DEVELOPMENT AND TESTING OF A TRACTOR OPERATED COCONUT BASIN LISTER CUM FERTILIZER APPLICATOR

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THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY, TAVANUR - 679 573

KERALA, INDIA

2023

DECLARATION

I, hereby declare that this thesis entitled **"DEVELOPMENT AND TESTING OF A TRACTOR OPERATED COCONUT BASIN LISTER CUM FERTILIZER APPLICATOR"** 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, associate ship, fellowship or other similar title of any other university or Society.

Place: Tavanur

Date: 4/2/23

JINUKALA SRINIVAS

(2018-28-011)

CERTIFICATE

Certified that this thesis entitled **"DEVELOPMENT AND TESING OF A TRACTOR OPERATED COCONUT BASIN LISTER CUM FERTILIZER APPLICATOR"** is a record of research work done independently by **Er. JINUKALA SRINIVAS (2018-28-011)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to him.

Place: Tavanur

Date: 30.1.23

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Major Advisor, Advisory Committee

Dean of Faculty (Agrl. Engg.)

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JINUKALA SRINIVAS

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SYMBOLS AND ABBREVIATIONS

Symbols		Abbreviations
Anon.	:	Anonymous
GVA	:	Gross Value Added
&	:	And
Rs.	:	Rupees
etc.	:	et cetera
ha	:	Hectare
viz.	:	Namely
N	:	Nitrogen
P	:	Phosphorous
K	:	Potassium
deg.	:	Degree
IAEA	:	International Atomic Energy Agency
DA&FW	:	Department of agriculture and farmers welfare
CDB	:	Coconut development board
IFA	:	International Fertilizer Industry Association
DEM	:	Discrete Element Method
DAP	:	Di-ammonium phosphate
SSP	:	Single super phosphate
CAD	:	Computer aided design
3D	:	Three dimensional

°C	:	Degree centigrade
CI	:	Cone index
d.b	:	dry basis
et al.	:	and others
×	:	Multiplication
±	:	Plus or minus
Fig.	:	Figure
rev	:	Revolution
mm	:	Millimeter
mm^2	:	Square millimeter
mm^3	:	Cubic millimeter
Cm	:	Centimeter
cm^2	:	Square centimeter
cm^3	:	Cubic centimeter
M	:	Meter
m^2	:	Square meter
m^3	:	Cubic meter
$m^3\ h^{-1}$	:	Cubic meter per hour
m ha	:	Million hectares
$kN\ m^{-2}$	:	Kilo newton per square meter
g	:	Gram
$g\ cm^{-2}$	:	Gram per square centimeter
$g\ cm^{-3}$	:	Gram per cubic centimeter

W	:	Watt
kW	:	Kilo watt
hp	:	Horse power
h	:	Hour
ha h^{-1}		Hectare per hour
kg	:	Kilogram
kg cm	:	Kilogram centimeter
kg cm^{-2}	:	Kilogram per square centimeter
kg ha^{-1}	:	Kilogram per hectare
kg m	:	Kilogram meter
kg mm	:	Kilogram millimeter
kg m^{-3}	:	Kilogram per cubic meter
kgf	:	Kilogram force
km h^{-1}	:	Kilometer per hour
kN	:	Kilo newton
kN m^{2}	:	Kilo newton per square meter
L	:	Litre
l h^{-1}	:	Litre per hour
l ha^{-1}	:	Litre per hectare
l m^{-3}	:	Litre per cubic meter
MJ	:	Mega joule
MJ h^{-1}	:	Mega joule per hour
MJ ha^{-1}	:	Mega joule per hectare

CODH	:	Combined offset disc harrow
ODH	:	Offset disc harrow
V	:	Volume
M	:	Meter
$m\ min^{-1}$	:	Meter per minute
$m\ s^{-1}$	:	meter per second
N	:	Newton
$N\ cm^{-2}$	:	Newton per square centimeter
$N\ s^{2}\ m^{-4}$	:	Newton square second per four power meter
$N\ m^{-1}$	:	Newton per meter
N m	:	Newton meter
P.T.O	:	Power Take Off
$N\ m^{-2}$	:	Newton per square meter
N m	:	Newton meter
N mm	:	Newton millimeter
$N\ mm^{-1}$	:	Newton per millimeter
$N\ mm^{-2}$	:	Newton per square millimeter
rpm	:	Revolutions per minute
rps	:	Revolutions per second
Hz	:	Hertz
$kg\ mm^{-1}$	:	Kilogram per millimeter
$kg\ mm^{-2}$	:	Kilogram per square millimeter
$kg\ mm^{-3}$	:	Kilogram per cubic millimeter

rad s^{-1}	:	Radian per second
kg ha^{-1} $dose^{-1}$ $year^{-1}$	:	Kilogram per hectare per dose per year
kg $palm^{-1}$ $dose^{-1}$ $year^{-1}$		Kilogram per palm per dose per year
Rs. ha^{-1}	:	Rupees per hectare
Rs. h^{-1}	:	Rupees per hour
SD	:	Standard deviation
CV	:	Coefficient of variation
C_U	:	Coefficient of uniformity
S.No.	:	Serial Number
w.r.t	:	With Respect To
A	:	Alpha
θ	:	Theta
µ	:	Mue
Π	:	Pi
ρ	:	Rho
η	:	Efficiency
MS	:	Mild steel
GI	:	Galvanized iron
IS	:	Indian standards
FMPE	:	Farm Machinery and Power Engineering
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology

INTRODUCTION

CHAPTER I

INTRODUCTION

1.1 Indian Agriculture

Agriculture plays an important role in the Indian economy. The total workforce involved in agriculture and allied sector activities in the country is 54.6 per cent. As per the land use statistics 2018-19, total geographical area of the country is 328.7 million hectares, of which 139.3 million hectares is the net sown area and 197.3 million hectares is the gross cropped area with a cropping intensity of 141.6 per cent while the net area sown and the net irrigated area works out to 42.4 per cent of the total geographical area and 71.6 million hectares respectively (DA&FW, 2021). As per the estimates of national income released by the Central Statistics Office, Ministry of Statistics and Programme Implementation; agriculture and allied sectors contributed approximately 17.8 per cent to Gross Value Added (GVA) at current prices during 2019-20. The GVA raised by 4.0 per cent in 2019-20 when compared with 2018-19.

The wide variable climate and soil of India is highly favourable for growing a range of horticultural crops such as vegetables, fruits, tuber crops, mushroom, ornamental crops, medicinal and aromatic plants, spices and plantation crops like coconut, cashew, cocoa, tea, coffee, rubber etc. The Indian topography and agro-climate are well suited to horticulture crops and it is an ideal choice of cultivation for small farmers to achieve sustainability. The plantation crops fall under the category of horticulture crops and constitute a wide range of crops such as coconut, areca nut, oil palm, cashew, tea, coffee, rubber, cocoa etc. The area coverage of plantation crops as compared to food grains is comparatively low and they are mostly confined to small holdings. However, they play a predominant role in domestic requirements, export revenue creation, employment generation and poverty mitigation programmes notably in rural areas.

1.2 Coconut cultivation in India - an overview

India is one of the largest coconuts producing country in the world and it contributes 34.73 per cent to the global production. Coconut (*Cocos nucifera*) plays a significant role in the economy of the country and about 12 million people depend on coconut cultivation, processing and related activities. Coconut is used in many ways such as raw form for edible and religious purposes, oil extraction by milling of copra, tender coconut form, edible copra production, desiccated coconut, cream, milk powder, coconut shell-based products etc. The coir pith obtained from coconut husk processing is made into brick like structure and used as soil supplement for horticultural plants especially in greenhouses. As per the all India estimate for the year 2019-20, the area and production of coconut in the country is 2.17 million hectares and 20,308.70 million nuts respectively with a productivity of 9,345 nuts per hectare. The area coverage of coconut in India for the year 2019-20 increased by 4.06 per cent but the production and productivity decreased by 8.38 and 11.95 per cent respectively than the previous five years from 2015-16 to 2019-20 (CDB, 2020).

Table 1.1 Area, production and productivity of coconut in Kerala

Year	Area (`000 ha)	Production (Million nuts)	Productivity (Nuts per hectare)
2015-16	770.62	7429.39	9641
2016-17	770.79	7448.65	9664
2017-18	807.13	8452.05	10472
2018-19	760.95	7683.55	10097
2019-20	760.68	6980.30	9175

Source: Coconut Development Board Statistics, Ministry of Agriculture and Farmers Welfare, Govt. of India

The coconut growing states and union territories in India are Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Orissa, West Bengal, Maharashtra, Goa, Assam, Gujarat, Bihar, Tripura, Chhattisgarh, Nagaland, Telangana, Arunachal Pradesh, Mizoram, Pondicherry, Lakshadweep and Andaman and Nicobar Islands. The four southern states namely, Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh account for 89.66 per cent of the production and 88.97 per cent of the area of coconut in the country. Kerala leads the charts in coconut production with largest share of

34.37 per cent in the country. Andhra Pradesh has the highest productivity of 13,969 nuts per hectare for the year 2019-20 in India. The production of coconut for the year 2019-20 in Kerala was 6980.30 million nuts from an area of 0.76 million hectares with a productivity level of 9,175 nuts per hectare. The area, production and productivity of coconut in Kerala for the year 2019-20 declined by 1.28, 6.04 and 4.83 per cent over previous five years from 2015-16 to 2019-20.

1.2 Basin Listing and Fertilizer Application

One of the major farm operations in coconut production is basin listing around the palm. The basin listing operation is performed to form a basin around coconut palm at about 1.8 m radius for holding the water in a confined space and for its easy uptake. Conventionally basins are formed manually around the palm using spades, crowbars and diggers. A few research works on mechanical methods for basin listing *viz.,* power tiller operated basin listers were carried out in research stations of Kerala and those models had the drawbacks of irregular basin and bund formation, lower depth of operation, time consuming, expensive, less ease of operation, trunk damage and involved drudgery. No research works were reported for tractor operated basin listers for coconut.

Another farm operation for coconut is the fertilizer application for favourable growth. The fertilizer is generally applied in circular basins at a radius of 1.8 m from base of the palm at a depth of 10 cm. The fertilizer rates to be applied for a coconut palm are; 0.50 kg of N, 0.32 kg of P_2O_5 and 1.20 kg of K_2O for nutrient management (KAU, 2016). The fertilizer application is performed manually by digging ditch around coconut palm, dropping fertilizer and covering the ditch with soil by using crowbars, diggers, spades etc. This operation involves drudgery, time consuming, expensive, lower precision and with fertilizer losses. There exists no specific machines available for fertilizer application to coconut palms.

The total cost of cultivation for coconut production in Kerala escalated by 28.94 per cent over last five years and it was about Rs.1,73,850 per hectare for the year 2018-19. Of the total cost of cultivation in Kerala for the year 2018-19, labour and fertilizer charges were Rs.89,123 per hectare and it surged by 26.34 per cent over last five years. Hence, labour and fertilizer charges contribute the highest share of

51.26 per cent in the total cost of cultivation of coconut production in Kerala for the year 2018-19 (Indiastat, 2020). High labour charges, shortage of labour, lack of farm machinery, high cost of cultivation, fragmented land holdings, homestead nature of cultivation, incidence of pests and diseases, lack of adoption of scientific cultivation practices and low returns from coconut production are the major causes for decreased production and productivity of coconut in Kerala.

As there is a labour shortage and hike in labour and fertilizer charges, it is high time to introduce innovative machines for basin listing and fertilizer application operations. Hence a research work was undertaken to develop a tractor operated coconut basin lister cum fertilizer applicator with following objectives.

1. To study the soil, crop and fertilizer parameters for designing coconut basin lister cum fertilizer applicator
2. To design suitable metering mechanism for fertilizer applicator
3. To develop a tractor operated coconut basin lister cum fertilizer applicator
4. To test and optimize machine parameters of the developed coconut basin lister cum fertilizer applicator

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

This chapter illustrates a comprehensive review of relevant soil, crop and machine parameters affecting the design of tractor operated basin lister cum fertilizer applicator. Power requirement and its transmission system to determine the power range of tractor and working components of soil cutting and fertilizer metering units were also reviewed. The previous research works of developed basin listers and fertilizer applicators are reviewed for obtaining the best designed machine. The performance evaluation parameters of soil tilling and fertilizer applicator machines were examined for the optimization of machine parameters through experimental trial of the machine. The above aspects of the study under investigation are briefed in this chapter under the following headings.

i. Soil parameters
ii. Crop parameters
iii. Soil-tool interaction dynamics of rotary tillage
iv. Development and testing of basin listers
v. Fertilizer properties
vi. Development and testing of fertilizer applicators

2.1 SOIL PARAMETERS

Sahu and Raheman (2006) studied the draft requirements of tillage implement combinations *viz.,* single disk, mould board plough with disk gang and cultivator with disk gang tillage implements at different depths of 50, 75 and 100 mm, wet bulk densities in the range of 1270 to 1850 kg m^{-3} and forward speeds of 1.2, 2.2, 3.2 and 4.2 km h^{-1}. It was reported that the draft of the implements increased with increase in soil compaction, depth and speed of operation.

Adeniran and Babatunde (2010) investigated the soil properties affecting the tillage of soil. A cone penetrometer and vane shear apparatus were used to determine the cone index and force required to shear the soil at different moisture contents. The study revealed that the cone index and shear strength of the soil increased with depth and decreased with increase in moisture content. It was reported that the high moisture content reduced the soil cohesion. The angle of internal friction of soil was observed as 37.9 deg. The soil cohesion values of 112, 62, 38, 30 and 12 kN m^{-2} were obtained at moisture contents of 0, 5, 10, 15 and 20 per cent respectively. The moisture content of 10 to 15 per cent was ideal for soil tillage and the critical moisture content was found out as 23.72 per cent. It was suggested that the soil moisture content beyond critical level needs to be drained before the tillage operation.

Kumar *et al.* (2012) studied soil cone index in relation to soil texture, moisture content and bulk density for no-tillage and conventional tillage. The results showed that for both no-tillage and conventional tillage, values of cone index decreased with the increase in clay fraction and increased with the increase in sand and silt fractions of soil. Similarly, higher bulk density and greater soil depth resulted in higher cone index while higher moisture content reduced cone index. The regression equations had good agreement with the field measurements, indicated by the relative errors of 20 per cent or lower.

Ojomo *et al.* (2012) studied the effect of soil moisture contents *viz.*, 10, 13 and 16 per cent and types of cutting blades *viz.*, flat, spike tooth and curved blades on the machine efficiency, quality performance efficiency, percentage of uprooted weeds and partially uprooted weeds. The Duncan Multiple Range Test revealed that the soil moisture content and type of cutting blades statistically affected the machine performance at 5 per cent level of significance. The spike tooth blade gave the best machine efficiency of 94 per cent, quality performance efficiency of 84 per cent and least percentage of partially uprooted weeds of 1.8 per cent at 16 per cent soil moisture content.

Thorat (2013) studied soil properties for the design and development of ridge profile weeder. Soil parameters such as moisture content, bulk density and soil resistance were studied. The interactions between these parameters directly affected the performance of weeding system which were measured in terms of weeding efficiency, plant damage percentage and power requirement to operate the machine under field conditions. The soil bulk density measured were 1591, 1452 and 1370 kg m^{-3} at three different levels of soil moisture content of 15.26, 12.42 and 9.44 per cent respectively. Similarly, soil resistances measured were 18.81, 20.98 and 22.87 N cm^{-2} at 15.26, 12.42 and 9.44 per cent soil moisture content respectively. The average value of soil resistance was found out as 20.89 N cm^{-2}.

2.2 CROP PARAMETERS

IAEA (1975) conducted a study to analyze the root activity patterns, competition between palms and fertilizer placement for coconut palms. The experiments were carried out in wet and dry season on 50 year old coconut palms planted at a spacing of 7.8×8.3 m on a well-drained sandy loam soil type. At 10 cm depth, root activity was highest at 1.0 and 0.5 m distance for all four sampling dates with 10, 20, 30 and 40 day intervals in the wet and dry season respectively. The experiment showed that fertilizer application near the coconut palm lead to more efficient use than the midway placement. The fertilizer application in a larger area of 0.8 m^2 within the zone of highest root density lead to better utilization of fertilizer than application in a smaller area.

Maheswarappa *et al.* (2000) studied the root distribution pattern of coconut palms in sandy soils. The soil of experimental field was composed of 99.1 per cent sand, 0.2 per cent silt and 0.7 per cent clay. Two age groups of palms *viz.*, pre-bearing period of 6 years and adult palms of 26 years were selected. A sector of one-sixteenth of full circle to a distance of 4.0 m at a depth of 1.5 m was separated out by excavating the soil at three sectors around coconut palm. From the study it was concluded that effective root zone for efficient management of agronomic inputs lies within 1.0 m radius for 6 year old coconut palms and within 2.0 m radius for 26 year old coconut palms cultivated in sandy soils.

2.3 SOIL-TOOL INTERACTION DYNAMICS OF ROTARY TILLAGE

Shibusawa (1993) studied reverse rotational rotary tiller dynamics with scoop type of rotary blade (J-shaped) for reducing the power requirement in deep tillage. Increase in operating power generally resulted when a large amount of tilled soil was re-tilled in the zone of blade rotation. A backward throwing model of soil by the blade was developed on the basis of trochoidal motion of the blade and sliding motion of the soil over a scoop-surface on the horizontal portion of the blade of tilled soil. The throwing model estimated the conditions for avoiding re-tillage by changing the direction of rotation and shape of scoop-surface. The throwing model was applied to the design of the shape of the scoop-surface which enabled maximum backward throwing of the soil sufficient to avoid re-tilling. At tilling depths greater than 300 mm, reverse rotation with the new shaped blades brought about a tillage power reduction by about a half compared to forward or reverse rotation with conventional blades.

Takashi and Sakae (2002) investigated soil cutting and clod crack formation process during reverse-rotational rotary tillage. Tillage resistance showed a higher cross-correlation between sequential rotations within a certain distance of tilling. Forward distance of untilled soil that was disturbed by tillage blade was 36.4 mm. Fluctuation in tillage resistance frequencies of a single blade was nearly equal to predicted occurrence of crack intervals on the tilled clod’s surface and it was 120 Hz. When these frequencies were translated into distance along the trochoid trajectory of cutting blade edge, they were same as the length of clods tilled by reverse-rotational rotary tiller. These analytical results were utilized for the active occurrence of cracks with natural frequency of blade and operating condition of reverse-rotational rotary tiller.

Lee *et al.* (2003) determined the strip tillage characteristics of rotary tiller blades in a laboratory soil bin. Two general purpose rotary blades used with tractors and power tillers, and a levelling rotary blade for tractor were used for study. Rotation in the opposite direction to travel which cut soil upwards resulted in soil scatter out of the seeding furrow. Rotation in the direction opposite to travel cut soil upwards which inturn scatter the soil out of the seeding furrow. The ratio of soil breaking was 11.6 per cent during the upward cut process and 5.5 per cent during the downward cut process. The rotor shaft with four rotary blades had the lowest torque variation and torque requirement and ratio of soil breaking was 24.4 per cent. The results showed that strip tillage technique by the power tiller blade with a downward cut process could be effectively used for a dryland direct rice seeder.

Salokhe and Ramalingam (2003) conducted performance evaluation of rotary tiller equipped with conventional C-type blades and reverse rotary tiller with new type of blades at tractor forward speeds of 1.0, 1.5 and 2.0 km h^{-1}. The results indicated that the PTO power consumption was less for reverse-rotary tiller compared to the conventional rotary tiller for all passes and forward speeds. For both rotary tillers, power consumption decreased as the number of passes increased, whereas power consumption increased when the forward speed was increased. At all forward speeds, the power consumption was the highest during the first pass and lowest during the third pass. The reverse rotary tiller consumed about 34 per cent less PTO power than conventional rotary tiller.

Ajay and Surendra (2004) studied the effect of various parameters on field performance of rotary tiller. L-type and C-type of blades were used for field evaluation. The rear shield position was adjusted at full down and full up positions and at two different rotor speeds of 185 and 210 rpm. It was found that the draft for L-shaped and C-shaped blades decreased from163 to 63 kgf as the rotor speed increased from 185 to 210 rpm for the shield kept in the lowered position. Rotary power requirement of C-shaped blades was 19 per cent less as compared to L-shaped blades. Soil break-up resulting from the action of L-shaped and C-shaped blades was the lowest at rotor speed of 210 rpm. The extent of residue incorporation was the maximum of 99 per cent while operating the rotavator with the shield in lowered position for both types of blades and at both rotor speeds studied.

Celik and Altikat (2008) analyzed rotary tiller blade paths to simulate the distribution of soil slice size. A program was written in the Lisp language for AutoCAD to draw blade paths based on the number of blades on one side of a flange, the rotor radius, tractor forward speed, and rotor rotational speed. Slice area on the drawn paths was calculated using the AREA command of AutoCAD. Data indicated that soil slice size increased as rotor radius and tractor forward speed increased and the number of blades on one side of a flange decreased. The maximum volume of soil was observed at rotor speed of 190 rpm and decreased further. The number of cuts of a soil slice increased with the number of blades on one side of a flange, rotor radius, soil fragmentation and rotor rotational speed while the size of each part decreased.

Chertkiattipol *et al.* (2008) investigated the effect of shape of prototype rotary blades on the performance of rotary power tiller. Three sets of rotors, i.e. 14-blade rotor of the Japanese C-shape blade having 4.5 cm tilling width, 14-blade rotor of the prototype rotary blade having 4.5 cm tilling width and 10-blade rotor of the prototype rotary blade having 6.5 cm tilling width were chosen to test in a dryland field condition. The soil moisture content of 16.04 per cent and dry bulk density of 1.51 g cm^{-3} at different rotational speeds of 300, 350 and 400 rpm at one and two tilling passes were other test conditions. For all rotors, experimental results revealed that the mean soil clod diameter decreased and soil inversion increased with rotational speed of the rotor. The mean soil clod diameter decreased at pass 2 and soil inversion during pass 2 was higher than pass 1. The three sets of rotors showed no significant difference on mean soil clod diameter and soil inversion.

Davut and Kamil (2008) investigated the effect of velocity ratios of a forward rotational rotary tiller on the distribution of wheat stubbles incorporated into soil layers at soil depths of 0-5, 5-10 and 10-15 cm. Velocity ratios of the rotary tiller were maintained at 6.01, 7.51, 9.39 and 11.77. Results showed that there were no significant differences among velocity ratios and soil depths in terms of stubble mass. This indicated that there was no advantage of increasing velocity ratios of rotary tiller to bury more stubble mass into the soil since fuel consumption of the tractor and the power requirement of the rotary tiller increased. There was significant difference among the soil depths in terms of distribution of stubble length. Longer stubbles accumulated at soil depth of 0-5 cm whereas shorter stubbles buried at 5-15 cm soil depths regardless of velocity ratio.

Sahay *et al.* (2009) designed and developed a novel power tiller operated oscillatory tillage implement for reduced draught. The study included modification of transmission system of the power tiller to provide required frequency of 9-13 Hz, designing a new rotary shaft to impart oscillation and provided required amplitude of 15 to 35 mm. The oscillatory tillage implement having a tool width of 25 cm operated up to a depth of 15.3 cm in dry, untilled field conditions. The implement was also tested up to 7.4 cm depth in non-oscillatory mode of operation. The volume of soil handled per unit time, fuel consumption and tillage performance index were found out as 94.88 m^3 h^{-1}, 2.70 l h^{-1} and 2.99 respectively with the prototype as compared with the implement working in non-oscillatory mode of operation.

Cakmak *et al.* (2010) conducted performance assessment of developed rotary tiller fitted with pneumatic seeder which can perform tillage and cereal seeding in one pass. The seeding uniformity of developed machine was examined in laboratory conditions and compared with conventional seeding machine in field tests for forward speeds of 1.0, 1.5, and 2.0 km h^{-1} and at field slopes of 5, 10 and 15 per cent. The results inferred that developed machine had similar seedling emergence rates of 80 and 82 per cent with conventional, while allowing reduced tillage for cereal seeding along with fuel saving when compared to conventional seeding system. The fuel consumption of developed machine was 16.16 l ha^{-1}. There was no statistical difference among two systems regarding plant emergence, shoots ratios, grain yield, stalk to grain ratio, and number of plants per m^2.

Kazuaki *et al.* (2013) assessed the leveling performance of a rotary tiller by developing a rotary tillage model that can estimate pile height of tilled soil with the discrete element method. The comparison between the pile height in the experiment and those predicted by the model revealed that the model was able to predict the pile shape and height of tilled soil. The coefficient of root mean square value of pile height distribution was 0.799. It was also indicated that this model was capable of predicting the effect of mechanical specification of rotary tiller *viz.*, tilling width, blade arrangement and shape on the flatness of soil after tillage.

Abdul *et al.* (2014) evaluated strip-tillage seeding of modified rotary cultivators fitted to two-wheeled tractors. The effect of three blade geometries *viz.*, conventional, half-width and straight at four rotary speeds of 125, 250, 375, and 500 rpm on the furrow seedbed parameters was investigated. Analysis of high-speed video showed that the straight blade reduced the soil carrying and throwing. The level of soil pulverization increased with rotary speed, but was not affected by blade geometry. Each of the blades produced different furrow shapes with a higher furrow volume tilled by the conventional and straight blades as compared to that by the half-width blades. Based on high backfill and large furrow volume, the straight blade was found better for rotary strip-tillage.

Prasad *et al.* (2014) studied the design parameters of rotavator. They concluded that L-shaped blades were better than C or J shaped blades in trashy conditions as these were more effective in killing and they do not pulverize the soil as much. At forward rotation of the rotary tiller, power consumption decreased 10-15 per cent in comparison with reverse rotation. When the rotor blades cutting upwards, the tilled soil was scattered out of the seeding furrow and seedbed was not formed. Decreasing velocity ratio by increasing forward travel speed, results in an increase in the power requirement but a reduction in the specific power. Increasing velocity ratio results in a greater value of ratio between cutting area and the volume of the soil slice cut.

Matin *et al.* (2015) optimized the blade geometry and operational settings by investigating the effect of three blade geometries *viz.*, conventional, half-width and straight at four rotary speeds of 125, 250, 375 and 500 rpm respectively on torque, power and energy characteristics. A single row rotary tiller was tested in soil bin to analyze the blade motion. It revealed that the peak torque occurred at a higher blade penetration depth as the speed increased indicating transformation of the peak torque requirement due to initial soil failure at a low speed to final soil cutting and throwing at a high speed. The straight blade design required the least torque, average power, peak power, specific energy and effective specific energy at 375 to 500 rpm. The straight blade saved 20 to 25 per cent power when compared with the conventional and half-width blades at 500 rpm. Although average power, peak power and specific energy requirements increased with the rotary speed for all the blades with a steep rise over 375 rpm, the effective specific energy requirement remained almost unchanged for the straight blade indicating its high effectiveness for strip-tillage operations.

Ramesh *et al.* (2015) undertaken a study to examine the influence of λ-ratio, depth of cut with an offset rotavator in different orchards fields such as mango, guava, and sapota. The minimum draft in mango, guava and sapota orchard were found to be 74.36, 49.93 and 85.45 kgf at λ-ratio of 2.1 and depth of cut of 5 cm respectively. The minimum fuel consumption for mango, guava and sapota orchards were found to be 3.23 l h^{-1} at λ-ratio of 1.3 and depth of cut of 5 cm respectively. The minimum power consumption for mango, guava and Sapota orchards were found 2.65, 2.68 and 3.19 kW at λ-ratio of 1.3 and depth of cut of 5 cm respectively. The maximum field efficiency in mango orchards was found to be 98.09 per cent at λ-ratio of 2.1 and depth of cut 5 cm respectively. The results indicated that draft, fuel consumption, power consumption and field efficiency increased with λ-ratio and depth of cut.

Ramesh *et al.* (2016) evaluated the performance of rotavator at different soil moisture contents under actual field conditions. The moisture contents of 11.27, 17.04 and 22.87 per cent were recorded in different field conditions. The rear shield position adjustments at full down, full up and middle positions and tractor forward speeds of 2.5, 3 and 3.5 km h^{-1} and depth of cut of 5, 8 and 12 cm respectively were considered for field trials. The minimum mean mass diameter of 1.2 mm was attained at forward speed of 3 km h^{-1}, depth of cut of 12 cm and middle shield position for moisture content of 17.04 per cent. The minimum fuel consumption was 5 l h^{-1} at forward speed of 2.5 km h^{-1}, depth of cut 12cm and up shield position for moisture content of 11.27 per cent. The minimum draft was found as 140 kgf at forward speed of 2.5 km h^{-1}, depth of cut of 5 cm and up-shield position for moisture content of 11.27 per cent. The draft, fuel consumption and power consumption increased with forward speed from 2.5 to 3.5 km h^{-1} and depth of cut from 5 to 12 cm respectively.

Rahul *et al.* (2017) investigated the effect of different combinations of primary and secondary tillage implement in terms of field capacity, fuel consumption, actual field capacity, operating speed, field performance index and energy requirement for seed bed preparation. The combination of ploughing and cultivating, ploughing and disc harrowing, ploughing and rotavator, single operation of rotavator and double operation of rotavator were tested in an area of 60×20 m^2. The maximum and minimum field performance indices were found with ploughing and rotavator and ploughing and disc harrow combinations respectively. The maximum and minimum mean weight diameter were found out as 14.54 and 4.5 mm with mould board plough and ploughing and rotavator respectively. The maximum and minimum energy requirements were 783.63 and 183.93 MJ ha^{-1} with ploughing and disc harrow and rotavator single pass respectively.

Sharad *et al.* (2017) evaluated the performance of modified offset rotavator in guava orchard for intercultural operation. Draft for the L-shaped blades increased from 1203.4 to 1841.4 N as the forward speed increased from 2 to 3 km h^{-1} with increase in depth of cut from 80 to 120 mm for the shield kept in lowered position and fuel consumption was higher at 9.93 l h^{-1} for the forward speed of 3.0 km h^{-1} and depth of cut of 120 mm. The mean mass diameter of soil increased from 1.05 to 1.95 mm as the forward speed increased from 2.0 to 3.0 km h^{-1}. The residue incorporation was maximum at 97.30 per cent for the forward speed of 2.0 km h^{-1} and depth of cut of 120 mm. The field performance index was 88.28 per cent for the forward speed of 3.0 km h^{-1}. The minimum area uncovered near the girth was reported as 0.143 m^2 at higher girth of 0.48 m. The plant injury at forward speed of 3.0 km h^{-1} was found out as 50 per cent in the form of scratch on the girth due to impact of sensing assembly.

Sharad and Rajnarayan (2017) evaluated the performance of modified offset rotavator in mango orchard. It was found that the draft for L-shaped blades increased from 1086.8 to 1651.3 N as the forward speed increased from 2.0 to 3.0 km h^{-1} and depth of cut increased from 80 to 120 mm for the shield kept at lowered position. The fuel consumption was higher at 9.4 l h^{-1} for the forward speed of 3 km h^{-1} and depth of cut of

120 mm. The mean mass diameter of soil increased from 1.21 to 2.2 mm as the forward speed increased from 2.0 to 3.0 km h^{-1}. The residue incorporation was the maximum at 96.68 per cent for the forward speed of 2.0 km h^{-1} and depth of cut of 120 mm. The field performance index was 89.54 per cent for the forward speed of 3.0 km h^{-1}. The plant injury was 83.3 per cent at forward speed of 3 km h^{-1} due to the impact of sensing assembly on the plant girth.

Sharad *et al.* (2018) evaluated the work efficiency of rotary offset tiller in litchi orchard. Draft developed with L-shaped blades increased from 918.9 to 1449.4 N as the forward speed increased from 2.0 to 3.0 km h^{-1} with increase in depth of cut (80 to 120 mm) for the shield kept in the lowered position. The fuel consumption was higher at 8.84 l h^{-1} for the forward speed of 3.0 km h^{-1} and depth of cut of 120 mm. The mean mass diameter increased from 1.04 to 2.07 mm with the increase in forward speed of 2.0 to 3.0 km h^{-1}. The extent of residue incorporation was maximum at 97.46 per cent for the forward speed of 2.0 km h^{-1} and depth of cut of 120 mm. At higher forward speed of 3.0 km h^{-1}, field performance index was 86.45 per cent. The plant injury at forward speed of 3.0 km h^{-1} was observed as 66.6 per cent.

Prathuang and Kittikhun (2019) conducted experiments with a combined tillage implement of subsoiler and rotary harrow to reduce the cost in seedbed preparation. Three tillage operations, two forward speeds, and two rotational rotor speeds were determined as input factors to investigate soil clod size, performance parameters and the specific energy requirements. Increasing the rotor speed from 299 to 526 rpm, the mean soil clod diameter decreased from 22.98 to 19.83 mm and 31.77 to 26.57 mm for the selected fields at a depth of 0 to 200 mm. The specific energy requirement was affected significantly by rotor speed and tillage operation. The specific energy requirements for the combined tillage implement with an on-frame pivot joint and on-pivotable-shank joint were found minimum of 10.4 and 21.1 per cent and by 18.4 and 24.7 per cent respectively for the selected fields compared to the total power requirement for the separate use of subsoiler and rotary harrow.

Ganesh and Hifjur (2020a) carried out a comparative analysis between an active-passive configuration of combined offset disc harrow (CODH) and conventional passively-driven mode of offset disc harrow (ODH) to achieve maximum tillage quality with a minimum expenditure of power. Better penetration ability and uniformity in tilling depth were observed with CODH compared to passively-driven ODH. The soil pulverizing ability, stubble cutting, and crop residue burial efficiency were observed as better with CODH compared to passively-driven ODH. The CODH exhibited best tillage performance index at rotational speed of 133 rpm, at which draught requirement and the corresponding driving wheel slip were reduced by 50.73 to 55.01 per cent and 68.70 to 79.55 per cent respectively as compared to free rolling ODH. The results indicated that the active-passive CODH performed well over the conventional passively-driven ODH with respect to energy consumption and quality of soil tilth.

Ganesh and Hifjur (2020b) studied the effect of velocity ratio on the performance of an active-passive combined offset disc harrow. The results indicated that increase in velocity ratio from 1.48 to 3.49 helped to reduce both draught and torque requirements with negligible reduction when velocity ratio increased beyond 3.49. At the velocity ratio of 2.91, the specific energy consumption was minimum. Attempts were made to select a suitable velocity ratio based on tillage performance index considering both fuel energy input and tillage effectiveness measures *viz.*, crop residue burial efficiency and soil pulverization. It is revealed that this type of implement at the velocity ratio of 3.09 and 4.06 during the first and second passes resulted maximum tillage performance with minimum energy consumption.

Jyotirmay *et al.* (2020) optimized the power tiller operated rotavator blades design for the best utilization of available power and obtain desired soil condition. The specific work done by the rotavator was carried out with for different combinations of blade design and kinematic parameters. The best combination of parameters that produced the desired soil condition with minimum specific energy consumption while utilizing the available power was selected. The velocity ratio of 5.12, forward velocity of 0.41 m s^{-1}, rotor speed of 80 rpm, operating width of 7.5 dm and 30 number of blades mounted on 5 number of flanges were the optimized kinematic parameters of machine.

Matin *et al.* (2021) studied strip-tillage blade designs and settings to optimize rotary strip-till system in soil bin. Three designs of 'C' type rotary blades *viz.*, conventional, medium and straight and two blade settings *viz.*, four and six blades per row with 50 and 100 mm cutting widths were tested at three blade operating depths of 50, 75, and 100 mm using a tillage test rig. A high speed camera in the soil bin was installed to study the processes of soil cutting, throwing, backfilling, and creation of furrow seedbed. At four blades per row setting, all blades created high amounts of optimum clods of 1 to 20 mm size. The conventional and medium blades inverted more soil in the strip-tilled furrow while the straight blade created adequate backfill at 75 and 100 mm operating depths. The study indicated that the use of straight blades operated at a depth of 75 or 100 mm was ideal for considering the machine and energy costs, blade performance and the necessity of minimizing soil disturbance in strip-tillage.

2.4 DEVELOPMENT AND TESTING OF BASIN LISTERS

Muhammad (2005) developed a power tiller operated basin lister for tree crops. The machine was anchored to the tree using a horizontally mounted over hanging 'L' shaped member. A set of soil scraping blades inclined at appropriate angles were fixed behind the rotor shaft on which only two outermost blades of power tiller were fixed. A series of vertical pegs of uniformly varying heights were fixed on the 'L' member to remove weeds near palm. The power tiller is driven forward in such a way that 'L' member was locked onto the trunk around which basin was made. The machine width and length were 150 and 167 cm respectively. The machine was operated for 3 to 4 minutes per basin, including the time required to move from one palm to another.

Muthamil *et al.* (2005) designed and developed a tractor operated basin lister cum seeder as an attachment to 9-tyne cultivator suitable for 35-45 hp tractors. The width of machine was decided as 1.8 m as it was operated by attaching to tractor drawn cultivator. The top and bottom widths of the formed basin were 300 and 75 mm respectively. The basins were formed between two adjacent rows of 450 mm. The machine formed ridges and furrows in the field at specified intervals. It conserved 18 per cent more moisture as compared to ploughing with country plough or tractor drawn cultivator. The effective field capacity, field efficiency and labour requirement were 0.60 ha h^{-1}, 80 per cent and 2 man h ha^{-1} respectively.

Singh *et al.* (2016) designed and developed a tractor operated bund former cum packer to overcome the drudgery involved in manual operation. An attempt was made to combine operations of bund forming and packing in single pass that can save fuel, time and other resources. The machine consisted of commercially available disc type bund former, rectangular tool bar frame, and packing unit with concentric cylindrical roller, drive shaft, conical discs, compressive shanks etc. The bund formed by bund former-cum-packer was field tested and found neither water seepage nor breakage of bund during flood irrigation. The field capacity was 1.4 ha h^{-1} at the forward speed of 2.93 km h^{-1} in second low gear. It reduced about 96 per cent labour requirement for packing the bund. The resource productivity increased by 38 per cent with the developed machine.

Onkar *et al.* (2018) developed a coconut tree basin digging cum fertilizer application machine. The rotary tiller was operated with 2.0 hp petrol engine mounted on a frame with two ground wheels. The weeding operation was also performed along with basin digging operation. It was observed that at deeper depths, slow operational speed aided efficient weed removal. The number of basins formed by rotary tiller was more than manual operation of basin listing. The cost of operation was found to be less than manual basin digging operation.

Rahul *et al.* (2018) evaluated the performance of a tractor drawn ridge plastering machine. The machine consisted of 8-tyne rotavator, leveler, a rotating disc and a roller. Of the machine, the rotating disc trimmed the bund and plastered the pulverized soil while the long roller compressed the soil to form a good bund. The capacity of machine was 1000 m per hour when operated at an average speed of 1.0 km h^{-1} and the fuel consumption of the machine was 4.0 l h^{-1}. The operational cost of machine and cost saving were reported as Rs.712 h^{-1} and Rs.2248 h^{-1} respectively over conventional method.

2.5 FERTILIZER PROPERTIES

Moysey and Shane (1985) studied frictional properties *viz.*, angle of internal friction and angle of repose for different fertilizers viz., potash, urea and ammonium phosphate. The angle of internal friction was determined with the help of Wykeham-Farrance standard shear test apparatus. The angle of repose was determined by filling fertilizer in a rectangular box having dimensions 300 × 200 × 250 mm made of Plexiglas material, where one side of the rectangular surface was removed to determine the angle between heap formed by the fertilizer and flat surface. The internal friction angle of potash, urea and ammonium phosphate were reported as 32.8, 30.9 and 29.8 deg. The angle of repose of potash, urea and ammonium phosphate were determined as 33, 36 and 33 deg.

Rutland (1986) prepared a manual for determining the physical properties of the fertilizers. The particle sizes of prilled urea, muriate of potash and ammonium phosphate were reported as 1 to 2.4 mm, 0.85 to 2 mm and 2 to 4 mm respectively. The angle of repose for prilled urea, muriate of potash and ammonium phosphate were obtained as 28, 41 and 37 deg. respectively. The bulk density of prilled urea, muriate of potash and ammonium phosphate were reported as 760 kg m^{-3}, 1040 kg m^{-3} and 1000 kg m^{-3}.

Hofstee (1992) studied the handling and spreading of fertilizers which were influenced by fertilizer physical properties. The procedure for measuring coefficient of friction, aerodynamic resistance coefficient, coefficient of restitution, breaking force and particle strength for various fertilizers were detailed. From the experiment, it was concluded that coefficient of friction was 30 per cent higher for stainless steel and aluminium surfaces compared to PVC and nylon surfaces. Coefficient of restitution of PVC, stainless steel, and aluminium surfaces had 50 per cent of nylon surface values. Fertilizers with a rough surface texture had high aero dynamic resistance coefficient than smooth surface. The breaking force of particles increased when the size increased and it was concluded that urea prills need higher breaking force of more than 15 N.

Morsy *et al.* (2012) determined the relationship between the fertilizer particles motion in the hopper and fertilizer distribution disc. It was reported that the quality of distribution pattern of the fertilizer for rotary disc distributer will depend on the physical and engineering properties of fertilizer. The particle shape was measured with the vernier callipers and particle size distribution with the sieve analysis. The angle of repose was measured with the help of digital photography and the particle density with graduated cylinder. The observed values of particle density of ammonia sulphate and urea were 1791 kg m^{-3} and 1297 kg m^{-3} respectively. The angle of repose of urea and ammonia sulphate varied from 34 to 38 deg. and 35 to 41 deg. The coefficient of dynamic friction of urea and ammonia sulphate were 0.53 and 0.42 respectively.

Deo *et al.* (2019) studied the physical and engineering properties of urea briquettes to design a mechanical urea applicator. The length, breadth and thickness of urea briquettes were determined as 18.8, 18.3 and 13.7 mm respectively. The geometrical mean diameter, roundness, sphericity, angle of repose and bulk density of urea briquettes were reported as 16.8 mm, 0.82, 0.89, 32 deg. and 1.29 g cm^{-3} respectively. The shape of the cup of metering mechanism was decided as hemi-spherical by considering the mean dimensions of urea briquettes. The diameter and depth of cup of metering mechanism were taken as 20.6 and 6.5 mm respectively.

IFA (2014) evaluated the moisture content of fertilizers using Karl Fischer method and Vacuum Gravimetric method. It was reported that the Karl Fischer method was used for only nitrogen and potassium-based fertilizers and low temperature Vacuum Gravimetric method for potassium chloride and phosphorus-based fertilizers. The results revealed that the Karl Fischer method was the only measurement technique where water molecules could be titrated to the end point.

Gilbertson and Vallin (2016) studied the process to evaluate the flow rate of fertilizer in solid fertilizer blending. It was reported that the flowability of is reduced when there exists fertilizer caking tendency due to the reaction between fertilizer particles and presence of moisture which resulted in the problems of handling operations.

Therefore, a standard method was determined for calculating the flow rate of fertilizer on time basis by allowing 2 kg of fertilizer to flow from a funnel with aperture of 25 mm diameter. Then the time taken to flow 2 kg of fertilizer from the funnel aperture was measured.

Hamzah *et al.* (2018) studied the angle of repose of granular fertilizers. The angle of repose of different granular fertilizers were studied in the discrete element model simulation. The factors *viz.,* particle size and shape, rolling friction coefficient, coefficient of restitution, static sliding friction coefficient, amount of material used in the measurement and method of measurement influenced the angle of repose. It was reported that angle of repose increased with the sliding and rolling friction coefficients, particle and impacted surface roughness, moisture content and revolving drum speed.

