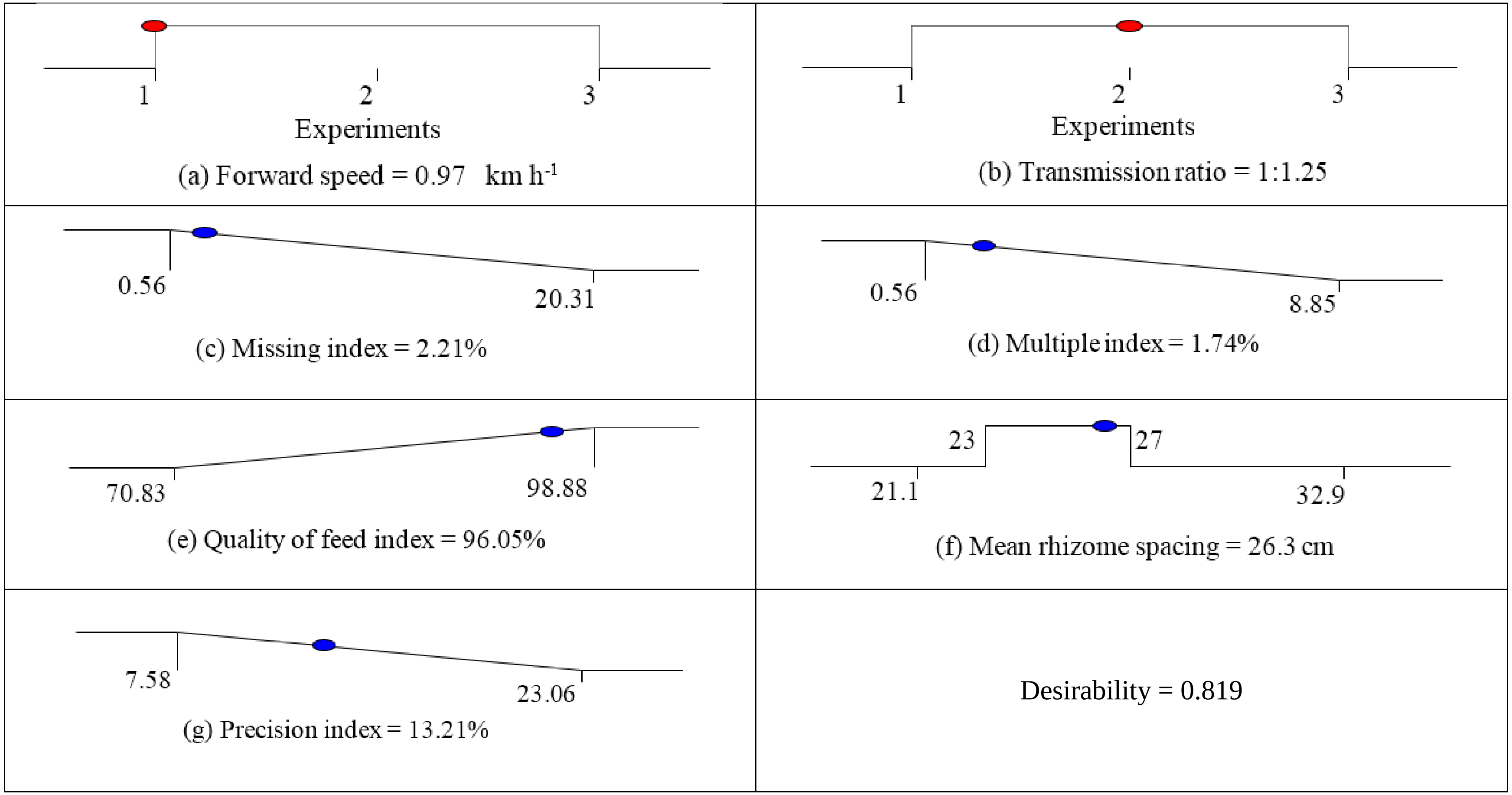


Fig. 4.11 Optimum setting of forward speed and transmission ratio for minimum missing index, multiple index, precision index, mean rhizome spacing and maximum for quality of feed index for ginger