2.6 DEVELOPMENT AND TESTING OF FERTILIZER APPLICATORS

Khilael *et al*. (2004) developed a metering device for both organic and chemical fertilizers, which consists of a transparent device housing for the visual observation of metering device, two solid acrylic resin rollers each of 90 mm diameter. These rollers are fixed to each other with an offset of 60 deg. and each roller has 3 cells and a regulator to control the fertilizer that feed into the cells of the roller. The performance evaluation of developed metering device was done in comparison with the commercial metering device by using organic and chemical fertilizers. The commercial metering device consists of flexible rubber roller of 50 mm diameter with 6 cells. It was observed that the developed device metered more fertilizer granules with size more than 10 mm. The results revealed that the developed unit meters fertilizer consistently with lower power consumption and torque than commercial metering device.

Maleki *et al.* (2006) developed a multi-flight auger metering device for grain drills. The design parameters were auger groove depth and width, number of grooves or flights, auger outer diameter and rotational speed. The performance evaluation of grain drill was carried out to study the seed distribution uniformity of multi-flight auger metering device. The results revealed that seed distribution uniformity increased with the outer diameter of auger, depth and width of grooves, number of auger flights and rotational speed of the auger. It was found out that the coefficient of uniformity of the multi-flight auger mechanism was higher when compared to the flouted-roller mechanism.

Tola *et al.* (2008) developed a granular fertilizer application rate control system with integrated output volume measurement for precise application. They developed a fertilizer rate control system using a real-time fertilizer discharge sensor to enable variable-rate application. It tested for various fertilizer output rates with different operating speeds of 0.45, 0.91 and 1.36 m s^{-1} and distances of 1, 2, 3, 4 and 5 m respectively. The results indicated that fertilizer application rate and output were controlled precisely. The automatic setting enabled the variable fertilization application rate for precise application.

Sandip and Thakur (2010) designed and developed a subsoiler-cum-differential rate fertilizer applicator. The equipment consisted of a rectangular frame, a main winged tine, two shallow leading winged tines, a depth control device, a fertilizer box of 100 kg capacity, edge cell type fertilizer metering device and a ground wheel with chain and sprockets for transmitting power to the metering mechanism. The equipment placed fertilizers up to a 500 mm soil depth by the main winged tine and up to 250 mm deep by the leading tines, which in turn helped to place fertilizer at different depths in a single pass. The laboratory evaluations indicated a coefficient of uniformity of more than 90 per cent for the application rates of 250, 500, 750 and 1000 kg ha^{-1}. The results showed an increase of 16.2, 16.4 and 35.4 per cent in the yield as compared to conventional ploughing with in furrow fertilizer application control.

Talha *et al.* (2011) designed and developed a pneumatic system for granular fertilizer flow rate control to modify the mechanical fertilizer rate adjustment system. The control system was equipped with pneumatic drive and composed of a double acting cylinder, a double solenoid operated valve, a computer, a micro-controller, a rotary encoder and other operating parts. The developed control system performance and discharge characteristics were evaluated in the laboratory. The results revealed that automatic setting of target fertilizer application rate performed efficiently and the developed system performed variable rate application for granular fertilizer with an overall error in the range of ±6 per cent.

Ozturk *et al*. (2012) studied optimization of seed flow evenness of fluted rollers used in seed drills for wheat. The evaluation of machine was conducted according to Taguchi optimization method and L9 orthogonal array by selecting three shapes of fluted rollers having lengths of 5, 10 and 15 mm and axis rotational speeds of 25, 30 and 35 rpm respectively. The minimum coefficient of variation was obtained with the trapezoid fluted roller, flute length of 15 mm and axis rotation speed of 35 rpm. The coefficient of variation for placing the seeds was obtained as 2.87 at the optimum conditions.

Kumar *et al.* (2014) designed and developed a power tiller operated seed cum fertilizer till drill machine for the purpose of simultaneous ploughing and seeding. The machine consisted of a seed and fertilizer box, 4-fluted rollers as the metering mechanism for the fertilizer and simple knob mechanism for the seeds, and a ground wheel for operating the metering mechanism. Four rigid tynes were provided for the formation of grooves in the field. The cost of sowing and energy requirement per hectare was found as Rs.1413 and 658 MJ respectively.

Verma and Gupta (2016) developed and tested a power tiller operated multi-crop seed cum fertilizer drill. The metering mechanism was modified with nylon roller suitable for multiple use. The performance of metering of different rollers was also found within acceptable range except in case of pea and found acceptable for sowing wheat, maize, green gram, bengal gram, jowar and rajmah crop. The performance of fluted roller mechanism for metering fertilizer was also in the desired range of 36 to 221 kg ha^{-1}.

Bholuram *et al*. (2017) designed a variable rate fertilizer metering mechanism by changing the speed of the feed shaft. The speed of the feed shaft was varied with the help of microcontroller unit programmed with a pulse width modulation motor driver. The straight and helical fluted rollers of flute numbers 6 and 8 were used for the analysis with two different fertilizers viz., Di-ammonium phosphate (DAP) and Single super phosphate (SSP). From the experimental results, it was found that the discharge rate of DAP was lesser than that of SSP and there is no difference in discharge rate of straight and helical fluted rollers. It was concluded that different metering system should be used to achieve higher rpm for SSP fertilizer.

Patil *et al*. (2017) developed a mechanical hydrogel applicator with suitable metering mechanism to conserve the soil moisture at root zone depth with the help of hydrogel small granules. The three different types of metering mechanism viz., star wheel, screw feed and brush feed were used for the study in the laboratory. Three different sizes of hydrogel viz., 0.85, 0.60 and 0.42 mm were taken at three levels: hydrogel mixed with soil, fertilizer and sand for the experiment. The experiment was conducted in the laboratory by arranging the sticky belt and it was observed that coefficient of variation for star wheel, screw feed and brush feed metering for hydrogel mixed sand were 9, 5 and 17.5 per cent. Experimental results showed that screw metering mechanism was found to be having better uniform distribution and application rate compared to other two metering devices.

Salsan (2017) designed and developed a lime applicator attachment to tractor drawn rotavator for simultaneous application of lime with tilled soil. The power output to the lime applicator attachment was taken from the rotavator shaft. The trapezoidal hopper was made up of galvanized iron sheet folded in 54 deg. with dimension of 1600×460×340 mm. The single shaft baffle type metering mechanism was used in the machine for lime application. The desired lime application rate of 350 kg ha^{-1} was resulted at 2000 rpm of tractor engine under L_1 gear. The forward speed obtained was 2.56 km h^{-1} with a wheel slippage of 11.67 per cent. The actual field capacity, theoretical field capacity and field efficiency were found out as 0.33 ha h^{-1}, 0.39 ha h^{-1} and 84 per cent respectively. A saving in cost of operation per hour and hectare was reported as Rs.60 and Rs.267 respectively.

Cezario *et al*. (2018) developed a helical conic cylindrical thread fertilizer metering mechanism. It consists of two sections viz., conductive thread shaped propeller and conic propeller made of nylon. The statistical analysis was done for the factors viz., fertilizer level in the reservoir, speed, position of the spreader and rotation of the fertilizer spreader axis. From the results, it was revealed that the metering mechanism showed positive results in terms of homogeneity and uniformity of flow with coefficient of variation of 3.1 to 5.8 per cent, longitudinal distribution of fertilizers with coefficient of variation of 4 per cent.

Shangpeng *et al.* (2018) designed and developed a dual band fertilizer applicator which simultaneously delivered starter and base fertilizer as separate bands into the soil. The working process of the applicator was modelled using the discrete element method (DEM) to examine the effects of machine parameters on the ratio of discharged starter and base fertilizer and the separation distance of fertilizer bands. DEM model generated optimal machine parameters for fertilizer application in the given condition. For wheat, the optimum machine speed was 3.9 km h^{-1} and the optimum spacings of vertical and longitudinal fertilizer delivery tubes were 66 and 194 mm respectively. The simulated values of separation distances obtained from the DEM model had low relative errors of 11.86 per cent with respect to the field measurements. The results inferred that DEM model was able to simulate the dual banding fertilizer application with good accuracy.

Singh and Thakur (2018) developed a tractor drawn subsoiler cum vermicompost and soil amendments applicator for placement of organic manures and inorganic fertilizers in subsoil at different depths up to 40 cm. The developed machine was evaluated in laboratory for discharge rate and distribution pattern of different organic manures such as vermicompost, pressmud, farm yard manure and soil amendments such as gypsum, lime, cement and rice husk. It was observed that the bulk density was uniform throughout the soil profile when operated at 40 cm depth and reduced to a maximum of 13.88 per cent under field conditions. The specific draft for 40 cm depth of operation was found lower by 33.26 per cent than that at 250 mm depth of operation. A substantial increase in yield of mustard crop due to the subsoiling and deep placement of organic and inorganic fertilizers with the developed machine was also reported.

Zhang *et al.* (2018) studied fertilizer feeding performance of spiral grooved wheel types. Spiral grooved-wheel was used to replace the straight grooved-wheel to overcome the feeding pulsation problem. Design optimization was carried out on the key structural parameters of the spiral grooved-wheel fertilizer feeder by discrete element method. The experimental study revealed that the fertilizer feeding quantity of the spiral grooved wheel was higher than that of the straight grooved-wheel when the helix angle was 60.83 deg. The fertilizer feeding uniformity of the spiral grooved-wheel fertilizer feeder was better than that of the straight grooved-wheel fertilizer feeder when the revolving speed was low.

Edwin *et al*. (2019) developed an electronically controlled variable rate fertilizer broadcaster consisting of fluted metering roller, spreading unit, storage tank and variable rate controller unit. The performance evaluation of developed unit was done in the laboratory and the application rate was found to be 28, 64, 95 and 140 kg ha^{-1} for the exposure lengths of flute 10, 20, 30 and 40 mm respectively. The observed coefficient of variation for fertilizer application were 3.95, 2.94, 3.82 and 2.66 per cent at 10, 20, 30 and 40 mm exposure lengths of flute. The actual field capacity and field efficiency of the developed unit were 0.30 ha h^{-1} and 83 per cent respectively.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The methods adopted in design, development and testing of tractor operated basin lister cum fertilizer applicator as influenced by the soil, crop, fertilizer and machine parameters are dealt in this chapter. The design and development of the machine are explained in this chapter. The development of machine was executed at the research workshop of department of FMPE, KCAET, Tavanur. The levels of independent variables selected for testing and optimization procedure for achieving the maximum output of the developed machine are also elucidated. The performance evaluation of machine was conducted at Instructional Farm, KCAET, Tavanur. The cost economics of the developed machine was worked out and analyzed for its optimum use.

The major soil, crop, fertilizer and machine parameters affecting the design and development of tractor operated basin lister cum fertilizer applicator are elaborated below.

3.1 SOIL PARAMETERS

The standard procedures for measuring soil parameters such as moisture content, bulk density, cone index and shear strength affecting the design and development of tractor operated coconut basin lister cum fertilizer applicator are detailed below.

3.1.1 Moisture content

The moisture content of soil is the ratio of the weight of water to the weight of the solids. It is expressed in percentage and was found out by oven dry method. Soil samples of different locations were collected from the field at depths of 10 cm. The soil samples of 50 g each were collected in different containers and placed in a hot electric oven under a controlled temperature of 105°C for a time period of 24 hours (IS, 1993). The weights before and after drying were found out using an electronic weighing balance. The moisture content (d.b) of soil sample was determined by using the following equation.

$$MC\ (d.b) = \frac{W_1 - W_2}{W_1} \times 100$$

where,

MC	=	Soil moisture content, per cent (d.b)
W_1	=	Initial weight of soil sample, g
W_2	=	Final weight of dry soil sample, g

3.1.2 Bulk density

The compactness of the soil is determined by the bulk density. It was measured by core cutter as shown in Plate. 3.1 (a). Initially, the volume of a cylinder was determined by measuring the internal diameter and height of the core cutter. Then empty core cutter was weighed and recorded. The experimental field was cleared and the surface was levelled. A cylindrical core cutter having 10 cm diameter and 10 cm height was pressed into the soil mass using the rammer with dolley placed over the top of the core cutter. Pressing was stopped when the dolley protruded 15 mm above the surface. Surrounding soil of core cutter was removed and taken out. Top and bottom surfaces of the core cutter were carefully trimmed using a straight edge. Core cutter filled with soil was removed and weighed. The bulk density was found out by using the equation (Ahmed *et al.*, 2018).

$$\rho = \frac{M}{V}$$

where,

P	=	Bulk density of soil, kg m^{-3}
M	=	Mass of the oven dried soil, kg
V	=	Volume of core sampler, m^3

3.1.3 Cone index

Cone index indicates soil resistance and is expressed as force per square centimeter required for a cone of standard base area to penetrate into soil at different depths. Cone index of soil varies with cone apex angle, area of cone base and depth of penetration (Hummel *et al.*, 2004). Cone index of soil was measured as shown in Plate. 3.1 (b). The cone penetrometer was positioned near the coconut palm and a uniform force was applied on the handle and deflection of dial gauge was noted for different depths. The solid stem penetrated into the soil and force was measured from the deflection of the needle of proving ring corresponding to the insertion of 30 deg. cone. The cone index was measured uniformly from 2.5 to 10 cm depth at an interval of 2.5 cm and recorded manually. The same procedure was repeated to measure cone index at various location of the study area.

3.1.4 Shear strength

Shear strength of a soil is the maximum resistance offered by the soil to shearing stress (Punmia *et al.,* 2017). The in-situ measurement of shear strength of soil was carried out using shear stress apparatus as shown in Plate. 3.1 (c). A bore hole of depth 10 cm was dug out and the casing was extended up to this depth and the entire unit was fixed at the location during the test. Torque applicator was fixed on the stand with the help of spikes. A vane of 37.5 mm diameter was connected to the vane rod having the same female thread and it was loaded to the required depth. It was pushed downward with a moderate steady force up to a depth of 50 mm below the bottom of the bore hole and allowed to move further for 5 minutes after the insertion of the vane. The initial dial gauge reading was set to zero and gear handle was turned so that the vane was rotated at the rate of 0.1 deg. per second, this in turn helped to acquire a uniform rate of 12 turns per minute. The vane was rotated ten times to disturb the soil. The dial gauge reading of torque indicator was noted at 30 s interval and the rotation of vane was continued until the reading dropped from the maximum value. The shear strength of soil was found out using the following equation.

$$S = \frac{T}{\pi\left(\frac{D^2H}{2} + \frac{D^3}{6}\right)}$$

where,

S = Shear strength, kg cm^{-2}

T = Torque, kg cm

D = Overall diameter of vane, cm

H = Height of the vane, cm

3.1 (a) Bulk density by core cutter method

3.1 (b) Cone index of soil using proving ring cone penetrometer

3.1 (c) Shear strength of soil using shear test apparatus

Plate. 3.1. In-situ measurements of soil parameters

3.2 CROP PARAMETERS

The major crop parameters such as trunk diameter and root zone depth of coconut palm were measured and recorded. The root zone depth was studied at the time of basin listing and fertilizer application for coconut palm. These parameters are important in the design of tractor operated coconut basin lister cum fertilizer applicator.

3.2.1 Trunk diameter of coconut palm

About 25 coconut palms were selected randomly in the experimental plot to determine the trunk diameter of coconut palm at the base. The circumference of trunk of coconut palm at the base was found out using a measuring tape and the average of these readings was determined. The trunk diameter of coconut palm was determined by dividing the circumference with π. It helped in deciding the working width of machine and in turn its field capacity.

3.2.2 Root zone depth

To measure root zone depth, 25 coconut palms were chosen at random in the coconut farm. An area of 1.5 m radius around the coconut palm was marked and the soil was dug out carefully until the roots appear. Then measuring tape was used to measure the root zone depth of coconut palm from the flat top layer of soil and the average root zone depth was found out. Root zone depth was one of the parameters for deciding the depth of operation of the machine. Accordingly, the other dimensions for the major components of the machine were also decided.

3.3 FERTILIZER PARAMETERS

The straight fertilizers used for growth of coconut palms are urea, muriate of potash and rock phosphate. According to the package of practices of Kerala Agricultural University; 0.36 kg urea, 0.67 kg muriate of potash and 0.53 kg rock phosphate per dose per coconut palm was recommended (KAU, 2016). The physical properties of fertilizer *viz.*, angle of repose, bulk density, tapped density and coefficient of friction are required for the design of fertilizer applicator of the machine. The standard procedures followed for the determination of fertilizer properties were discussed below.

3.3.1 Angle of repose

Angle of repose is the angle made by the fertilizer sample with the horizontal surface when piled from a certain height and is expressed in degree. The angle of repose of fertilizer influences the design of hopper and fertilizer flowability of metering roller of the fertilizer applicator. Angle of repose of fertilizers was measured by dropping the sample into a conical container to form a heap on the base plate of this apparatus as shown in Plate. 3.2 (a). The angle of repose of fertilizer samples was determined by the following equation (Sahay and Singh, 2004).

$$\theta = \tan^{-1}(\frac{h}{r})$$

where,

θ = Angle of repose, deg.

h = Height of heap, mm

r = Radius of the heap, mm

3.3.2 Bulk density

Bulk density is the total mass of fertilizer per unit of its total volume. The bulk density of fertilizer is the deciding factor for fixing the hopper dimensions of fertilizer applicator. It was found out by measuring the known weight of fertilizer samples in a container. The bulk density of fertilizer sample was calculated by the following expression (Landry *et al.,* 2004).

$$\rho = \frac{m}{v}$$

where,

ρ = Bulk density, kg m^{-3}

m = Weight of fertilizer, kg

v = Volume of container, m^3

3.3.3 Tapped density

Tapped density is the weight per unit volume of a material including voids between particles. Tapped density represents the maximum density to which a material might be reduced by vibration during operation. The test sample was filled into the metal box and the box was dropped 15 cm off the floor in multiple times. The voids created by dropping was refilled and the dropping was continued until compaction was completed. The box with test sample was then weighed, and the weight of the empty box was subtracted to obtain the weight of the test sample. The tapped density was calculated by the following equation (Rutland, 1986).

$$D_t = \frac{W_1 - W_2}{V}$$

where,

D_t = Tapped density, kg m^{-3}

W_1 = weight of fertilizer with container, kg

W_2 = Volume of container, m^3

V = Volume of container, m^3

3.3.4 Coefficient of friction

The coefficient of friction is an important parameter to judge the sliding effect of fertilizer over a sheet as compared to angle of friction. The apparatus used for finding the coefficient of friction consisted of a horizontal platform, bottomless open container and a pan as shown in Plate. 3.2 (b). Known weights of fertilizer in the container were taken. The weights were added in the pan and the instant at which the pan weight exceeded the fertilizer, the container started to slide. The coefficient of friction was measured for both external and internal contact of fertilizer with the horizontal plane. Following equation was used for determination of coefficient of friction (Singh and Singh, 2014).

$$\mu = \frac{F}{N}$$

where,

μ = Coefficient of friction

F = Force applied, kg

N = Weight of the fertilizer, kg

3.2 (a) Angle of repose

3.2 (b) Coefficient of friction

Plate. 3.2 Measurement of fertilizer parameters

3.4 FUNCTIONAL REQUIREMENTS OF THE MACHINE

The following functional requirements were taken into consideration for the design of different components of tractor operated basin lister cum fertilizer applicator.

1. The power unit of developed machine shall be able to drive the machine at the required speed under full load.
2. The machine shall perform basin listing and fertilizer application operations around the coconut palm simultaneously in a single pass.
3. The basins are to be formed by rotary tilling of blades which scatters the soil to form bund around coconut palm.
4. The rotary tilling of blades of the machine shall form a uniform basin at the required depth of 10.0 cm at a radius of 1.8 m around coconut palm.
5. Uniform bund shall be formed around coconut palm with rotary tilling of blades of machine so that it holds the irrigated water in the confined space of formed basin.
6. The fertilizer applicator shall apply the recommended quantity of fertilizer in the basin by using proper metering mechanism.
7. Damage to the root zone during basin listing and fertilizer application operations by the machine shall be minimum.
8. The machine shall not damage the trunk of coconut palm during basin listing and fertilizer application operations.
9. The machine shall be operated by tractors in the power range of 45 to 60 hp.

3.5 WORKING DEPTH OF THE MACHINE

The working depth of the machine is dependent on type of soil, moisture content and root zone depth of coconut palm. The quantity of water required per coconut palm is 500 to 800 litres (KAU, 2016). The working depth of machine must be such that the basin formed by the machine shall accommodate the recommended water requirement of the palm and should not damage the root zone of coconut palm.

The volume of water requirement per coconut palm (V) was determined by the following equation.

$$V = \frac{v}{\rho}$$

$$= \frac{800}{1000}$$

$$= 0.8 \text{ m}^3$$

where,

V = Volume of water requirement per coconut palm = 500 to 800 l

ρ = Density of water = 1000 l m^{-3}

The schematic diagram of a basin around the coconut palm is shown in Fig. 3.1. The area of basin around the coconut palm (A) was calculated by the following equation.

$$A = \pi \times (R^2 - S^2)$$

$$= 3.14 \times (1.8^2 - 0.45^2)$$

$$= 9.53 \text{ m}^2$$

where,

A = Area of basin around the coconut palm, m^2

R = Recommended radius of basin listing, m

S = Space left around the coconut palm, m

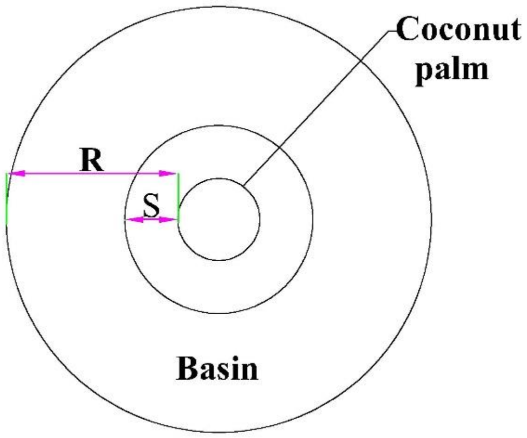

Fig. 3.1 Plan of the basin around a coconut palm

The working depth (D) of machine was calculated by the following equation.

$$D = \frac{V}{A}$$

$$= \frac{0.8}{9.53}$$

$$= 0.083 \text{ m}$$

where,

D = Working depth of machine, m

V = Volume of water requirement per coconut palm, m^3

A = Area of basin around coconut palm, m^2

The working depth of machine was calculated as 0.083 m or 8.38 cm. Therefore, the machine shall be able to dug out soil up to a depth of 10.0 cm around the palm.

3.6 WORKING WIDTH OF THE MACHINE

The working width of the tractor operated basin lister cum fertilizer applicator is designed with respect to the power, peripheral force, moment, speed of rotor shaft, working depth and forward speed of the tractor. It was calculated with the following equations proposed by Bernacki *et al.* (1972).

As the most used tractor segment is 41-50 hp on Indian farms, 45 hp tractor was selected as the prime mover to drive the tractor operated basin lister cum fertilizer applicator. The PTO horse power of tractor was calculated with the following equation by assuming 15 per cent power loss from tractor horse power.

$$\text{PTO hp} = 0.85 \times 45$$

$$= 38.25 \text{ hp}$$

The power available at rotor shaft of machine (P) was then calculated with the following equation by assuming 10 per cent power loss from PTO horse power.

$$P = 0.9 \times \text{PTO hp}$$

$$= 0.9 \times 38.25$$

$$= 34.42 \text{ hp}$$

The common speed range of rotor shaft for rotary tillage machines is 200 to 400 rpm (Klenin *et al.*, 1985). Therefore, the speed of rotor shaft was selected as 305 rpm for better soil throw by cutting blades to form a bund around the coconut palm. The peripheral force acting on rotor shaft was calculated with the following equation (Bernacki *et al.*, 1972).

$$K_o = \frac{P}{2\pi NR}$$

$$= \frac{25.66}{2 \times 3.14 \times 5.08 \times 0.242}$$

$$= 3.32 \text{ kN}$$

where,

K_o = Peripheral force acting on rotor shaft, kN

P = Power available at rotor shaft of machine = 25.66 W

N = Speed of rotor shaft = 305 rpm = 5.08 rps

R = Radius of rotor = 0.242 m

The static specific work of basin lister (A_o) was calculated with the following equation:

$$A_o = 1.5 \times K_i$$

$$= 1.5 \times 147.15$$

$$= 220.72 \text{ kN m}^{-2}$$

where,

K_i = Soil cone index = 1.50 kg cm^{-2} = 147.15 kN m^{-2}

The dynamic specific work of basin lister (A_B) was calculated with the following equation:

$$A_B = 4\,\pi^2\,\alpha\,N^2\,R^2$$

$$= 4\,\pi^2 \times 2.943 \times 5.08^2 \times 0.242$$

$$= 175.41 \text{ kN m}^{-2}$$

where,

α = Dynamic coefficient = 2.943 kN s^2 m^{-4}

N = Speed of rotor shaft = 305 rpm = 5.08 rps

R = Radius of rotor = 0.242 m

The specific work of basin lister (A) was calculated with the following equation:

$$A = A_o + A_B$$
$$= 220.72 + 175.41$$
$$= 396.14 \text{ kN m}^{-2}$$

where,

A_o = Static specific work of basin lister = 220.72 kN m^{-2}

A_B = Dynamic specific work of basin lister = 175.41 kN m^{-2}

The moment acting on rotor shaft (M) was calculated with the following equation:

$$M = K_o \times R$$
$$= 3.32 \times 0.242$$
$$= 0.8 \text{ kN m}$$

where,

K_o = Peripheral force acting on rotor shaft = 3.32 kN

R = Radius of rotor = 0.242 m

The working width of machine (W) was calculated with the following equation:

$$W = \frac{2\pi NM}{V A D}$$
$$= \frac{2\pi \times 5.08 \times 0.8}{0.55 \times 396.14 \times 0.1}$$
$$= 1.1 \text{ m}$$

where,

N = Speed of rotor shaft = 305 rpm = 5.08 rps

M = Moment acting on rotor shaft = 0.8 kN m

V = Forward speed of tractor = 2 km h^{-1} = 0.55 m s^{-1}

A = Specific work of basin lister = 396.14 kN m^{-2}

D = Working depth of machine = 0.1 m

Therefore, the working width of basin lister shall be 1.1 m to obtain the desired efficiency from the machine.

3.7 DESIGN AND DEVELOPMENT OF THE BASIN LISTER

The basin lister was designed and developed by considering the measured soil and crop parameters. The mechanical basin listing is an operation in which a basin is dug out at a radius of 1.8 m around the coconut palm by rotary action of blades without affecting the root zone and damaging trunk of the palm. The main aim of the study was to design and develop a basin lister which consumes minimum power, provides efficient operation and shall not damage the root zone and trunk of coconut palm.

3.7.1 Frame

The frame provides a housing for the major components of the machine. It mainly consists of a top cover, centre side plate, chain side plate and curve side plate as shown in Fig. 3.2. The top cover (Fig. 3.2a) was provided above the cutting blades of basin lister. It restricts heavy boulders, stones and trash from moving out of the basin to avoid accidents to the operators of machine. The cut slice of soil gets pulverized when hit the top cover. The top cover was welded to a rectangular pipe, chain side plate and centre side plate. The main shaft cover was also fixed to the top cover.

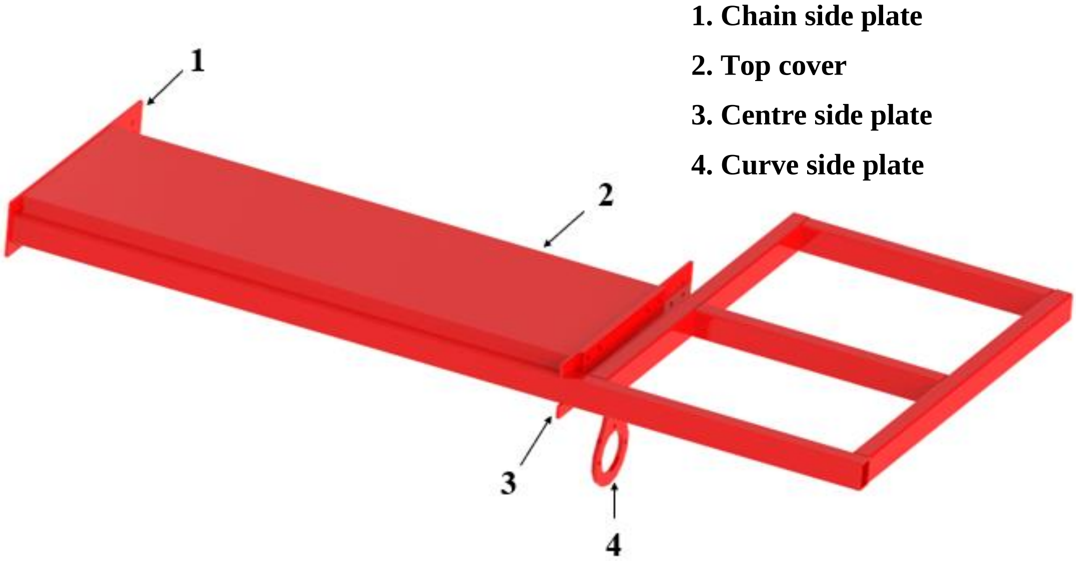

Fig. 3.2 Frame

In order to provide a base for all the machine parts, the centre side plate support was given at the middle (Fig. 3.2b). It was also welded to the rectangular frame pipe and top cover of the machine. It also had provision to fit the rod of back shield and put it in raised, middle or lower positions with nuts and bolts. The curve side plate gets fixed to the centre side plate with nuts and bolts.

The chain side plate (Fig. 3.2c) supports the offset part of the machine which is the part of basin lister. It was also welded to the rectangular frame of the top cover of the machine. It also had provision to fit the chain cover plate with nuts and bolts. The shield was fixed at the backside of the frame to keep it in raised, middle or lower positions with nuts and bolts.

The rotor shaft is the main part where in the cutting blades are bolted. A curve side plate (Fig. 3.2d) was provided to fit the rotor shaft at its bottom side. It provides a base for rotor shaft and cutting blades in striking the soil surface during basin listing operation. It was fixed with the centre side plate at the top and rotor shaft at the bottom with nuts and bolts.

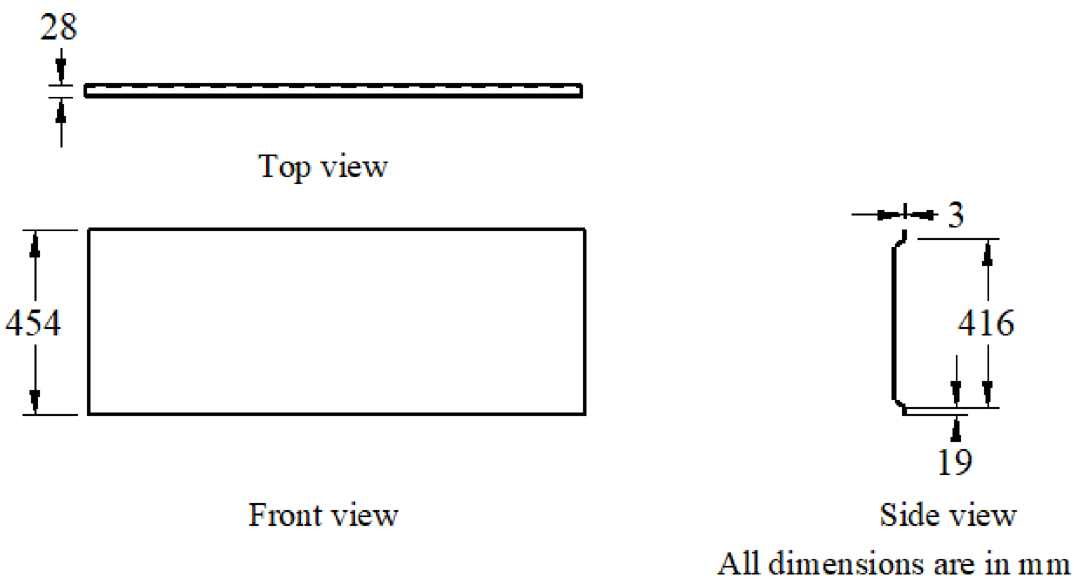

Fig. 3.2a Top cover

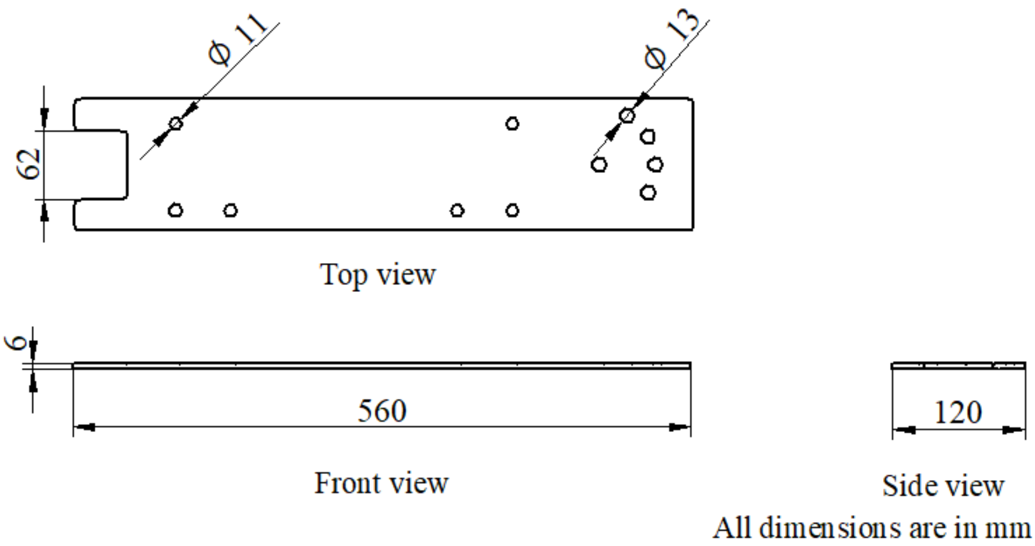

Fig. 3.2b Centre side plate

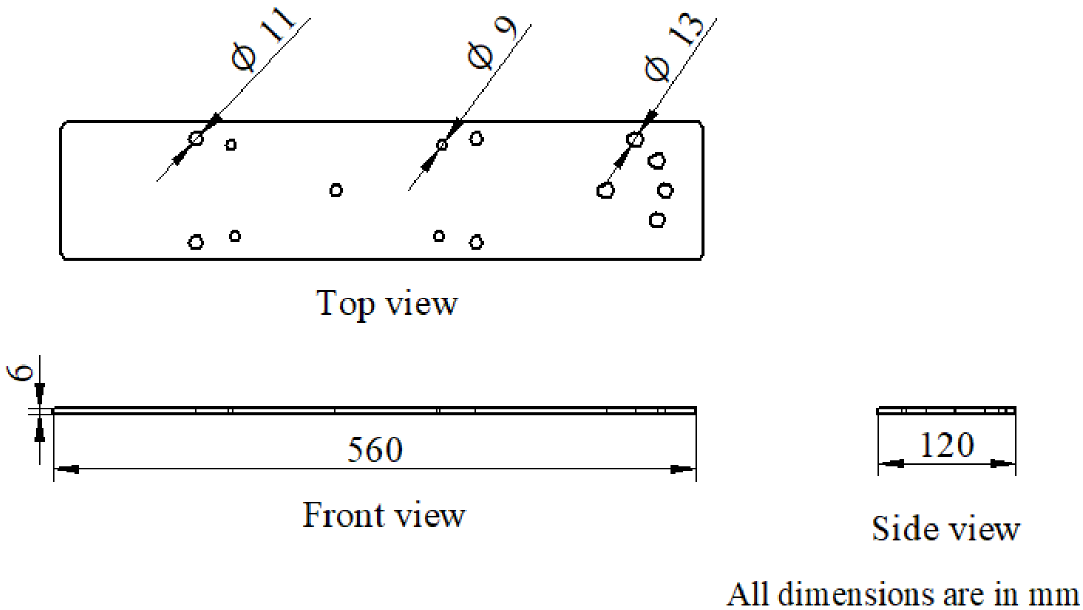

Fig. 3.2c Chain side plate

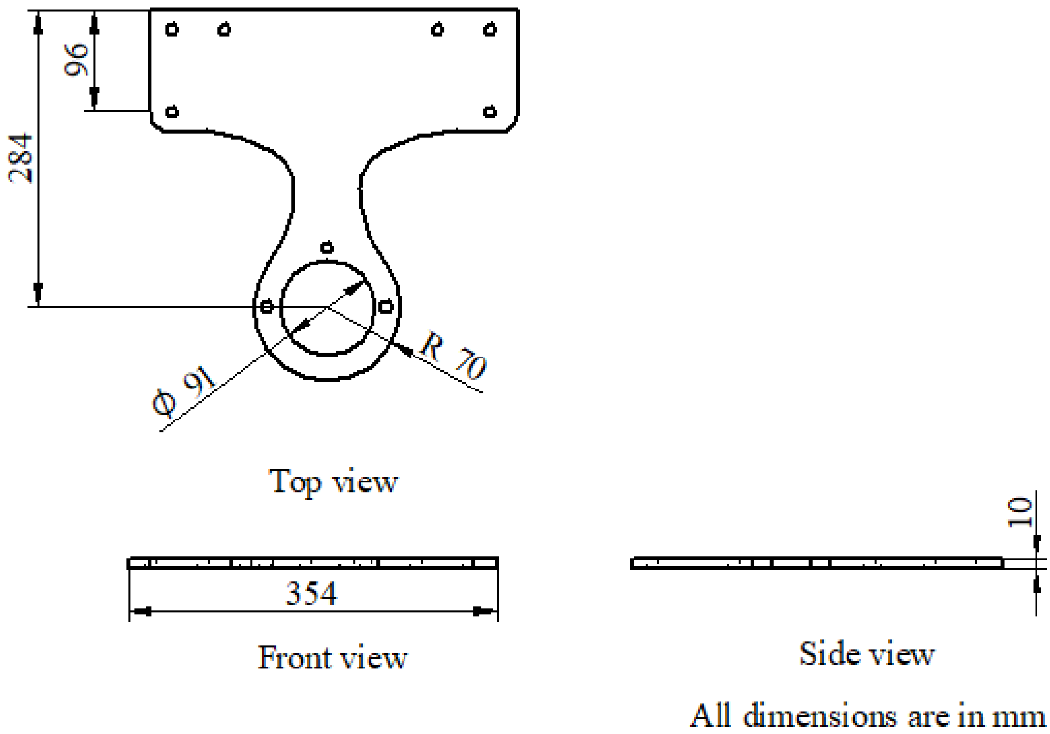

Fig. 3.2d Curve side plate

3.7.2 POWER TRANSMISSION UNITS

The basin lister was provided with a drive for basin listing operation through a suitable power transmission system. It was provided at three stages. In the first stage, power was transmitted from the tractor P.T.O to a gear box. Reverse rotary tilling has less power consumption than forward rotary tilling in deep tillage (Shibusawa, 1993; Takashi and Sakai, 2002). Therefore, reverse rotary tilling was selected for the rotor shaft with cutting blades. In the second stage, power was transmitted from main shaft of gearbox to chain and sprocket drive of the basin lister to rotate the cutting blades in reverse rotary direction to the forward speed of tractor for basin listing operation. In the third stage, power was transmitted from main shaft of gearbox to chain and sprocket drive of the fertilizer applicator reduction shaft to run the fertilizer delivery mechanism of machine. The power train of the basin lister is shown in Fig. 3.3.

The speed ratios, speed of shafts and length of chains of power transmission were calculated using the equation given by Sahay (2013).

A gearbox with 13 teeth pinion gear and 23 teeth bevel gear was purchased to provide drive for basin lister. In the first stage of power train, P.T.O speed of tractor reduced from 540 to 305 rpm of gearbox shaft.

1. Main shaft, 2. Fertilizer applicator drive sprocket 22T, 3. Bevel gear 23T, 4. Pinion 13T, 5. Sprocket 10T, 6. Sprocket 10T, 7. Rotor shaft

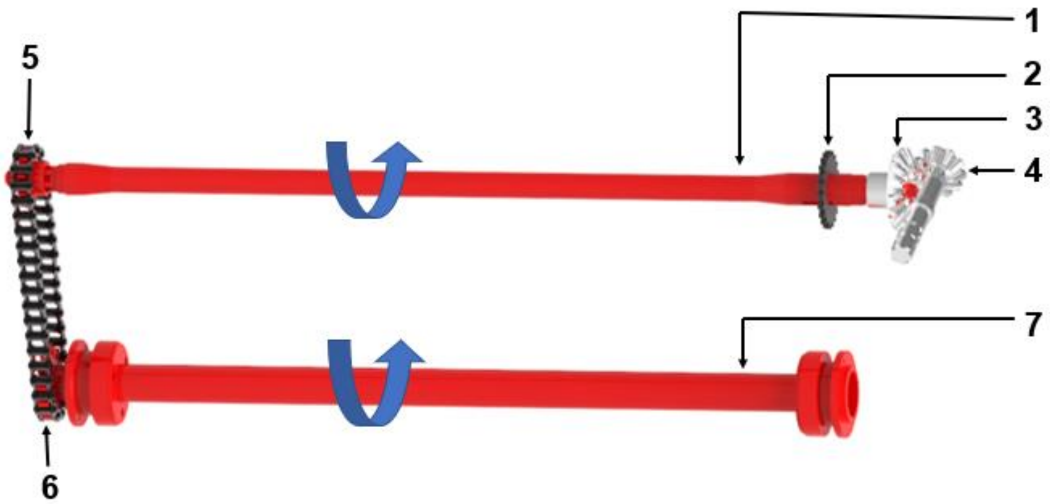

Fig. 3.3 Power train of the basin lister

The number of teeth of sprocket (T_3) in side chain drive mounted on gearbox shaft as 10 and number of teeth of sprocket (T_4) in side chain drive mounted on rotor shaft as 10 were assumed. The speed ratio for second stage power transmission was calculated from the equation.

$$SR = \frac{T_4}{T_3}$$

$$= \frac{10}{10}$$

$$= 1.0$$

where,

SR = Speed ratio

T_3 = Number of teeth of sprocket in side chain drive on gearbox shaft

T_4 = Number of teeth of sprocket in side chain drive on rotor shaft

The rotor shaft speed (N_3) of power transmission system was calculated by using the following equation.

$$N_3 = \frac{N_2\, T_3}{T_4}$$

$$= \frac{305 \times 10}{10}$$

$$= 305 \text{ rpm}$$

where,

N_2 = Speed of sprocket in side chain drive on gearbox shaft, rpm

N_3 = Speed of sprocket in side chain drive on rotor shaft, rpm

T_3 = Number of teeth of sprocket in side chain drive on gearbox shaft

T_4 = Number of teeth of sprocket in side chain drive on rotor shaft

In the second stage power transmission, P.T.O speed of tractor reduced from 540 to 305 rpm of rotor shaft.

The length of chain from sprocket inside chain drive mounted on gearbox shaft to sprocket in side chain drive mounted on rotor shaft for power transmission to rotor shaft (L) was calculated by using the following equation.

$$L = \frac{T_3 + T_4}{2} + \frac{2C}{P} + \frac{T_4 - T_3}{4\pi^2} + \frac{P}{C}$$

$$= \frac{10 + 10}{2} + \frac{2 \times 35.5}{2.54} + \frac{10 - 10}{4 \times \pi^2} + \frac{2.54}{35.5}$$

$$= 38.0$$

where,

T_3 = Number of teeth of sprocket in side chain drive on gearbox shaft, rpm

T_4 = Number of teeth of sprocket in side chain drive on rotor shaft

C = Centre distance between main shaft and rotor shaft, cm

P = Chain pitch, cm

Therefore, the length of chain in second stage power transmission was determined as 38 number of pitches or links.

The number of teeth of sprocket (T_5) for fertilizer applicator drive mounted on gearbox shaft as 22 and number of teeth of sprocket (T_6) mounted on first reduction shaft of fertilizer applicator as 22 were assumed. The speed ratio for third stage power transmission was calculated from the equation.

$$SR = \frac{T_6}{T_5}$$

$$= \frac{22}{22}$$

$$= 1.0$$

where,

SR = Speed ratio

T_5 = Number of teeth of sprocket for fertilizer applicator drive on gearbox shaft

T_6 = Number of teeth of sprocket mounted on first reduction shaft of fertilizer applicator

The first reduction shaft speed (N_4) of fertilizer applicator in power transmission system was calculated with the equation.

$$N_4 = \frac{N_2\ T_5}{T_6}$$

$$= \frac{305 \times 22}{22}$$

$$= 305 \text{ rpm}$$

where,

N_2 = Speed of sprocket for fertilizer applicator drive mounted on gearbox shaft, rpm

N_4 = Speed of sprocket mounted on first reduction shaft of fertilizer applicator, rpm

T_5 = Number of teeth of sprocket for fertilizer applicator drive mounted on gearbox shaft

T_6 = Number of teeth of sprocket mounted on first reduction shaft of fertilizer applicator

In the third stage power transmission, P.T.O speed of tractor reduced from 540 to 305 rpm of first reduction shaft of fertilizer applicator.

The length of chain from sprocket for fertilizer applicator drive mounted on gearbox shaft to sprocket mounted on first reduction shaft of fertilizer applicator for power transmission to fertilizer delivery mechanism was calculated by using the following equation.

$$L = \frac{T_5 + T_6}{2} + \frac{2C}{P} + \frac{T_6 - T_5}{4\pi^2} + \frac{P}{C}$$

$$= \frac{22 + 22}{2} + \frac{2 \times 23.65}{1.58} + \frac{22 - 22}{4 \times \pi^2} + \frac{1.58}{23.65}$$

$$= 52.0$$

where,

T_5 = Number of teeth of sprocket for fertilizer applicator drive on gearbox shaft

T_6 = Number of teeth of sprocket on first reduction shaft of fertilizer applicator

C = Centre distance between main shaft and rotor shaft, cm

P = Chain pitch, cm

Therefore, the length of chain in third stage power transmission was determined as 52 number of pitches or links.

3.7.2.1 Main shaft

The main shaft is the major driving unit of the machine as it provides the required drive for both basin lister and fertilizer applicator. The bevel gear of gearbox was mounted on one side of main shaft while the other side was fitted with 10 teeth sprocket to provide drive to the rotor shaft with cutting blades. It also accommodates 22 teeth sprocket to give drive to the fertilizer applicator. The design of main shaft was done with the equations proposed by Robert *et al*. 2018.

The diameter of main shaft (d) was calculated with the following equation:

$$d = \left(\frac{16\,T}{\pi\,\tau}\right)^{\frac{1}{3}}$$

$$= \left(\frac{16 \times 805.15 \times 1000}{\pi \times 90.8}\right)^{\frac{1}{3}}$$

$$= 35.6 \text{ mm}$$

where,

T = Torque transmitted by the main shaft

τ = Allowable stress on the main shaft

The power available at main shaft (P) was calculated with the following equation by considering 10 per cent power loss from PTO horse power of tractor:

$$P = 0.9 \times 38.25$$
$$= 34.42 \text{ hp}$$
$$= 25686.5 \text{ W}$$

The torque transmitted by the main shaft (T) was calculated with the following equation:

$$T = \frac{P \times 1000}{2 \pi N}$$

$$= \frac{25686.5 \times 1000}{2 \times \pi \times 5.08}$$

$$= 805.15 \times 10^3 \text{ N mm}$$

where,

P = Power available at main shaft = 25686.5 W

N = Speed of main shaft = 305 rpm = 5.08 rps

The allowable stress on main shaft (τ) was calculated with the following equation:

$$\tau = \frac{0.577 \, k \, \sigma_y}{f}$$

$$= \frac{0.577 \times 0.75 \times 420}{2}$$

$$= 90.8 \text{ N mm}^{-2}$$

where,

K = Coefficient of stress concentration = 0.75

F = Coefficient of safety = 2

σ_y = Yield Stress of high carbon steel = 420 N mm^{-2}

Thus, a diameter of 40 mm was opted for main shaft to drive the cutting blades and fertilizer applicator of the machine. The orthographic view of main shaft is shown in Fig. 3.4.

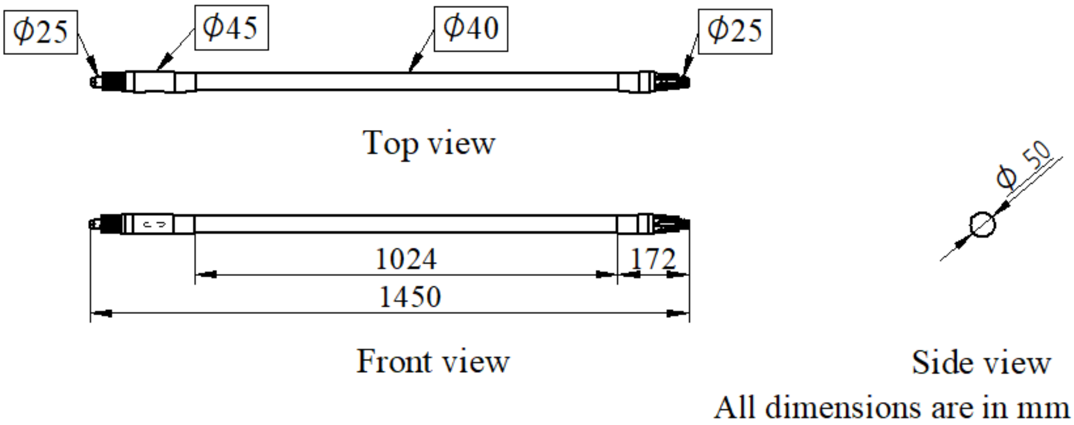

Fig. 3.4 Main shaft

3.7.2.2 Rotor shaft

The rotor shaft supports cutting blades in tilling the soil and throwing it outwards to form a basin. It accommodates the blade holders to which the cutting blades are fixed with nuts and bolts. It was fixed to the couplings on either side to chain side plate and curve side plate with nuts and bolts. The diameter of rotor shaft (d) was calculated by the following equation (Robert *et al.*, 2018).

$$d = \left(\frac{16\ M_S}{\pi\ \tau}\right)^{\frac{1}{3}}$$

$$= \left(\frac{16 \times 134866.6}{\pi \times 4.63}\right)^{\frac{1}{3}}$$

$$= 52.9 \text{ mm}$$

where,

M_S = Maximum moment on rotor shaft = 134866.6 kg mm

T = Allowable stress on rotor shaft = 4.63 kg mm^{-2}

The maximum moment on rotor shaft (M_S) was calculated by the equation (Robert *et al.*, 2018).

$$M_S = K_S \times R$$

$$= 557.3 \times 242$$

$$= 134866.6 \text{ kg mm}$$

where,

K_S = Maximum tangential force sustained by the rotor shaft = 557.3 kg

R = Rotor radius = 242 mm

The maximum tangential force sustained by the rotor shaft (K_S) was calculated using the following equation (Bernacki *et al*., 1972).

$$K_S = \frac{75\ C_S\ N_C\ \eta_C\ \eta_Z}{U_{min}}$$

$$= \frac{75 \times 2 \times 45 \times 0.85 \times 0.75}{7.72}$$

= 557.3 kg

where,

C_S = Reliability factor = 2

N_C = Power of the tractor = 45 hp

η_C = Traction efficiency for reverse rotation of rotor shaft is 0.8 to 0.9

η_Z = Coefficient of reservation of tractor power is 0.7 to 0.8

U_{min} = Peripheral speed of cutting blades = 7.72 m s^{-1}

The peripheral speed of cutting blades (U_{min}) was calculated by using the equation (Bernacki *et al*., 1972).

$$U_{min} = \frac{2\ \pi\ N\ R}{60}$$

$$= \frac{2 \times \pi \times 305 \times 0.242}{60}$$

= 7.72 m s^{-1}

where,

N = Speed of rotor shaft = 305 rpm

R = Rotor radius = 0.242 m

The allowable stress on rotor shaft (τ) was calculated using the following equation (Robert *et al*., 2018).

$$\tau = \frac{0.577\ k\ \sigma_y}{f}$$

$$= \frac{0.577 \times 0.75 \times 42.8}{4}$$

$= 4.63 \text{ kg mm}^{-2}$

where,

k = Coefficient of stress concentration = 0.75

f = Factor of safety = 4

σ_y = Yield Stress of high carbon steel = 42.8 kg mm^{-2}

Thus, a rotor shaft of Ø60 mm diameter was hence selected to accommodate and support the cutting blades. The orthographic view of rotor shaft is shown in Fig. 3.5.

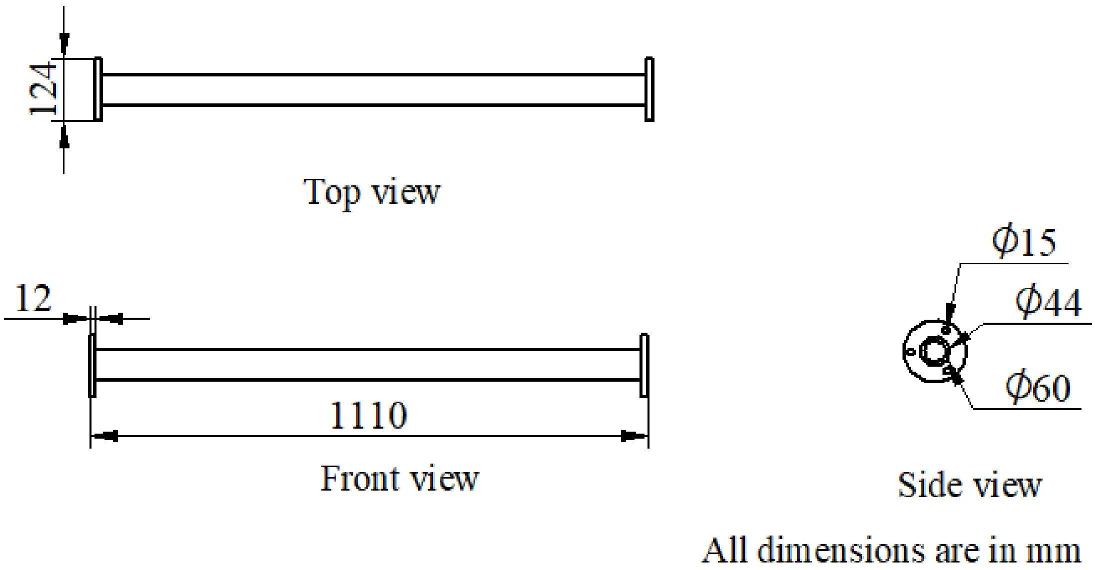

Fig. 3.5 Rotor shaft

3.7.3 Cutting blades

The design of cutting blade of the basin lister has a considerable effect on the basin listing operation as it is responsible for tilling and displacing the soil slice from soil. The shape of cutting blade was selected as per the literature review. The different shapes of cutting blades used for rotary tilling are flat, 'C', 'L', 'J' type blades etc. Among the different cutting blade shapes, 'J' type blade was primarily used for deep tillage and has better soil throwing ability. These types of blades are suitable for orchards (Ahmad, 2009; Jyotirmay, 2017). The power requirement of 'J' type blades was less when compared to 'L' type blades for deep tillage (Shibusawa, 1993). Therefore, 'J' type blade was hence selected for the study by considering its utility to till and throw the soil out of the basin around coconut palm. It was fixed with nuts and bolts to the blade holder which was welded to the rotor shaft.

The peripheral force acting on each of the cutting blades (K) was found out by the following equation (Bernacki *et al*., 1972).

$$K = \frac{K_o}{\left(\frac{n}{4}\right)}$$

$$= \frac{3327}{\frac{19}{4}}$$

$$= 700.4 \text{ N}$$

where,

K_o = Peripheral force acting on rotor shaft = 3.327 kN

n = Number of cutting blades = 19

The maximum moment acting on each of the cutting blades (M) was calculated by the following equation (Bernacki *et al*., 1972).

$$M = K \times R$$

$$= 700.4 \times 0.242$$

$$= 169.4 \text{ N m}$$

where,

K = Peripheral force acting on each of the cutting blades, N

R = Rotor radius, m

The commercially available ‘J’ type blades were used in the machine and the width (h_e), thickness (b_e), cutting width (S_s) and height (S) of blade were 24.5, 9.5, 51.46 and 158 mm respectively. A plate was welded to the cutting blade end so that it helped in scooping of cut soil to form a bund around coconut palm. The different blade to plate angles of 100, 110 and 120 deg. were used in the field to evaluate the developed basin lister. The orthographic view and fabricated cutting blade were shown in Fig. 3.6 and Plate. 3.3 respectively.

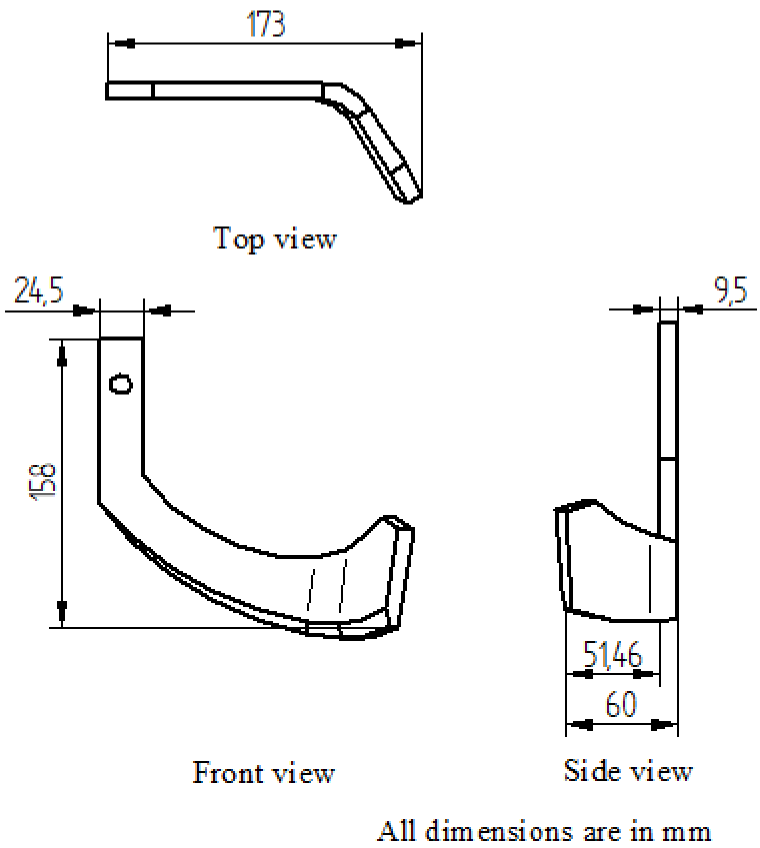

Fig. 3.6 Cutting blade

Plate. 3.3 Cutting blade

The bending stress (σ_{zg}), shear stress (τ_{skt}), and equivalent stress (σ_{zt}) of blades were determined and compared with the results obtained by various researchers (Zareiforoush *et al.*, 2010; Thorat, 2013). These stresses were calculated using the following equations proposed by Bernacki *et al*. (1972).

$$\sigma_{zg} = \frac{6\,K\,S}{b_e\,h_e^{\,2}}$$

$$= \frac{6 \times 700.4 \times 158}{9.5 \times 24.5^2}$$

$= 116.4\ N\ mm^{-2}$

$$\tau_{skt} = \frac{3\ K\ S_S \times 60}{\left(\frac{h_e}{b_e} - 0.63\right) {b_e}^3 \times 100}$$

$$= \frac{3 \times 700.4 \times 51.46 \times 60}{\left(\frac{24.5}{9.5} - 0.63\right) \times 9.5^3 \times 100}$$

$= 38.8\ N\ mm^{-2}$

$$\sigma_{zt} = \sqrt{{\sigma_{zg}}^2 + 4\ {\tau_{skt}}^2}$$

$$= \sqrt{116.4^2 + (4 \times 38.8^2)}$$

$= 139.8\ N\ mm^{-2}$

The bending stress, shear stress and equivalent stress acting on cutting blades bolted to blade holders welded on rotor shaft were 116.4, 38.8 and 139.8 N mm^{-2} respectively.

3.7.4 Chain cover

The chain cover accommodated two 10 teeth sprockets with chain for power transmission from main shaft of gearbox to rotor shaft of basin lister. It also carries oil for lubricating the chain and sprocket to prevent wear and tear during power transmission. Inlet port was provided to chain cover for filling the lubrication oil. The chain cover was fixed to the chain side plate with bolts and nuts. The orthographic view and fabricated chain cover were depicted in Fig. 3.7 and Plate. 3.4 respectively.

3.7.5 Main shaft cover

The main shaft cover houses the entire length of main shaft of the machine. It was provided to avoid any accidents to the operators during operation of the machine. The main shaft was fixed on the top cover of the machine with nuts and bolts. The orthographic view of main shaft cover is shown in Fig. 3.8.

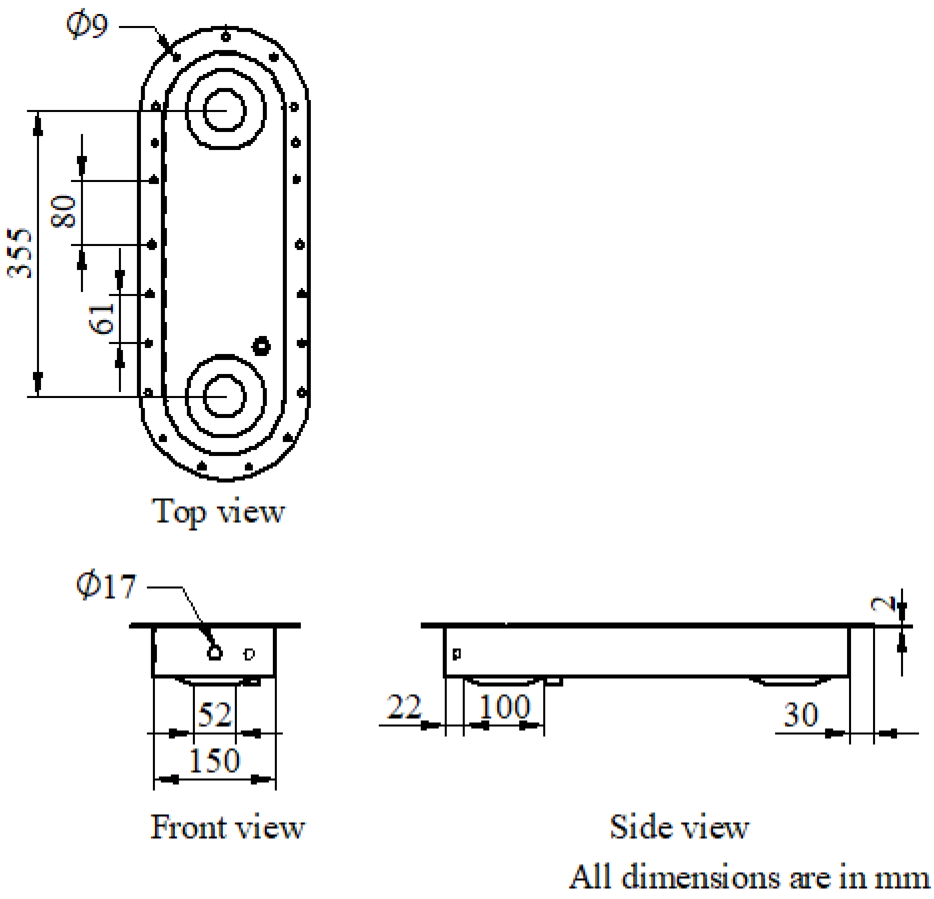

Fig. 3.7 Chain cover

Plate. 3.4 Chain cover

3.7.6 Shield

The shield was provided at the back end of cutting blades of basin lister. It stopped heavy boulders, stones and trash from moving out of the basin and avoided accidents to the operators of machine. The shield was fixed at the backside of frame chain side plate and frame centre side plate to keep it in raised, middle or lower positions with nuts and bolts. The orthographic view of shield is shown in Fig. 3.9.

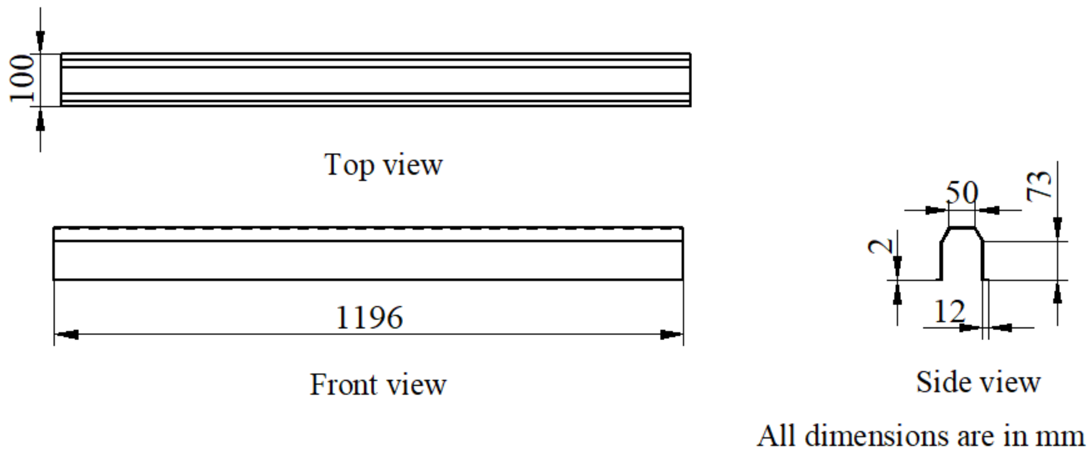

Fig. 3.8 Main shaft cover

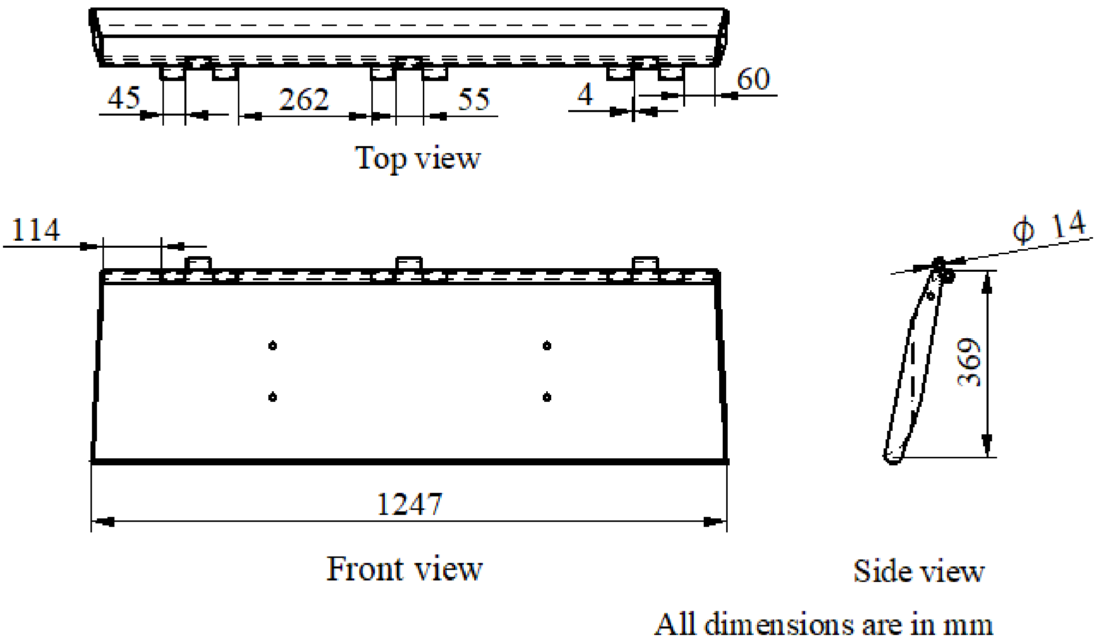

Fig. 3.9 Shield

3.7.7 Skid

Skid was provided at the side of the chain side plate and chain cover. It helps in maintaining the depth of operation of basin lister. Skid has a curve plate to which two plates were welded at each end to fix the skid adjuster plate. Skid adjuster plate was fixed to the chain side plate through welded plate by nut and bolt. The orthographic view and fabricated skid were shown in Fig. 3.10 and Plate 3.5 respectively. Three positions of skid height from ground level viz., 20.0, 17.5 and

15.0 cm were provided to change the depth of operation to low, medium and high respectively according to the requirement in the field.

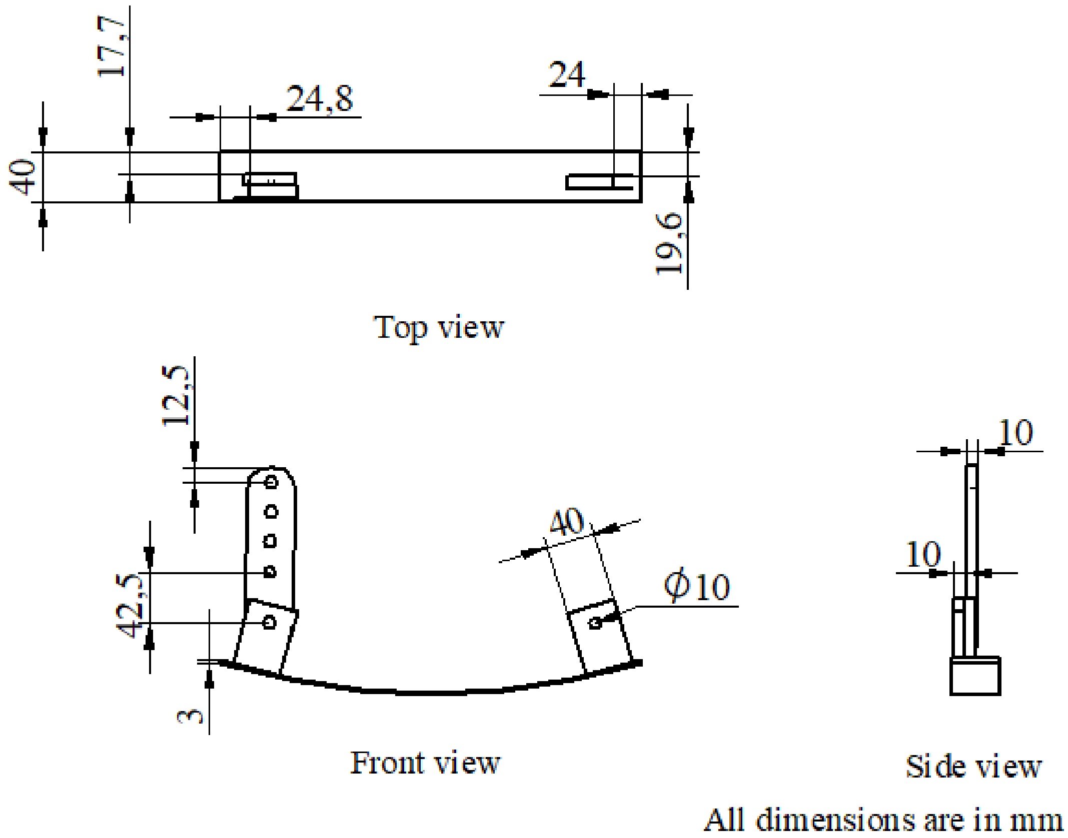

Fig. 3.10 Skid

Plate. 3.5 Skid

3.8 FERTILIZER APPLICATOR

The design of fertilizer applicator was accomplished by taking into account the fertilizer parameters and its requirement for coconut palms and was detailed below.

3.8.1 FERTILIZER REQUIREMENT FOR COCONUT PALMS

The fertilizers should be applied in three equal doses during the months of April-May, August-September, December and February-March every year. The fertilizer recommendation for good management per coconut palm per year for three equal doses are respectively as 0.50 N : 0.32 P_2O_5 : 1.20 K_2O kg (KAU, 2016). The fertilizers used for growth of coconut palms are urea, rock phosphate and muriate of potash. The fertilizer requirement was calculated as 1.56 kg palm^{-1} dose^{-1} year^{-1} using the equation proposed by Hasanuzzaman (2020) and their calculations were given in Appendix-III.

3.8.2 DESIGN AND DEVELOPMENT OF LAB MODEL OF A FERTILIZER APPLICATOR

An experimental setup with lab model of fertilizer applicator was made before the development of prototype of fertilizer applicator to finalize its metering mechanism. The lab model design of fertilizer applicator is shown in Fig. 3.11.

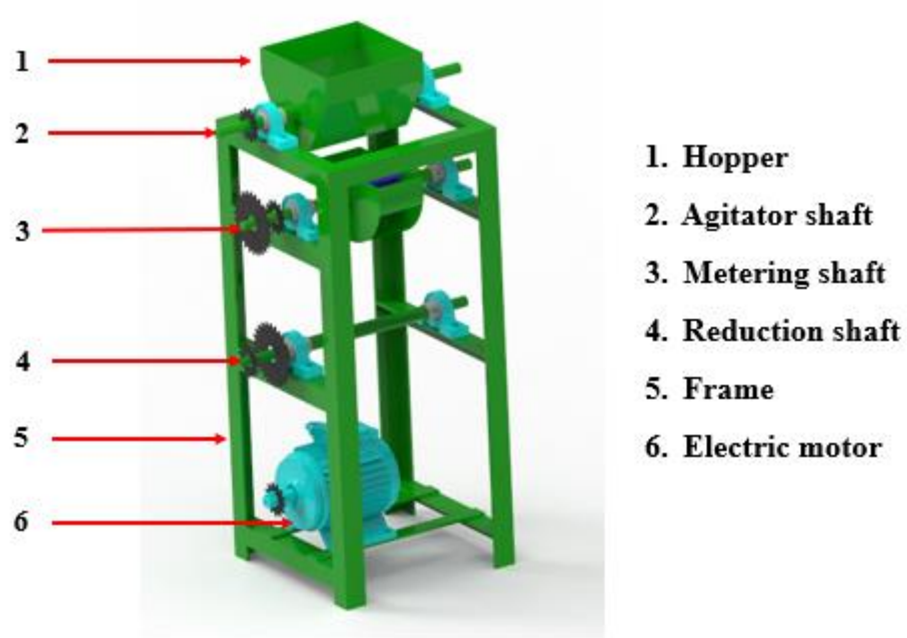

Fig. 3.11 Lab model of fertilizer applicator

3.8.2.1 Frame

A frame for the lab model of the fertilizer applicator consists of platform to support all parts. It accommodates hopper, agitator, metering roller, metering housing, delivery pipe, sprockets, chain, bearing blocks, drive shafts and other parts. The frame is shown in Fig. 3.12.

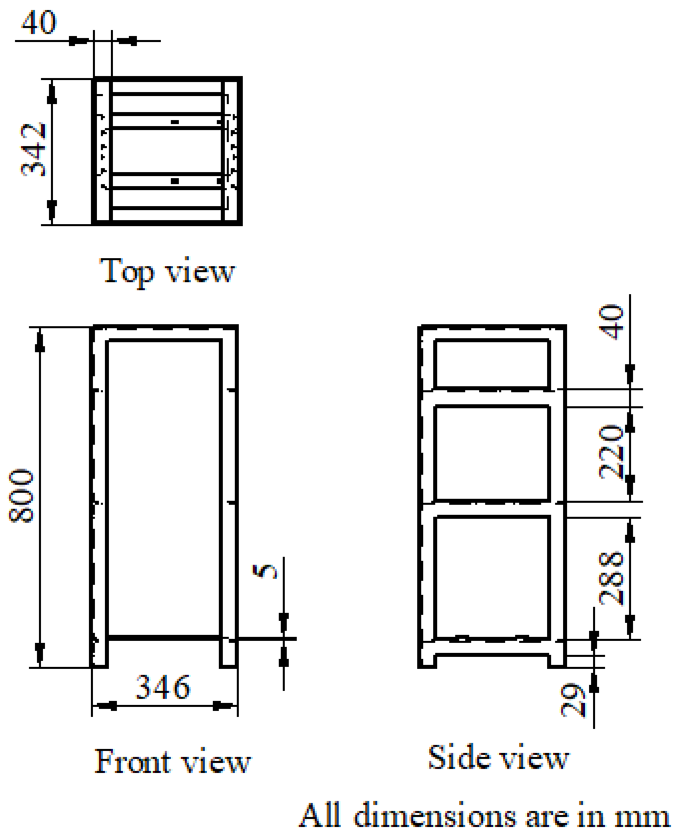

Fig. 3.12 Frame

3.8.2.2 Hopper

The hopper was designed to carry a weight of 5 kg fertilizer. The volume of hopper for lab model of fertilizer applicator (V) was calculated using the equation (Kumar, 2015).

$$V = \frac{W}{BD}$$

$$= \frac{5}{1100 \times 10^{-9}}$$

$$= 4546 \times 10^3 \text{ mm}^3$$

where,

V = Volume of hopper, mm^3

W = Weight of fertilizer = 5 kg

BD = Bulk density of fertilizer = 1100×10^{-9} kg mm^{-3}

The bottom and top sections of hopper were made of MS trapezoidal and square sections. The inclination of sides of hopper were made with respect to measured angle of repose of fertilizer of 40.8 deg. to enable the uniform flow of fertilizer from the hopper to metering roller. A hopper having a volume of 4800×10^3 mm^3 was designed to carry 5.28 kg fertilizer. The hopper of the lab model of the fertilizer applicator was fitted on frame by providing support flats at back and front end to fix to frame with nuts and bolts. It was also designed to accommodate the agitator and its shaft to prevent fertilizer from clogging and to deliver the recommended fertilizer quantity. A sliding shutter was fixed at the bottom of hopper to provide an outlet for fertilizer delivery to the metering roller. The details of the hopper were shown in Fig. 3.13.

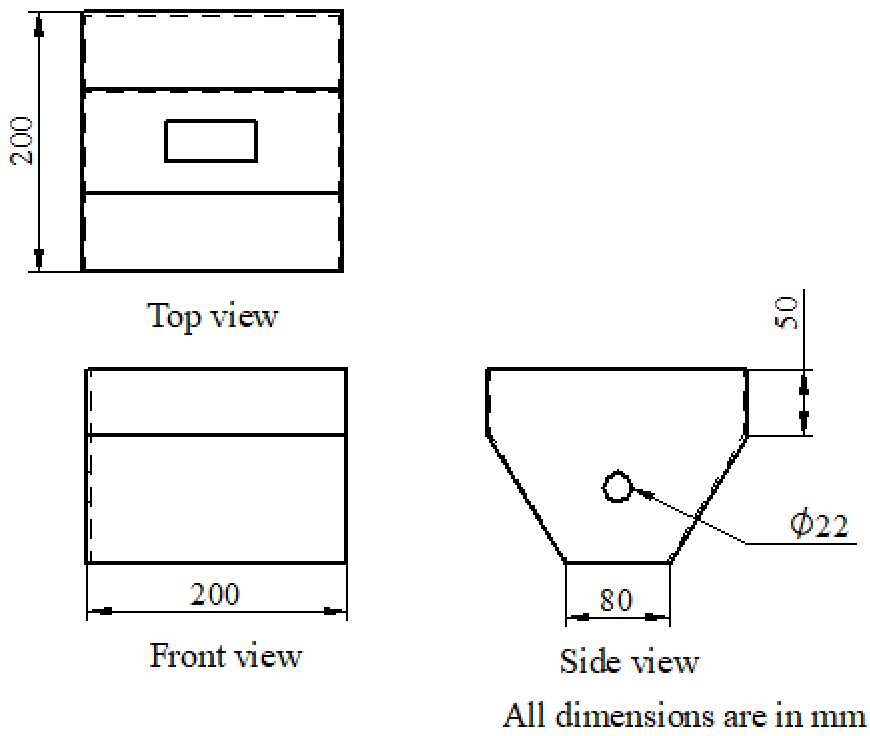

Fig. 3.13 Hopper

3.8.2.3 Power transmission units

The power transmission unit for the lab model (Fig. 3.14) was provided in three stages and were explained below.

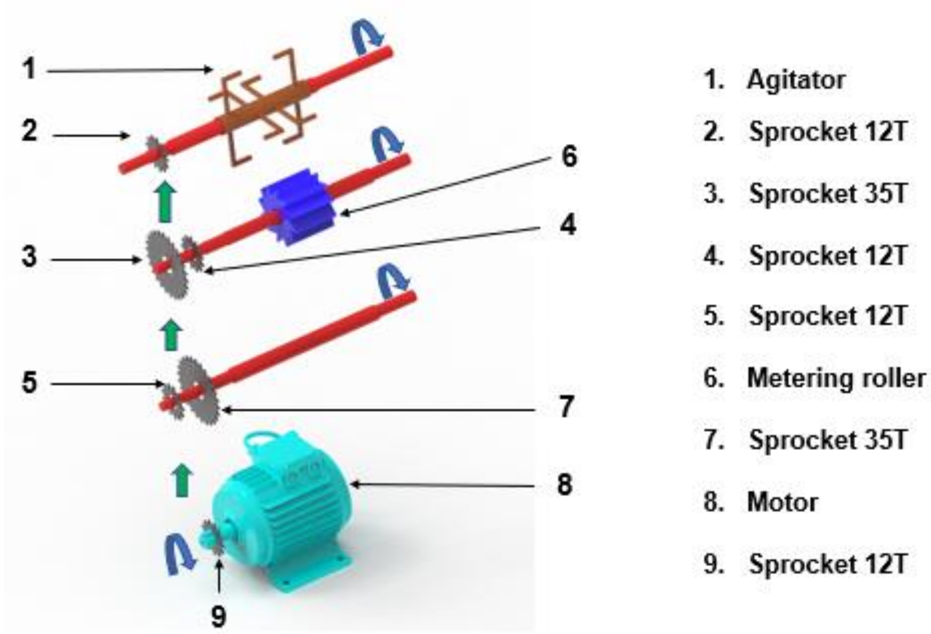

Fig. 3.14 Power transmission unit of the lab model

The speed ratios, speed of shafts and length of chains of power transmission were calculated using the equation given by Sahay (2013).

In the first stage of power transmission, the number of teeth of sprocket mounted on electric motor shaft (T_1) and reduction shaft (T_2) of the lab model are 12 and 35 respectively. The speed ratio for this stage of power transmission was found out as 2.91.

The reduction shaft speed (N_2) of the lab model was calculated as 104 rpm. Thus, in the first stage power transmission, the speed of electric motor reduced from 305 to 104 rpm for the reduction shaft of the lab model of the fertilizer applicator. The length of chain from sprocket mounted on electric motor shaft to sprocket mounted on reduction shaft of the lab model was calculated by using the following equation.

$$L = \frac{T_1 + T_2}{2} + \frac{2C}{P} + \frac{T_2 - T_1}{4\pi^2} + \frac{P}{C}$$

$$= \frac{12 + 35}{2} + \frac{2 \times 30.3}{1.9} + \frac{35 - 12}{4 \times \pi^2} + \frac{1.9}{30.3}$$

$$= 56$$

where,

T_1 = Number of teeth of sprocket mounted on electric motor shaft = 12

T_2 = Number of teeth of sprocket mounted on reduction shaft = 35

C = Centre distance between electric motor and reduction shaft = 30.3 cm

P = Chain pitch = 1.9 cm

Therefore, the length of chain in first stage power transmission was determined as 56 number of pitches or links. The reduction shaft provided drive from electric motor to the metering shaft of lab model of the fertilizer applicator by reducing the speed with sprockets and chain. The orthographic view of the reduction shaft is shown in Fig. 3.15.

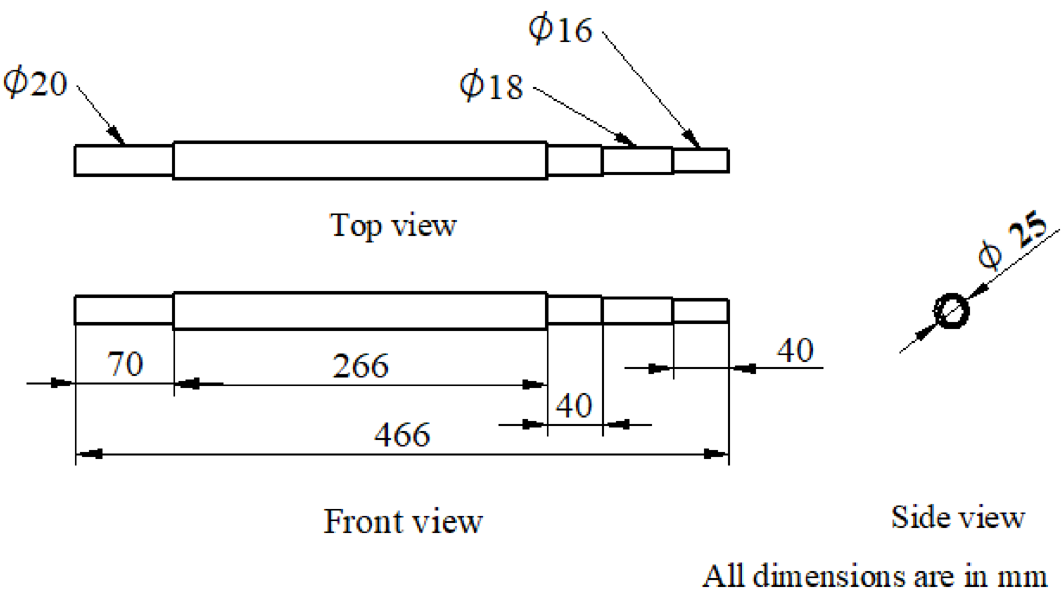

Fig. 3.15 Reduction shaft

In the second stage of power transmission, the number of teeth of sprocket mounted on reduction shaft (T_3) and metering shaft (T_4) of lab model of fertilizer applicator were taken as 12 and 35 respectively. The speed ratio for this stage of power transmission was calculated as 2.91.

The speed of metering shaft (N_3) of the lab model was calculated as 35 rpm. Thus, in second stage power transmission, the speed further reduced from 104 to 35 rpm of metering shaft of the lab model of fertilizer applicator.

The length of chain from sprocket mounted on reduction shaft to sprocket mounted on metering shaft was found out as 54 using the following equation.

$$L = \frac{T_3 + T_4}{2} + \frac{2C}{P} + \frac{T_4 - T_3}{4\pi^2} + \frac{P}{C}$$

$$= \frac{12 + 35}{2} + \frac{2 \times 28.2}{1.9} + \frac{35 - 12}{4 \times \pi^2} + \frac{1.9}{28.2}$$

$$= 54$$

where,

T_3 = Number of teeth of sprocket mounted on reduction shaft = 12

T_4 = Number of teeth of sprocket mounted on metering shaft = 35

C = Centre distance between second and metering shaft = 28.2 cm

P = Chain pitch = 1.9 cm

The metering shaft receives the drive from reduction shaft to run the metering roller and agitator by reducing the speed with the sprockets and chain. It was accommodated in a housing and the metering roller was provided at the centre to deliver recommended fertilizer quantity. The details of the metering shaft were illustrated in Fig. 3.16.