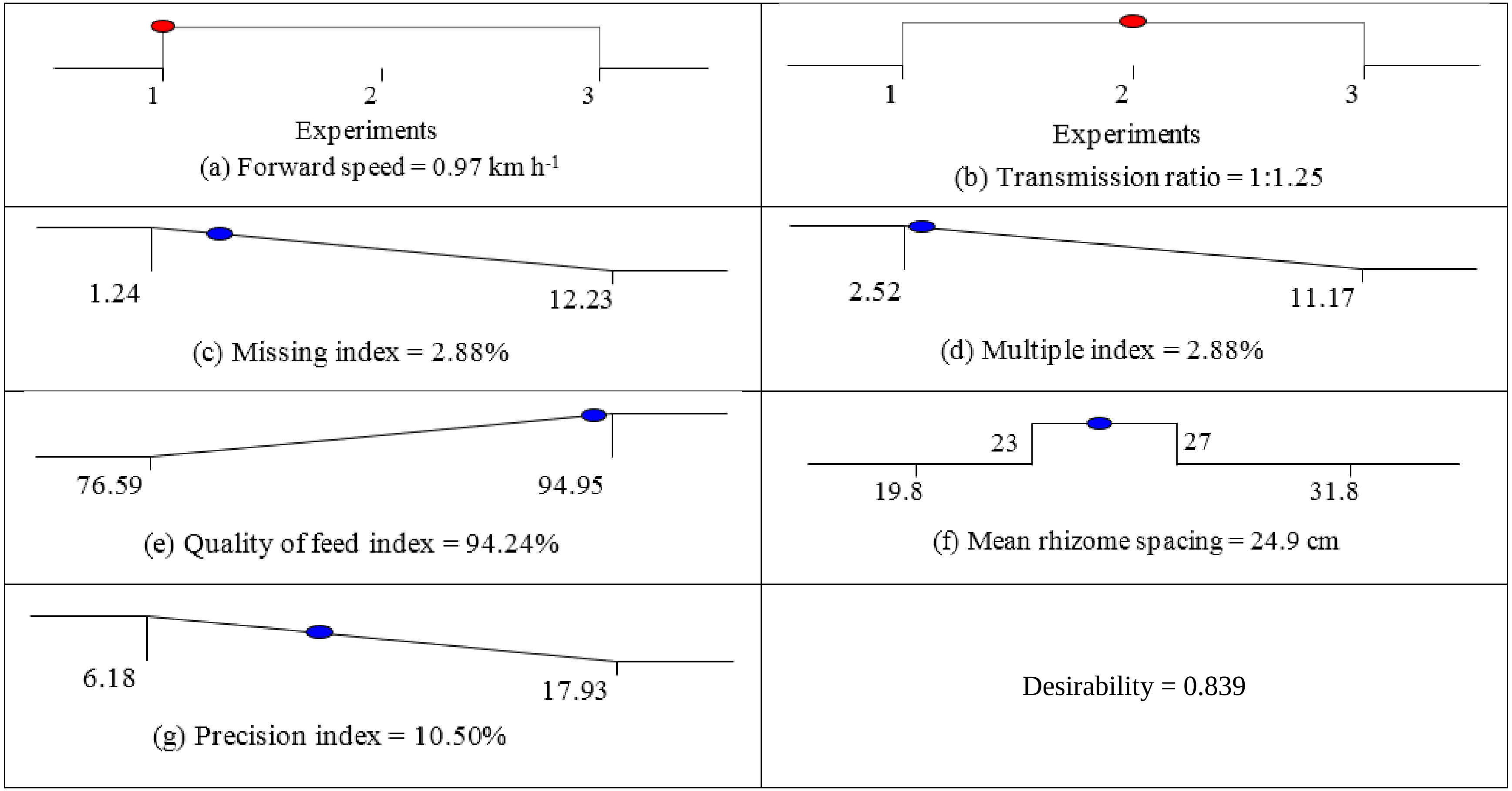


Fig. 4.12 Optimum setting of forward speed and transmission ratio for minimum missing index, multiple index, precision index, mean rhizome spacing and maximum for quality of feed index for turmeric

the above levels of the above forward speed and transmission ratio, the missing index was 2.21, multiple index was 1.74, the quality of feed index was 96.05, precision index was 13.21 and mean spacing index was 26.30.

In case of turmeric planting performance, the desirability value obtained for the multiple responses was 0.839 at a forward speed of 0.97 km h^{-1} and a transmission ratio of 1:1.25. The performance values of the multi responses obtained for the above levels of forward speed and transmission ratio, the missing index was 2.88, the multiple index was 2.88, the quality of feed index was 94.23, precision index was 10.50 and mean spacing index was 24.90, as showed in Fig. 4.12.

4.6.4 Uniformity of rhizome spacing

Uniformity of rhizomes spacing was measured by coefficient of variation as described in section 3.6.2.8. The average spacing between the rhizome setts planted by tractor drawn mechanical rhizome planter for ginger and turmeric is given in Table 4.14. The spacing observed for ginger planting was 22.54 cm, 26.83 cm and 30.61 cm at a recommended spacing of 20 cm, 25 cm and 30 cm respectively. Similarly the average spacing between turmeric rhizomes were 20.84cm, 25.42 cm and 30.50 cm for recommended spacing of 20 cm, 25 cm and 30 cm respectively. The coefficient of variation of uniformity of rhizome spacing for both ginger and turmeric are given in Table 4.14.

Table 4.14 Coefficient of variation of uniformity of rhizome spacing

Experiments	**Type of crop**					
	Ginger			**Turmeric**		
	R_1	R_2	R_3	R_1	R_2	R_3
S_1	0.136	0.126	0.108	0.112	0.105	0.099
S_2	0.151	0.156	0.148	0.134	0.130	0.116
S_3	0.173	0.164	0.178	0.155	0.152	0.142

The lowest coefficient of variation observed was 0.108 for a forward speed of 0.97 km h^{-1} and transmission ratio of 1:1.5 for ginger planting. But for turmeric planting performance, the lowest coefficient of variation observed was 0.099 at a forward speed of 0.97 km h^{-1} and transmission ratio of 1:1.5. The low values of coefficient of variation for uniformity of rhizome spacing indicated the accuracy and uniformity of spacing of rhizomes in conformity with the results of Shivaji (1998).