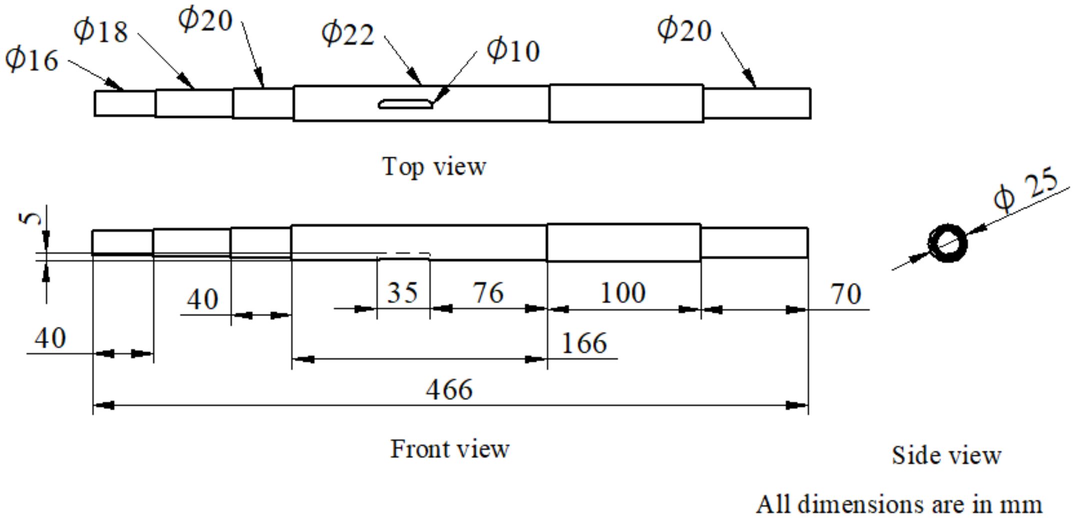

Fig. 3.16 Metering shaft

In the third stage of power transmission, the number of teeth of sprocket mounted on metering shaft (T_5) and agitator shaft (T_6) of lab model was taken as 12. The speed ratio for this stage of power transmission was obtained as 1. Accordingly, the speed of agitator shaft (N_4) of lab model was calculated as 35 rpm by using the standard equation. Also, in the third stage power transmission, the speed of electric motor shaft was further reduced from 305 to 35 rpm for the agitator shaft of lab model of fertilizer applicator.

The length of chain from sprocket mounted on metering shaft to sprocket mounted on agitator shaft was found out as 28 by using the equation,

$$L = \frac{T_5 + T_6}{2} + \frac{2C}{P} + \frac{T_6 - T_5}{4\pi^2} + \frac{P}{C}$$

$$= \frac{12 + 12}{2} + \frac{2 \times 15}{1.9} + \frac{12 - 12}{4 \times \pi^2} + \frac{1.9}{15}$$

$$= 28$$

where,

T_5 = Number of teeth of sprocket mounted on metering shaft = 12

T_6 = Number of teeth of sprocket mounted on agitator shaft = 12

C = Centre distance between second and metering shaft = 15 cm

P = Chain pitch = 1.9 cm

The agitator shaft receives the drive from the metering shaft to rotate the agitator at the reduced speed. It accommodated the agitator at the centre to deliver the recommended fertilizer without clogging. The orthographic view of the agitator shaft is shown in Fig. 3.17.

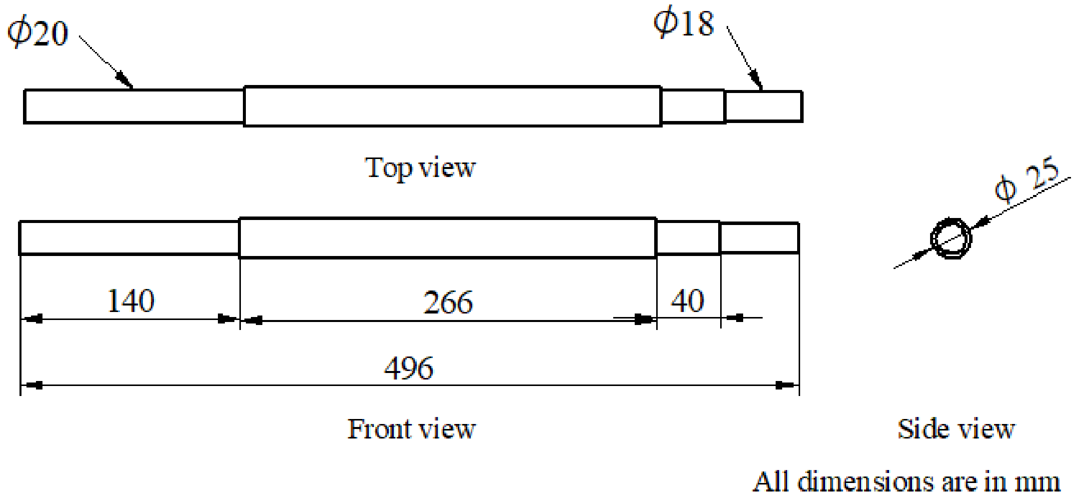

Fig. 3.17 Agitator shaft

3.8.2.4 Metering mechanism

The metering mechanism of the lab model of fertilizer applicator must be designed to deliver the required fertilizer quantity. It consists of metering roller, metering shaft and chain and sprockets drive. The detailed description and calculations of metering mechanism are described below.

The circumference of fertilizer droppage by machine (C) in the basin was determined by the following equation by assuming the distance of fertilizer droppage (d) as 1.2 m from coconut palm.

$$C = \pi\,(d + BD + d)$$

$$= \pi\,(1.2 + 0.35 + 1.2)$$

$$= 8.63 \text{ m}$$

where,

C = Circumference of fertilizer droppage by the machine, m

d = Distance of fertilizer droppage from coconut palm, m

BD = Trunk diameter of coconut palm, m

The time required to cover the circumference of fertilizer droppage by the machine (t) around coconut palm was calculated with the following equation.

$$t = \frac{C}{S}$$

$$= \frac{8.63 \times 60 \times 60}{2000}$$

$$= 15.5 \text{ s}$$

where,

C = Circumference of fertilizer droppage by the machine, m

S = Forward speed of machine, m s^{-1}

The number of revolutions of metering roller (n) to deliver the required fertilizer by covering the circumference of coconut palm was calculated with the following equation.

$$n = N_6 \times t$$

$$= \frac{35}{60} \times 15.5$$

= 9 rev

where,

n = Number of revolutions of metering roller to deliver required fertilizer, rev

N_6 = Speed of metering roller = 35 rpm = 35/60 rps

t = Time required to cover circumference of fertilizer droppage by machine, s

The three types of metering rollers viz., Edge cell, fluted cell and baffle cell (Bosai *et al.,* 1987; Devnai, 1991; Kepner *et al.,* 2005; Salsan, 2017) were designed to determine the optimum fertilizer delivery from the lab model of fertilizer applicator. The design of three metering rollers were illustrated in the Appendix-IV.

i. Edge cell metering roller

The weight of fertilizer per palm delivered by edge cell metering roller (W) was found out as 1.56 kg as explained in section 3.8.1. The orthographic view and 3-D printed edge cell metering roller were shown in Fig. 3.18 and Plate 3.6 respectively.

ii. Fluted cell metering roller

The weight of fertilizer per palm delivered by fluted cell metering roller (W) was found out as 1.56 kg as explained in section 3.8.1. The orthographic view and 3-D printed fluted cell metering roller were shown in Fig. 3.19 and Plate 3.7 respectively.

iii. Baffle cell metering roller

The weight of fertilizer per palm delivered by baffle cell metering roller (W) was found out as 1.56 kg as explained in section 3.8.1. The orthographic view and 3-D printed baffle cell metering roller were shown in Fig. 3.20 and Plate 3.8 respectively.

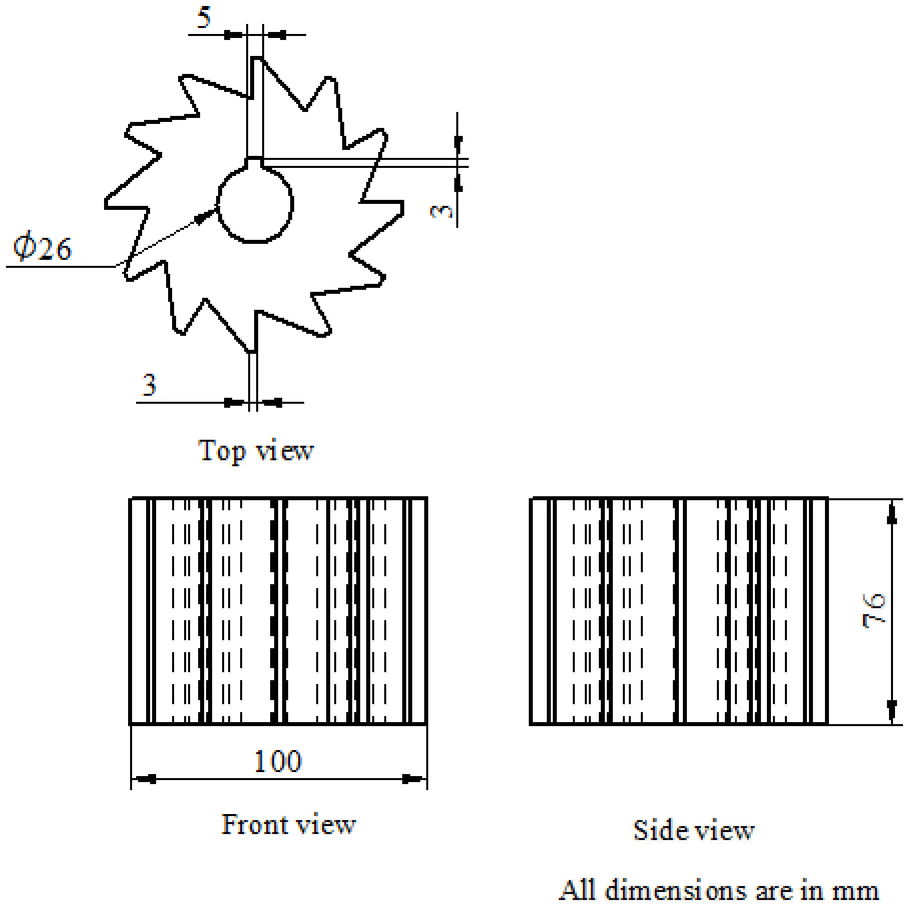

Fig. 3.18 Edge cell metering roller

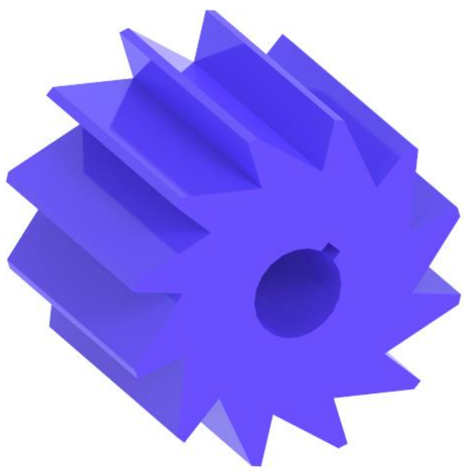

Plate. 3.6 Edge cell metering roller

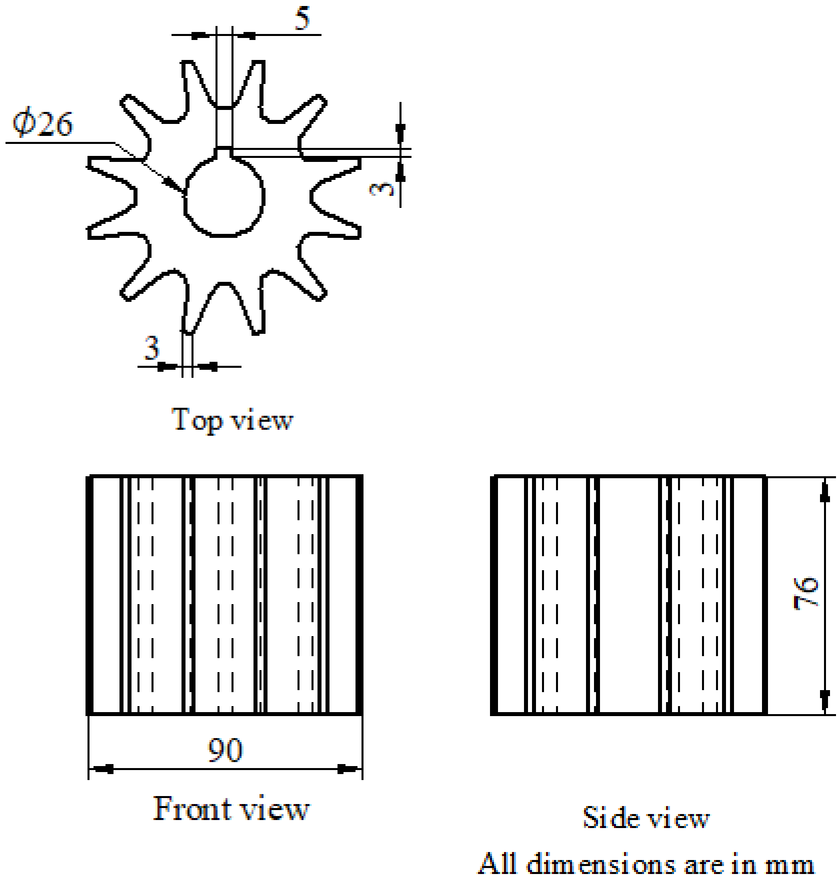

Fig. 3.19 Fluted cell metering roller

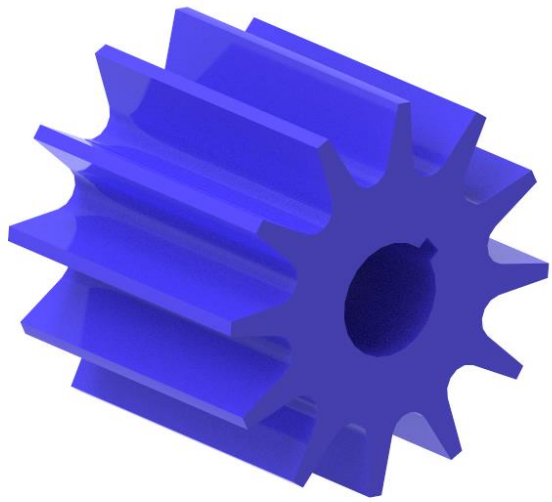

Plate. 3.7 Fluted cell metering roller

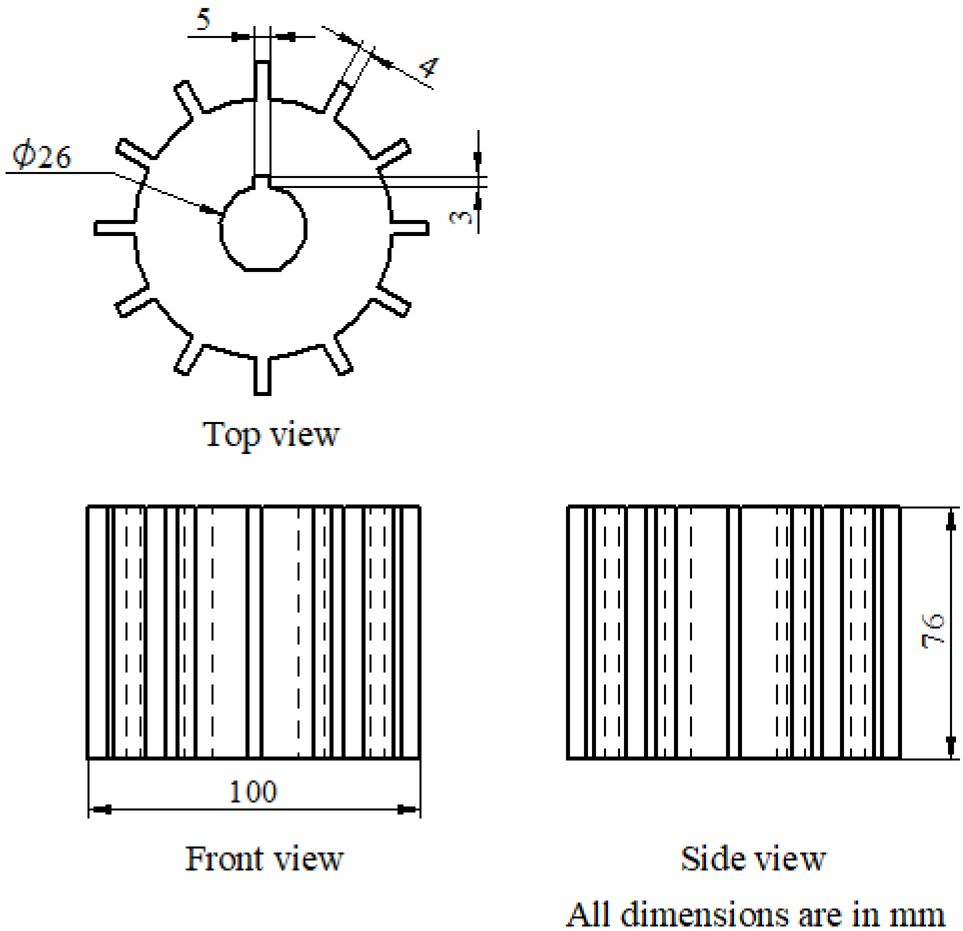

Fig. 3.20 Baffle cell metering roller

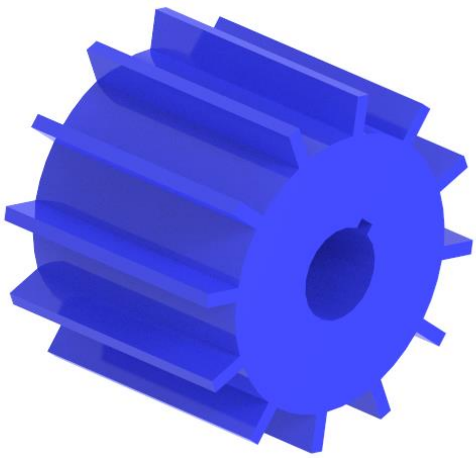

Plate. 3.8 Baffle cell metering roller

The metering housing accommodated the metering roller inside it. It prevented the fertilizer to flow out and allowed the fertilizer to be contained in the metering roller so that the recommended quantity of fertilizer was delivered. It was arranged offset to the downside of hopper opening so that a fertilizer buffer was created at the back so that continuous fertilizer band was delivered. The orthographic view of metering housing is shown in Fig. 3.21.

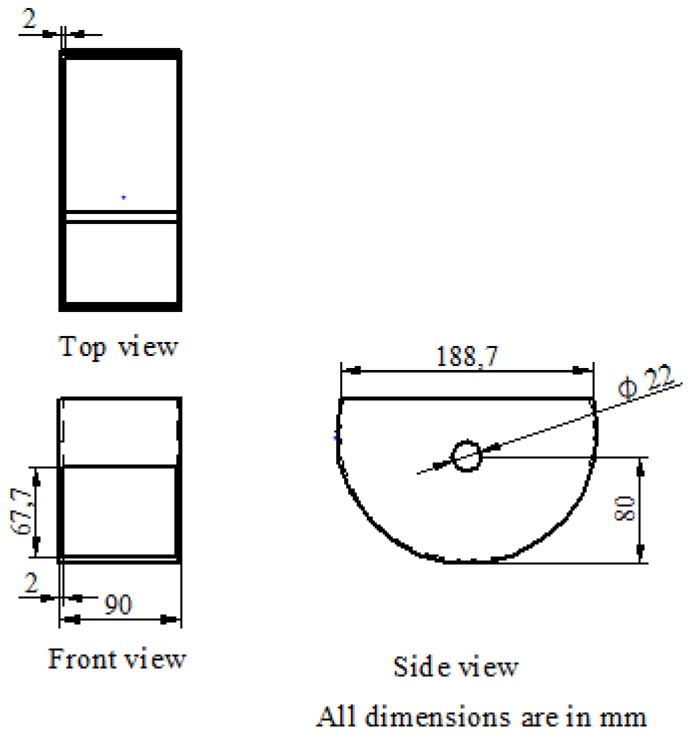

Fig. 3.21 Metering housing

3.8.2.5 Agitator

The agitator prevented fertilizer from clogging in hopper and delivered the recommended fertilizer quantity. L- shape agitator was placed in the hopper by fixing to the agitator shaft with clips, nuts and bolts. The orthographic view and fabricated agitator were presented in Fig. 3.22 and Plate. 3.9 respectively.

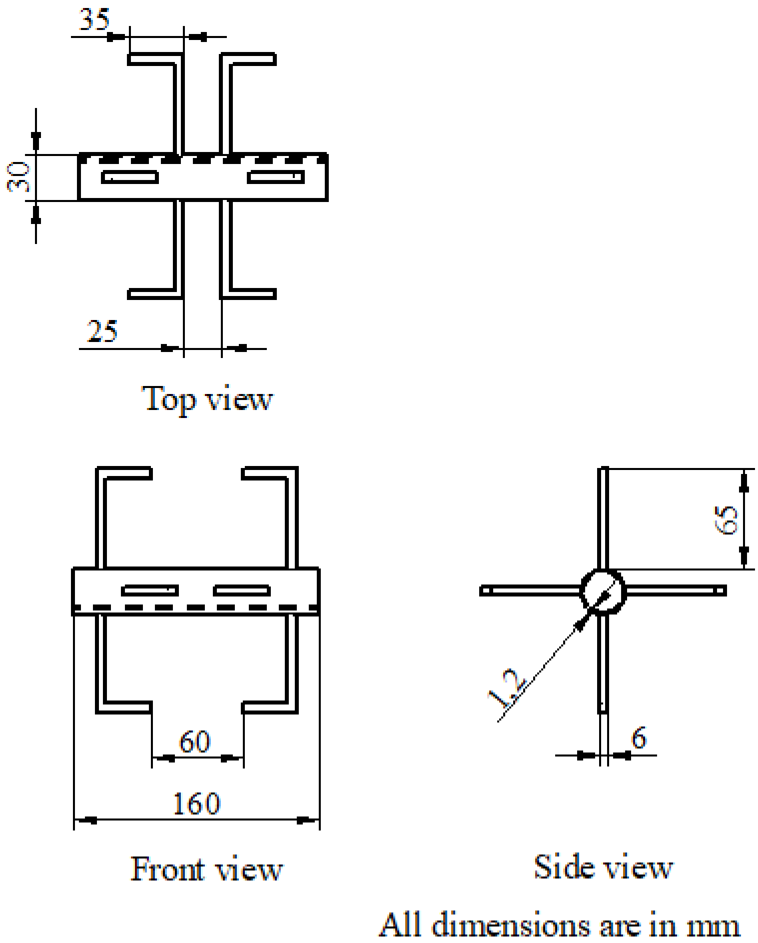

Fig. 3.22 Agitator

Plate. 3.9 Agitator

The developed lab model of fertilizer applicator is shown in Plate. 3.10.

Plate. 3.10 Lab model of fertilizer applicator

3.8.3 EVALUATION OF THE LAB MODEL OF THE FERTILIZER APPLICATOR

The lab model of fertilizer applicator was evaluated for different metering roller types *viz.*, edge, fluted and baffle cell in terms of fertilizer discharge. It was evaluated to obtain the recommended fertilizer discharge of 1.56 kg. The procedure of fertilizer discharge measurement was explained below.

3.8.3.1 Fertilizer discharge

The fertilizer discharge was measured while operating the lab model of fertilizer applicator with an electric motor driven by the variable frequency drive equipment. A polythene cover was tied at the outlet of metering housing to collect the fertilizer from lab model of a fertilizer applicator. The performance evaluation was conducted to optimize the different metering roller types *viz.*, edge, fluted and baffle cell to determine the recommended fertilizer discharge of 1.56 kg palm^{-1}. The evaluation was repeated for 30 times to determine the optimum metering roller.

3.8.4 DEVELOPMENT OF THE PROTOTYPE OF FERTILIZER APPLICATOR

The prototype of fertilizer applicator was developed by considering the measured soil, crop and fertilizer parameters. This fertilizer applicator was designed in the same way as that of the lab model. In mechanical fertilizer application, the recommended fertilizer quantity of 1.56 kg palm^{-1} is applied from hopper through metering roller and delivery pipe to the basins formed by basin lister from base of the coconut palm so that it is utilized by the root zone for optimum growth.

3.8.4.1 Frame

The frame of prototype of fertilizer applicator provides a platform for hopper, agitator, metering roller, metering housing, delivery pipe, sprockets, chain, bearing blocks and other parts. It was mounted behind the gearbox to take drive from it. It was fixed to the angle pieces welded on frame of machine with nuts and bolts. The orthographic view of frame is shown in Fig. 3.23.

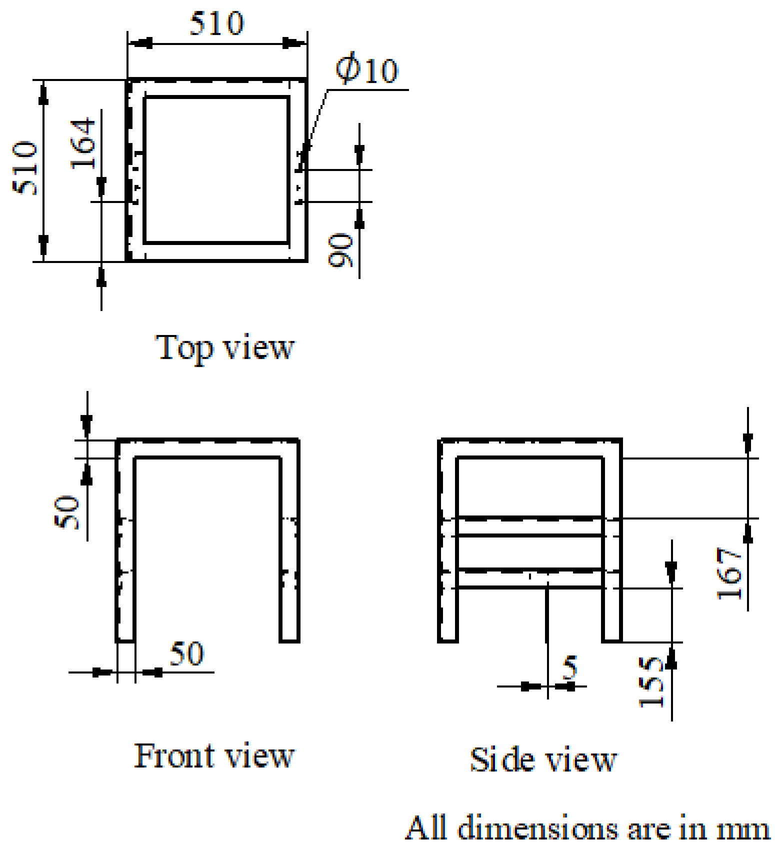

Fig. 3.23 Frame

3.8.4.2 Hopper

The hopper was designed to carry a weight of 90 kg fertilizer with the consideration of more than 3 refills per hectare as the fertilizer application rate per hectare for coconut palms is 312 kg. The volume of hopper (V) was calculated as the following (Kumar, 2015).

$$V = \frac{W}{BD}$$

$$= \frac{90}{1100 \times 10^{-9}}$$

$$= 81818 \times 10^3 \text{ mm}^3$$

where,

V = Volume of hopper, mm^3

W = Weight of fertilizer = 90 kg

BD = Bulk density of fertilizer = 1100×10^{-9} kg mm^{-3}

The hopper was considered in the shape of trapezoidal footing to uniformly deliver the fertilizer through a single outlet to the metering roller. The following dimensions of hopper were assumed.

1. Top length (L_1) = 600 mm
2. Top width (B_1) = 600 mm
3. Bottom length (L_2) = 100 mm
4. Bottom width (B_2) = 80 mm
5. Height (H) = 600 mm

The top area of hopper (A_1) was calculated by the following equation.

$$A_1 = L_1 \times B_1$$

$$= 600 \times 600$$

$$= 36 \times 10^4 \text{ mm}^2$$

The bottom area of hopper (A_2) was calculated by the following equation.

$$A_2 = L_2 \times B_2$$

$$= 100 \times 80$$

$$= 8 \times 10^3 \text{ mm}^2$$

The volume of hopper (V) was calculated by the following equation.

$$V = \frac{H}{3}\left[A_1 + A_2 + \sqrt{A_1 A_2}\right]$$

$$= \frac{600}{3} \times \left[(36 \times 10^4) + (8 \times 10^3) + \sqrt{(36 \times 10^4) \times (8 \times 10^3)}\right]$$

$$= 84333 \times 10^3 \text{ mm}^3$$

A hopper having a volume of 84333×10^3 mm^3 was designed to carry 92.7 kg fertilizer.

The hopper was fixed to frame of the prototype of fertilizer applicator with the support flats welded at its front and back. It accommodates the agitator and its shaft to prevent fertilizer from clogging and deliver the required quantity to coconut palm. The door was fixed with hinges and latch at the top to prevent the fertilizer from foreign objects intrusion. A sliding shutter was fixed at the bottom of hopper to provide an outlet for fertilizer delivery to the metering roller. The orthographic view and fabricated hopper were shown in Fig. 3.24 and Plate. 3.11 respectively.

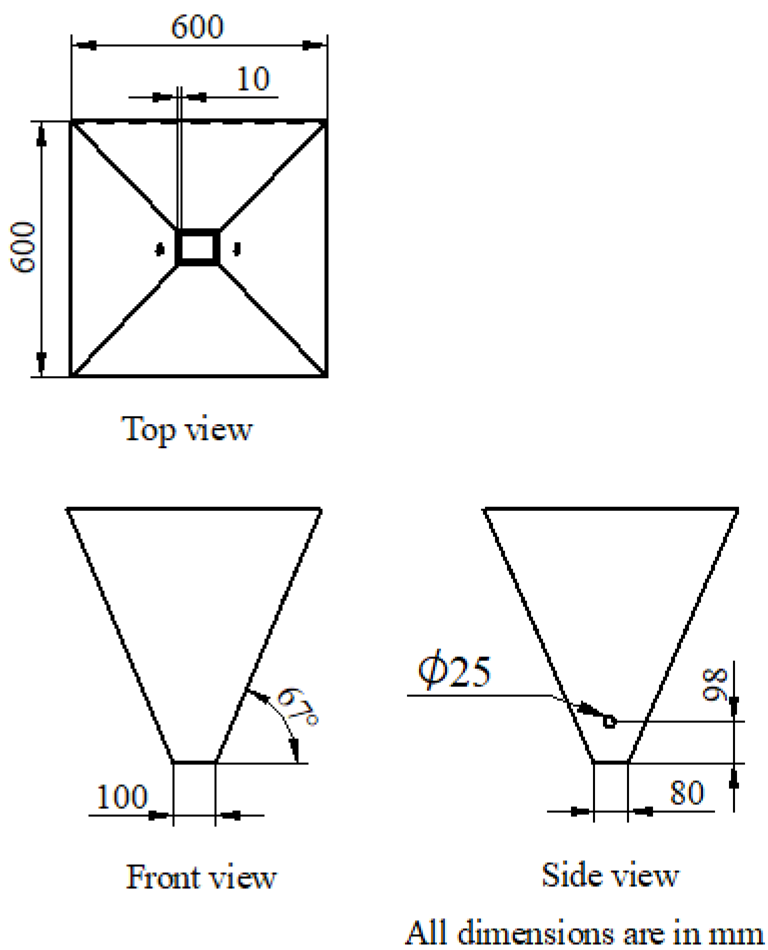

Fig. 3.24 Hopper

3.8.4.3 Power transmission units

The power transmission of prototype of fertilizer applicator is shown in Fig. 3.25. The three power transmission stages of the prototype of fertilizer applicator were explained with calculations in this section. The speed ratios, speed of shafts and length of chains of power transmission were calculated using the equation given by Sahay (2013).

1. Main shaft

2. Agitator

3. Agitator shaft

4. Edge cell metering roller

5. Metering shaft

6. Second reduction shaft

7. First reduction shaft

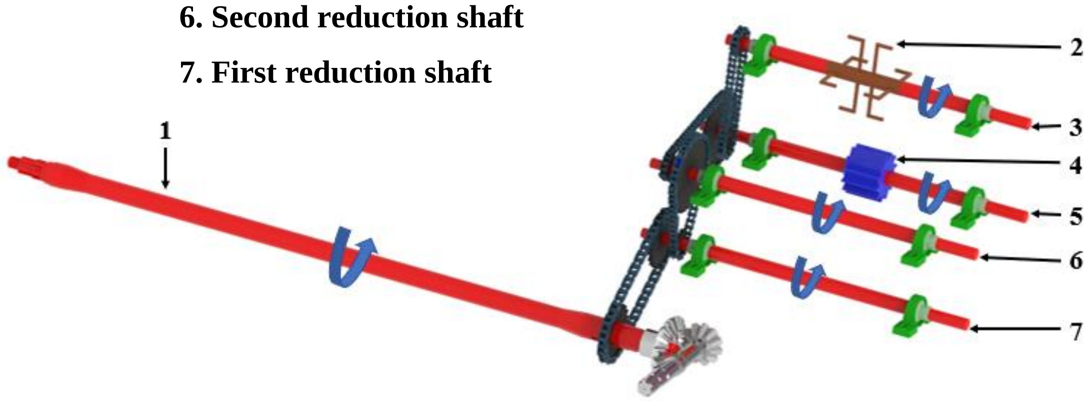

Fig. 3.25 Power transmission of prototype of fertilizer applicator

In the first stage of power transmission, the number of teeth of sprocket mounted on first reduction shaft (T_7) and second reduction shaft (T_8) of the prototype of fertilizer applicator were 12 and 35 respectively. The speed ratio for this stage of power transmission was calculated with the following equation.

$$SR = \frac{T_8}{T_7}$$

$$= \frac{35}{12}$$

$$= 2.91$$

where,

SR = Speed ratio

T_7 = Number of teeth of sprocket mounted on first reduction shaft

T_8 = Number of teeth of sprocket mounted on second reduction shaft

The speed ratio for first stage power transmission is determined as 2.91 according to the calculation mentioned above.

The speed of second reduction shaft (N_5) of the prototype of fertilizer applicator in power transmission system was calculated with the following equation.

$$N_5 = \frac{N_4 \, T_7}{T_8}$$

$$= \frac{305 \times 12}{35}$$

$$= 104 \text{ rpm}$$

where,

N_4 = Speed of first reduction shaft, rpm

N_5 = Speed of second reduction shaft, rpm

T_7 = Number of teeth of sprocket mounted on first reduction shaft

T_8 = Number of teeth of sprocket mounted on second reduction shaft

The length of chain from sprocket mounted on first reduction shaft to sprocket mounted on second reduction shaft of the prototype of fertilizer applicator for power transmission to fertilizer delivery mechanism was calculated as 48 using the following equation.

$$L = \frac{T_7 + T_8}{2} + \frac{2C}{P} + \frac{T_8 - T_7}{4\pi^2} + \frac{P}{C}$$

$$= \frac{12 + 35}{2} + \frac{2 \times 15}{1.27} + \frac{35 - 12}{4 \times \pi^2} + \frac{1.27}{15}$$

$$= 48$$

where,

T_7 = Number of teeth of sprocket mounted on first reduction shaft = 12

T_8 = Number of teeth of sprocket mounted on second reduction shaft = 35

C = Centre distance between first and second reduction shaft = 15 cm

P = Chain pitch = 1.27 cm

In the first stage power transmission, the speed of first reduction shaft was reduced from 305 to 104 rpm of second reduction shaft of the prototype of fertilizer applicator.

The reduction shafts provide drive from main shaft to fertilizer applicator by reducing the speed with sprockets and chain. The orthographic view of first and second reduction shafts were shown in Fig. 3.26 and Fig. 3.27 respectively.

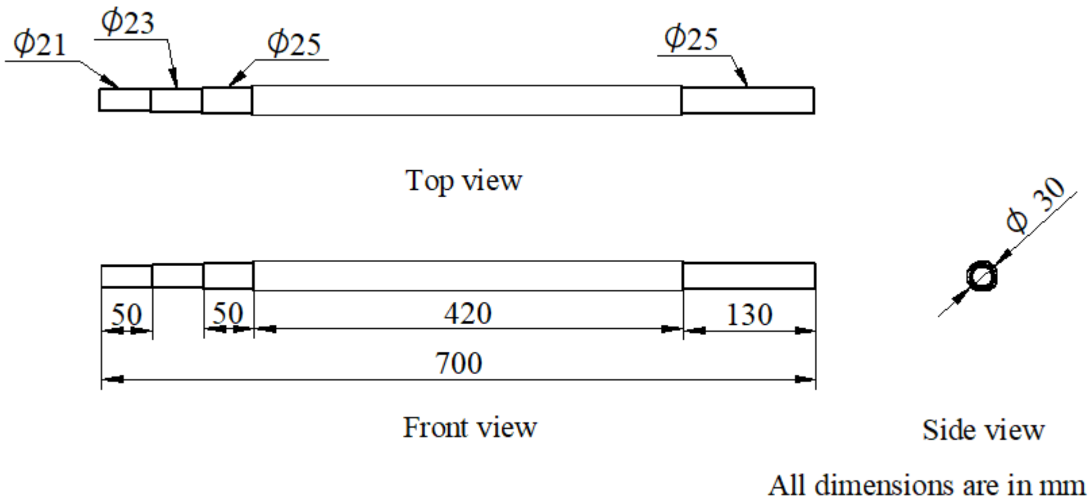

Fig. 3.26 First reduction shaft

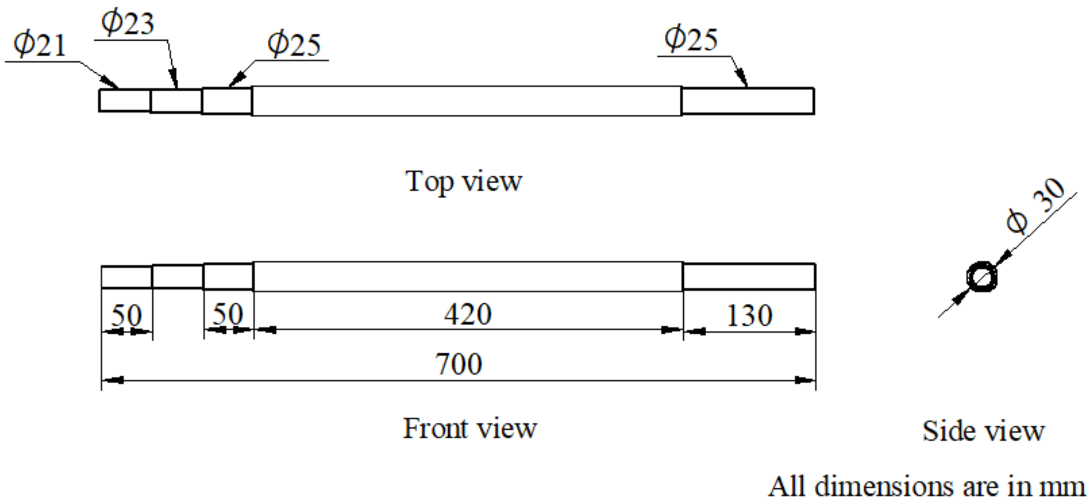

Fig. 3.27 Second reduction shaft

In the second stage power transmission, the number of teeth of sprocket mounted on second reduction shaft (T_9) and metering shaft (T_{10}) of the prototype of fertilizer applicator were taken as 12 and 35 respectively. The speed ratio for this stage of power transmission was calculated from the following equation.

$$SR = \frac{T_{10}}{T_9}$$

$$= \frac{35}{12}$$

$$= 2.91$$

where,

SR = Speed ratio

T_9 = Number of teeth of sprocket mounted on second reduction shaft

T_{10} = Number of teeth of sprocket mounted on metering shaft

The speed of metering shaft (N_6) of the prototype of fertilizer applicator in power transmission system was calculated with the following equation.

$$N_6 = \frac{N_5\, T_9}{T_{10}}$$

$$= \frac{104 \times 12}{35}$$

$$= 35 \text{ rpm}$$

where,

N_5 = Speed of second reduction shaft, rpm

N_6 = Speed of metering shaft, rpm

T_9 = Number of teeth of sprocket mounted on second reduction shaft

T_{10} = Number of teeth of sprocket mounted on metering shaft

In second stage power transmission, the speed of second reduction shaft reduced from 104 to 35 rpm of metering shaft of the prototype of fertilizer applicator.

The length of chain from sprocket mounted on second reduction shaft to sprocket mounted on metering shaft was calculated by using the following equation.

$$L = \frac{T_9 + T_{10}}{2} + \frac{2C}{P} + \frac{T_{10} - T_9}{4\pi^2} + \frac{P}{C}$$

$$= \frac{12 + 35}{2} + \frac{2 \times 24}{1.27} + \frac{35 - 12}{4 \times \pi^2} + \frac{1.27}{24}$$

$$= 62$$

where,

T_9 = Number of teeth of sprocket mounted on second reduction shaft = 12

T_{10} = Number of teeth of sprocket mounted on metering shaft = 35

C = Centre distance between second reduction shaft and metering shaft = 24 cm

P = Chain pitch = 1.27 cm

The metering shaft receives drive from second reduction shaft to rotate the metering roller and agitator by reducing the speed with the sprockets and chain. It accommodated the metering housing and metering roller at the centre to deliver the recommended fertilizer quantity. The orthographic view of metering shaft is shown in Fig. 3.28.

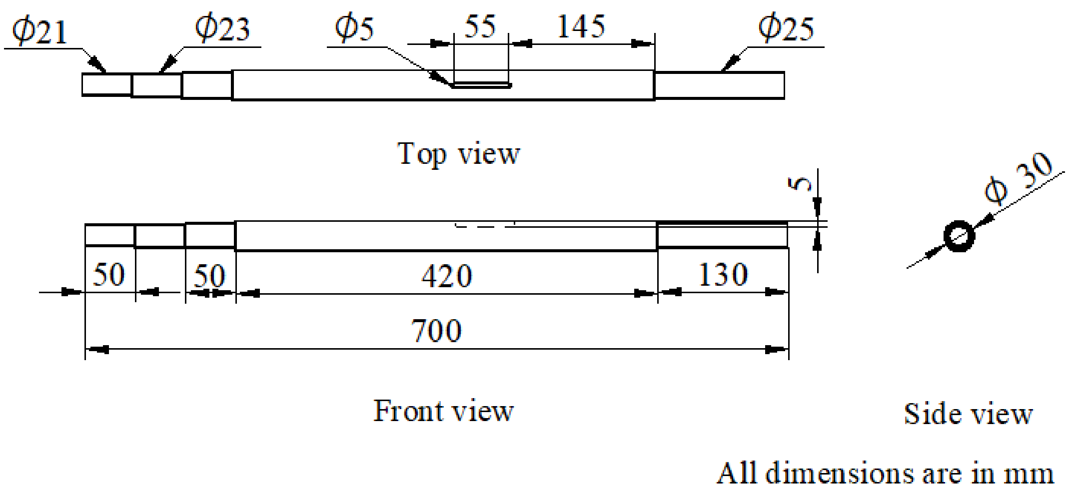

Fig. 3.28 Metering shaft

In the third stage power transmission, the number of teeth of sprocket mounted on metering shaft (T_{11}) and agitator shaft (T_{12}) of the prototype of fertilizer applicator were taken as 12. The speed ratio for this stage of power transmission was calculated from the equation.

$$SR = \frac{T_{12}}{T_{11}}$$

$$= \frac{12}{12}$$

$$= 1.0$$

where,

SR = Speed ratio

T_{11} = Number of teeth of sprocket mounted on metering shaft

T_{12} = Number of teeth of sprocket mounted on agitator shaft

The speed of agitator shaft (N_7) of the prototype of fertilizer applicator in power transmission system was calculated with the equation.

$$N_7 = \frac{N_6\, T_{11}}{T_{12}}$$

$$= \frac{35 \times 12}{12}$$

$$= 35 \text{ rpm}$$

where,

N_6 = Speed of metering shaft, rpm

N_7 = Speed of agitator shaft, rpm

T_{11} = Number of teeth of sprocket mounted on metering shaft

T_{12} = Number of teeth of sprocket mounted on agitator shaft

In the third stage power transmission, the speed of first reduction shaft reduced from 305 to 35 rpm of agitator shaft of the prototype of fertilizer applicator.

The length of chain from sprocket mounted on metering shaft to sprocket mounted on agitator shaft of the prototype of fertilizer applicator for power transmission to fertilizer delivery mechanism was calculated by using the following equation.

$$L = \frac{T_{11} + T_{12}}{2} + \frac{2C}{P} + \frac{T_{12} - T_{11}}{4\pi^2} + \frac{P}{C}$$

$$= \frac{12 + 12}{2} + \frac{2 \times 22.19}{1.27} + \frac{12 - 12}{4 \times \pi^2} + \frac{1.27}{22.19}$$

$$= 47$$

where,

T_{11} = Number of teeth of sprocket mounted on metering shaft = 12

T_{12} = Number of teeth of sprocket mounted on agitator shaft = 12

C = Centre distance between metering shaft to agitator shaft = 22.19 cm

P = Chain pitch = 1.27 cm

The agitator shaft receives drive from metering shaft to rotate the agitator by reducing the speed with sprockets and chain. It accommodated the agitator at the centre to deliver the recommended fertilizer without clogging. The orthographic view of agitator shaft is shown in Fig. 3.29.

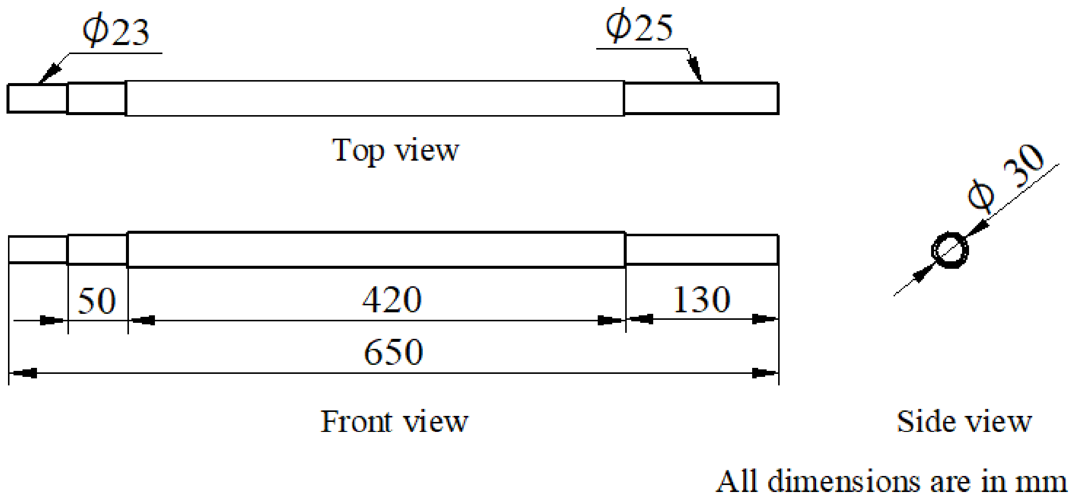

Fig. 3.29 Agitator shaft

3.8.4.4 Metering mechanism

The metering mechanism of the prototype of fertilizer applicator delivers the required fertilizer quantity to the coconut palm. It consists of edge cell metering roller, metering shaft and chain and sprockets drive. The performance evaluation of lab model of a fertilizer applicator revealed that the edge cell metering roller delivered the recommended fertilizer quantity. Therefore, the edge cell metering roller was used in the prototype of fertilizer applicator. The detailed description and calculations of metering mechanism were described below.

The three different flute volumes *viz.*, 1.3×10^{-5} (V_{100}), 1.43×10^{-5} (V_{110}) and 1.63×10^{-5} m^3 (V_{125}) of edge cell metering roller were designed to deliver 100, 110 and 125 per cent respectively of the recommended fertilizer quantity for the coconut palms from the prototype of fertilizer applicator (Devnani, 1991; Klenin *et al.*, 1985; Kepner *et al.*, 2005; Mandal and Thakur, 2010). The three edge cell metering rollers were 3-D printed and evaluated for fertilizer application rate in the laboratory and field test of the prototype of fertilizer applicator.

The design calculations of three edge cell metering rollers of the prototype of fertilizer applicator were detailed below.

i. V_{100} edge cell metering roller

The weight of fertilizer to be delivered by V_{100} edge cell metering roller (W) is the recommended fertilizer quantity to be applied per coconut palm i.e., 1.56 kg. The schematic of flute of V_{100} edge cell metering roller is shown in Fig. 3.30. The following dimensions of flute of V_{100} edge cell metering roller were assumed:

Height of flute (a) = 16 mm

Base length of flute (b) = 25 mm

Inclination of base of flute with vertical face (θ) = 59 deg.

The area of each flute (A) of V_{100} edge cell metering roller was calculated with the following equation.

$$A = \frac{1}{2} a\, b \sin\theta$$

$$= \frac{1}{2} \times 16 \times 25 \times \sin 59$$

$$= 172 \text{ mm}^2$$

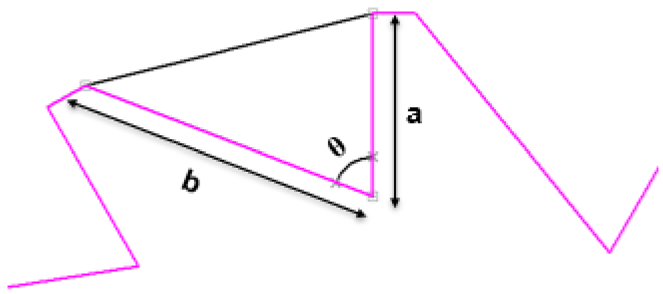

Fig. 3.30 Schematic of flute of V_{100} edge cell metering roller

The volume of each flute (v) of V_{100} edge cell metering roller was calculated with the following equation by considering the length of metering roller as 76 mm.

$$v = A \times L$$

$$= 172 \times 76$$

$$= 13072 \text{ mm}^3$$

$$= 1.3 \times 10^{-5} \text{ m}^3$$

The volume of V_{100} edge cell metering roller (V) was calculated with the following equation by considering number of flutes (N) as 12.

$$V = v \times N$$
$$= 1.3 \times 10^{-5} \times 12$$
$$= 15.6 \times 10^{-5}\ m^3$$

The weight of fertilizer delivered per revolution of V_{100} edge cell metering roller (w) was calculated with the following equation.

$$w = V \times \rho$$
$$= 15.6 \times 10^{-5} \times 1100$$
$$= 0.173\ kg$$

where,

V = Volume of edge cell metering roller = $15.6 \times 10^{-5}\ m^3$

P = Bulk density of fertilizer = 1100 kg m^{-3}

The weight of fertilizer delivered with V_{100} edge cell metering roller (W) to cover the circumference around coconut palm was calculated with the equation.

$$W = w \times n$$
$$= 0.173 \times 9$$
$$= 1.56\ kg$$

where,

W = Weight of fertilizer delivered with edge cell metering roller per coconut palm, kg

w = Weight of fertilizer delivered per revolution of edge cell metering roller, kg

n = Number of revolutions of metering roller to deliver required fertilizer, rev

The orthographic view and 3-D printed V_{100} edge cell metering roller were shown in Fig. 3.31 and Plate 3.11 respectively.

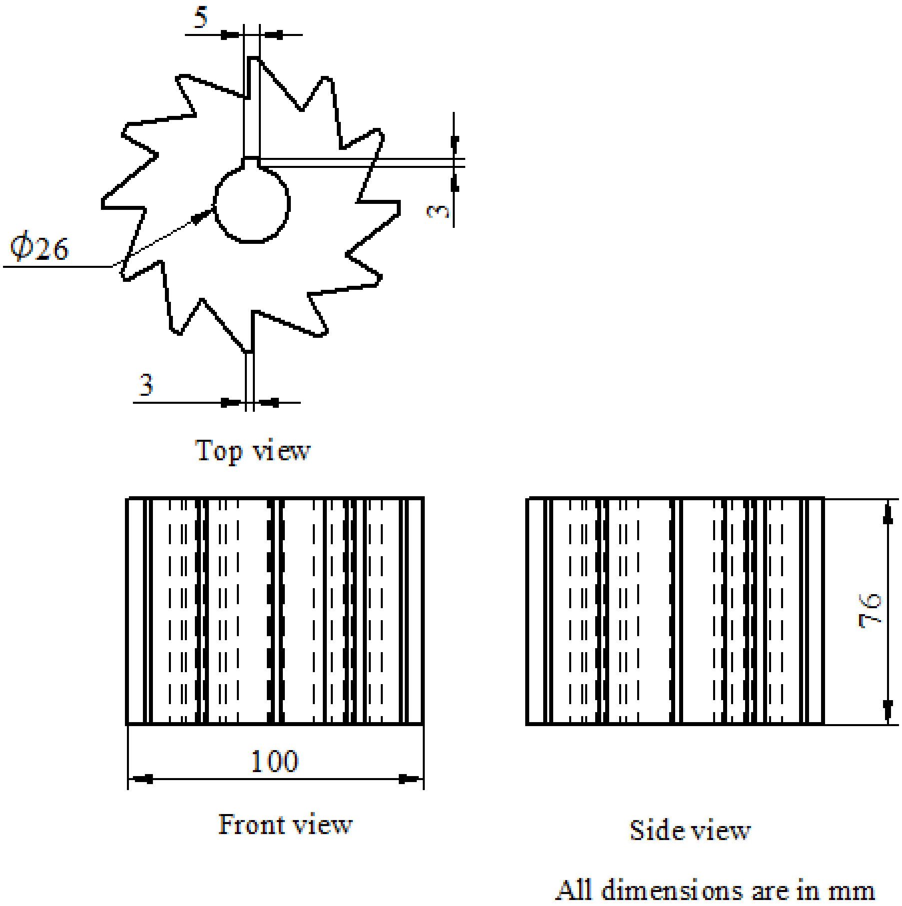

Fig. 3.31 V_{100} edge cell metering roller

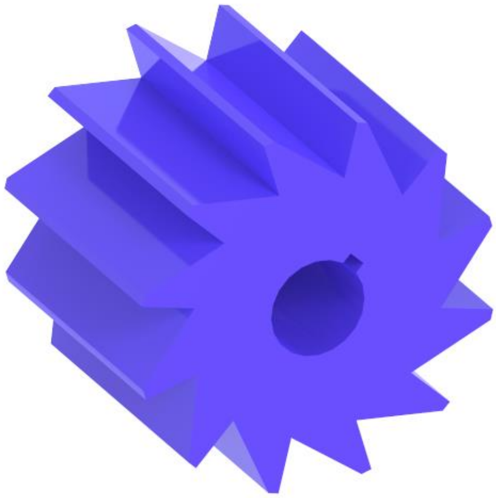

Plate. 3.11 V_{100} Edge cell metering roller

ii. V_{110} edge cell metering roller

The weight of fertilizer to be delivered by V_{110} edge cell metering roller (W_{110}) was calculated as mentioned below.

$$W_{110} = W_R + (W_R \times \frac{10}{100})$$

$$= 1.56 + (1.56 \times \frac{10}{100})$$

$$= 1.7 \text{ kg}$$

where,

W_{110} = Weight of fertilizer delivered by V_{110} edge cell metering roller, kg

W_R = Recommended fertilizer quantity per coconut palm = 1.56 kg

The flute volume of V_{110} edge cell metering roller is 10 per cent more than the flute volume of V_{100} edge cell metering roller i.e., 1.3×10^{-5} m^3 and was calculated with the following equation.

$$V_{110} = V_{100} + (V_{100} \times \frac{10}{100})$$

$$= (1.3 \times 10^{-5}) + ((1.3 \times 10^{-5}) \times \frac{10}{100})$$

$$= 1.43 \times 10^{-5} \text{ m}^3$$

where,

V_{110} = Flute volume of V_{110} metering roller, m^3

V_{100} = Flute volume of V_{100} metering roller = 1.3×10^{-5} m^3

The schematic of flute of V_{110} edge cell metering roller is shown in Fig. 3.32. The following dimensions of flute of V_{110} edge cell metering roller were assumed.

Height of flute (a) = 18 mm

Base length of flute (b) = 24.4 mm

Inclination of base of flute with vertical face (θ) = 59 deg.

The area of each flute (A) of V_{110} edge cell metering roller was calculated with the following equation.

$$A = \frac{1}{2} a\, b \sin\theta$$

$$= \frac{1}{2} \times 18 \times 24.4 \times \sin 59$$

$$= 188.2 \text{ mm}^2$$

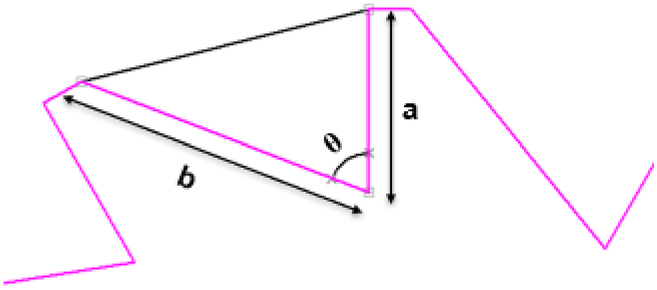

Fig. 3.32 Schematic of flute of edge cell metering roller

The volume of each flute (v) of V_{110} edge cell metering roller was calculated with the following equation by considering the length of metering roller as 76 mm.

$$v = A \times L$$
$$= 188.2 \times 76$$
$$= 14303.2 \text{ mm}^3$$
$$= 1.43 \times 10^{-5} \text{ m}^3$$

The volume of V_{110} edge cell metering roller (V) was calculated with the following equation by considering number of flutes (N) as 12.

$$V = v \times N$$
$$= 1.43 \times 10^{-5} \times 12$$
$$= 17.16 \times 10^{-5} \text{ m}^3$$

The weight of fertilizer delivered per revolution of V_{110} edge cell metering roller (w) was calculated with the following equation.

$$w = V \times \rho$$
$$= 17.16 \times 10^{-5} \times 1100$$
$$= 0.189 \text{ kg}$$

where,

V = Volume of edge cell metering roller = 17.16×10^{-5} m^3

P = Bulk density of fertilizer = 1100 kg m^{-3}

The weight of fertilizer delivered with V_{110} edge cell metering roller (W) to cover the circumference around coconut palm was calculated with the equation.

$$W = w \times n$$
$$= 0.189 \times 9$$

= 1.7 kg

where,

W = Weight of fertilizer delivered with edge cell metering roller per coconut palm, kg

w = Weight of fertilizer delivered per revolution of edge cell metering roller, kg

n = Number of revolutions of metering roller to deliver required fertilizer, rev

The orthographic view and 3-D printed V_{110} edge cell metering roller were shown in Fig. 3.33 and Plate 3.12 respectively.

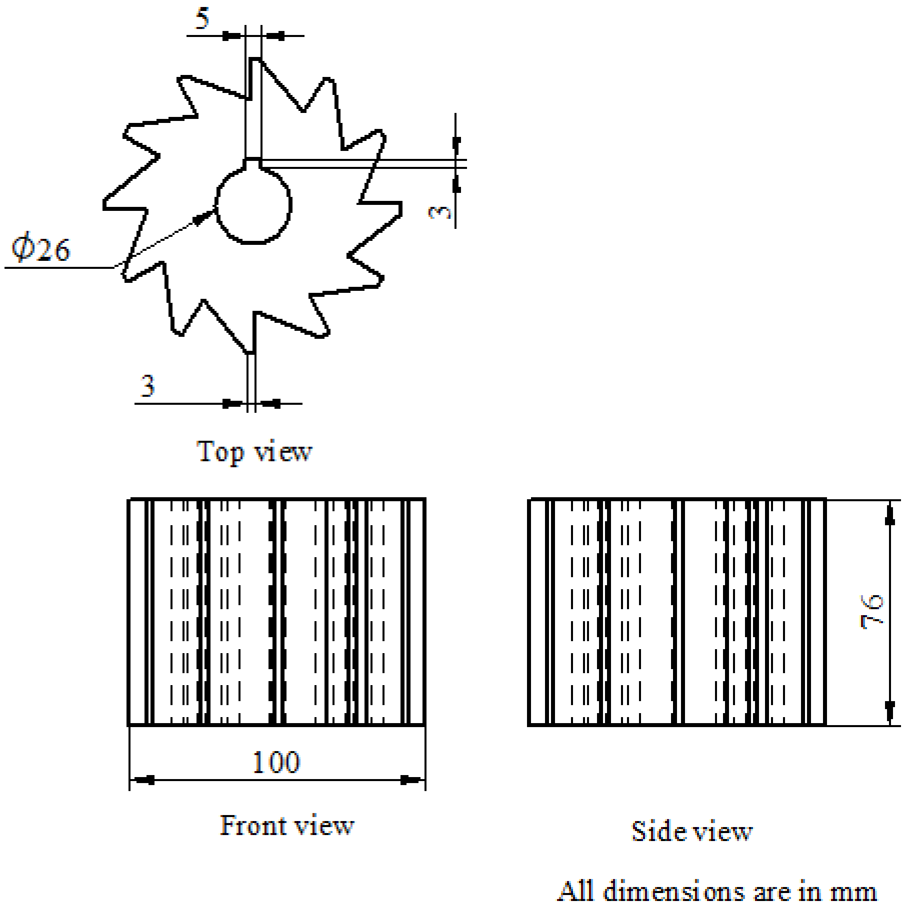

Fig. 3.33 V_{110} edge cell metering roller

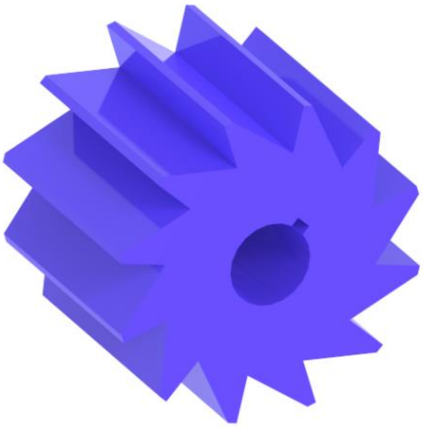

Plate. 3.12 V_{110} Edge cell metering roller

iii. V_{125} edge cell metering roller

The weight of fertilizer to be delivered by V_{125} edge cell metering roller (W_{125}) was calculated by the following equation.

$$W_{125} = W_R + (W_R \times \frac{25}{100})$$

$$= 1.56 + (1.56 \times \frac{25}{100})$$

$$= 1.9 \text{ kg}$$

where,

W_{125} = Weight of fertilizer delivered by V_{125} edge cell metering roller, kg

W_R = Recommended fertilizer quantity per coconut palm = 1.56 kg

The flute volume of V_{125} edge cell metering roller is 25 per cent more than the flute volume of V_{100} edge cell metering roller i.e., 1.3×10^{-5} m^3 and it was calculated with the following equation.

$$V_{125} = V_{110} + (V_{110} \times \frac{25}{100})$$

$$= (1.3 \times 10^{-5}) + ((1.3 \times 10^{-5}) \times \frac{25}{100})$$

$$= 1.63 \times 10^{-5} \text{ m}^3$$

where,

V_{125} = Flute volume of V_{125} metering roller, m^3

V_{100} = Flute volume of V_{110} metering roller = 1.3×10^{-5} m^3

The schematic of flute of V_{125} edge cell metering roller is shown in Fig. 3.34. The following dimensions of flute of edge cell metering roller were assumed.

Height of flute (a) = 20 mm

Base length of flute (b) = 24.9 mm

Inclination of base of flute with vertical face (θ) = 59 deg.

The area of each flute (A) of V_{125} edge cell metering roller was calculated with the following equation.

$$A = \frac{1}{2} a\, b \sin\theta$$

$$= \frac{1}{2} \times 20 \times 24.9 \times \sin 59$$

$$= 213.43 \text{ mm}^2$$

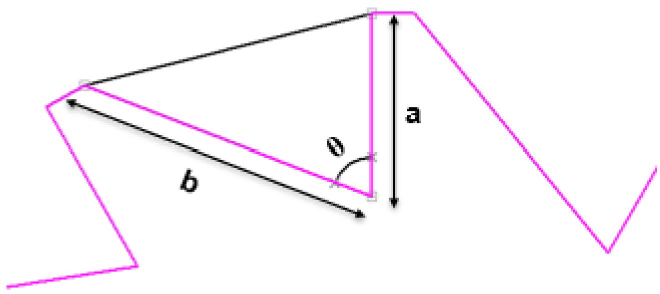

Fig. 3.34 Schematic of flute of V_{125} edge cell metering roller

The volume of each flute (v) of V_{125} edge cell metering roller was calculated with the following equation by considering the length of metering roller as 76 mm.

$$v = A \times L$$

$$= 213.4 \times 76$$

$$= 16300 \text{ mm}^3$$

$$= 1.63 \times 10^{-5} \text{ m}^3$$

The volume of V_{125} edge cell metering roller (V) was calculated with the following equation by considering number of flutes (N) as 12.

$$V = v \times N$$

$$= 1.63 \times 10^{-5} \times 12$$

$$= 19.5 \times 10^{-5} \text{ m}^3$$

The weight of fertilizer delivered per revolution of V_{125} edge cell metering roller (w) was calculated with the following equation.

$$w = V \times \rho$$
$$= 19.5 \times 10^{-5} \times 1100$$
$$= 0.214 \text{ kg}$$

where,

V = Volume of edge cell metering roller = 1.9×10^{-5} m^3

P = Bulk density of fertilizer = 1100 kg m^{-3}

The weight of fertilizer delivered with V_{125} edge cell metering roller (W) to cover the circumference around coconut palm was calculated with the equation.

$$W = w \times n$$
$$= 0.214 \times 9$$
$$= 1.9 \text{ kg}$$

where,

W = Weight of fertilizer delivered with edge cell metering roller per coconut palm, kg

w = Weight of fertilizer delivered per revolution of edge cell metering roller, kg

n = Number of revolutions of metering roller to deliver required fertilizer, rev

The orthographic view and 3-D printed V_{125} edge cell metering roller were shown in Fig. 3.35 and Plate 3.13 respectively.

The metering housing accommodates the metering roller inside it. It prevents the fertilizer to flow out and allows the fertilizer to be contained in the metering roller so that the recommended quantity of fertilizer was delivered through delivery pipe to the coconut palm. It was fixed to frame of the prototype of fertilizer applicator with bent flats, nuts and bolts. It was arranged offset to the downside of hopper opening so that a fertilizer buffer is created at the back so that continuous fertilizer band is delivered. The orthographic view and fabricated metering housing were shown in the Fig. 3.36 and Plate. 3.14 respectively.

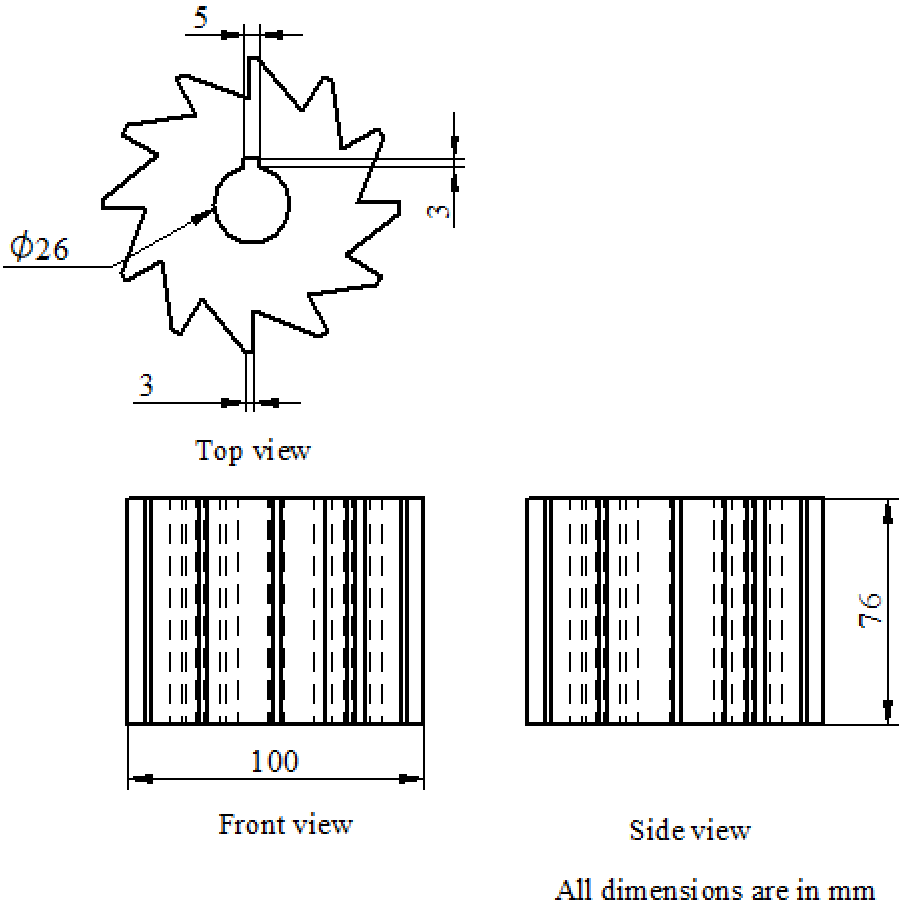

Fig. 3.35 V_{125} edge cell metering roller

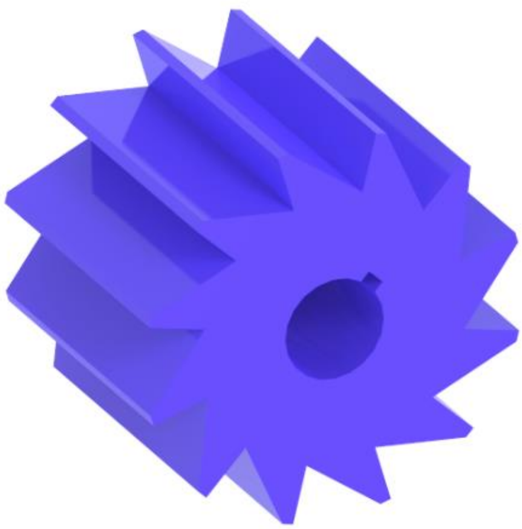

Plate. 3.13 V_{125} Edge cell metering roller

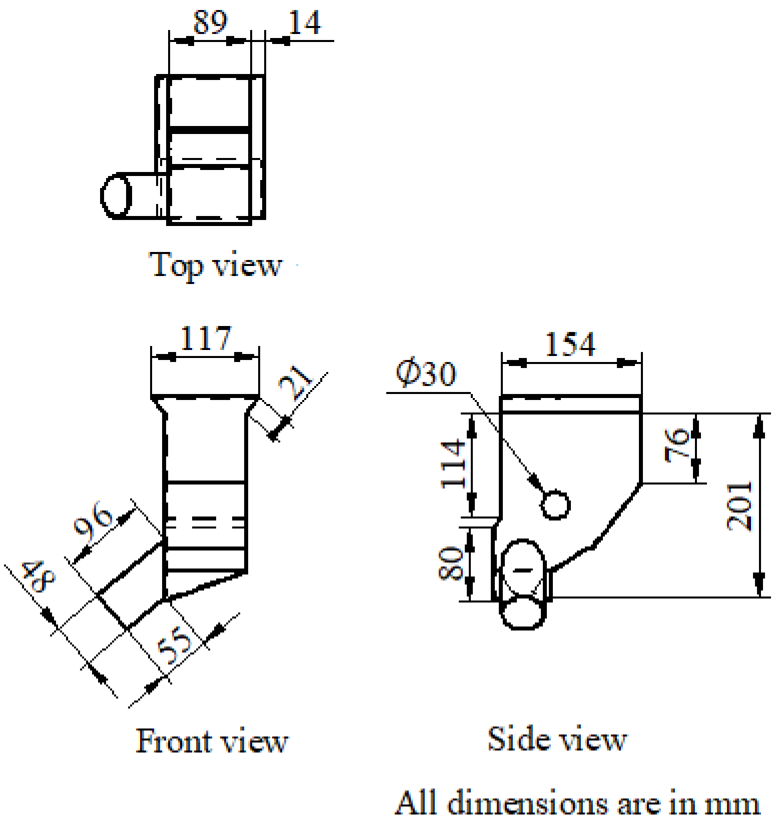

Fig. 3.36 Metering housing

Plate. 3.14 Metering housing

3.8.4.5 Agitator

The agitator prevents fertilizer from clogging in hopper and delivers the recommended fertilizer quantity. It was placed in hopper by fixing to the agitator shaft with clips, nuts and bolts. Three different shapes of agitators *viz.,* 'J', 'L' and

‘C’ were chosen for the performance evaluation of prototype of fertilizer applicator to deliver the recommended fertilizer quantity. The orthographic view of ‘J’, ‘L’ and ‘C’ shape agitators were shown in Fig. 3.37, Fig. 3.38 and Fig. 3.39 respectively while the fabricated ‘J’, ‘L’ and ‘C’ shape agitators were shown in Plate. 3.15, Plate. 3.16 and Plate. 3.17 respectively.

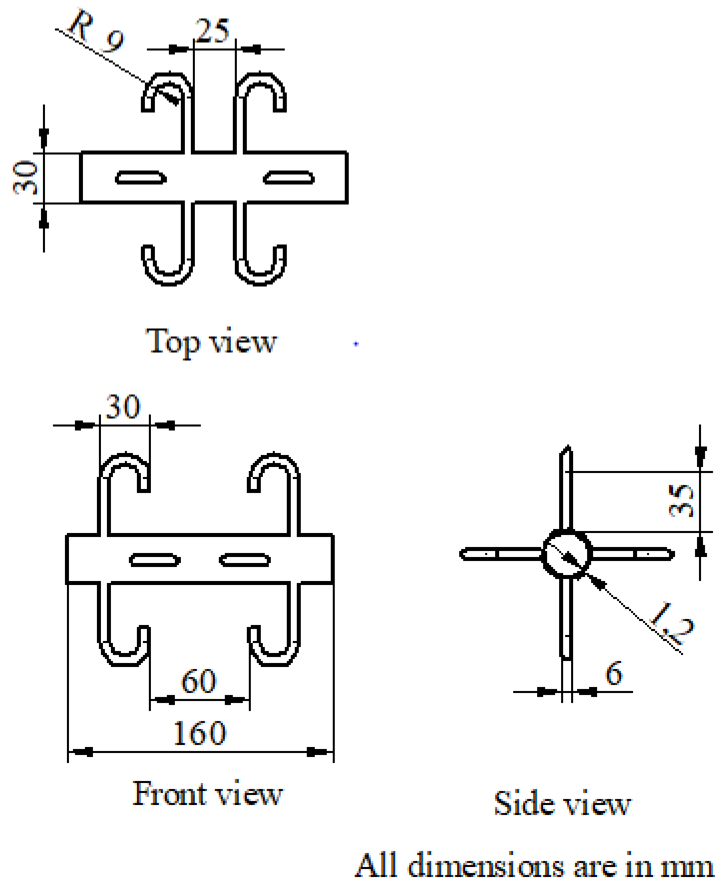

Fig. 3.37 ‘J’ shape agitator

Plate. 3.15 'J' shape agitator

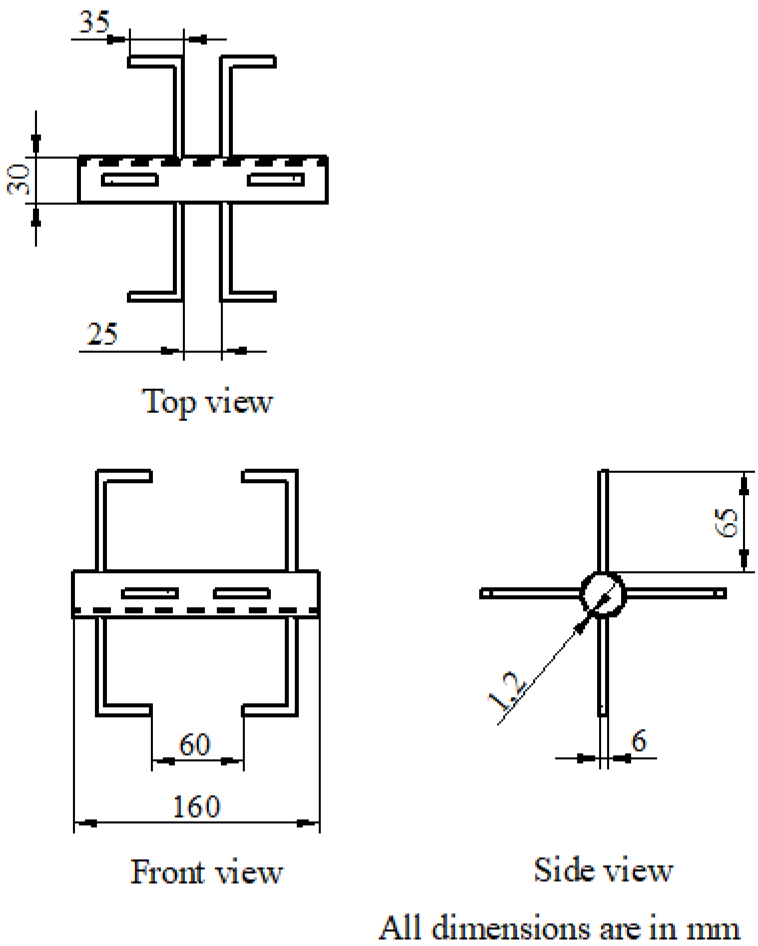

Fig. 3.38 'L' shape agitator

Plate. 3.16 'L' shape agitator

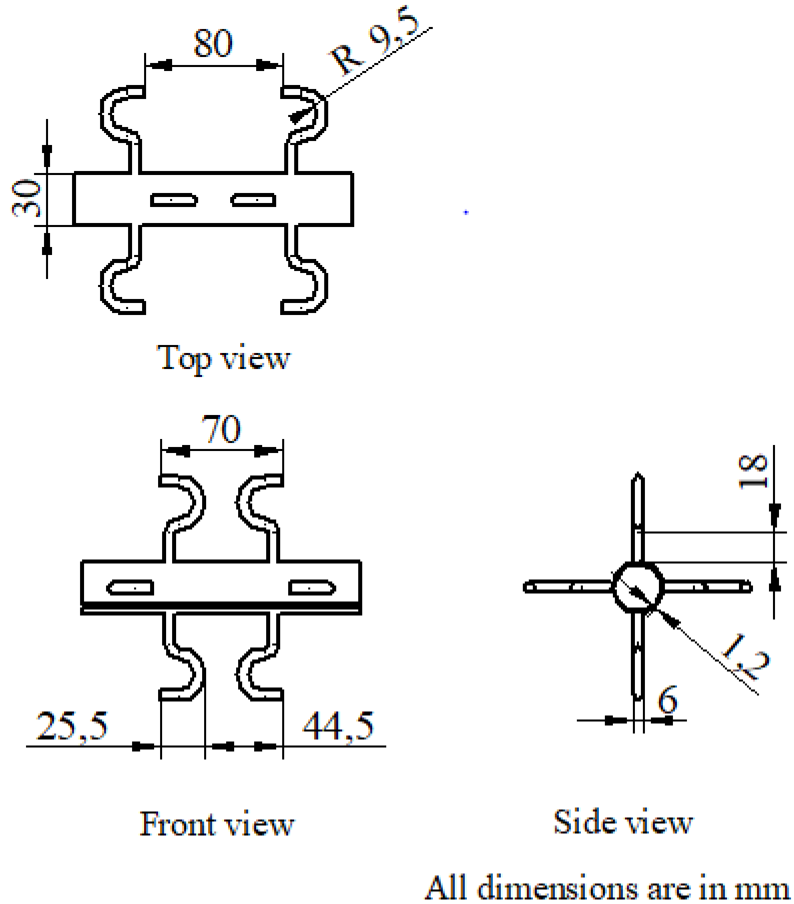

Fig. 3.39 'C' shape agitator

Plate. 3.17 ‘C’ shape agitator

3.9 TRACTOR OPERATED BASIN LISTER CUM FERTILIZER APPLICATOR

The tractor operated basin lister cum fertilizer applicator was developed after the accomplishment of design. The machine consisted of gearbox, main shaft, frame, rotor shaft, shield, main shaft cover, cutting blade, chain cover, hopper, metering roller, agitator, metering housing, metering and reduction shafts and other power transmission parts. The orthographic view and design of tractor operated basin lister cum fertilizer applicator were shown in Fig. 3.40 and Fig. 3.41 respectively.

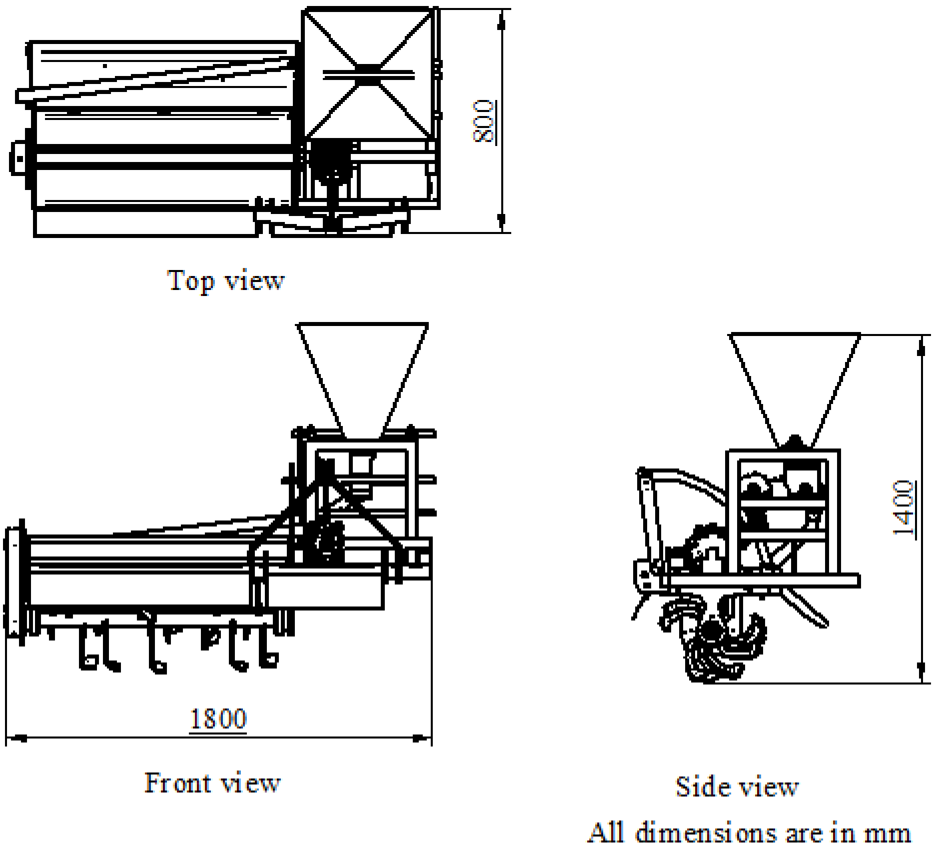

Fig. 3.40 Tractor operated basin lister cum fertilizer applicator

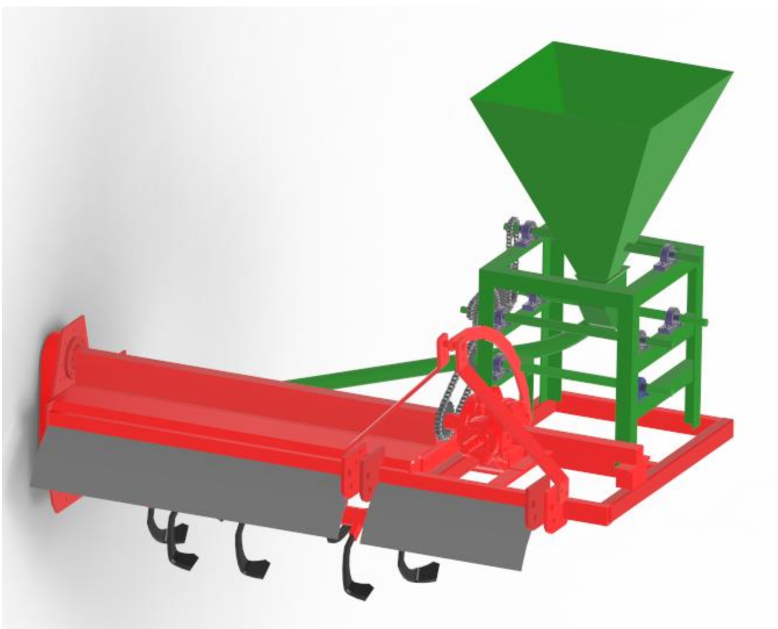

Fig. 3.41 Tractor operated basin lister cum fertilizer applicator

3.10 LABORATORY EVALUATION OF THE PROTOTYPE OF FERTILIZER APPLICATOR

The laboratory evaluation of prototype of fertilizer applicator was performed for different metering roller flute volumes *viz.*, 1.3, 1.43 and 1.63 × 10^{-5} m^3 and agitator shapes *viz.*, 'J', 'L' and 'C' respectively. It was tested in the laboratory to evaluate the distribution pattern of fertilizer band and fertilizer application rate of machine. The experiment was repeated for three replications. The levels of parameters of lab testing of prototype of fertilizer applicator were given in Table 3.1.

Table 3.1 Factors selected for lab testing of fertilizer applicator

Independent parameters	**Levels**
Flute volume (×10^{-5} m^3)	1.3, 1.43, 1.63
Agitator type	J, L, C
Dependent parameter	Fertilizer application rate, kg $palm^{-1}$
Replications = 3	
Total number of experiments = 3 × 3 × 3 = 27	

3.10.1 DISTRIBUTION PATTERN OF FERTILIZER BAND

The distribution pattern of fertilizer band was determined by dropping the fertilizer on 15 collection trays of 600×200 mm placed on the flat ground while running the machine linearly by hitching with tractor for different metering roller flute volumes *viz.*, 1.3 × 10^{-5}, 1.43 × 10^{-5} and 1.63 × 10^{-5} m^3 and agitator shapes *viz.*, 'J', 'L' and 'C' respectively as shown in Plate. 3.18. The weight of fertilizer was measured by placing each collection tray on an electronic weighing balance. The data obtained were analyzed for uniformity of distribution of fertilizer band of machine. Reed and Wacker (1970) analyzed the coefficient of variation of distribution pattern to test the uniformity of dry fertilizer spreaders placement. Bansal and Thierstein (1984) determined the coefficient of variation to analyze distribution patterns of oscillating trough type applicator. Mandal and Thakur (2010) studied the uniformity of distribution of fertilizers with Christensen's coefficient of uniformity. Therefore, the fertilizer distribution pattern was determined with Christensen's coefficient of uniformity as discussed below.