4.7 FIELD PERFORMANCE TESTS

4.7.1 Draft

The draft developed by tractor for operating the rhizome planter was measured by rolling method as described in RNAM tests code (1983) mentioned in section 3.7.6. The average draft developed by the tractor mounted rhizome planter at the working test speeds selected for planting operation in the sandy loam soil was 7708.02 N for ginger or turmeric during the experiments.

4.7.2 Ground wheel slip

The tractor ground wheel slip was measured as described in section 3.7.4. The tractor ground wheel slip measured was 5% which is within the recommended range of 18 % (Bjerkan, 1947).

4.7.3 Depth of rhizome placement

The depth of rhizome placement was measured by the procedure as described in section 3.7.11. The average depth of rhizome planting was 6.6 cm to 7.1 cm which was within the recommended value of 5 cm to 10 cm for ginger and turmeric, respectively (Jayashree *et al.*, 2014 Kandiannan *et al.,* 2008). The depth of rhizome placement in the furrow by the planter is given in Table 4.15. From this table, it was observed that the standard deviation and coefficient of variation of actual field measurements made were computed with respect to the recommended depth. The standard deviation of rhizome depth in the furrow was 1.075 and 0.875 respectively for ginger and turmeric. Also, the coefficient of variation of depth of rhizome placement was 1.63 and 0.123 for ginger and turmeric respectively.

Table 4.15 Depth of rhizome placement for ginger and turmeric

Experimental trails	Ginger	Turmeric
1	7	6
2	6	7
3	7	8
4	5	7
5	7	6
6	6	8
7	8	7
8	5	8
9	8	6
10	7	8
Mean	6.6	7.1
Standard deviation	1.075	0.875
Coefficient of variation	0.163	0.123

4.7.4 Fuel consumption

The fuel consumption was measured by the procedure as described in the section 3.7.5. The planter was operated in an area of 0.75 ha. The time and fuel consumption for the test area was measured. The fuel consumption obtained was 4.1 *l* ha^{-1}.

4.7.5 Field capacity and field efficiency

The mean field capacity and efficiency of the rhizome planter were 0.11 ha h^{-1} and 84.63% at a forward speed of 0.97 km h^{-1} while field capacity was 0.14 ha h^{-1} and 78.76% at a forward speed of 1.37 km h^{-1}. The maximum field capacity of 0.19 ha h^{-1} observed at a forward speed of 0.97 km h^{-1} with a field efficiency of 78.68%. Field capacity and field efficiency of tractor drawn semi-automatic mechanical rhizome planter given in Appendix V. The field efficiency of the rhizome planter was within the acceptable level as recommended by Kepner *et al.* (1978) for planters.

4.7.6 Surface profile of ridge planting

The tractor drawn semi-automatic rhizome planter made a ridge and furrow surface pattern in the field. The rhizomes are planted in the furrows and are covered with soil form a uniform regular ridge. The surface profile of rhizome ridge planting pattern was measured by the procedure explained in section 3.7.10. The ridge and furrow profile pattern after planting was measured by a soil surface profile meter and the measured ridge and furrow profile is shown in Fig. 4.13. From the figure, it is observed that the average ridge height at the center of ridge is 0.2 m and width of the ridge is 0.44 m.

4.8 COST OF OPERATION

The cost economics of tractor operated rhizome planter was worked and given in appendix VII. Cost of planting by using rhizome planter is Rs. 5059.45 ha^{-1} and by manual method is Rs. 12500 ha^{-1}.The cost and time saved over manual planting was about 59.52% and 96.57%. The cost of rhizome planter (Appendix VI) was Rs.50263/-. The benefit-cost ratio of the developed machine was 1.47:1.

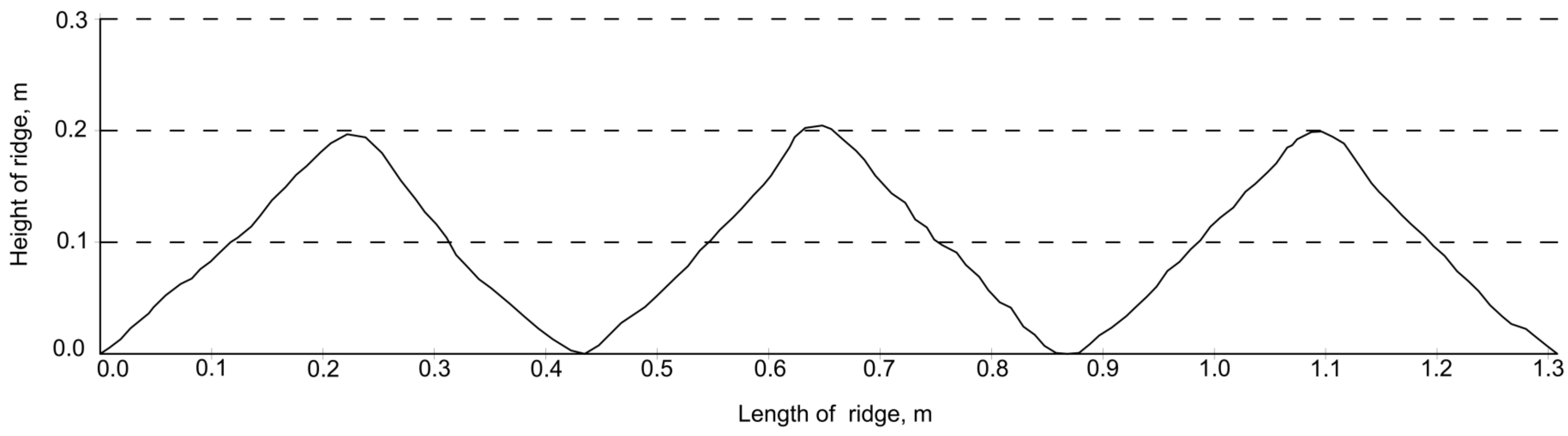


Fig.4.13 Ridge and furrow profile obtained in the field

CHAPTER V

SUMMARY AND CONCLUSIONS

Ginger (*Zingiber officinale Roscoe*) and Turmeric (*Curcuma longa* L.) are rhizomes are widely cultivated in India. Both ginger and turmeric are used as spices in cooking for flavour and as a medicine in Indian Ayurvedic treatments due to an oil called “gingerol” in ginger and “cocomin” in turmeric. Turmeric is also used as a colouring agent. Both ginger and turmeric are having a lot of uses in the manufacture of medicines and other products used in daily life.

The farmers face a lot of labour and management problems in ginger and turmeric cultivation. The crops are raised in beds in which three or four rows are planted at close spacing without much scope for mechanizing other farm operations including harvesting. It requires about 200-250 man hours per hectare for planting operation. Also, the harvesting is also done manually which consumes a lot of labour and cost in cultivation. Nevertheless, the mechanization of farm operations in ginger and turmeric farming can boost higher productivity and considerably reduce cost of production. Therefore, the present study was undertaken to design, develop and evaluate the performance of a rhizome planter for ginger and turmeric planting in ridge and furrow pattern of cultivation.

A tractor operated semi-automatic horizontal plate type rhizome planter for ridge and furrow planting was designed and developed. The planting parameters considered were row spacing of 0.45 m, plant to plant spacing of 0.15 m to 0.2 m, number of rhizome setts per hill for a recommended seed rate of 1500 to 1800 kg ha^{-1} and 2000 to 2500 kg ha^{-1} for ginger and turmeric. A disc type rhizome and vermicompost metering mechanisms driven by a planter ground wheel was designed. A furrow opener and ridger type covering device with adjustable wings for making ridges for ridge-furrow seed bed configuration were developed. The developed rhizome planter performed all planting operations in a single pass.

The rhizome planter was developed based on the agronomic planting considerations, engineering and physical properties of rhizomes. The rhizome planter components were designed base on the materials selected for the functional parts. Adjustable furrow opener and ridger bottoms were mounted to change the spacing as well as depth of placement of rhizomes. The intra row rhizome spacing was varied by changing the sprockets to change speed ratio.

The performance of the tractor operated ginger and turmeric planter was tested in the laboratory and field respectively. The developed rhizome planter was field tested with three different forward speeds and three transmission ratios. Performance planter parameters spacing indices which includes, rhizome missing index (I_{miss}), rhizome multiple index (I_{multi}), quality of feed index (I_{qf}) and precision (I_p) in rhizome spacing were used to evaluate functional performance rhizome planter. The minimum values of missing index 0.94%, multiple index 0.75%, precision index 11.02% and maximum value of quality of feed index 98.31% were observed for ginger. For turmeric, the minimum values of missing index 1.83%, multiple index 2.87%, precision index 9.92% and maximum value of quality of feed index 94.26% were observed. Average spacing for ginger and turmeric was range from 21.66 to 32.63 cm and 20.53 to 31.13 cm. By using the developed rhizome planter, the rhizome rate and vermicompost rate can be reduced. So that planting area can be enhanced.

The optimum performance of rhizome planter for both ginger and turmeric planting were at a forward speed of 0.97 km h^{-1} and transmission ratio (1:1.25) with desirability value of 0.819 for ginger and 0.839 for turmeric respectively. Uniformity of rhizome spacing was measured by coefficient of variation. The coefficient of variation, 0.108194 and 0.098795 were lowest at a forward speed of 0.97 km h^{-1} and transmission ratio (1:1.5) for ginger and turmeric respectively. The lower values of coefficient of variation obtained for rhizome spacing indicated that there was precision and uniformity in rhizome spacing. The average depth of rhizome planting was 6.6 cm - 7.1 cm which is within the recommended value of 5 to 10 cm for ginger and turmeric. The maximum field capacity and field efficiency of mechanical rhizome planter was 0.19 ha h^{-1} and 84.63 % respectively.

Cost of planting using rhizome planter was Rs. 5059.45 ha^{-1} compared Rs. 12500 ha^{-1} by manual method. The per cent of cost and time saved by mechanical planting over manual planting was about 59.52% and 96.57% respectively. The benefit cost ratio of the rhizome planter was 1.47:1. The manufacturing cost of mechanical rhizome planter was Rs.50263/-. Based on the field evaluation of rhizome planter, it is concluded that the developed rhizome planter can perform efficiently and economical for planting operation.