3.10.1.1 Christensen's coefficient of uniformity

The Christensen's coefficient of uniformity of fertilizer distribution pattern was calculated by the following equation.

$$C_U = \left[1 - \frac{\sum|X - \bar{X}|}{N\bar{X}}\right] \times 100$$

where,

C_U = Christensen's coefficient of uniformity, per cent

X = Weight of fertilizer in each collection tray, g

$\bar{X}$ = Mean weight of fertilizer, g

N = Total number of observations

Plate. 3.18 Laboratory test for fertilizer distribution pattern

3.10.2 Fertilizer application rate

The fertilizer application rate was measured while running the machine by hitching with tractor on flat ground in laboratory as shown in Plate 3.19. A polythene cover was tied at the end of delivery tube to collect the fertilizer from the prototype of fertilizer applicator and it was repeated for different metering roller flute volumes *viz.,* 1.3×10^{-5}, 1.43×10^{-5} and 1.63×10^{-5} m^3 and agitator shapes *viz.,* ‘J’, ‘L’ and ‘C’ respectively to determine the recommended fertilizer application rate of 1.56 kg per coconut palm.

Plate. 3.19 Laboratory test for fertilizer application rate

3.11 FIELD TESTING OF MACHINE

The experimental trials of machine in the field were conducted at the Instructional Farm of KCAET as shown in Plate. 3.20. The moisture content of field was 15.20 per cent. Each trial of the machine was repeated three times. The machine parameters of tractor operated basin lister cum fertilizer applicator were evaluated in the field. The basin lister was evaluated in terms of depth of cut, time taken per palm, bund height, bund width, pulverization index, draft, actual field capacity and fuel consumption for three independent parameters such as different forward speeds of 1.5, 2.0 and 2.5 km h^{-1}; blade to plate angles of 100, 110 and 120 deg. and skid height from ground level of 20.0, 17.5 and 15.0 cm respectively. The levels of parameters for field test of tractor operated basin lister cum fertilizer applicator were given in Table 3.2.

Plate. 3.20 Testing of tractor operated basin lister cum fertilizer applicator

Plate. 3.21 Basin formed by developed machine

Table 3.2 Factors selected for field testing of machine

Independent parameters	Levels
Forward speed, km h^{-1}	1.5, 2.0, 2.5
Blade to plate angle, deg.	100, 110, 120
Skid height from ground level, cm	20.0, 17.5, 15.0

Replications = 3

Total number of treatments = 3 × 3 × 3 × 3 = 81

The performance of the tractor operated basin lister cum fertilizer applicator was evaluated in terms of the following dependent parameters.

3.11.1 Depth of cut

The depth of cut of basin listing by the machine was measured by a steel rule at different locations in the basin. It was measured by placing the steel rule in the dug basin by keeping it against the flat top soil layer.

3.11.2 Time taken per basin formation

The time taken per basin formation by the machine was known by recording the time for basin listing and fertilizer application with stopwatch. It was repeated for different independent parameters mentioned.

3.11.3 Bund height

The bund height formed by the machine after basin listing operation was recorded by a measuring tape at different locations in the basin. It was measured by placing the tape against the bund and flat top soil layer.

3.11.4 Bund width

The bund width formed by the machine was recorded by a measuring tape at different locations in the basin. It was measured by placing the tape across the bund around basin formed around coconut palm.

3.11.5 Soil pulverization index

The soil pulverization index indicates the process of fragmentation of soil into small aggregates. In order to obtain soil pulverization index of the disintegrated soil by basin lister, sieve analysis of soil sample collected from field was done using standard set of sieves. The tilled soil sample was taken from an area of 50 × 50 cm of basin formed by basin lister. The collected soil sample was weighed and passed through sieves of various sizes. The soil retained on each sieve was weighed after shaking the sieve for 10 minutes. The following equation was used to calculate the soil pulverization index of soil sample tilled by basin lister.

$$\text{Soil pulverization index} = \frac{\text{Sum of product of sieve size and soil mass retained}}{\text{Total mass of soil}}$$

3.11.6 Draft

The draft of machine was measured using a load cell. The machine was mounted on tractor A and it was towed by another tractor ‘B’ in a linear motion. A load cell was connected in between tractors A and B and the draft was measured by engaging tractor A in neutral gear condition and operating condition. In neutral gear condition, the machine was in lift position while in operating condition, the machine was loaded. The difference between two draft readings of machine was measured and recorded.

3.11.7 Actual field capacity

The actual output in terms of area covered per hour was expressed as the effective field capacity. The total time taken by the machine to complete the operation in each experiment trial was recorded. The effective field capacity was calculated using the following expression (Kepner *et al.*, 2005).

$$\text{EFC} = \frac{A}{T}$$

where,

EFC = Actual field capacity, ha h^{-1}

A = Area covered, ha

T = Time of operation, h

3.11.8 Fuel consumption

The fuel consumption of machine for basin listing and fertilizer application operations was measured by top fill method. The fuel was filled into full tank capacity before and after the start of experimental trial of machine. The amount of fuel needed to refill after the trial was the fuel consumed and can be expressed in litre per hour or litre per hectare (Srinivas and Meena, 2020).

3.12 OPTIMIZATION OF MACHINE PARAMETERS

The machine parameters of the tractor operated basin lister cum fertilizer applicator were separately optimized for basin lister, fertilizer applicator and basin lister cum fertilizer applicator. The effects of independent parameters of the machine on the dependent variables were analyzed statistically. Three level factorial method was used in the study for statistical analysis and numerical optimization of machine parameters to obtain desirability in Design-Expert version 13 software. This technique was applied to explain the individual and interactive influence of independent parameters on the response or dependent parameters. It is a set of statistical and mathematical techniques which are helpful for developing, improving and optimizing the parameters. Factorial method of statistical analysis is widely used in the particular conditions where a number of input variables significantly affect performance measures of the experiment. By precise design of experiments, the objective is to optimize a response or dependent parameter which is influenced by a number of independent parameters. An experiment is a series of tests, called runs, in which changes are made in the independent variables in order to recognize the cause for changes in the output response.

3.13 COST ECONOMICS

The cost economics of tractor operated basin lister cum fertilizer applicator would be helpful for individual farmer or group of farmers to make a decision regarding ownership or custom hiring of the machine. The cost of operation for basin listing and fertilizer application operations was worked out on the basis of the prevailing input and fabrication cost, rental wages of operator, fuel costs etc.

Under the cost economics aspect; break-even point, payback period and benefit-cost ratio were calculated according to BIS standard IS: 9164-1979. The description of the cost economics terms was explained in the following sections and the detailed calculations were given in Appendix-XIII. The performance of machine was compared with conventional method of basin listing and fertilizer application in terms of saving in cost of operation.

3.13.1 Break Even Point (BEP)

The break-even point is at which neither profit nor loss is incurred. The break-even point is equal to the annual fixed cost divided by difference between the custom rate per hour and the operating cost per hour. The break-even point was calculated by the following equation.

$$BEP = \frac{AFC}{CF - C}$$

where,

BEP = Break-even point, h year^{-1}

AFC = Annual fixed cost for the machine, Rs. year^{-1}

CF = Cost of operation + 25 per cent overhead charges + 25 per cent profit over new cost, Rs. h^{-1}

C = Operating cost, Rs. h^{-1}

3.13.2 Payback period (PBP)

The payback period is the number of years it would take for an investment to return its original cost through the annual cash revenues it generates, if the net cash revenues are constant each year. The payback period was calculated by the following equation.

$$PBP = \frac{IC}{ANP} = \frac{IC}{(CF - C) \times AU}$$

where,

PBP = Payback period, year

IC = Investment cost of the machine, Rs.

ANP = Average net annual profit, Rs. $year^{-1}$

CF = Custom Fee, Rs. h^{-1}

C = Operating cost, Rs. h^{-1}

AU = Annual use, h $year^{-1}$

3.13.3 Benefit-Cost Ratio

The benefit-cost ratio of machine should be more than one and it was calculated by the following equation.

$$B:C = \frac{B}{C}$$

where,

B = Total benefit, Rs. $year^{-1}$

C = Investment cost of the machine, Rs.

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The soil, crop, fertilizer and machine parameters regarding the design of tractor operated basin lister cum fertilizer applicator were elucidated in this chapter. Experimental trials were conducted to determine the optimum levels of basin listing and fertilizer application units under different operating conditions. The data obtained from results of the study were statistically analysed and discussed in the following sections. The effects of operational parameters on performance of the machine under actual field conditions were also discussed. The experimental trials aided in optimising the operational parameters of machine to achieve higher efficiency and upgrade the overall performance of the machine. The cost economics of the developed machine is estimated in detail with the concerned economic terms to predict the economic viability of the machine.

4.1 SOIL PARAMETERS

The soil parameters such as moisture content, bulk density, cone index and shear strength were measured at the time of basin listing and fertilizer application. The data obtained from experiments is statistically analysed and the results were rationalized in the subsequent sections. The observations of soil parameters were given in Appendix-I.

4.1.1 Moisture content

The soil moisture content is measured at different places of the experimental plot at the time of basin listing and fertilizer application operations. The moisture content of the soil is determined and statistically analysed. The moisture content varied from 13.20 to 15.60 per cent with a mean of 14.6 per cent, coefficient of variation of 6.77 per cent and standard deviation of 0.993 as mentioned in Table 4.1. Before a day of field testing of machine, irrigation was given to coconut palms to maintain the soil moisture content in the measured range.

4.1.2 Bulk density

The soil bulk density is measured randomly in the experimental plot of coconut plantation. Soil samples were collected within the radius of 1.8 m of coconut palm as the basin formation and fertilizer application operations were performed in this area. The bulk density of the soil ranged from 1615 to 1865 kg m^{-3} with a mean of 1696.6 kg m^{-3}, coefficient of variation of 5.94 per cent and standard deviation of 100.84 as given in Table 4.1. Generally, the bulk density of soil varies with soil moisture content. It was observed that bulk density of soil increased with increase in soil moisture content. Soil bulk density is a major parameter affecting the design of rotary tilling unit of basin lister.

4.1.3 Cone index

The cone index of soil is an important consideration in the design of power requirement of machine. The cone index of soil was determined and statistically analysed. The cone index varied from 1.43 to 1.55 kg cm^{-2} with a mean of 1.50 kg cm^{-2}, coefficient of variation of 1.31 per cent and standard deviation of 0.02 as given in Table 4.1. The cone index of soil increased with depth as the bulk density increased and it was considered in the design of basin lister.

4.1.4 Shear strength

The shear strength of soil was determined and analysed statistically. The shear strength of soil varied from 0.77 to 0.82 kg cm^{-2} with mean of 0.80 kg cm^{-2}. The coefficient of variation was found out as 2.50 per cent while the standard deviation was 0.02 as reported in Table 4.1. The shear strength of soil increased with depth. Shear strength is a vital parameter in the design of rotary tilling unit of basin lister.

Table 4.1 Soil parameters

Parameter	Mean	Standard deviation	Coefficient of variation (per cent)
Moisture content (per cent)	14.6	0.993	6.77
Bulk density (kg m^{-3})	1696.6	100.84	5.94
Cone index (kg cm^{-2})	1.50	0.02	1.31
Shear strength (kg cm^{-2})	0.80	0.02	2.50

4.2 CROP PARAMETERS

The crop parameters such as trunk diameter and root zone depth of coconut palms were found out at the time of basin listing and fertilizer application. The data obtained from experiments was statistically analysed and the results were explained in the following sections. The observations of crop parameters were given in Appendix-II.

4.2.1 Trunk diameter of coconut palm

The trunk diameter of coconut palm is an important parameter in deciding the working width of machine and in turn the power requirement of machine. The trunk diameter of coconut palm was measured and statistically analysed. The trunk diameter of coconut palm varied from 32.3 to 38.1 cm with a mean of 34.7 cm. The coefficient of variation and standard deviation were 6.55 per cent and 2.27 respectively as given in Table 4.2. The trunk diameter varied with variety and age of coconut palms.

4.2.2 Root zone depth

The root zone depth of coconut palms was considered as the rotary tilling operation of basin lister must not cause damage to the roots of coconut palm. The root zone depth of coconut palm varied from 13.4 to 15.2 cm at a radius of 1.8 m from base of palm. The mean and standard deviation were 14.3 cm and 0.73 respectively while the coefficient of variance was 5.11 per cent as given in Table 4.2. Hence, the depth of operation of machine was selected as 10 cm such that the machine dose not interfere with root zone of coconut palms.

Table 4.2 Crop parameters

Parameter	Mean (cm)	Standard deviation	Coefficient of variation (per cent)
Trunk diameter	34.7	2.27	6.55
Root zone depth	14.3	0.73	5.11

4.3 FERTILIZER PARAMETERS

The fertilizer parameters such as angle of repose, bulk density, tapped density and coefficient of friction of urea, muriate of potash and rock phosphate fertilizers were determined and given in Table 4.3. The observations of fertilizer parameters were given in Appendix-V, Appendix-VI and Appendix-VII. The data acquired from experiments was statistically analysed and the results were explained in the following sections that helped in the design of fertilizer applicator.

4.3.1 Angle of repose

Angle of repose of the selected fertilizers namely; urea, muriate of potash and rock phosphate were 32.9, 38.1 and 40.8 deg. respectively as given in Table 4.3. Therefore, inclination of sides of hopper was set at more than 41 deg. so that the fertilizer flows easily to metering roller and delivery pipe.

4.3.2 Bulk density

Bulk density of urea, muriate of potash and rock phosphate were 740.6, 1081.6 and 1326 kg m^{-3} respectively as given in Table 4.3. The bulk density of urea, muriate of potash and rock phosphate mixture was 1100 kg m^{-3} considering the recommended rates of N, P and K fertilizers given in the Package of Practices of Kerala Agricultural University. Based on this, the dimensions of hopper were decided to accommodate fertilizer mixture volume for application in field.

4.3.3 Tapped density

The tapped density of fertilizer was taken into consideration for designing the hopper and metering roller of fertilizer applicator. Tapped density of urea, muriate of potash and rock phosphate were 834.3, 1167 and 1419 kg m^{-3} respectively as given in Table 4.3. The design of hopper and metering roller were accomplished considering the tapped density of fertilizer.

4.3.4 Coefficient of friction

The coefficient of friction was taken into consideration for designing the hopper and metering roller. Coefficient of friction of urea, muriate of potash and rock phosphate were found out as 0.31, 0.47 and 0.55 respectively and given in Table 4.3. It helped in the design of hopper and metering roller.

Table 4.3 Fertilizer parameters

Fertilizers	Angle of repose (deg.)	Bulk density (kg m^{-3})	Tapped density (kg m^{-3})	Coefficient of friction
Urea	32.9	740.6	834.3	0.31
Muriate of potash	38.1	1081.6	1167	0.47
Rock phosphate	40.8	1326	1419	0.55

4.4 TRACTOR OPERATED BASIN LISTER CUM FERTILIZER APPLICATOR

The tractor operated basin lister cum fertilizer applicator was developed to accomplish the operations of basin listing and fertilizer application. The machine consisted of main frame, power transmission system, main shaft, rotor shaft, cutting blades, chain cover, chain side plates, main hopper, agitator, metering roller, metering housing, delivery pipe and many other parts. The developed prototype of tractor operated basin lister cum fertilizer applicator was shown in Plate. 4.1. The specifications of machine were presented in Table 4.4.

Plate. 4.1 Prototype of tractor operated basin lister cum fertilizer applicator

Table 4.4 Specifications of machine

S.No.	Machine components	Specifications
1	Overall size	
	Length×Width×Height (mm)	1800×750×1400
2	Main frame	
	Length×Width×Height (mm)	1700×700×1400
3	Main shaft	
	Length×Diameter (mm)	1450×50
4	Rotor shaft	
	Length×Diameter (mm)	1110×60
5	Cutting blade	
	Length×Width×Thickness (mm)	173×24.5×9.5
6	Top cover	
	Length×Width×Thickness (mm)	1220×454×3
7	Frame centre side plate	
	Length×Width×Thickness (mm)	560×120×6
8	Frame chain side plate	
	Length×Width×Thickness (mm)	560×120×6
9	Frame curve side plate	
	Length×Width×Thickness (mm)	354×353.5×10
10	Main shaft cover	
	Length×Width×Thickness (mm)	1196×100×2
11	Hopper	
	Shape	Trapezoidal footing
	Capacity, cm^3	84333
12	Metering roller	
	Type	Edge cell
	Capacity, cm^3	171.98
13	Fertilizer applicator frame	
	Length×Width×Thickness (mm)	510×570×5
14	Fertilizer delivery pipe	
	Length×Diameter	1100×60
15	Metering housing	
	Length×Width×Height	154×117×220

The power transmission of machine was explained in two stages respectively for basin lister and fertilizer applicator. For basin lister, the power from tractor PTO is transferred through gearbox to the main shaft to drive the cutting blades mounted on rotor shaft. The cutting blades of basin lister till the soil to form basin and scoop the tilled soil to form bund around the coconut palm. The main frame accommodates the components of basin lister and fertilizer applicator.

In order to operate the fertilizer applicator, the drive is provided from the main shaft to the metering roller and agitator through reduction shafts. The hopper, metering roller, metering housing, agitator, delivery pipe, agitator shaft, metering shaft, reduction shafts and other parts were fitted on the frame of prototype of fertilizer applicator. The agitator of fertilizer applicator stirs the fertilizer to crush the lumps and so as to make a fine powder while the metering roller delivers the recommended amount of fertilizer through delivery pipe into the basin.

4.5 EVALUATION OF LAB MODEL OF FERTILIZER APPLICATOR

The independent variable selected for testing and optimization of lab model of fertilizer applicator is different types of metering roller *viz*., edge cell, fluted cell and baffle cell. The test procedure followed for the evaluation of lab model of fertilizer applicator was explained in Section 3.8.3. The effect of operational parameters was studied to evaluate the performance of experimental model of fertilizer applicator in terms of fertilizer discharge as mentioned in the following section.

4.5.1 Fertilizer discharge

The quantity of fertilizer discharged from the prototype fertilizer applicator is an important parameter to determine the performance of machine. The effect of metering roller type on fertilizer discharge of lab model of fertilizer applicator was detailed in Appendix-VIII.

The edge cell metering roller delivered 1.55 kg fertilizer while the fluted cell and baffle cell metering roller delivered 1.49 and 1.44 kg respectively as shown in Fig. 4.1. The recommended fertilizer to be delivered is 1.56 kg palm^{-1}. The edge cell metering roller performed better than fluted cell and baffle cell metering roller types. It may be due to the better ease of flow with the inclination of each flute in edge cell metering roller than fluted and baffle cell metering roller type. The results obtained are in close agreement with Manoj (2010) and Salsan (2017).

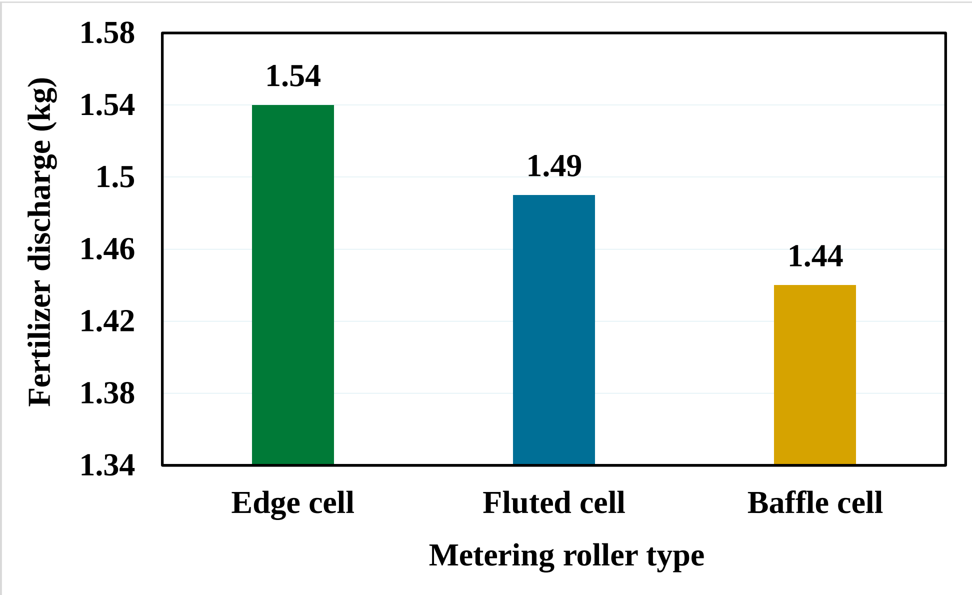

Fig. 4.1 Effect of metering roller type on fertilizer discharge

4.6 LABORATORY TEST OF PROTOTYPE OF FERTILIZER APPLICATOR

The independent variables selected for lab testing and optimization of prototype of fertilizer applicator were flute volumes of metering roller *viz*., 1.3×10^{-5}, 1.43×10^{-5} and 1.63×10^{-5} m^3 and agitator types *viz*., ‘J’, ‘L’ and ‘C’ respectively. The effect of operational parameters studied for lab evaluation of prototype of fertilizer applicator in terms of fertilizer application rate and coefficient of uniformity were explained in the following sections.

4.6.1 Coefficient of uniformity

The coefficient of uniformity is an important parameter for lab evaluation of the prototype of fertilizer applicator as it quantifies the fertilizer distribution pattern from the machine. The effect of independent parameters viz., flute volume of metering roller and agitator type on coefficient of uniformity of prototype of fertilizer applicator were given in Appendix-IX.

Analysis of variance revealed that the independent parameters viz., flute volume of metering roller and agitator type were significant at 5.0 per cent level of significance for the coefficient of uniformity of prototype of fertilizer applicator. The model was highly significant at 5.0 per cent level of significance and the coefficient of determination (R^2) was 0.94 which indicated the agreement of coefficient of uniformity with performance parameters as presented in Table 4.5. The mean, standard deviation and coefficient of variation were 95.83, 0.242 and 0.25 per cent respectively.

Table. 4.5 Analysis of variance of coefficient of uniformity

Source	Sum of Squares	Df	Mean Square	F-value
Model	129.78	8	16.22	277.00*
Flute volume (F)	115.24	2	57.62	983.87*
Agitator type (A)	14.27	2	7.13	121.83*
Residual	0.9370	16	0.0586	-
Cor Total	130.79	26	-	-
Std. Dev.	0.2420	**R^2**		0.9764
Mean	95.83	**Adjusted R^2**		0.9658
C.V. (per cent)	0.2525	**Predicted R^2**		0.9520

* Significant at 5 per cent level

The graph showing the effect of independent parameters on coefficient of uniformity was shown in Fig. 4.2. The coefficient of uniformity of fertilizer applicator ranged from 92 to 99.2 per cent. The coefficient of uniformity was low for the metering roller flute volume of 1.3×10^{-5} m^3 and ‘J’ shape agitator respectively while it is high for metering roller flute volume of 1.43×10^{-5} m^3 and ‘L’ shape agitator respectively. It may be due to the better conveyance of fertilizer at these levels of independent parameters which aided in higher coefficient of uniformity of fertilizer with prototype of fertilizer applicator. Similar results were obtained with Singh and Thakur (2018) and Mandal and Thakur (2010).

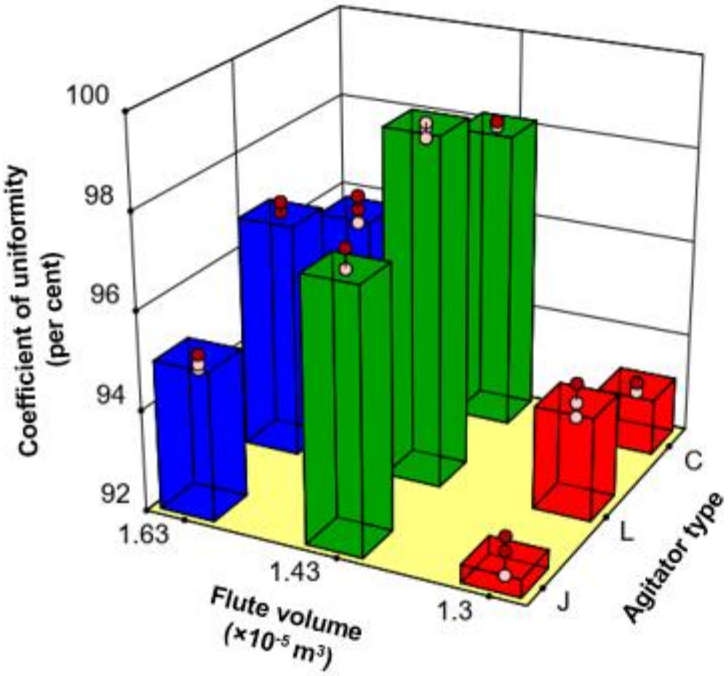

Fig. 4.2 Effect of metering roller flute volume and agitator type on coefficient of uniformity

4.6.2 Fertilizer application rate

The fertilizer application rate is an important parameter for lab evaluation of the prototype of fertilizer applicator as it measures the fertilizer quantity discharged from the machine. The effect of independent parameters viz., flute volume of metering roller and agitator type on fertilizer application rate of prototype of fertilizer applicator were detailed in Appendix-IX.

Analysis of variance proved that the independent parameters viz., flute volume of metering roller and agitator type were significant at 5.0 per cent level of significance for the fertilizer application rate of prototype of fertilizer applicator. The model was highly significant at 5.0 per cent level of significance and the coefficient of determination (R^2) was 0.96 which indicated the agreement of fertilizer application rate with performance parameters as presented in Table 4.6. The mean, standard deviation and coefficient of variation of fertilizer discharge were 1.47, 0.01 and 1.27 per cent respectively.

The graph showing the effect of independent parameters on fertilizer application rate was shown in Fig. 4.3. The fertilizer application rate of prototype of fertilizer applicator ranged from 0.95 to 1.86 kg. The fertilizer application rate was low for the metering roller flute volume of 1.3×10^{-5} m^3 and ‘J’ shape agitator respectively while it was high for the metering roller flute volume of 1.6×10^{-5} m^3 and ‘C’ shape agitator respectively.

It was revealed that the fertilizer application rate of prototype of fertilizer applicator increased with flute volume of metering roller from 1.3×10^{-5} to 1.63×10^{-5} m^3 respectively as the fertilizer quantity delivered per flute increased. The fertilizer application rate was lower with ‘J’ shape agitator due to the less contact area of its cross-section with fertilizer while it was higher with ‘C’ shape agitator as its cross-section aided in better agitation of fertilizer. The recommended fertilizer application rate of 1.56 kg was obtained for metering roller flute volume of 1.43×10^{-3} m^3 and agitator type of ‘L’. The results obtained are similar to Manoj (2010).

Table. 4.6 Analysis of variance of fertilizer application rate

Source	Sum of Squares	df	Mean Square	F-value
Model	2.21	8	0.276	791.93*
Flute volume (F)	1.97	2	0.987	2831.27*
Agitator type (A)	0.215	2	0.107	309.45*
F×A	0.018	4	0.004	13.50*
Residual	0.005	16	0.0003	-
Cor Total	2.21	26	-	-
Std. Dev.	0.0187	**R^2**	0.9682	
Mean	1.47	**Adjusted R^2**	0.9576	
C.V. (per cent)	1.27	**Predicted R^2**	0.9438	

* Significant at 5 per cent level

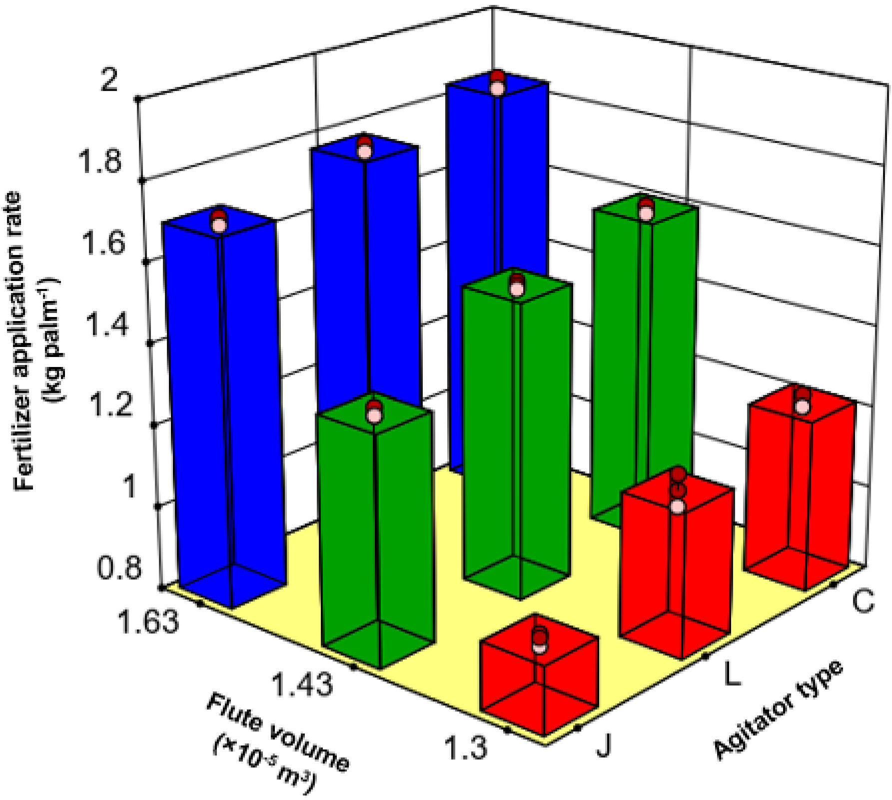

Fig. 4.3 Effect of metering roller flute volume and agitator type on fertilizer application rate

4.7 NUMERICAL OPTIMIZATION OF LAB TEST OF PROTOTYPE OF FERTILIZER APPLICATOR

The statistical analysis gave a clear understanding of effect of independent parameters on dependent parameters of lab test of prototype of fertilizer applicator. The optimum levels of independent parameters were found with numerical optimization method in Design Expert Version 13.0.5 software.

The numerical optimization of lab test of prototype of fertilizer applicator was performed by setting the constraints for all parameters as given in Table 4.7 to obtain optimum solutions. Then the desirability of lab test of prototype of fertilizer applicator was found out as shown in Fig. 4.4. The optimum parameters of machine were flute volume of 1.43×10^{-5} m^3 and agitator type of ‘L’. The desirability of optimum parameters of machine for the fertilizer application rate and coefficient of uniformity was 0.96 and 1 respectively. The combined desirability of optimum parameters of machine was highest i.e., 0.98 for the metering roller flute volume of 1.43×10^{-5} m^3 and agitator shape of ‘L’ as mentioned in Table 4.8.

These levels of independent parameters were selected to obtain optimum fertilizer application rate and coefficient of uniformity in field evaluation of prototype of fertilizer applicator.

Table 4.7 Constraints of lab test of fertilizer applicator

Parameters	Goal
Independent parameters	
Flute volume (×10^{-5} m^3)	is in range
Agitator type	is in range
Dependent parameters	
Fertilizer application rate (kg $palm^{-1}$)	target = 1.56 kg
Coefficient of uniformity (per cent)	maximize

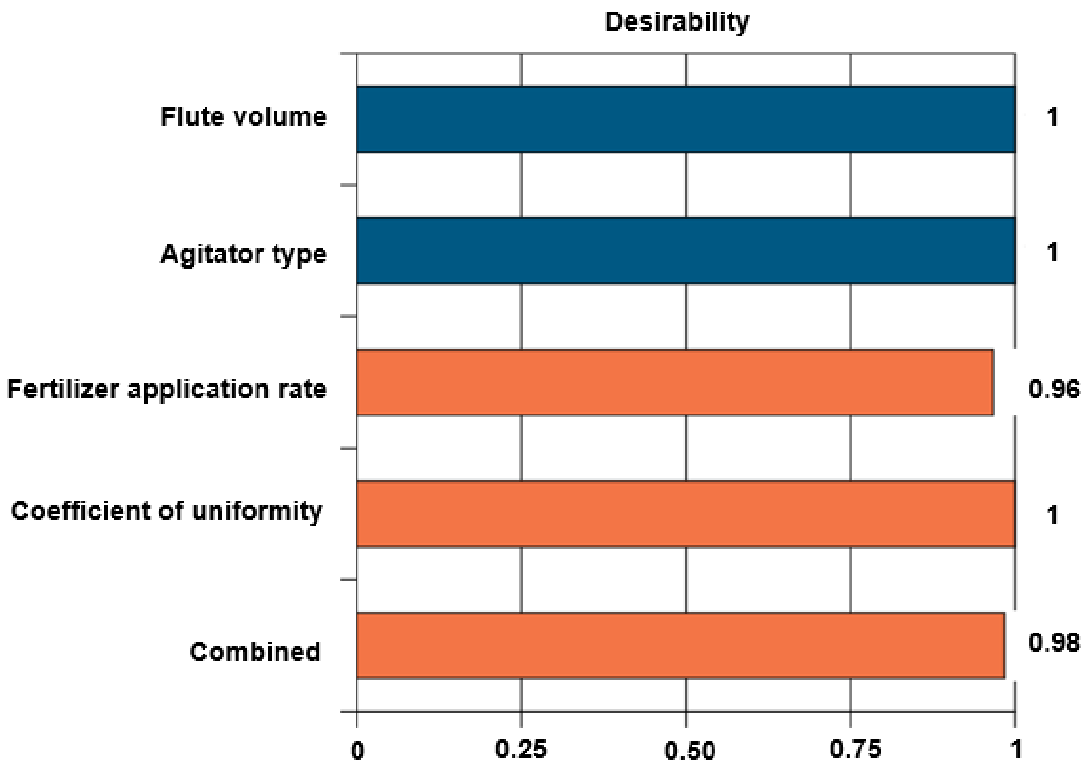

Fig. 4.4 Desirability of parameters of lab test of prototype of fertilizer applicator

Table 4.8 Optimum parameters of lab test of prototype of fertilizer applicator

S.No.	Independent parameters	Optimum values
1	Metering roller flute volume (m^3)	1.43×10^{-5}
2	Agitator type	L

4.8 EVALUATION OF TRACTOR OPERATED BASIN LISTER CUM FERTILIZER APPLICATOR

The tractor operated basin lister cum fertilizer applicator was tested in the field to determine the optimum operational parameters for basin listing and fertilizer application. The parameters selected for testing and optimization of machine in the field were forward speeds of 1.5, 2.0 and 2.5 $km \cdot h^{-1}$, blade to plate angles of 100, 110 and 120 deg. and skid heights from ground level of 20.0, 17.5 and 15.0 cm respectively. The field test was conducted at a field moisture of 15.2 per cent. The effect of operational parameters was studied to evaluate the performance of basin lister in terms of depth of cut, time taken per palm, bund width, bund height, pulverization index and draft as detailed in the following sections.

4.8.1 Depth of cut

Depth of cut is an essential performance parameter to evaluate the basin lister as it directly affects the quantity of irrigated water to be contained in the basin formed around the coconut palm. The effect of independent parameters viz., forward speed, blade to plate angle and skid height from ground level on depth of cut of basin lister were presented in Appendix-X.

Analysis of variance indicated that the independent parameters viz., forward speed, blade to plate angle, skid height from ground level, interaction of forward speed and blade to plate angle, interaction of blade to plate angle and skid height from ground level, interaction of forward speed and skid height from ground level were significant at 5.0 per cent level of significance for the depth of cut of basin lister. The model was highly significant at 5.0 per cent level of significance and the coefficient of determination (R^2) was 0.91 indicating the high accountancy of depth of cut with performance parameters as reported in Table 4.9. The mean, standard deviation and coefficient of variation were 9.85, 0.03 and 0.308 per cent respectively.

Table. 4.9 Analysis of variance of depth of cut

Source	Sum of Squares	df	Mean Square	F-value
Model	81.30	18	4.52	4878*
Forward speed (F)	6.48	2	3.24	3499.6*
Blade to plate angle (B)	0.556	2	0.278	300.4*
Skid height from ground level (S)	74.05	2	37.02	39984.4*
F×B	0.05	4	0.012	13.60*
F×S	0.148	4	0.037	40.00*
B×S	0.019	4	0.004	5.20*
Residual	0.007	8	0.0009	-
Cor Total	81.31	26	-	-
Std. Dev.	0.03		**R^2**	0.9162
Mean	9.85		**Adjusted R^2**	0.9056
C.V. (per cent)	0.308		**Predicted R^2**	0.8968

* Significant at 5 per cent level

The graphs representing the influence of independent parameters on depth of cut were shown in Fig. 4.5, 4.6 and 4.7. The depth of cut of basin lister for all treatments varied from 7.1 to 12.5 cm. Lower depth of cut was obtained for forward speed of 2.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 20.0 cm respectively while the higher depth of cut was obtained for forward speed of 1.5 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 15.0 cm respectively. The desirable depth of cut of 10.0 cm was obtained for forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm respectively.

It was observed that the depth of cut of basin lister increased with blade to plate angle from 100 to 110 deg. and decreased with skid height from ground level from 20.0 to 15.0 cm and forward speed from 2.5 to 1.5 km h^{-1} respectively. It may be due to the lower bite length obtained with lower forward speed and higher penetration obtained with skid height from ground level and blade to plate angle. The combination of forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm resulted in desired depth of cut of 10.0 cm. The obtained results are in close agreement with Sharad *et al.* (2017).

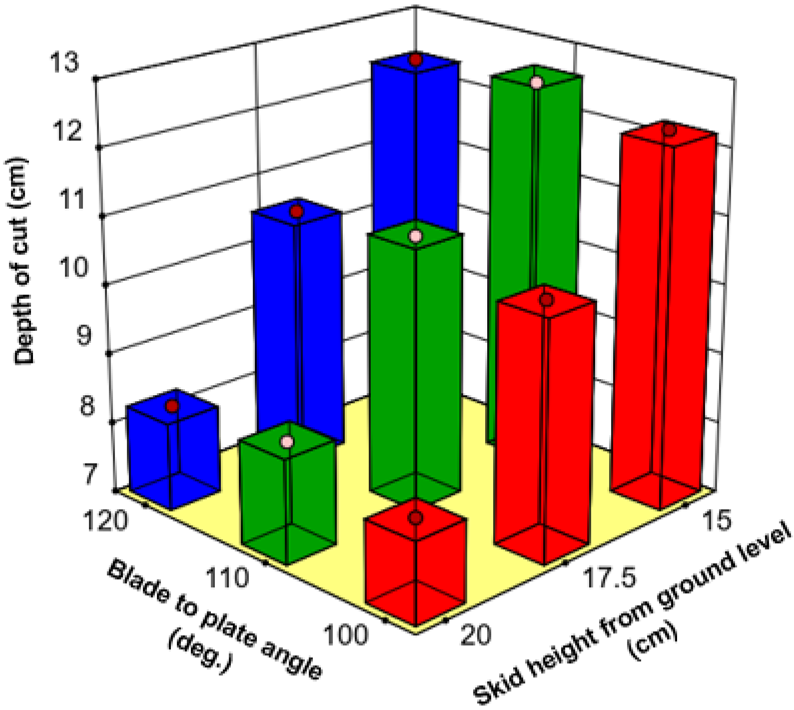

Fig. 4.5 Effect of blade to plate angle and skid height from ground level on depth of cut at forward speed of 1.5 km h^{-1}

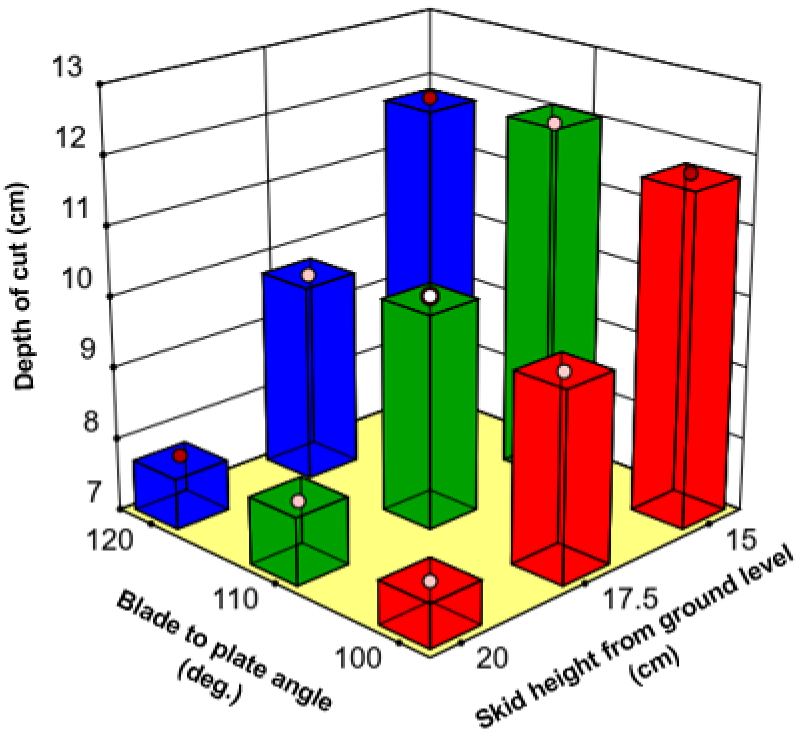

Fig. 4.6 Effect of blade to plate angle and skid height from ground level on depth of cut at forward speed of 2.0 km h^{-1}

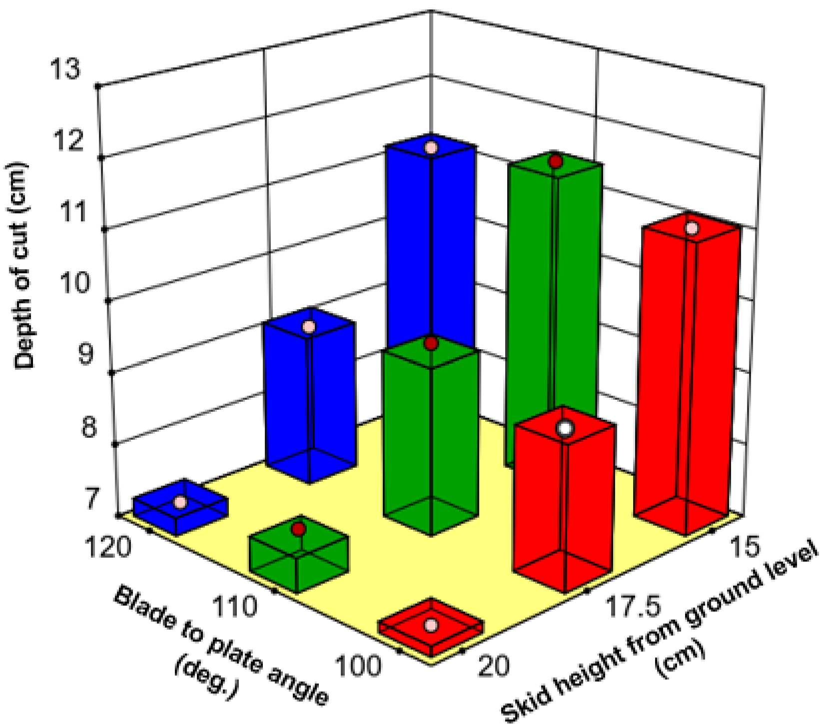

Fig. 4.7 Effect of blade to plate angle and skid height from ground level on depth of cut at forward speed of 2.5 km h^{-1}

4.8.2 Time taken per basin formation

Time taken per basin formation is a vital performance parameter to evaluate the basin lister as it affects the field coverage and economic viability of the machine. The effect of independent parameters viz., forward speed, blade to plate angle and skid height from ground level on time taken per basin formation were presented in Appendix-X.