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APPENDIX I

A. Calculation of rhizome sett rate for ginger

Width of planter = 3×0.45 = 1.35 m

Circumference of main drive wheel = $\pi \times 0.57$ = 1.79 m

Area covered per revolution = 1.79×1.35 = $2.41 m^2$

$$\text{Number of revolutions per hectare} = \frac{10000}{2.41}$$

= 4136.58 revolutions

a) For 20 cm rhizome spacing

$$\text{Rhizome rate required for 4136.58 revolutions} = \frac{4136.58 \times 5.3}{20}$$

Rhizome sett required in nos. = 109604

Rhizome sett rate = 1096.20 kg ha^{-1}

b) For 25 cm rhizome spacing

$$\text{Rhizome rate required for 4136.58 revolutions} = \frac{4136.58 \times 5.3}{25}$$

Rhizome sett rate = 876.95 kg ha^{-1}

c) For 30 cm rhizome spacing

$$\text{Rhizome rate required for 4136.58 revolutions} = \frac{4136.58 \times 5.3}{30}$$

Rhizome sett rate = 730.80 kg ha^{-1}

B. Calculation of rhizome sett rate for turmeric

Width of planter = $3 \times 0.45 = 1.35$ m

Circumference of main drive wheel = $\pi \times 0.57 = 1.79$ m

Area covered per revolution = $1.79 \times 1.35 = 2.41\ m^2$

$$\text{Number of revolutions per hectare} = \frac{10000}{2.41}$$

= 4136.58 revolutions

a) For 20 cm rhizome spacing

$$\text{Rhizome rate required for 4136.58 revolutions} = \frac{4136.58 \times 4.98}{20}$$

Rhizome sett rate = 1030.00 kg ha^{-1}

b) For 25 cm rhizome spacing

$$\text{Rhizome rate required for 4136.58 revolutions} = \frac{4136.58 \times 4.98}{25}$$

Rhizome sett rate = 824.00 kg ha^{-1}

c) For 30 cm rhizome spacing

$$\text{Rhizome rate required for 4136.58 revolutions} = \frac{4136.58 \times 4.98}{30}$$

Rhizome sett rate = 686.67 kg ha^{-1}

APPENDIX II

Calculation of manure rate

Width of planter = $3 \times 0.45 = 1.35$ m

Circumference of main drive wheel = $\pi \times 0.57 = 1.8$ m

Area covered per revolution = $1.8 \times 1.8 = 2.41$ m^2

$$\text{Number of revolutions per hectare} = \frac{10000}{2.41}$$

= 4136.58 revolutions

Manure rate per hectare with orifice 1 = Manure falling per revolution (kg) × Revolutions per ha

= 0.21×4136.58

= 868.68 kg ha^{-1}

Manure rate per hectare with orifice 2 = Manure falling per revolution (kg) × Revolutions per ha

= 0.40×4136.58

= 1675.31 kg ha^{-1}

APPENDIX III

Analysis of variance for ginger rhizome planter performance

Table 1 Analysis of variance of average mean spacing of ginger rhizome

Source	SS	DF	MS	F-Value	p-value Prob > F	
Model	382.95	8	47.87	66.72	< 0.0001	significant
A-Forward speed	11.27	2	5.64	7.86	0.0035	
B-Transmission ratio	370.42	2	185.21	258.17	< 0.0001	
AB	1.25	4	0.31	0.44	0.7800	
Pure Error	12.91	18	0.72			
Cor Total	395.86	26				

SD (0.85) Mean (26.98) CV (3.14) R-Square (0.9674)

Table 2 Analysis of variance of missing index of ginger rhizome

Source	SS	DF	MS	F-Value	p-value Prob > F	
Model	796.61	8	99.58	145.58	< 0.0001	significant
A-Forward speed	457.31	2	228.66	334.28	< 0.0001	
B-Transmission ratio	303.71	2	151.86	222.01	< 0.0001	
AB	35.59	4	8.90	13.01	< 0.0001	
Pure Error	12.31	18	0.68			
Cor Total	808.93	26				

SD (0.83) Mean (6.98) CV (11.86) R-Square (0.9848)

Table 3 Analysis of variance of multiple index of ginger rhizome

Source	SS	DF	MS	F-Value	p-value Prob > F	
Model	82.31	8	10.29	23.43	< 0.0001	significant
A-Forward speed	49.77	2	24.88	56.66	< 0.0001	
B-Transmission ratio	27.74	2	13.87	31.58	< 0.0001	
AB	4.80	4	1.20	2.73	0.0613	
Pure Error	7.90	18	0.44			
Cor Total	90.22	26				

SD (0.66) Mean (3.42) CV (19.38) R-Square (0.9124)

Table 4 Analysis of variance of Quality of feed index of ginger rhizome

Source	SS	DF	MS	F-Value	p-value Prob > F	
Model	1349.48	8	168.69	103.51	< 0.0001	significant
A-Forward speed	808.35	2	404.17	248.00	< 0.0001	
B-Transmission ratio	507.73	2	253.87	155.77	< 0.0001	
AB	33.41	4	8.35	5.12	0.0062	
Pure Error	29.33	18	1.63			
Cor Total	1378.82	26				

SD (1.28) Mean (89.61) CV (1.42) R-Square (0.9787)

Table 5 Analysis of variance of precision index of ginger rhizome

Source	SS	DF	MS	F-Value	p-value Prob > F	
Model	206.37	8	25.80	1.68	0.1726	not significant
A-Forward speed	174.70	2	87.35	5.68	0.0123	
B-Transmission ratio	18.85	2	9.43	0.61	0.5529	
AB	12.82	4	3.20	0.21	0.9305	
Pure Error	277.02	18	15.39			
Cor Total	483.39	26				

SD (3.92) Mean (16.26) CV (24.13) R-Square (0.4269)

APPENDIX IV

Analysis of variance turmeric rhizome planter performance

Table 1 Analysis of variance of average mean spacing of turmeric rhizome

Source	SS	DF	MS	F-Value	p-value Prob > F	
Model	422.93	8	52.87	218.25	< 0.0001	significant
A-Forward speed	2.34	2	1.17	4.83	0.0209	
B-Transmission ratio	419.91	2	209.95	866.78	< 0.0001	
AB	0.68	4	0.17	0.70	0.6023	
Pure Error	4.36	18	0.24			
Cor Total	427.29	26				

SD (0.49) Mean (25.59) CV (1.92) R-Square (0.9898)

Table 2 Analysis of variance of miss index of turmeric rhizome

Source	SS	DF	MS	F-Value	p-value Prob > F	
Model	262.26	8	32.78	99.09	< 0.0001	significant
A-Forward speed	223.50	2	111.75	337.79	< 0.0001	
B-Transmission ratio	27.98	2	13.99	42.29	< 0.0001	
AB	10.78	4	2.69	8.14	0.0006	
Pure Error	5.95	18	0.33			
Cor Total	268.22	26				

SD (0.58) Mean (5.48) CV (10.49) R-Square (0.9778)

Table 3 Analysis of variance of multiple index of turmeric rhizome

Source	SS	DF	MS	F-Value	p-value Prob > F	
Model	168.14	8	21.02	84.15	< 0.0001	significant
A-Forward speed	147.06	2	73.53	294.41	< 0.0001	
B-Transmission ratio	14.99	2	7.50	30.02	< 0.0001	
AB	6.09	4	1.52	6.10	0.0028	
Pure Error	4.50	18	0.25			
Cor Total	172.64	26				

SD (0.50) Mean (6.39) CV (7.83) R-Square (0.9740)

Table 4 Analysis of variance of Quality of feed index of turmeric rhizome

Source	SS	DF	MS	F-Value	p-value Prob > F	
Model	832.24	8	104.03	133.34	< 0.0001	significant
A-Forward speed	732.45	2	366.23	469.42	< 0.0001	
B-Transmission ratio	82.49	2	41.24	52.87	< 0.0001	
AB	17.29	4	4.32	5.54	0.0043	
Pure Error	14.04	18	0.78			
Cor Total	846.28	26				

SD (0.88) Mean (88.13) CV (1.00) R-Square (0.9834)

Table 5 Analysis of variance of precision index of turmeric rhizome

Source	SS	DF	SM	F-Value	p-value Prob > F	
Model	118.94	8	14.87	2.04	0.0993	not significant
A-Forward speed	103.59	2	51.80	7.12	0.0053	
B-Transmission ratio	14.86	2	7.43	1.02	0.3802	
AB	0.49	4	0.12	0.017	0.9994	
Pure Error	131.01	18	7.28			
Cor Total	249.95	26				

SD (2.70) Mean (13.09) CV (20.61) R-Square (0.4759)

APPENDIX V

Field capacity and field efficiency

$$\text{Theoretical field capacity} = \frac{\text{Width of operation (m)} \times \text{Travel speed (km hr}^{-1}\text{)}}{10}$$

$$\text{Effective field capacity ha h}^{-1} = \frac{\text{Area covered ha}^{-1}}{\text{Productive time, h} + \text{Non - productive time, h}}$$

$$\text{Field efficiency} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100$$

a) For a forward speed of 0.97 km h^{-1}

$$\text{Theoretical field capacity} = \frac{1.35 \times 0.97}{10}$$

$$= 0.13 \text{ ha h}^{-1}$$

$$\text{Effective field capacity ha h}^{-1} = \frac{20 \times 20}{18.3 + 3.5} \times \frac{60}{10000}$$

$$= 0.11 \text{ ha h}^{-1}$$

$$\text{Field efficiency} = \frac{0.11}{0.13} \times 100$$

$$= 84.00\%$$

b) For a forward speed of 1.37 km h^{-1}

$$\text{Theoretical field capacity} = \frac{1.35 \times 1.37}{10}$$

$$= 0.1849 \text{ ha h}^{-1}$$

$$\text{Effective field capacity ha h}^{-1} = \frac{20 \times 20}{12.98 + 3.5} \times \frac{60}{10000}$$

$$= 0.1456 \text{ ha h}^{-1}$$

$$\text{Field efficiency} = \frac{0.1456}{0.1849} \times 100$$

$$= 78.76\%$$

c) For a forward speed of 0.97 km h^{-1}

$$\text{Theoretical field capacity} = \frac{1.35 \times 1.98}{10}$$

$$= 0.2670 \text{ ha h}^{-1}$$

$$\text{Effective field capacity ha h}^{-1} = \frac{20 \times 20}{9.04 + 3.5} \times \frac{60}{10000}$$