Analysis of variance indicated that the independent parameters viz., forward speed, blade to plate angle, skid height from ground level and interaction of forward speed and skid height from ground level were significant at 5.0 per cent level of significance for the time taken per basin formation. The model was highly significant at 5.0 per cent level of significance and the coefficient of determination (R^2) was 0.89 specifying the high association of time taken per basin formation with performance parameters as given in Table 4.10. The mean, standard deviation and coefficient of variation were reported as 46.41, 0.41 and 0.90 per cent respectively.

Table. 4.10 Analysis of variance of time taken per basin formation

Source	Sum of Squares	df	Mean Square	F-value
Model	3357.11	10	186.51	1907.45*
Forward speed (F)	338.07	2	169.04	960.84*
Blade to plate angle (B)	40.52	2	20.26	115.16*
Skid height from ground level (S)	2957.85	2	1478.93	8406.53*
F×S	19.26	4	4.81	27.37*
Residual	1.41	16	0.1759	-
Cor Total	3358.52	26	-	-
Std. Dev.	0.4194		**R^2**	0.8926
Mean	46.41		**Adjusted R^2**	0.8814
C.V. (per cent)	0.9038		**Predicted R^2**	0.8728

* Significant at 5 per cent level

The graphs representing the influence of independent parameters with time taken per basin formation were shown in Fig. 4.8, 4.9 and 4.10. The time taken per basin formation for all treatments varied from 28 to 67 s. The minimum time per basin formation was attained for forward speed of 2.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 20.0 cm respectively while it was maximum for forward speed of 1.5 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 15.0 cm respectively.

It was observed that the time taken per basin formation decreased with increase in forward speed from 1.5 to 2.5 km h^{-1}, blade to plate angle from 110 to 100 deg. and skid height from ground level from 15.0 to 20.0 cm. It may be concluded that the time taken per basin formation increased with increase in depth of cut. The combination of forward speed of 2.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 20.0 cm resulted in desired lower time taken per palm. The results are similar to Muhammad (2005) and Onkar *et al.* (2018).

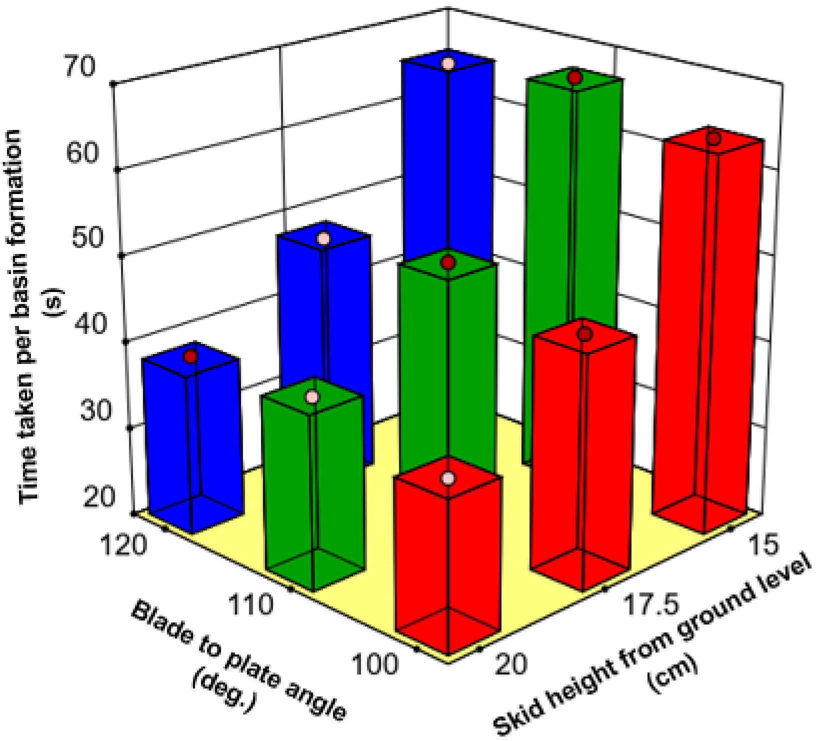

Fig. 4.8 Effect of blade to plate angle and skid height from ground level on time taken per basin formation at forward speed of 1.5 km h^{-1}

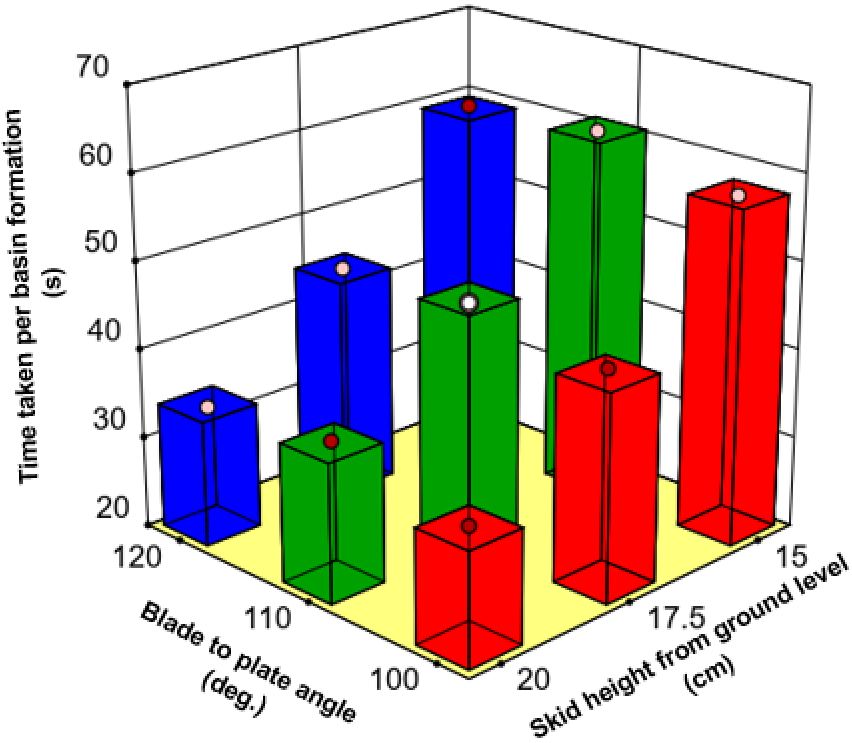

Fig. 4.9 Effect of blade to plate angle and skid height from ground level on time taken per basin formation at forward speed of 2.0 km h^{-1}

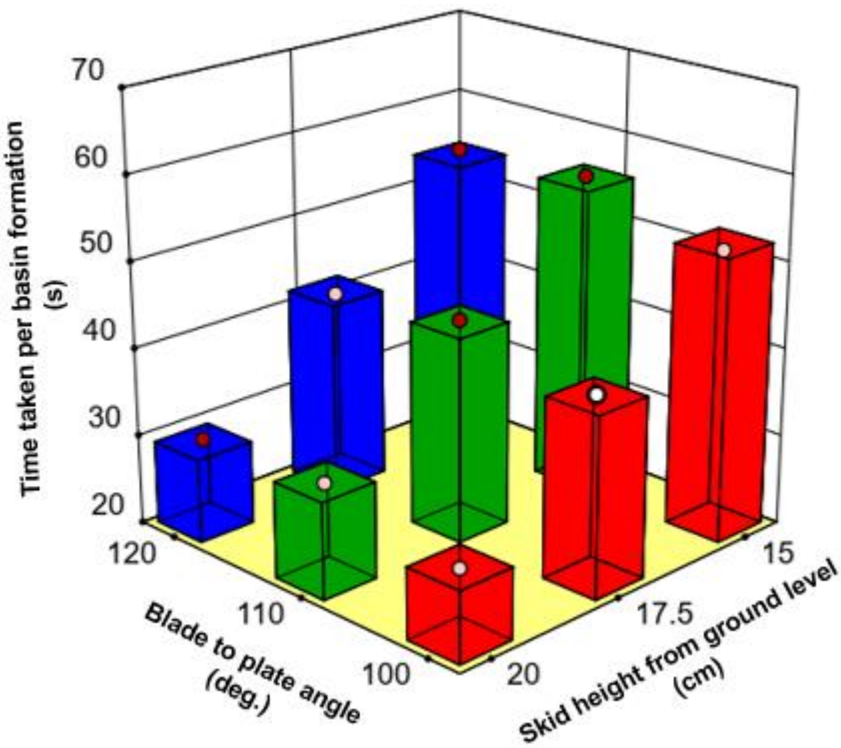

Fig. 4.10 Effect of blade to plate angle and skid height from ground level on time taken per basin formation at forward speed of 2.5 km h^{-1}

4.8.3 Bund height

Bund height is a prominent parameter to evaluate the performance of basin lister as it helps in accommodating the supplied irrigated water in the basin formed around the coconut palm. The effect of independent parameters viz., forward speed, blade to plate angle and skid height from ground level on bund height were reported in Appendix-XI.

Analysis of variance indicated that the independent parameters viz., forward speed, blade to plate angle, skid height from ground level, interaction of blade to plate angle and skid height from ground level were significant at 5.0 per cent level of significance for bund height. The model was highly significant at 5.0 per cent level of significance and the coefficient of determination (R^2) was 0.91 representing the strong relation of bund height with performance parameters as given in Table 4.11. The mean, standard deviation and coefficient of variation were 13.21, 0.06 and 0.51 per cent respectively.

Table. 4.11 Analysis of variance of bund height

Source	Sum of Squares	df	Mean Square	F-value
Model	48.53	10	4.85	1069.55*
Forward speed (F)	0.467	2	0.233	51.51*
Blade to plate angle (B)	42.63	2	21.32	4698.20*
Skid height from ground level (S)	5.23	2	2.62	576.57*
B×S	0.194	4	0.048	10.73*
Residual	0.072	16	0.004	-
Cor Total	48.60	26	-	-
Std. Dev.	0.067	**R^2**	0.9186	
Mean	13.21	**Adjusted R^2**	0.9064	
C.V. (per cent)	0.51	**Predicted R^2**	0.8968	

* Significant at 5 per cent level

The graphs depicting the effect of independent parameters on bund height were presented in Fig. 4.11, 4.12 and 4.13. The bund height for all treatments varied from 10.9 to 15.6 cm. The bund height was lower at forward speed of 1.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 20.0 cm respectively while the higher bund height was obtained at forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm respectively.

It was noted that the bund height increased with forward speed of 1.5 to 2.0 km h^{-1} and then decreased at 2.5 km h^{-1}, blade to plate angle of 100 to 110 deg. and then decreased at 120 deg. and skid height from ground level of 20.0 to 17.5 cm and further decreased at 15.0 cm. Due to accumulation of more amount of soil at slower forward speed, the bund height was lower as the soil throw was not proper. At 110 deg. blade to plate angle, better soil scooping was observed and higher bund height was formed. The combination of forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm resulted in desired higher bund height. The results are in close agreement with Singh *et al.* (2016) and Rahul *et al.* (2018).

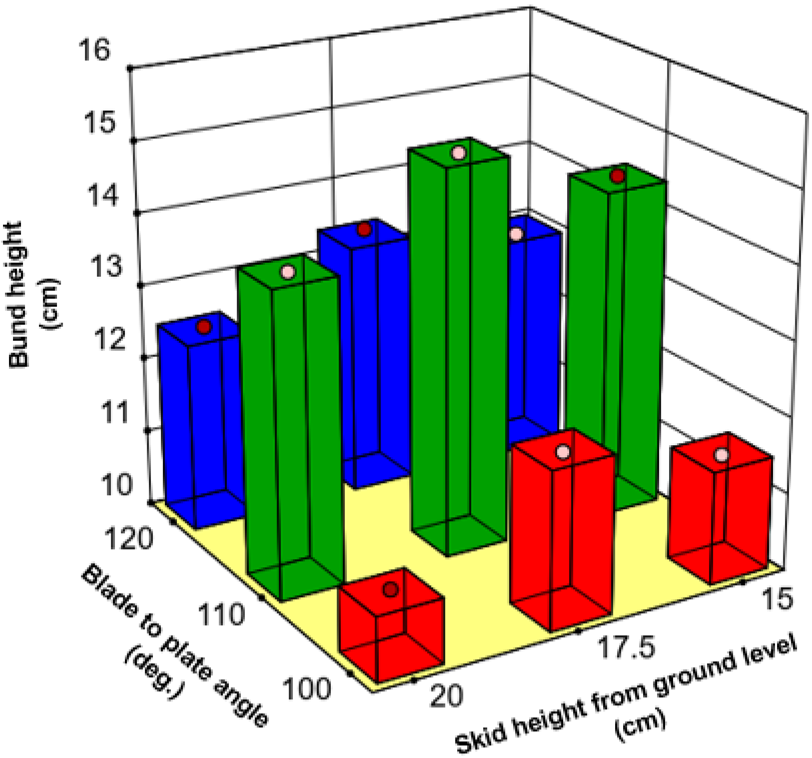

Fig. 4.11 Effect of blade to plate angle and skid height from ground level on bund height at forward speed of 1.5 km h^{-1}

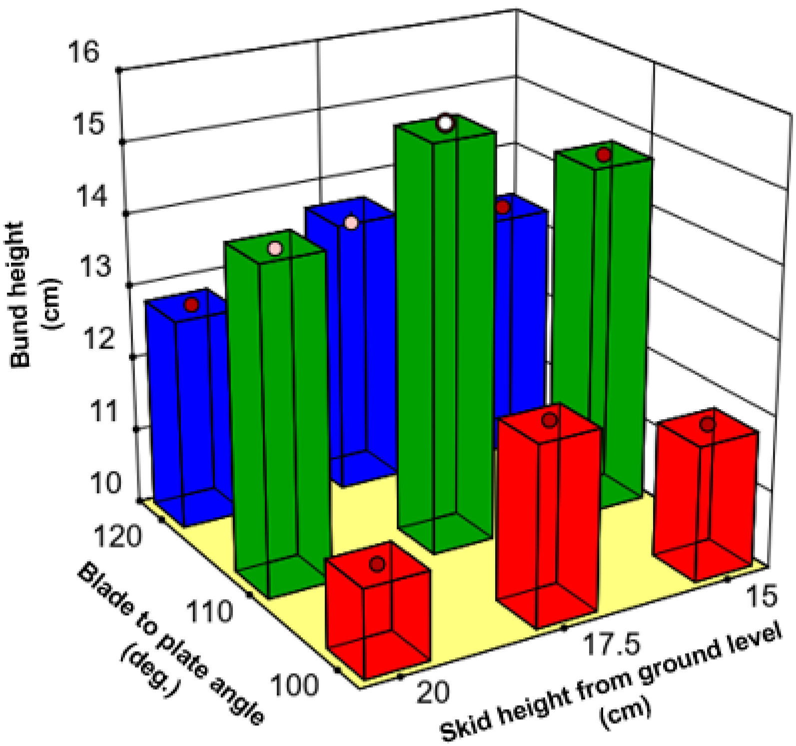

Fig. 4.12 Effect of blade to plate angle and skid height from ground level on bund height at forward speed of 2.0 km h^{-1}

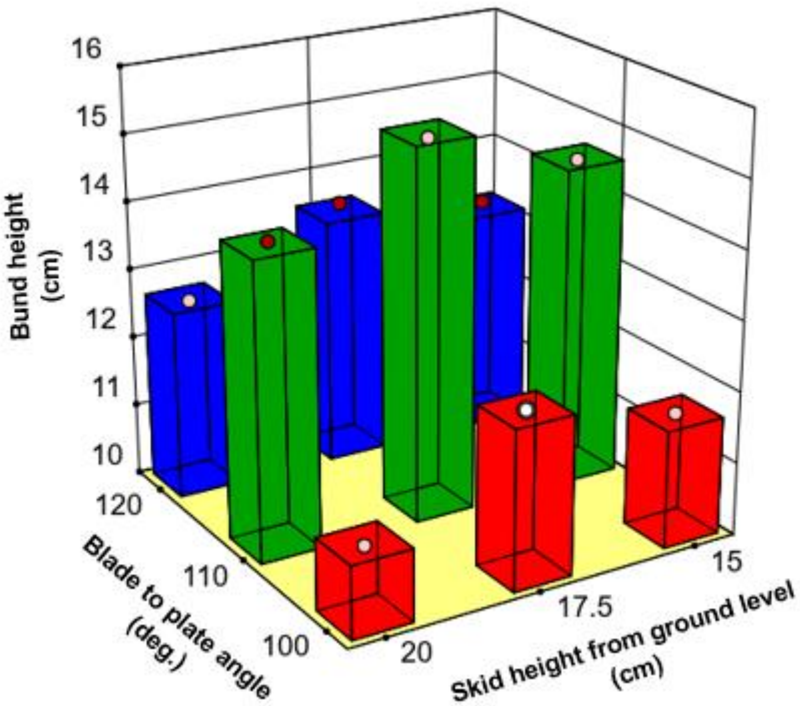

Fig. 4.13 Effect of blade to plate angle and skid height from ground level on bund height at forward speed of 2.5 km h^{-1}

4.8.4 Bund width

Bund width is an important parameter to evaluate the performance of basin lister as it helps in containing the supplied irrigated water in the basin formed around the coconut palm. The effect of independent parameters viz., forward speed, blade to plate angle and skid height from ground level on bund width were reported in Appendix-XI.

Analysis of variance indicated that the independent parameters viz., forward speed, blade to plate angle, skid height from ground level and interaction of blade to plate angle and skid height from ground level were significant at 5.0 per cent level of significance for the bund width. The model was highly significant at 5.0 per cent level of significance and the coefficient of determination (R^2) was 0.88 representing the agreement of bund width with performance parameters as given in Table 4.12. The mean, standard deviation and coefficient of variation were 34.49, 0.1694 and 0.4913 per cent respectively.

Table. 4.12 Analysis of variance of bund width

Source	Sum of Squares	df	Mean Square	F-value
Model	95.95	10	9.60	334.29*
Forward speed (F)	0.6541	2	0.327	11.39*
Blade to plate angle (B)	85.39	2	42.69	1487.39*
Skid height from ground level (S)	9.83	2	4.91	171.19*
B×S	0.0859	4	0.021	0.748*
Residual	0.4593	16	0.028	-
Cor Total	96.41	26	-	-
Std. Dev.	0.1694		**R^2**	0.8878
Mean	34.49		**Adjusted R^2**	0.8724
C.V. (per cent)	0.4913		**Predicted R^2**	0.8634

*Significant at 5 per cent level

The graphs showing the effect of independent parameters on bund width were shown in Fig. 4.14, 4.15 and 4.16. The bund width for all treatments varied from 31.2

to 37.6 cm. The bund width was lower for the forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm respectively while the higher bund width was attained for forward speed of 1.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 15.0 cm respectively.

It was noted that the bund width increased with forward speed of 1.5 to 2.0 km h^{-1} and then decreased at 2.5 km h^{-1}, blade to plate angle of 100 to 110 deg. and further decreased at 120 deg. and skid height from ground level of 20.0 to 17.5 cm and further decreased at 15.0 cm. Due to accumulation of more amount of soil at slower forward speed, the bund width was more as the soil throw was not proper. At 110 deg. blade to plate angle, better soil scooping was observed and lower bund width was formed. The combination of forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm resulted in desired lower bund width. The obtained results are similar to Singh *et al.* (2016) and Rahul *et al.* (2018).

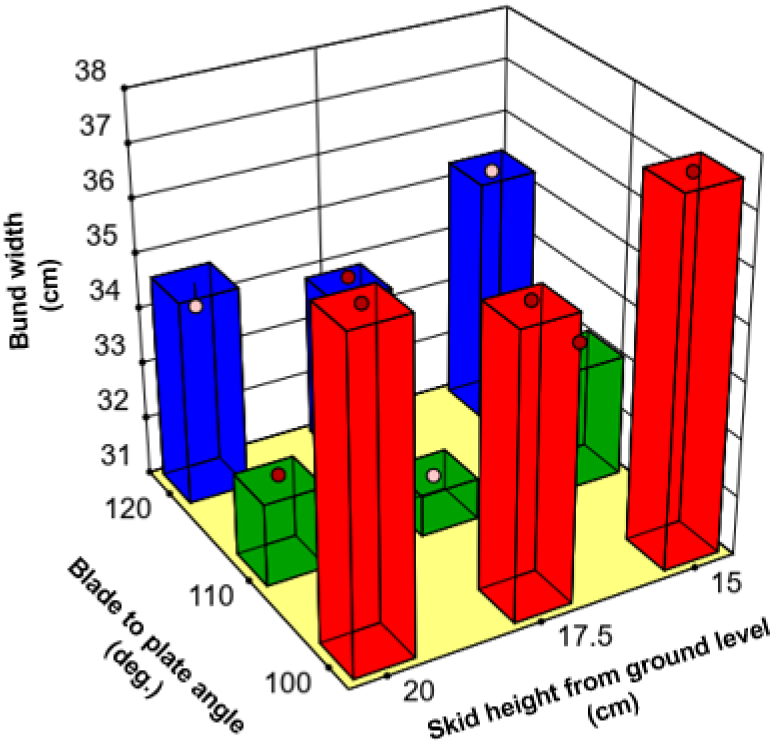

Fig. 4.14 Effect of blade to plate angle and skid height from ground level on bund width at forward speed of 1.5 km h^{-1}

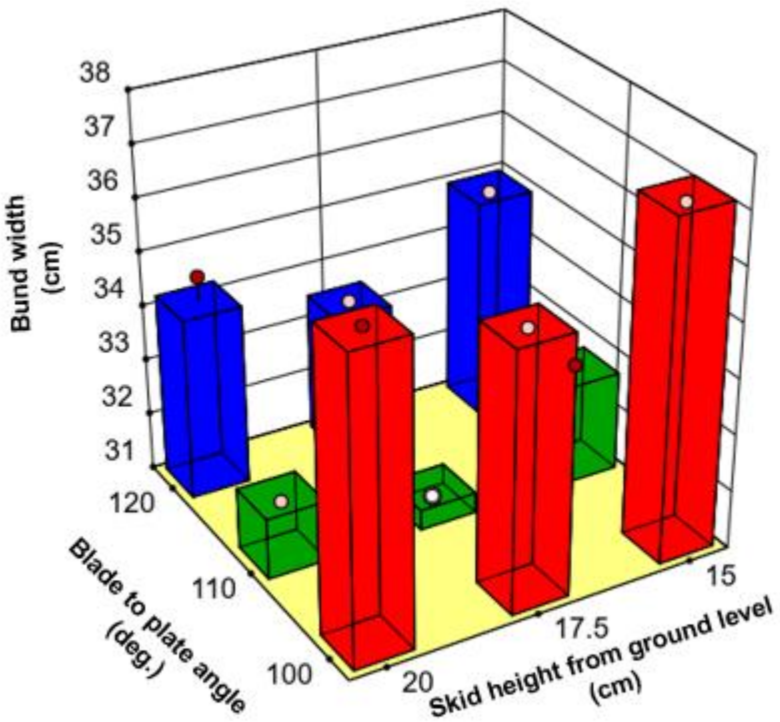

Fig. 4.15 Effect of blade to plate angle and skid height from ground level on bund width at forward speed of 2.0 km h^{-1}

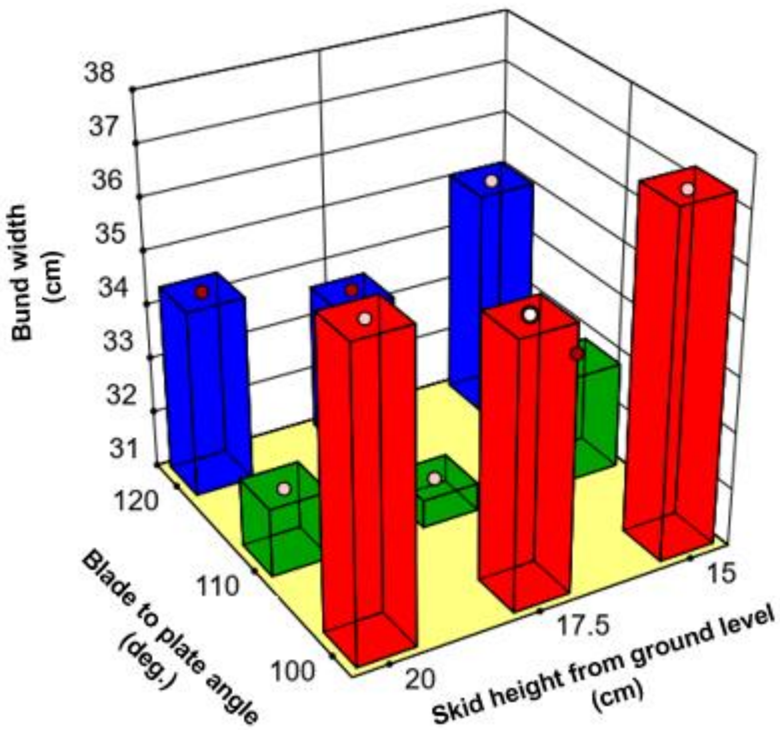

Fig. 4.16 Effect of blade to plate angle and skid height from ground level on bund width at forward speed of 2.5 km h^{-1}

4.8.5 Soil pulverization index

Soil pulverization index quantifies the soil disintegration of rotary unit which helps in better soil throw to form uniform bund around coconut palm. The effect of independent parameters viz., forward speed, blade to plate angle and skid height from ground level on soil pulverization index were reported in Appendix-XII.

Analysis of variance indicated that the independent parameters viz., forward speed, blade to plate angle, skid height from ground level and interaction of forward speed and skid height from ground level were significant at 5.0 per cent level of significance for the soil pulverization index. The model was highly significant at 5.0 per cent level of significance and the coefficient of determination (R^2) was 0.92 representing the agreement of soil pulverization index with performance parameters as given in Table 4.13. The mean, standard deviation and coefficient of variation were 4.41, 0.04 and 1.03 per cent respectively.

Table. 4.13 Analysis of variance of soil pulverization index

Source	Sum of Squares	df	Mean Square	F-value
Model	84.06	10	8.41	4065.5*
Forward speed (F)	77.03	2	38.51	18626.7*
Blade to plate angle (B)	0.162	2	0.081	39.29*
Skid height from ground level (S)	6.46	2	3.23	1561.2*
F×S	0.415	4	0.103	50.25*
Residual	0.033	16	0.002	-
Cor Total	84.09	26	-	-
Std. Dev.	0.04		**R^2**	0.9288
Mean	4.41		**Adjusted R^2**	0.9164
C.V. (per cent)	1.03		**Predicted R^2**	0.9046

* Significant at 5 per cent level

The graphs showing the effect of independent parameters on soil pulverization index were shown in Fig. 4.17, 4.18 and 4.19. The soil pulverization index for all treatments varied from 1.4 to 6.9 mm. The soil pulverization index was lower for the forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm respectively while the higher soil pulverization index was attained for forward speed of 2.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 20.0 cm respectively.

It was noted that the soil pulverization index decreased with forward speed of 2.5 to 2.0 km h^{-1} and then increased at 1.5 km h^{-1}, blade to plate angle of 120 to 110 deg. and further increased at 100 deg. and skid height from ground level of 20.0 to 17.5 cm and further increased at 15.0 cm. Pulverization index was low at slower speed due to the lower bite length. Blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm aided in lower pulverization index. The combination of forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm resulted in desired lower pulverization index. Similar results are obtained by Sharad *et al.* (2018).

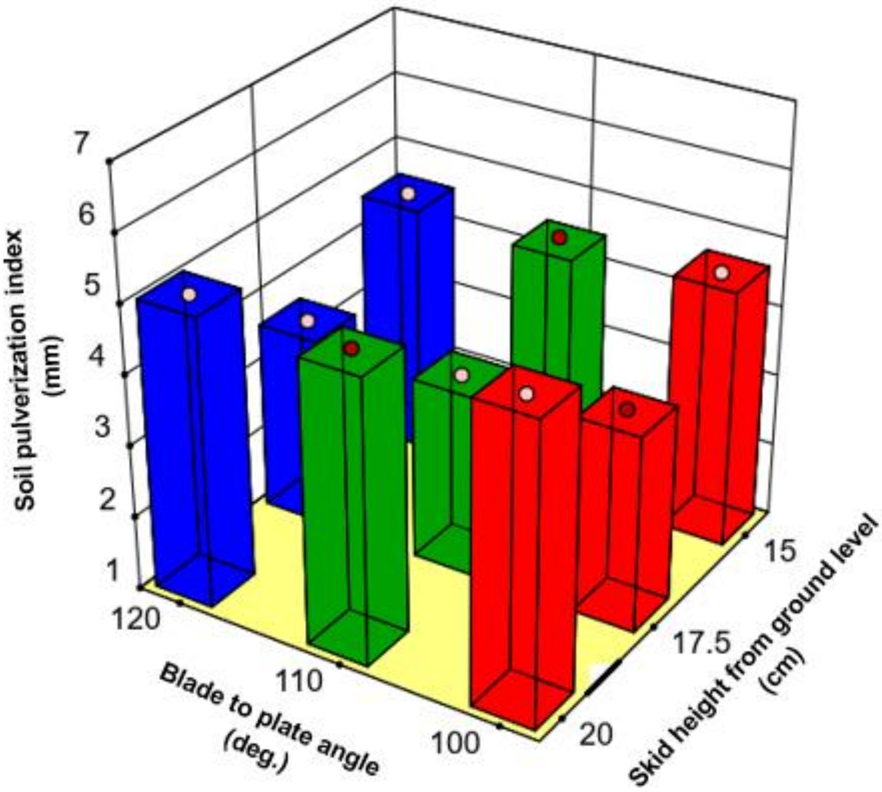

Fig. 4.17 Effect of blade to plate angle and skid height from ground level on soil pulverization index at forward speed of 1.5 km h^{-1}

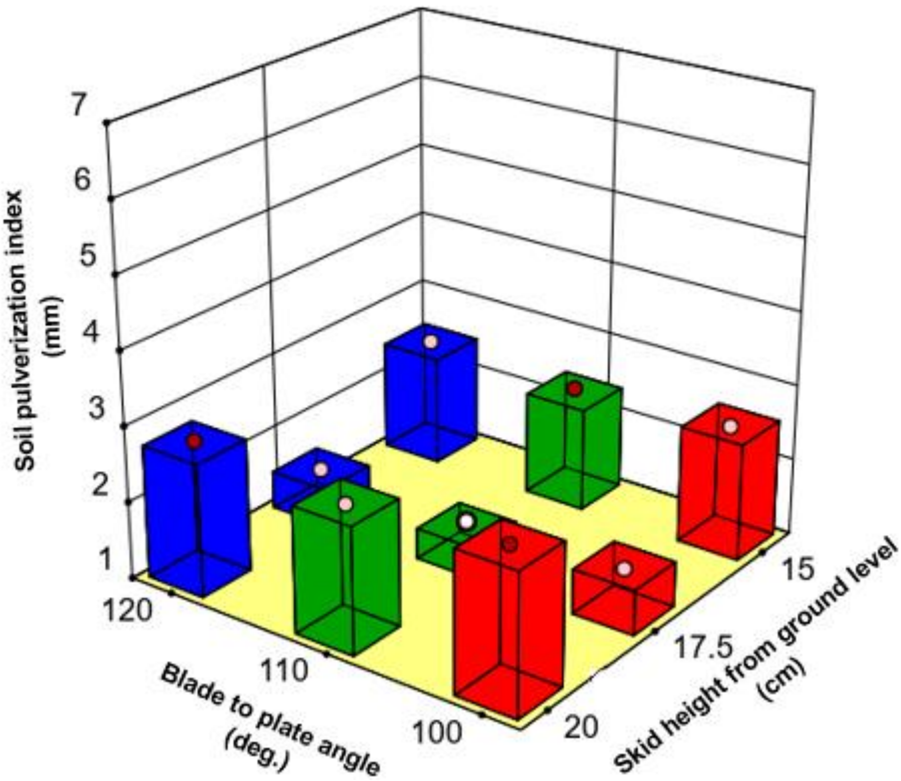

Fig. 4.18 Effect of blade to plate angle and skid height from ground level on soil pulverization index at forward speed of 2.0 km h^{-1}

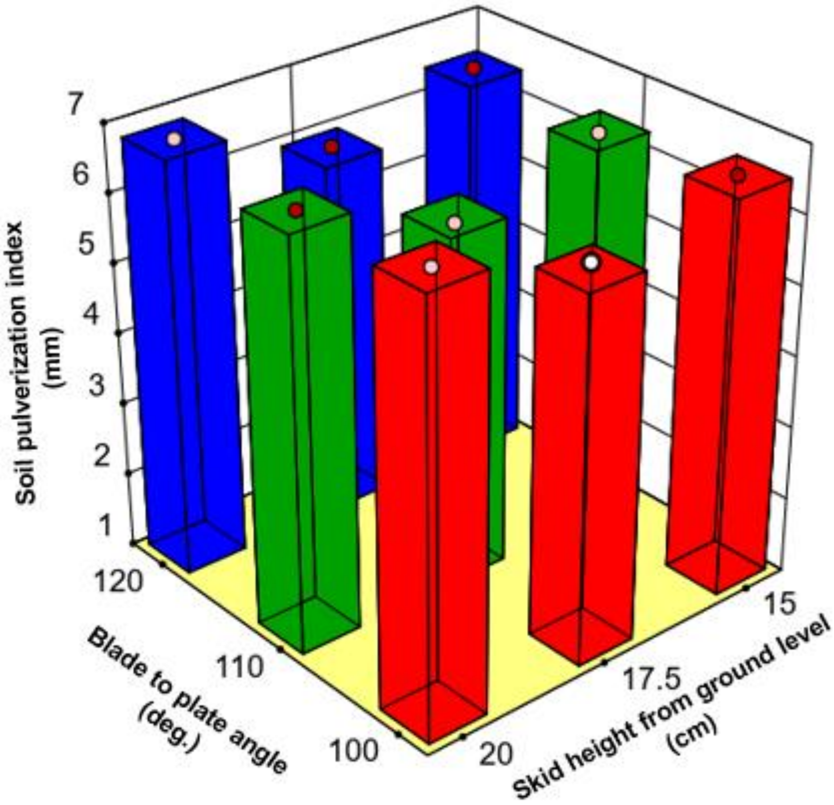

Fig. 4.19 Effect of blade to plate angle and skid height from ground level on soil pulverization index at forward speed of 2.5 km h^{-1}

4.8.6 Draft

Draft is an important parameter to evaluate the performance of basin lister as it affects the power requirement of machine. The effect of independent parameters viz., forward speed, blade to plate angle and skid height from ground level on draft were reported in Appendix-XII.

Analysis of variance indicated that the independent parameters viz., forward speed, blade to plate angle, skid height from ground level and interaction of forward speed and skid height from ground level were significant at 5.0 per cent level of significance for the draft. The model was highly significant at 5.0 per cent level of significance and the coefficient of determination (R^2) was 0.89 representing the agreement of draft with performance parameters as given in Table 4.14. The mean, standard deviation and coefficient of variation were 1212.11, 3.71 and 0.3 per cent respectively.

Table 4.14 Analysis of variance of draft

Source	Sum of Squares	df	Mean Square	F-value
Model	2.75×10^5	10	27510.2	1996.7*
Forward speed (F)	2.34×10^5	2	1.17×10^5	8515.1*
Blade to plate angle (B)	2208.22	2	1104.1	80.1*
Skid height from ground level (S)	35579.56	2	17789.7	1291.1*
F×S	2673.78	4	668.4	48.5*
Residual	220.44	16	13.78	-
Cor Total	2.753E+05	26	-	-
Std. Dev.	3.71	**R^2**	0.8956	
Mean	1212.1	**Adjusted R^2**	0.8842	
C.V. (per cent)	0.306	**Predicted R^2**	0.8768	

* Significant at 5 per cent level

The graphs showing the effect of independent parameters on draft were shown in Fig. 4.20, 4.21 and 4.22. The draft for all treatments varied from 1033 to 1384 N.

The draft was lower for the forward speed of 2.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 20.0 cm respectively while the higher draft was attained for forward speed of 1.5 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 15.0 cm respectively.

It was noted that the draft increased with decrease in forward speed of 2.5 to 1.5 km h^{-1}, blade to plate angle of 100 to 110 deg. and then decreased at 120 deg. and skid height from ground level of 20.0 to 15.0 cm. Draft increased at slower speed and lower skid position due to lower bite length and higher depth of cut. Draft at blade to plate angle of 110 deg. was higher due to the higher volume of soil handled. The combination of forward speed of 2.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 20.0 cm resulted in desired lower draft. The obtained results are in close agreement with Sharad *et al.* (2017).

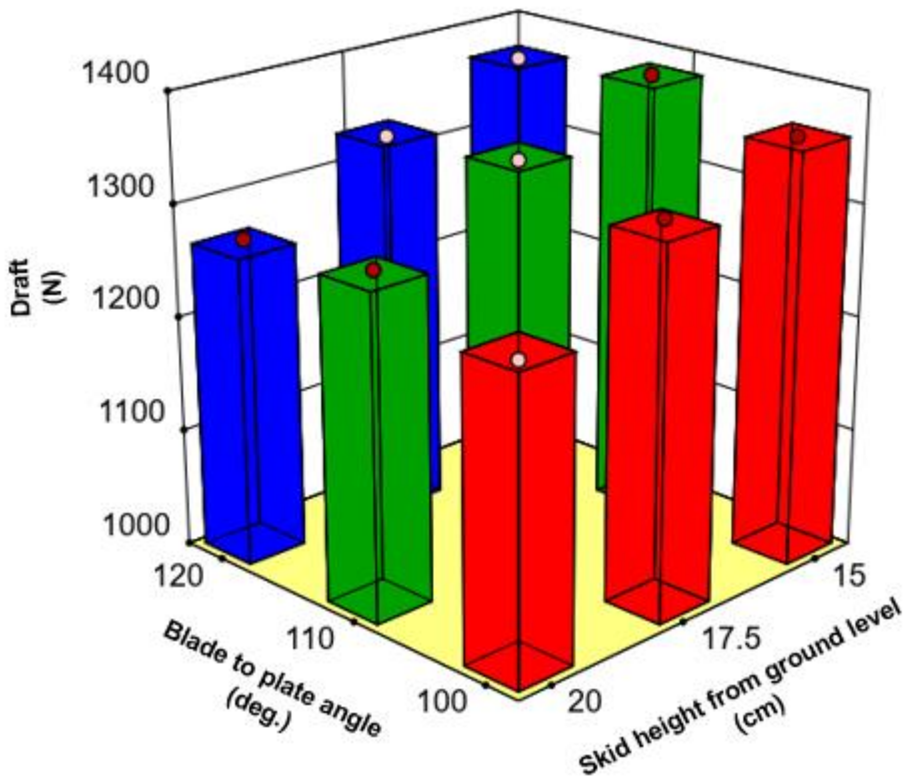

Fig. 4.20 Effect of blade to plate angle and skid height from ground level on draft at forward speed of 1.5 km h^{-1}

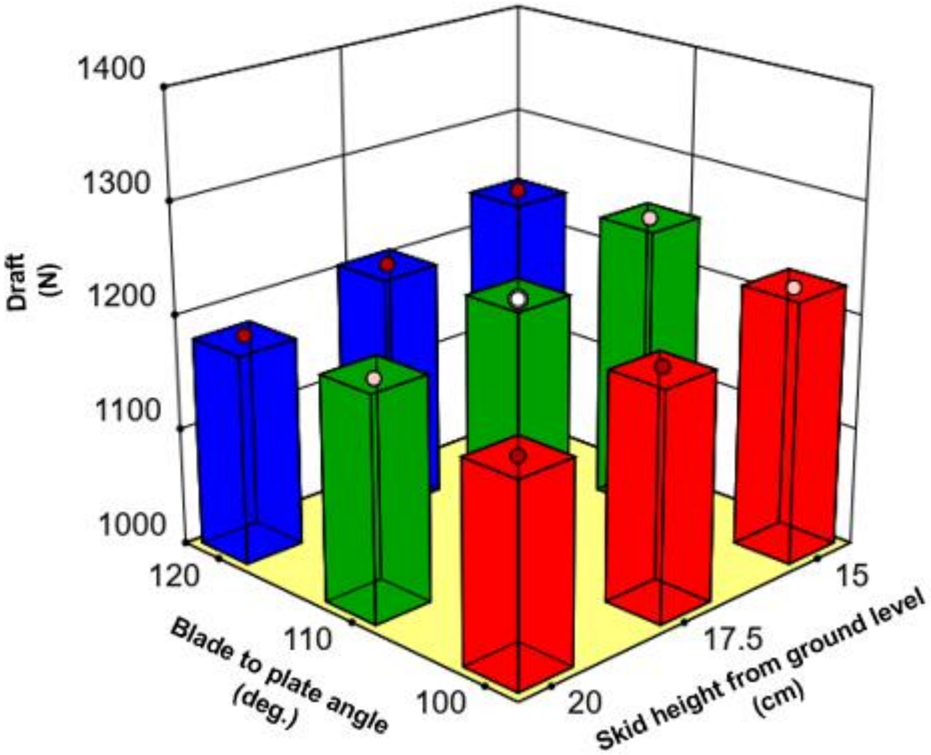

Fig. 4.21 Effect of blade to plate angle and skid height from ground level on draft at forward speed of 2.0 km h^{-1}

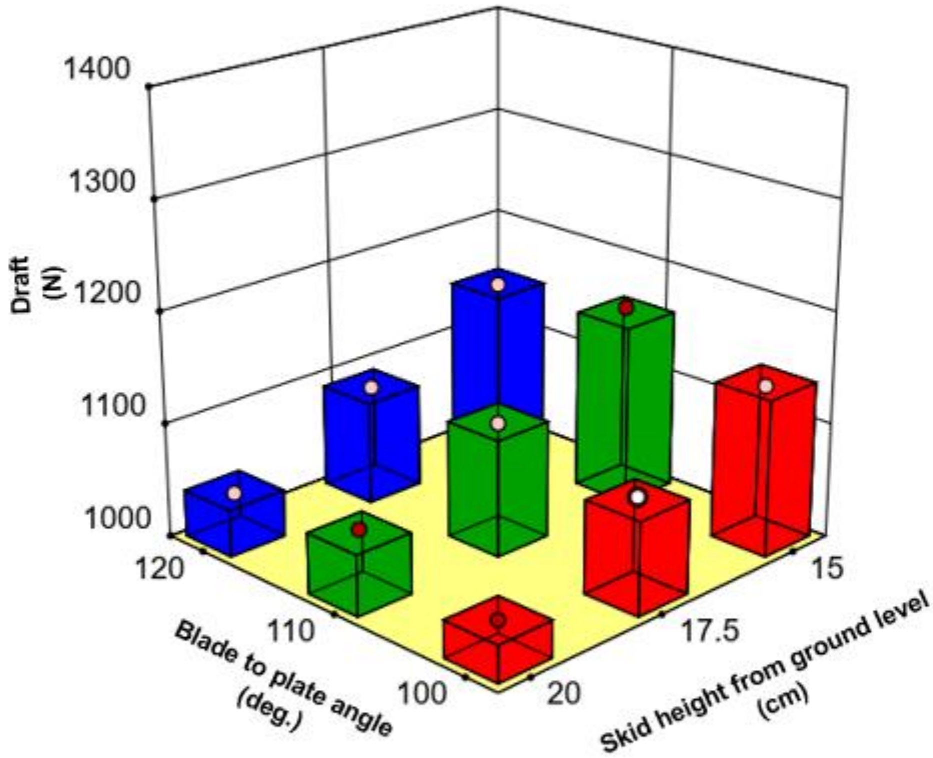

Fig. 4.22 Effect of blade to plate angle and skid height from ground level on draft at forward speed of 2.5 km h^{-1}

4.9 NUMERICAL OPTIMIZATION OF MACHINE

The statistical analysis gave a clear understanding of both dependent and independent parameters of machine which in turn aided in finding the optimum levels of independent parameters with numerical optimization method in Design Expert Version 13.0.5 software as discussed in the following section.