$$= 0.1914 \text{ ha h}^{-1}$$

$$\text{Field efficiency} = \frac{0.1914}{0.2670} \times 100$$

$$= 71.68\%$$

APPENDIX VI

Estimation of cost of the machine

Sl. No.	Material	Qty, nos	Specification, mm	Length, m	Weight, kg m^{-2}	Total weight, kg	Cost, Rs.
I.	**Main frame**						
1.	MS square pipe	1	80×80×4	5.3	8.557	45.35	2231.22
2.	MS iron angle	1	50×50×5	5	3.0	19	934.8
II	**Hitch frame**						
1.	MS Flat	1	75×19	1.6	11.8	18.88	929
2.	MS Flat	1	50×12	2	4.7	9.4	462.50
3.	MS Flat	1	16	0.12	125.6	15	738
4.	Lower hitch pins	2	-	2	-	-	300
III	**Ridger bottom and Furrow opener**						
1.	MS Flat	1	75×25	2.8	14.7	41.16	2025
2.	MS Flat	1	50×19	1.5	7.8	11.77	579
3.	MS Sheet (m^2)	1	5	1	39.2	39.2	1928.64
4.	MS Sheet (m^2)	1	2.8	0.1	22	2.2	108.25
5.	Tynes	4	-	-	-	300 each	1200
IV	**Rhizome and Compost boxes**						
1.	MS sheet (m^2)	1	20 gauge	2	7.151	14.30	703.56
2.	MS sheet (m^2)	1	20 gauge	2.6	7.151	18.60	915.12
V	**Ground wheel**						
1.	MS Flat	1	63×6	4	3	12	590
2.	Spring	1	50 (Dia.)	-	-	-	1500
VI	**Round shafts**						
1.	MS Shaft	1	25	3	3.8	11.4	560.88
2.	MS Shaft	1	16	4.5	1.6	7.2	354.25
VII	**Metering discs**						
1.	Metering Disc	3	30 (Dia.)	-	-	-	2800
2.	MS Sheet	1	3	0.4	24.75	9.9	487

VIII	**Seating unit**						
1.	MS iron angle	1	40×40×5	11	3.3	36.3	1786
2.	MS iron angle	1	25×25×3	8	1.1	8.8	433
3.	Fly wood	1	2440×1220×19	-	-	-	3500
IX	**Clamps**						
1.	MS Flat	12	65×10	5.5	5.1	28.05	1380
2.	MS Flat	6	100×10	3	5.1	15.3	752.75
X	**Sprockets and bevel gears**						
1.	Sprocket	5	18 teeth	-	-	240 each	1200
2.	Sprocket	1	23 teeth	-	-	-	400
3.	Sprocket	1	27 teeth	-	-	-	380
4.	Sprocket	1	36 teeth	-	-	-	800
5	Bevel gears	6	20 teeth	-	-	360 each	2160
6.	Chain	1	12.77mm pitch	5	-	-	2500
7.	Solid bearings	3	25			125 each	375
XI	**PVC Pipes**						
1.	PVC pipe	1	76 mm (Dia.)	1.5	-	-	600
2.	PVC pipe	1	40 mm (Dia.)	3	-	-	500
XII	**Others**						
1.	Nut and bolts(kg)	10	-	-	-	-	1000
2.	Welding rods	-	-	-	-	-	750
3.	Paint	-	-	-	-	-	800
Total cost						**38663.97**	
		Fabrication				**11599.19**	
Total cost of planter						**50263.16**	

APPENDIX VII

Cost of operation of rhizome planter

1. Tractor

Cost of tractor, C = Rs. 5,00,000

Expected life, L = 10 years

Salvage value, S = 10% of C = Rs. 50,000

Annual operating hours, H = 1000 hrs

Annual interest or interest on Investment, I = 10%

i. Fixed cost

a) $\text{Depreciation} = \frac{C-S}{L \times H}$

Where,

C = Total cost of machine

S = Salvage value 10% of C

H = Annual use in hours

$$\text{Depreciation} = \frac{500000-50000}{10 \times 1000}$$

= Rs. 45.00 h^{-1}

b) $\text{Interest} = \frac{C+S}{2} \times \frac{i}{H}$

Where,

i = % rate of interest per year

$$\text{Interest} = \frac{500000+50000}{2 \times 1000} \times \frac{10}{100}$$

=Rs. 27.5 h^{-1}

c) Housing cost (1% of the initial cost of tractor)

$$= \frac{500000}{1000} \times \frac{1}{100}$$

= Rs. 5 h^{-1}

d) Insurance and taxes (2% of the initial cost of tractor)

$$= \frac{500000}{1000} \times \frac{2}{100}$$

$= 10\ h^{-1}$

Total fixed cost = a + b+ c + d = Rs. 87.5h^{-1}

ii. Variable cost

a) Average diesel consumption = 4.1 lit h^{-1}

Fuel cost (4.1×Rs. 64.5 lit^{-1}) = Rs. 264.45 lit^{-1}

b) Lubrication cost (30% of fuel cost)

$$= 264.45 \times \frac{30}{100}$$

= Rs. 79.33 h^{-1}

c) Repair and maintenance cost (10% of initial cost)

$$= \frac{500000}{1000} \times \frac{10}{100}$$

= Rs. 30 h^{-1}

d) Operator wages (Rs. 750 per day of 8 hours)