4.9.1 Numerical optimization

The numerical optimization of machine was performed by setting the constraints for all parameters as given in Table 4.15 to obtain optimum solutions. Then the desirability of machine was found out as shown in Fig. 4.23. The optimum parameters of machine for higher output were forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm. The desirability of optimum parameters of machine for the dependent parameters of depth of cut, time taken per basin formation, bund height, bund width, soil pulverization index and draft were 0.97, 0.52, 0.98, 0.98, 1 and 0.45 respectively. The combined desirability of machine was highest i.e., 0.78 for the optimum parameters of forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm as mentioned in Table 4.16.

4.10 COST ECONOMICS OF DEVELOPED TRACTOR OPERATED BASIN LISTER CUM FERTILIZER APPLICATOR

The cost of prototype of tractor operated basin lister cum fertilizer applicator is Rs.85,000. The calculations of economic evaluation of machine were given in Appendix-XIII. The cost of operation per hour and hectare was determined as Rs.881 and Rs.5874 respectively. The breakeven point, payback period and benefit cost ratio of the machine is 75 hours per annum, 1.60 years and 3.08:1 respectively. The saving in cost is Rs.18,126 ha^{-1} and 75.50 per cent when compared to manual basin listing and fertilizer application operations.

Table 4.15 Constraints of parameters

Parameters	Goal
Independent parameters	
Forward speed (km h^{-1})	is in range
Blade to plate angle (deg.)	is in range
Skid height from ground level (cm)	is in range
Dependent parameters	
Depth of cut (cm)	target = 10 cm
Time taken per palm (s)	Minimize
Bund height (cm)	Maximize
Bund width (cm)	Minimize
Pulverization index (mm)	Minimize
Draft (N)	Minimize

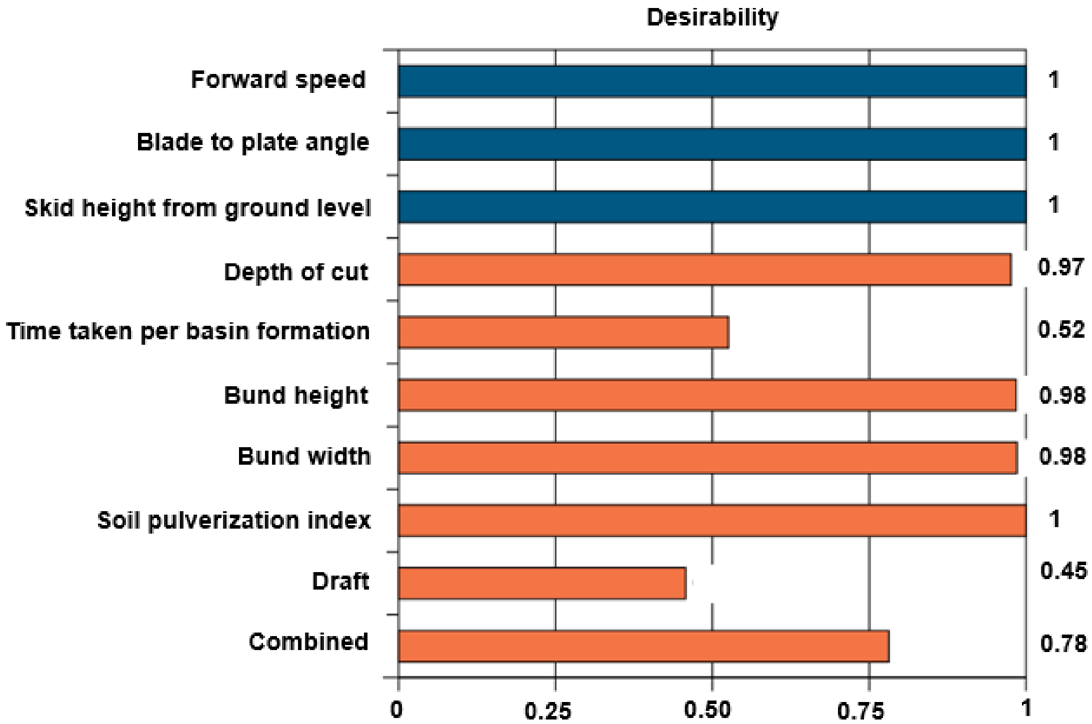

Fig. 4.23 Desirability of machine

Table 4.16 Optimum parameters of machine

S.No.	Independent parameters	Optimum values
1	Forward speed (km h^{-1})	2.0
2	Blade to plate angle (deg.)	110
3	Skid height from ground level (cm)	17.5

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

The basin listing and fertilizer application are important operations for the optimum growth of coconut palms. The conventional methods of basin listing and fertilizer application for coconut palms are labour intensive, drudgery prone, time consuming, accident prone, cost intensive and requires skilled labour. Due to the increasing urban culture among the population, there is an acute shortage of labour while the available labour demand high wages for the basin listing and fertilizer application operations of coconut palms. These factors lead to the development of a suitable mechanical basin lister cum fertilizer applicator for coconut palms. The tractors are a prominent part of Indian Agriculture in the present age for performing all the farm operations. The mechanical basin lister cum fertilizer applicator driven by a tractor of sufficient power to accomplish basin listing and fertilizer application operations with higher field efficiency, timeliness and cost saving when compared to conventional method is the most adaptable technology for Indian farms. Therefore, a research work was undertaken to develop a tractor operated basin lister cum fertilizer applicator and optimize its machine parameters for optimum operation.

The soil parameters *viz.*, moisture content, bulk density, cone index and shear strength and crop parameters *viz.*, trunk diameter and root zone depth were studied in coconut plantation area as they influence the design of tractor operated basin lister cum fertilizer applicator. The fertilizer parameters *viz.*, angle of repose, bulk density, tapped density and coefficient of friction of urea, muriate of potash and rock phosphate fertilizers were determined.

The experimental model of fertilizer applicator was developed to finalize the optimum machine parameters for prototype of fertilizer applicator. The experimental model of fertilizer applicator was tested for metering roller types *viz.*, edge cell, fluted cell and baffle cell to determine optimum fertilizer discharge of 1.56 kg. The results revealed that edge cell metering roller delivered the recommended fertilizer quantity than the fluted cell and baffle cell metering rollers. The optimised edge cell metering roller was used in the prototype of fertilizer applicator for optimum fertilizer application rate.

The lab evaluation of prototype of fertilizer applicator was accomplished for different metering roller flute volumes of 1.3×10^{-5}, 1.43×10^{-5} and 1.63×10^{-5} m^3 and agitator types of ‘J’, ‘L’ and ‘C’ shapes to determine the optimum fertilizer application rate and coefficient of uniformity. The field test of tractor operated basin lister cum fertilizer applicator was conducted in KCAET Instructional Farm. The basin lister was tested in the field for different forward speeds *viz.,* 1.5, 2.0 and 2.5 km h^{-1}; blade to plate angles *viz.,* 100, 110 and 120 deg. and skid height from ground level *viz.,* 20.0, 17.5 and 15.0 cm respectively to determine the optimum dependent parameters *viz.*, depth of cut, time taken per palm, bund height, bund width, soil pulverization index, draft, number of basins per hour, actual field capacity and fuel consumption.

The three-level factorial method was selected for statistical analysis and the optimization of independent parameters was performed by numerical optimization technique to obtain optimum levels and the desirability was found out for lab evaluation of prototype of fertilizer applicator and field test of basin lister using “Design Expert 13.0.5” version software.

The results revealed that the flute volume of 1.43×10^{-5} m^3 and ‘L’ shape agitator delivered the recommended fertilizer quantity of 1.56 kg $palm^{-1}$. This optimised set of independent parameters of flute volume and agitator shape were tested in the field with prototype of fertilizer applicator. The results of field test of machine revealed that the optimum parameters were forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm.

The cost economics of tractor operated basin lister cum fertilizer applicator was found out in terms of break-even point, payback period and benefit-cost ratio. The saving in cost of operation of developed machine over conventional method of basin listing and fertilizer application operations was also determined to predict the economic viability of developed machine.

The conclusions of the study are detailed as the following.

- The soil moisture content varied from 13.2 to 15.6 per cent with a mean of 14.66 per cent, coefficient of variation of 6.77 per cent and standard deviation of 0.993.
- The soil bulk density varied from 1615 to 1865 kg m^{-3} with a mean of 1696.6 kg m^{-3}, coefficient of variation of 5.94 per cent and standard deviation of 100.842.
- The cone index of soil varied from 1.43 to 1.55 kg cm^{-2} with a mean of 1.50 kg cm^{-2}, coefficient of variation of 1.31 per cent and standard deviation of 0.02
- The shear strength of soil varied from 0.77 to 0.82 kg cm^{-2} with mean of 0.8 kg cm^{-2}, coefficient of variation of 2.5 per cent and standard deviation of 0.02.
- The trunk diameter of coconut palms varied from 32.3 to 38.1 cm with a mean of 34.7 cm, coefficient of variation of 6.55 per cent and standard deviation of 2.27.
- The root zone depth of coconut palms varied from 13.4 to 15.2 cm with a mean of 14.34 cm, coefficient of variation of 5.11 per cent and standard deviation of 0.73.
- The angle of repose of urea, muriate of potash and rock phosphate fertilizers were 32.9, 38.1 and 40.8 deg. respectively.
- The bulk density of urea, muriate of potash and rock phosphate fertilizers were 740.6, 1081.6 and 1326 kg m^{-3} respectively.
- The tapped density of urea, muriate of potash and rock phosphate fertilizers were 834.3, 1167 and 1419 kg m^{-3} respectively.
- The coefficient of friction of urea, muriate of potash and rock phosphate fertilizers were 0.31, 0.47 and 0.55 respectively.
- The recommended fertilizer discharge of 1.56 kg $palm^{-1}$ was obtained for edge cell metering roller with experimental model of fertilizer applicator.
- The recommended fertilizer application rate of 1.56 kg $palm^{-1}$was obtained for edge cell metering roller flute volume of 1.43×10^{-5} m^3 and ‘L’ shape agitator with lab test of prototype of fertilizer applicator.

- The coefficient of uniformity was highest i.e., 99.2 per cent for edge cell metering roller flute volume of 1.43×10^{-5} m^3 and ‘L’ shape agitator with lab test of prototype of fertilizer applicator.
- The desirability was highest i.e., 0.98 for the optimum parameters of edge cell metering roller flute volume of 1.43×10^{-5} m^3 and ‘L’ shape agitator with lab test of prototype fertilizer applicator.
- The desirable depth of cut of 10.0 cm was obtained for forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm respectively with basin lister in the field.
- The minimum time per basin formation was attained for forward speed of 2.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 20.0 cm respectively with basin lister in the field.
- The higher bund height was obtained for forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm respectively with basin lister in the field.
- The bund width was lower for the forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm respectively with basin lister in the field.
- The soil pulverization index was lower for the forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm respectively with basin lister in the field.
- The draft was lower for the forward speed of 2.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 20.0 cm respectively with basin lister in the field.
- The combined desirability of field test of machine was highest i.e., 0.78 for the optimum parameters of forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm.
- The number of basins formed per hour by tractor operated basin lister cum fertilizer applicator is 20.

- The actual field capacity of tractor operated basin lister cum fertilizer applicator is 0.15 ha h^{-1}.
- The fuel consumption of tractor operated basin lister cum fertilizer applicator is 6.7 l h^{-1}.
- The cost of prototype of tractor operated basin lister cum fertilizer applicator is Rs.85,000.
- The cost of operation of machine for basin listing and fertilizer application operations is found out as Rs.881 h^{-1} and Rs.5874 ha^{-1}.
- The breakeven point, payback period and benefit cost ratio of the machine is calculated as 75 hours per annum, 1.60 years and 3.08:1 respectively
- The saving in cost of operation of machine is calculated as Rs.18,126 ha^{-1} and 75.50 per cent when compared to conventional method of basin listing and fertilizer application operations.

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APPENDICES

APPENDIX - I

Soil parameters

S. No.	Moisture content (per cent)	Bulk density (kg m^{-3})	Cone index (kg cm^{-2})	Shear strength (kg cm^{-2})
1	14.8	1865	1.53	0.77
2	15.5	1705	1.43	0.82
3	13.2	1672	1.55	0.82
4	14.2	1615	1.50	0.79
5	15.6	1626	1.49	0.80
Range	2.4	250	0.06	0.05
Mean	14.66	1696.6	1.50	0.80
S.D	0.993	100.84	0.02	0.02
C.V (per cent)	6.77	5.94	1.31	2.5

APPENDIX - II

Crop parameters

S. No.	Base diameter (cm)	Root zone depth (cm)
1	32.3	14.5
2	38.1	13.4
3	35.8	15.2
4	34.2	14.8
5	33.3	13.8
Range	5.8	1.8
Mean	34.7	14.3
S.D	2.27	0.73
C.V (per cent)	6.55	5.11

APPENDIX - III

Determination of fertilizer doses

1. Urea

The urea requirement per coconut palm per dose per year (U) was found out by the following equation.

$$U = \frac{R}{C \times D}$$

$$= \frac{0.5}{\frac{46}{100} \times 3}$$

$$= 0.36 \text{ kg palm}^{-1} \text{ dose}^{-1} \text{ year}^{-1}$$

where,

U = Urea requirement, kg palm^{-1} dose^{-1} year^{-1}

R = Recommended fertilizer rate, kg palm^{-1} year^{-1}

C = Nutrient quantity in fertilizer

D = Number of doses per year

The number of coconut palms per hectare (N) was assumed as 200 and the urea requirement per hectare per dose per year (F_1) was determined by the following equation.

$$F_1 = U \times N$$

$$= 0.36 \times 200$$

$$= 72 \text{ kg ha}^{-1} \text{ dose}^{-1} \text{ year}^{-1}$$

2. Rock phosphate

The rock phosphate requirement per coconut palm per dose per year (P) was found out by the following equation.

$$P = \frac{R}{C \times D}$$

$$= \frac{0.32}{\frac{20}{100} \times 3}$$

$$= 0.53 \text{ kg palm}^{-1} \text{ dose}^{-1} \text{ year}^{-1}$$

where,

P = Rock phosphate requirement, kg palm^{-1} dose^{-1} year^{-1}

R = Recommended fertilizer rate, kg palm^{-1} year^{-1}

C = Nutrient quantity in fertilizer

D = Number of doses per year

The number of coconut palms per hectare (N) was assumed as 200 and the rock phosphate requirement per hectare per dose per year (F_2) was determined by the following equation.

$$F_2 = P \times N$$

$$= 0.53 \times 200$$

$$= 106 \text{ kg ha}^{-1} \text{ dose}^{-1} \text{ year}^{-1}$$

3. Muriate of potash

The muriate of potash requirement per coconut palm per dose per year (K) was found out by the following equation.

$$K = \frac{R}{C \times D}$$

$$= \frac{1.2}{\frac{60}{100} \times 3}$$

$$= 0.67 \text{ kg palm}^{-1} \text{ dose}^{-1} \text{ year}^{-1}$$

where,

K = Muriate of potash requirement, kg palm^{-1} dose^{-1} year^{-1}

R = Recommended fertilizer rate, kg palm^{-1} year^{-1}

C = Nutrient quantity in fertilizer

D = Number of doses per year

The number of coconut palms per hectare (N) was assumed as 200 and the Muriate of potash requirement per hectare per dose per year (F_3) was determined by the following equation.

$$F_3 = K \times N$$

$$= 0.67 \times 200$$

$= 134$ kg ha^{-1} dose^{-1} year^{-1}

The total fertilizer requirement per coconut palm per dose per year (f) was given by the following equation.

$$f = U + P + K$$
$$= 0.36 + 0.53 + 0.67$$
$$= 1.56 \text{ kg palm}^{-1} \text{ dose}^{-1} \text{ year}^{-1}$$

The total fertilizer requirement per hectare per dose per year (F) was given by the following equation.

$$F = F_1 + F_2 + F_3$$
$$= 72 + 106 + 134$$
$$= 312 \text{ kg ha}^{-1} \text{ dose}^{-1} \text{ year}^{-1}$$

The total fertilizer requirement of coconut palm was calculated as 1.56 kg palm^{-1} dose^{-1} year^{-1} and 312 kg ha^{-1} dose^{-1} year^{-1} respectively.

APPENDIX - IV

Design of lab model of fertilizer applicator

1. Design of hopper

The following dimensions of hopper were assumed.

1. Bottom width of trapezoidal section (a) = 80 mm
2. Top width of square section (b) = 200 mm
3. Height of trapezoidal section (h_2) = 100 mm
4. Height of square section (h_1) = 50 mm

The volume of top square section of hopper (V_1) was calculated by the following equation.

$$V_1 = b \times b \times h_1$$
$$= 200 \times 200 \times 50$$
$$= 2000 \times 10^3 \text{ mm}^3$$

The volume of bottom trapezoidal section of hopper (V_2) was calculated by the following equation.

$$V_2 = \frac{1}{2} (a + b)\, h_2\, b$$
$$= \frac{1}{2} \times (80 + 200) \times 100 \times 200$$
$$= 2800 \times 10^3 \text{ mm}^3$$

The volume of hopper for experimental model of a fertilizer applicator (V) was calculated by the following equation.

$$V = V_1 + V_2$$
$$= (2000 \times 10^3) + (2800 \times 10^3)$$
$$= 4800 \times 10^3 \text{ mm}^3$$

2. Design of metering rollers

The design of three metering rollers viz., edge cell, fluted cell and baffle cell were illustrated with following calculations.

2.1. Design of edge cell metering roller

The schematic of flute of edge cell metering roller was shown in Fig. 1. The following dimensions of flute of edge cell metering roller were assumed respectively as:

Height of flute (a) = 16 mm

Base length of flute (b) = 25 mm and

Inclination of base of flute with vertical face (θ) = 59 deg.

The area of each flute (A) was calculated with the following equation:

$$A = \frac{1}{2} a\, b \sin\theta$$

$$= \frac{1}{2} \times 16 \times 25 \times \sin 59$$

$$= 172 \text{ mm}^2$$

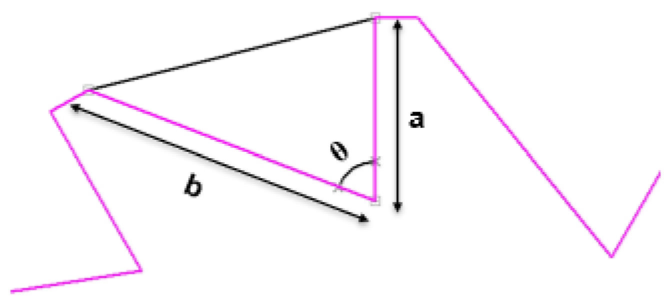

Fig. 1 Schematic of flute of edge cell metering roller

The volume of each flute (v) was calculated with the following equation by considering the length of metering roller as 76 mm.

$$v = A \times L$$

$$= 172 \times 76$$

$$= 13072 \text{ mm}^3$$

The volume of edge cell metering roller (V) was calculated with the following equation by considering number of flutes (N) as 12.

$$V = v \times N$$
$$= 13072 \times 12$$
$$= 156864 \text{ mm}^3$$

The weight of fertilizer delivered per revolution of edge cell metering roller (w) was calculated with the following equation.

$$w = V \times \rho$$
$$= 15864 \times 10^{-9} \times 1100$$
$$= 0.173 \text{ kg}$$

where,

V = Volume of edge cell metering roller = 15864×10^{-9} m^3

ρ = Bulk density of fertilizer = 1100 kg m^{-3}

The weight of fertilizer delivered with edge cell metering roller (W) to cover the circumference around coconut palm is calculated with the equation.

$$W = w \times n$$
$$= 0.173 \times 9$$
$$= 1.56 \text{ kg}$$

where,

W = Weight of fertilizer delivered with edge cell metering roller per coconut palm, kg

w = Weight of fertilizer delivered per revolution of edge cell metering roller, kg

n = Number of revolutions of metering roller to deliver required fertilizer, rev

2.2 Design of fluted cell metering roller

The area of flute (A) is divided into two sections viz., segment and trapezoidal section areas. The schematic of flute of fluted cell metering roller was shown in Fig. 2. The following dimensions of flute of fluted cell metering roller are assumed.

Radius of circle subtended by sector of flute (R) = 5 mm

Angle subtended by sector of flute (θ) = 59 deg.

Width of flute (b) = 22.8 mm

Height of trapezoidal section of flute (h) = 10 mm

The segment area (A_1) of flute was calculated with the following equation.

$$A_1 = \frac{1}{2} R^2 [(\frac{\pi}{180} \times \theta) - \sin\theta]$$

$$= \frac{1}{2} \times 5^2 \times [(\frac{\pi}{180} \times 59) - \sin 59]$$

$$= 15.37 \text{ mm}^2$$

The segment length (a) of flute was calculated with the following equation.

$$a = 2R \text{ Sin } \frac{\theta}{2}$$

$$= 2 \times 5 \times \text{Sin } \frac{59}{2}$$

$$= 8.6 \text{ mm}$$

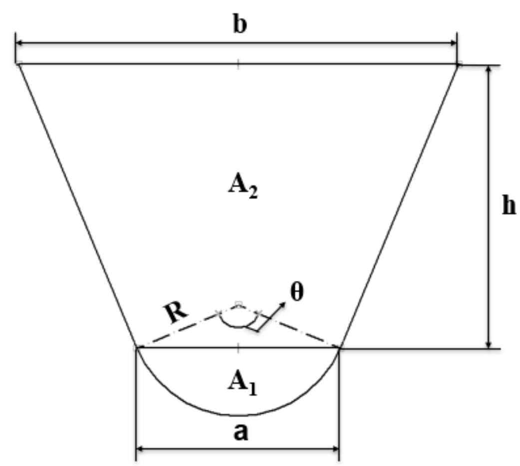

Fig. 2 Schematic of flute of fluted cell metering roller

The area of trapezoidal sectional (A_2) of flute was calculated with the following equation.

$$A_2 = \frac{1}{2}(a + b) h$$

$$= \frac{1}{2} \times (8.6 + 22.8) \times 10$$

$$= 157 \text{ mm}^2$$

The area of flute (A) of fluted cell metering roller was calculated with the following equation.

$$A = A_1 + A_2$$

$$= 15.37 + 157$$

$= 172.37\ mm^2$

The volume of flute (v) of fluted cell metering roller was calculated with the following equation by considering the length of flute (L) as 76 mm.

$$v = A \times L$$

$$= 172.37 \times 76$$

$$= 13100\ mm^3$$

The volume of roller (V) of fluted cell metering roller was calculated with the following equation by considering number of flutes (N) as 12.

$$V = v \times N$$

$$= 13100 \times 12$$

$$= 157200\ mm^3$$

The weight of fertilizer delivered per revolution of fluted cell metering roller (w) was calculated as follows.

$$w = V \times \rho$$

$$= 157200 \times 10^{-9} \times 1100$$

$$= 0.173\ kg$$

where,

w = Weight of fertilizer delivered per revolution of fluted cell metering roller, kg

V = Volume of fluted cell metering roller = $157200 \times 10^{-9}\ m^3$

ρ = Bulk density of fertilizer = 1100 kg m^{-3}

The weight of fertilizer delivered with fluted cell metering roller (W) to cover the circumference around coconut palm was calculated as follows.

$$W = w \times n$$

$$= 0.173 \times 9$$

$$= 1.56\ kg$$

where,

W = Weight of fertilizer delivered with fluted cell metering roller per coconut palm, kg

w = Weight of fertilizer delivered per revolution of fluted cell metering roller, kg

n = Number of revolutions of metering roller to deliver required fertilizer, rev

2.3 Design of baffle cell metering roller

The schematic of flute of baffle cell metering roller was shown in Fig. 3. The following dimensions of flute of baffle cell metering roller were assumed.

Bottom width of flute (a) = 15 mm

Top width of flute (b) = 19.5 mm

Height of flute (h) = 10 mm

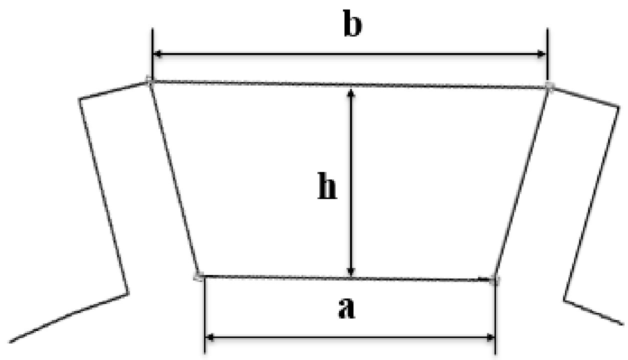

Fig. 3 Schematic of flute of baffle cell metering roller

The area of flute of baffle cell metering roller (A) was calculated with the following equation.

$$A = \frac{1}{2}(a + b)\ h$$

$$= \frac{1}{2} \times (15 + 19.5) \times 10$$

$$= 172.7\ mm^2$$

The volume of each flute of baffle cell metering roller (v) was found out by the following equation by considering the length of flute (L) as 76 mm.

$$v = A \times L$$

$$= 172.7 \times 76$$

$= 13125 \text{ mm}^3$

The volume of baffle cell metering roller (V) was found out with the following equation by assuming the number of flutes (N) as 12.

$$V = v \times N$$
$$= 13125 \times 12$$
$$= 157500 \text{ mm}^3$$

The weight of fertilizer delivered per revolution of baffle cell metering roller (w) was calculated as follows.

$$w = V \times \rho$$
$$= 157500 \times 10^{-9} \times 1100$$
$$= 0.173 \text{ kg}$$

where,

V = Volume of baffle cell metering roller $=157500 \times 10^{-9} \text{ m}^3$

ρ = Bulk density of fertilizer = 1100 kg m^{-3}

The weight of fertilizer delivered with baffle cell metering roller (W) to cover the circumference around coconut palm was calculated as follows.

$$W = w \times n$$
$$= 0.173 \times 9$$
$$= 1.56 \text{ kg}$$

where,

W = Weight of fertilizer delivered with baffle cell metering roller per coconut palm, kg

w = Weight of fertilizer delivered per revolution of baffle cell metering roller, kg

n = Number of revolutions of metering roller to deliver required fertilizer, rev

APPENDIX - V

Parameters of Urea

S.No	Angle of repose (deg.)	Bulk density (kg m^{-3})	Tapped density (kg m^{-3})	Coefficient of friction
1	32.9	740.8	830.0	0.35
2	32.8	740.6	831.2	0.32
3	33.2	741.2	836.8	0.28
4	32.5	738.5	835.4	0.31
5	33.1	742.0	838.2	0.29
Range	0.7	3.5	8.2	0.07
Mean	32.9	740.6	834.3	0.31
S.D	0.27	1.30	3.56	0.02
C.V (per cent)	0.82	0.175	0.426	6.45

APPENDIX - VI

Parameters of Muriate of Potash

S.No	Angle of repose (deg.)	Bulk density (kg m^{-3})	Tapped density (kg m^{-3})	Coefficient of friction
1	38.3	1082.5	1167.8	0.41
2	38.2	1081.2	1166.7	0.48
3	37.9	1083.4	1167.3	0.45
4	37.9	1079.6	1166	0.47
5	38.2	1081.6	1167.2	0.54
Range	0.4	3.8	1.8	0.13
Mean	38.1	1081.6	1167	0.47
S.D	0.18	1.43	0.68	0.04
C.V (per cent)	0.47	0.13	0.05	8.51

APPENDIX - VII

Parameters of Rock Phosphate

S.No	Angle of repose (deg.)	Bulk density (kg m^{-3})	Tapped density (kg m^{-3})	Coefficient of friction
1	38.2	1330.2	1421.1	0.51
2	38.9	1321.4	1418.1	0.58
3	42.5	1325	1418.0	0.56
4	40.9	1326.2	1418.6	0.57
5	43.9	1327.2	1419.2	0.54
Range	5.7	8.8	3.1	0.07
Mean	40.8	1326	1419	0.55
S.D	2.38	3.21	1.26	0.02
C.V (per cent)	5.83	0.24	0.08	3.63

APPENDIX - VIII

LAB MODEL OF FERTILIZER APPLICATOR

Effect of metering roller type on fertilizer discharge

S.No	Metering roller type	Fertilizer discharge (kg)
1	Edge cell	1.54
2	Edge cell	1.54
3	Edge cell	1.53
4	Edge cell	1.55
5	Edge cell	1.56
6	Edge cell	1.55
7	Edge cell	1.54
8	Edge cell	1.55
9	Edge cell	1.56
10	Edge cell	1.54
11	Fluted cell	1.49
12	Fluted cell	1.49
13	Fluted cell	1.49
14	Fluted cell	1.51
15	Fluted cell	1.48
16	Fluted cell	1.49
17	Fluted cell	1.50
18	Fluted cell	1.48
19	Fluted cell	1.50
20	Fluted cell	1.49
21	Baffle cell	1.44
22	Baffle cell	1.47
23	Baffle cell	1.44
24	Baffle cell	1.45

25	Baffle cell	1.44
26	Baffle cell	1.46
27	Baffle cell	1.44
28	Baffle cell	1.45
29	Baffle cell	1.46
30	Baffle cell	1.44

APPENDIX – IX

LAB EVALUATION OF PROTOTYPE OF FERTILIZER APPLICATOR

Effect of flute volume and agitator type on fertilizer application rate and coefficient of uniformity

Run	Flute volume ($\times 10^{-5}$ m^3)	Agitator type	Fertilizer application rate (kg $palm^{-1}$)	Coefficient of uniformity (per cent)
1	1.43	J	1.38	97.4
2	1.63	C	1.84	95.6
3	1.3	L	1.12	93.8
4	1.43	L	1.55	99.1
5	1.63	L	1.78	97.1
6	1.43	C	1.62	98.2
7	1.3	J	0.95	92.8
8	1.63	J	1.71	94.8
9	1.3	C	1.25	93.2
10	1.63	L	1.79	96.9
11	1.43	L	1.54	99.2
12	1.3	L	1.16	94.1
13	1.63	C	1.86	95.9
14	1.43	J	1.36	97.4
15	1.3	J	0.98	92.5
16	1.3	C	1.22	93
17	1.43	C	1.62	98.3
18	1.63	J	1.72	94.9
19	1.43	C	1.6	98.3

20	1.3	J	0.97	92
21	1.63	J	1.7	95.1
22	1.63	C	1.83	96.2
23	1.43	J	1.36	97.8
24	1.3	L	1.2	94.5
25	1.43	L	1.53	98.9
26	1.3	C	1.22	93.2
27	1.63	L	1.77	97.1

APPENDIX - X

FIELD TEST OF MACHINE

Effect of forward speed, blade to plate angle and skid height from ground level on depth of cut and time taken per basin formation

Run	Forward speed (km h^{-1})	Blade to plate angle (deg.)	Skid height from ground level (cm)	Depth of cut (cm)	Time taken per basin formation (s)
1	2.5	110	17.5	9.5	44
2	2.5	100	20	7.1	28
3	1.5	100	20	8.2	37
4	2	100	15	11.8	58
5	2.5	100	15	11.1	52
6	2.5	120	17.5	9.1	42
7	2	110	17.5	10.1	46
8	1.5	110	15	12.5	67
9	2.5	120	15	11.2	55
10	1.5	120	20	8.3	39
11	1.5	110	20	8.5	40
12	1.5	110	17.5	10.8	50
13	2	120	15	11.9	60
14	2.5	110	20	7.6	31
15	2.5	100	17.5	9	41
16	1.5	120	17.5	10.6	48
17	2.5	110	15	11.5	56
18	2	110	15	12	61
19	2.5	120	20	7.2	30

20	2	100	20	7.6	33
21	1.5	100	15	12.3	64
22	1.5	100	17.5	10.5	47
23	2	120	20	7.8	34
24	2	110	20	7.9	36
25	2	120	17.5	9.8	45
26	2	100	17.5	9.7	44
27	1.5	120	15	12.4	65

APPENDIX – XI

FIELD TEST OF MACHINE

Effect of forward speed, blade to plate angle and skid height from ground level on bund height and bund width

Run	Forward speed (km h^{-1})	Blade to plate angle (deg.)	Skid height from ground level (cm)	Bund height (cm)	Bund width (cm)
1	2.5	110	17.5	15.3	31.5
2	2.5	100	20	11	36.6
3	1.5	100	20	10.9	36.9
4	2	100	15	11.9	37.1
5	2.5	100	15	11.7	37.3
6	2.5	120	17.5	13.7	33.8
7	2	110	17.5	15.6	31.2
8	1.5	110	15	14.5	33.4
9	2.5	120	15	13.3	35.2
10	1.5	120	20	12.6	34.3
11	1.5	110	20	14.1	32.6
12	1.5	110	17.5	15.2	31.7
13	2	120	15	13.4	35
14	2.5	110	20	14.3	32.2
15	2.5	100	17.5	12.3	35.9
16	1.5	120	17.5	13.5	34.1
17	2.5	110	15	14.6	33.1
18	2	110	15	14.8	32.9
19	2.5	120	20	12.7	34.5

20	2	100	20	11.2	36.5
21	1.5	100	15	11.5	37.6
22	1.5	100	17.5	12.1	36.2
23	2	120	20	12.9	34.8
24	2	110	20	14.4	32
25	2	120	17.5	13.6	33.6
26	2	100	17.5	12.5	35.7
27	1.5	120	15	13	35.4

APPENDIX – XII

FIELD TEST OF MACHINE

Effect of forward speed, blade to plate angle and skid height from ground level on soil pulverization index and draft

Run	Forward speed (km h^{-1})	Blade to plate angle (deg.)	Skid height from ground level (cm)	Soil pulverization index (mm)	Draft (N)
1	2.5	110	17.5	5.81	1105
2	2.5	100	20	6.9	1033
3	1.5	100	20	5.22	1254
4	2	100	15	2.58	1230
5	2.5	100	15	6.56	1139
6	2.5	120	17.5	6.02	1093
7	2	110	17.5	1.48	1220
8	1.5	110	15	4.58	1384
9	2.5	120	15	6.46	1151
10	1.5	120	20	5.15	1274
11	1.5	110	20	5.1	1286
12	1.5	110	17.5	3.62	1342
13	2	120	15	2.52	1244
14	2.5	110	20	6.72	1058
15	2.5	100	17.5	6.18	1087
16	1.5	120	17.5	3.72	1330
17	2.5	110	15	6.32	1169
18	2	110	15	2.46	1254
19	2.5	120	20	6.81	1040

20	2	100	20	2.92	1176
21	1.5	100	15	4.71	1362
22	1.5	100	17.5	3.86	1328
23	2	120	20	2.84	1188
24	2	110	20	2.7	1194
25	2	120	17.5	1.51	1212
26	2	100	17.5	1.57	1204
27	1.5	120	15	4.62	1370

APPENDIX - XIII

Economic evaluation of developed tractor operated basin lister cum fertilizer applicator

The cost economics of machine was worked out based on the following assumptions.

1. Capital cost of tractor = Rs.8,00,000
2. Capital cost of machine = Rs.85,000
3. Annual usage of tractor = 1,000 h
4. Daily usage of tractor = 8 h day^{-1}
5. Annual usage of machine= 250 h
6. Life of tractor = 10 years
7. Life of machine = 8 years
8. Salvage value of tractor (10 per cent of capital cost) = Rs.80,000
9. Salvage value of machine (10 per cent of capital cost) = Rs.8,500
10. Rate of interest, i = 10 per cent per annum
11. Housing and Taxes cost = 2.5 per cent of capital cost of machine
12. Insurance cost = 1 per cent of capital cost of machine
13. Fuel (diesel) cost = Rs.85 per litre
14. Average fuel consumption of machine = 5.3 l h^{-1}
15. Repair and maintenance cost = 8 per cent of capital cost of machine
16. Lubrication cost = 20 per cent of fuel cost
17. Wages of driver @Rs.18000 per month for 8 h day^{-1} = Rs.75 h^{-1}

A. Fixed cost of tractor operated coconut basin lister cum fertilizer applicator

S. No.	Annual fixed cost	Tractor		Machine	
		Annual	Per hour	Annual	Per hour
1	Depreciation, Rs.	(800000-80000)/10=72000	72	(85000-8500)/8=9563	39
2	Interest, Rs.	((800000+80000)/2)×(10/100) = 44000	44	((85000+8500)/2)×(10/100) = 4675	19
3	Housing and taxes @2.5% of capital cost, Rs.	(800000×(2.5/100)) = 20000	20	((85000×(2.5/100)) =2125	9
4	Insurance @ 1 % of initial cost	(800000×(1/100)) = 8000	8	(85000×(1/100)) = 850	4
5	Fixed cost, Rs. h^{-1}	144000	144	17213	71
6	Total fixed cost, Rs. h^{-1}	144 + 71 = 215			
7	Annual fixed cost, Rs.	144×250 = 36000		17213	
8	Total annual fixed cost, Rs.	36000 + 17213 = 53213			

B. Variable cost of machine

1	Repair and maintenance charges @ 8 per cent of capital cost, Rs. h^{-1}	28
2	Operator wages @ Rs.18000 per month, Rs. h^{-1}	75
3	Fuel cost @ Rs.85 l^{-1} (5.3 l h^{-1}), Rs. h^{-1}	451

4	Lubrication charges @ 20% of fuel cost, Rs. h^{-1}	114
5	Total variable cost, Rs. h^{-1}	668

C. Total cost of operation of machine = Total Fixed cost + Total variable cost

= 213 + 668

= **Rs. 881 h^{-1}**

D. Total cost of operation of machine per hectare

Actual Field capacity = 0.15 ha h^{-1}

Therefore, total cost of operation of machine = 881/0.15

= **Rs.5874 ha^{-1}**

E. Total cost of basin listing and fertilizer application by conventional method

Manual operation for basin listing = 12 basins day^{-1} $labour^{-1}$

Number of palms in a hectare = 200

Total labour per hectare for basin listing = 200/12 = 17 labour ha^{-1}

Total labour per hectare for fertilizer application = 13 labour ha^{-1}

Total labour per hectare for basin listing and fertilizer application

=17+13

= 30 labour ha^{-1}

Total cost of basin listing and fertilizer application by conventional method (30 labour ha^{-1} @Rs.800 day^{-1})

= 30 × 800

= **Rs.24000 ha^{-1}**

F. Saving in cost

Total cost of operation by conventional method = Rs.24000 ha^{-1}

Total cost of operation by machine = Rs.5874 ha^{-1}

Saving in cost = 24000 - 5874

= Rs.18126 ha^{-1}

Saving in cost = (18126/24000) × 100

= **75.5 per cent**

G. Break Even Point

$$BEP = \frac{AFC}{CF - V}$$

where,

BEP = Break-even point, h $year^{-1}$

AFC = Annual fixed cost for the machine, Rs. $year^{-1}$

CF = Custom fee, Rs. h^{-1}

V = Variable cost of machine, Rs. h^{-1}

Total fixed cost = Rs.53,213 $year^{-1}$

Custom fee (CF) = (Cost of operation h^{-1} + 25 per cent overhead charges) × (25 per cent profit over new cost)

= (881 + (881×0.25)) × 1.25

= Rs.1377 h^{-1}

Variable cost of machine (V) = Rs.668 h^{-1}

Actual field capacity, ha h^{-1} = 0.15

$$BEP = \frac{53213}{1377 - 668}$$

= 75 h $year^{-1}$

Annual utility = Effective field capacity × Annual utility period

= 0.15 x 250

= 37.50 ha

Thus, BEP can be obtained at (75×100)/250 = 30 per cent of the annual utility of 250 hours of the developed tractor operated basin lister cum fertilizer applicator.

H. Payback Period

$$\text{Payback period} = \frac{\text{Initial investment}}{\text{Average net annual benefit}}$$

Average net annual benefit = (CF-V) x Annual usage of the machine

= (1377 – 668) x 250

= Rs.1,77,250

Initial investment = Initial cost of tractor for 250 h + Initial cost of machine

= ((800000×250)/881) + 85000

= Rs.3,12,014

Therefore, Payback period = 285000/177250

= 1.60 years

I. Benefit-cost (B:C) ratio

$$\text{B:C ratio} = \frac{\text{Benefit cost}}{\text{Cost of machine operation}}$$

$$= \frac{18126}{5874}$$

= 3.08

where,

Benefit cost = Cost of manual operation - Cost of machine operation

= 24000 - 5874

= Rs.18126 ha^{-1}

DEVELOPMENT AND TESTING OF A TRACTOR OPERATED COCONUT BASIN LISTER CUM FERTILIZER APPLICATOR

by

JINUKALA SRINIVAS

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ABSTRACT OF THE THESIS

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Kerala Agricultural University

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

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ABSTRACT

The basin listing and fertilizer application are important operations for the optimum growth of coconut palms. The conventional methods of basin listing and fertilizer application for coconut palms are labour intensive, drudgery prone, time consuming, accident prone, cost intensive and requires skilled labour. Therefore, a research work was undertaken to develop a tractor operated coconut basin lister cum fertilizer applicator considering soil, crop, fertilizer and machine parameters. The developed machine composed of gear box, power transmission system, main frame, main shaft and its cover, rotor shaft, cutting blades, frame, chain cover, hitch system, hopper, agitator, metering roller, metering housing, delivery pipe and other parts. The lab model of fertilizer applicator was developed and tested to finalize the metering roller type for prototype of fertilizer applicator.

The recommended fertilizer application rate of 1.56 kg $palm^{-1}$ was obtained for edge cell metering roller with lab model of fertilizer applicator. The recommended fertilizer application rate of 1.56 kg $palm^{-1}$, highest coefficient of uniformity of 99.2 per cent and desirability of 0.98 was obtained for edge cell metering roller flute volume of 1.43×10^{-5} m^3 and 'L' shape agitator with lab evaluation of prototype of fertilizer applicator.

The desirable depth of cut of 10.0 cm was obtained for forward speed of 2.0 $km \cdot h^{-1}$, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm; minimum time per basin formation was attained for forward speed of 2.5 km h^{-1}, blade to plate angle of 100 deg. and skid height from ground level of 20.0 cm respectively; higher bund height, lower bund width and lower soil pulverization index was obtained for forward speed of 2.0 km h^{-1}, blade to plate angle of 110 deg. and skid height from ground level of 17.5 cm respectively with basin lister in the field. By numerical optimization, the optimum parameters of machine are 2.0 km h^{-1} forward speed, 110 deg. blade to plate angle and 17.5 cm skid height from ground level. The number of basins formed per hour, actual field capacity and fuel consumption of tractor operated basin lister cum fertilizer

applicator is 20, 0.15 $ha \cdot h^{-1}$ and 6.7 l h^{-1} respectively. The cost of prototype of tractor operated basin lister cum fertilizer applicator is Rs.85,000. The cost of operation of machine for basin listing and fertilizer application operations is found out as Rs.881 h^{-1} and Rs.5874 ha^{-1}. The breakeven point, payback period and benefit cost ratio of the machine is 75 hours per annum, 1.60 years and 3.08:1 respectively. The saving in cost of operation of machine is Rs.18,126 ha^{-1} and 75.50 per cent when compared to conventional method of basin listing and fertilizer application operations.