$$= \frac{750}{8} = 93.75\ h^{-1}$$

Total variable cost = a + b+ c + d = Rs. 467.28 h^{-1}

Total operating cost of tractor = Fixed cost + Variable cost

= 87.5 + 467.28

= Rs. 554.78 h^{-1}

2. Rhizome planter

Cost of rhizome planter, C = Rs. 50263

Expected life, L = 10 years

Salvage value, S = 10% of C = Rs. 5026.3

Annual operating hours, H = 200 hrs

Annual interest, i = 10%

i. Fixed cost

a) $$\text{Depreciation} = \frac{C - S}{L \times H}$$

Where,

C = Total cost of machine

S = Salvage value 10% of C

H = Annual use in hours

$$\text{Depreciation} = \frac{50263 - 5026.3}{10 \times 200}$$

= Rs. 22.61 h^{-1}

b) $$\text{Interest} = \frac{C + S}{2} \times \frac{i}{H}$$

Where,

i = % rate of interest per year

$$\text{Interest} = \frac{50263 + 5026.3}{2 \times 200} \times \frac{10}{100}$$

=Rs. 13.82 h^{-1}

c) Housing cost (1% of the initial cost of tractor)

$$= \frac{50263}{200} \times \frac{1}{100}$$

= Rs. 2.51 h^{-1}

Total fixed cost = a + b+ c = Rs. 38.94 h^{-1}

ii. Variable cost

a) Repair and maintenance cost (5% of initial cost)

$$= \frac{50263}{200} \times \frac{5}{100}$$

= Rs. 12.56 h^{-1}

b) Operator wages (3 labours Rs. 350 per day of 8 hours)

$$= \frac{1050}{8} = 131.25\ h^{-1}$$

Total variable cost = a + b = Rs. 143.81 h^{-1}

Total operating cost of tractor = Fixed cost + Variable cost

= 38.94 + 143.81

= Rs. 182.75 h^{-1}

Total operating cost of tractor and rhizome planter = Tractor cost + Planter cost

= 554.78 + 182.75

= Rs. 737.53 h^{-1}

Theoretical field capacity of planter = 0.1849

Actual field capacity of planter = 0.1456

Field efficiency of rhizome planter = 78.76 %

Time required to cover 1 ha, h $= \frac{1}{AFC}$

$$= \frac{1}{0.1456}$$

= 6.86 h ha^{-1}

Cost of operation of rhizome planter = 6.86 × 737.53 = Rs. 5059.45 ha^{-1}

Cost of planting by traditional method (manual planting)

Labour requirement = 200 man h ha^{-1}

Cost of planting Rs. 500 per labour $= \frac{200}{8} \times 500$

= Rs. 12500 ha^{-1}

Cost saved over manual planting = 12500 - 5059.45

= 7440.55 ha^{-1}

Cost saved over manual planting (%) $= \frac{7440.55}{12500} \times 100 = 59.52\%$

Time saved over manual planting = 200 – 6.86

= 193.14 h ha^{-1}

Time saved over manual planting (%) $= \frac{193.14}{200} \times 100 = 96.57\%$

3. Benefit-cost-ratio

Benefit cost per hectare = Cost of manual planting - Cost of machine planting

= Rs. 12500 – 5059.45

= Rs. 7440.55

Therefore,

$$\text{Benefit cost ratio} = \frac{\text{Benefit cost}}{\text{Cost of machine planting}}$$

$$\text{Benefit cost ratio} = \frac{7740.55}{5059.45} = 1.47$$

ABSTRACT

Ginger (Zingiber Officinale Roscoe) and Turmeric (Curcuma longa L.) are the oldest rhizome crops widely cultivated in India. These crops provide excellent opportunities in raising the income of farmers. This also provides higher productivity and offers great scope for value addition. At present, it is observed that the farmers in the state had faced problems in ginger and turmeric planting due to lack of labour shortage. Manual planting consumes more time and labour. Therefore, a mechanical rhizome planter is required for planting ginger and turmeric. Therefore, the present study was undertaken to design, develop and evaluate the performance of a rhizome planter for ginger and turmeric. A tractor drawn semi-automatic horizontal disc planter was developed and field tested. The rhizome planter was designed to suit various soil type and conditions to perform several functions simultaneously by opening the furrows, application of manure and planting of rhizomes and covering of rhizomes by soil and forming ridges in single pass.

The field evaluation of rhizome planter was tested for different forward speeds and transmission ratios. Performance indices such as missing index (I_{miss}), rhizome multiple index (I_{multi}), quality of feed index (I_{qf}), precision index (I_p) and rhizome spacing (I_s) were used to evaluate performance of rhizome planter. The mean spacing for ginger and turmeric was ranged from 21.66 to 32.63 cm and 20.53 to 31.13 cm respectively. The optimum performance for planting ginger and turmeric were at a forward speed of 0.97 km hr^{-1} and transmission ratio of 1:1.25. The average field capacity and efficiency was 0.14 ha hr^{-1} and 78.76%. The savings in cost and time for mechanical planting was about 59.52% and 96.57% compared to manure planting. Based on the performance evaluation results, it is concluded that the developed rhizome planter is economical and efficient for rhizome planting.