DEVELOPMENT AND TESTING OF A POWER OPERATE PRE-GERMINATED PADDY SEED BROADCASTER

by

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(2016 – 18 – 013)

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

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

KERALA, INDIA

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ABSTRACT OF THE THESIS

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

KERALA, INDIA 2019

DEDICATION

This thesis is dedicated to my Parents and Guide, who sacrificed much to bring me up to this level and to my loveable sisters, friends and their families for the devotion they made to make my life successful.

DECLARATION

I, hereby declare that this thesis entitled **"DEVELOPMENT AND TESTING OF A POWER OPERATED PRE-GERMINATED PADDY SEED BROADCASTER"** 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 **SREEDHARA B**

Date: **(2016-18-013)**

CERTIFICATE

Certified that this thesis entitled **"DEVELOPMENT AND TESTING OF A POWER OPERATED PRE-GERMINATED PADDY SEED BROADCASTER"** is a record of research work done independently by **Er.SREEDHARA B (2016-18-013)** 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

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We, the undersigned members of the advisory committee of **Er. SREEDHARA B (2016-18-013)** a candidate for the degree of Master of Technology in Agricultural Engineering with major in Farm Power Machinery and Energy, agree that the thesis entitled **"DEVELOPMENT AND TESTING OF A POWER OPERATED PRE-GERMINATED PADDY SEED BROADCASTER"** may be submitted by **Er. SREEDHARA B.,** in partial fulfilment of the requirement for the degree.

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SREEDHARA. B

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SYMBOLS AND ABBREVIATIONS

Symbols		Abbreviations
<	:	Less than
>	:	Greater than
%	:	Per cent
±	:	Plus or minus
×	:	Multiplication
÷	:	Division
≤	:	Less than or equal to
≥	:	Greater than or equal to
°	:	Degree
°C	:	Degree centigrade
ASAE	:	American Society of Agricultural Engineers
cm	:	Centimeter
cm^2	:	Square centimeter
CV	:	Coefficient of variation
db	:	dry basis
DC	:	Direct current
et al.	:	and others
etc.	:	et cetera
Fig.	:	Figure
g	:	Gram
g cm^{-3}	:	Gram per cubic centimeter
GI	:	Galvanized iron
H	:	Height
ha	:	Hectare
hp	:	Horse power
hr	:	Hour
ha day^{-1}	:	Hectare per day

ha hr^{-1}	:	Hectare per hour
IS	:	Indian standards
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
kg	:	Kilogram
kg ha^{-1}	:	Kilogram per hectare
kg hr^{-1}	:	Kilogram per hour
kg m^{-3}	:	Kilogram per cubic meter
kg min^{-1}	:	Kilogram per minute
km hr^{-1}	:	Kilometer per hour
kW	:	Kilo Watt
L	:	Length
LHS	:	Left hand side
l hr^{-1}	:	Litre per hour
m	:	Meter
m min^{-1}	:	Meter per minute
mm	:	Millimeter
mm^2	:	Square millimeter
mm^3	:	Cubic millimeter
mm^2	:	Square millimeter
Mha	:	Million hectare
m s^{-1}	:	meters per second
MT	:	Million Tons
RHS	:	Right hand side
rpm	:	Revolutions per minute
Rs ha^{-1}	:	Rupees per hectare
rad s^{-1}	:	Radian per second
R^2	:	Regression coefficient
S	:	Skewness ratio

SD	:	Standard deviation
Sl. No.	:	Serial Number
viz.	:	Namely
UCD(CU)		Uniformity coefficient of distribution
W	:	Width
Wb	:	Wet basis
α	:	Alpha
θ	:	Theta
μ	:	mue
π	:	Pi
ρ	:	Rho

INTRODUCTION

CHAPTER I

INTRODUCTION

Rice (Oryza sativa L.) is important leading food crop of the world and it is a staple food of over approximately one-half of the world population. In Asia, where 95% of the world's rice is produced and consumed. It contributes about 40-80 % of the calories of the people diet (Farahmandfar *et al*., 2009). India positions second in both production and utilization of rice, next to China. The zone under rice development in India is 43.86 million hectares with an yearly production of 104.78 million tonnes and productivity 2390 kg ha^{-1}, which is not as much as half of the yield of rice-producing countries, at USA 6750 kg ha^{-1}, China 6300 kg ha^{-1} and Japan 6400 kg ha^{-1}. However, in Kerala, the average area under cultivation of paddy is about 0.198 Mha, production is about 0.558MT and productivity is about 2818 kg ha^{-1} (Indianstat., 2015).

Agriculture is the main source of income for families in India. India is the second leading producer of paddy in the entire world, preceded only by china. India's annual paddy production is around 85-90 million tons. Annual consumption is around 85 million tons. In India, Paddy is cultivated in both seasons – winter and summer. West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Tamil Nadu, Bihar, Orissa, Assam, Karnataka and Haryana are the major rice producing states. More than 50% of total production comes from the first four states.

Rice is grown all over India under varying diverse soil and climatic conditions. The geographical location of paddy cultivation in India extends from 8^oN to 35 ^oN latitude and from below sea-level in Kuttanad area of Kerala up to an elevation of 2000 m in Jammu and Kashmir, hills of Uttaranchal, Himachal Pradesh and North-Eastern Hills (NEH) areas in India. Rice crop needs a hot and humid climate. It is best suited to regions which have high humidity, prolonged sunshine and an assured supply of water. The average temperature required throughout the life period of the crop ranges from 21^o C to 37^o C. Maximum temperature which the crop can tolerate 40^o C to 42^o C (Malik et al., 2017).

The minimum temperature for rice sprouting is 10^o C and it requires high temperature during the time of tillering. Minimum temperature required for flowering range from 22-23^o C. Temperature requirement for blooming is in the range of 26.5^o C to 29.5^o C. Minimum temperature for grain formation is 20^oC-21^oC and at the time of ripening the temperature range between 20-25^o C. Photo-periodically, rice is a short- day plant. However, there are varieties, which are non-sensitive to photoperiodic condition (Malik et al., 2017).

Rice can be established using different methods such as transplanting, system of rice **i**ntensification(SRI), sowing, direct seeding of rice(DSR). The direct seeding of rice involves broadcasting of dry or pre-germinated paddy seeds. The most common methods of rice crop establishment methods are broadcasting (dry direct seeding and wet direct seeding) and transplanting. Presently, direct seeded rice (DSR) is gaining momentum due to labour shortage during peak season of transplanting and availability of water for short periods (Kumar *et al.* 2015).

Direct seeding involves broadcasting of pre-germinated seeds in wet (saturated) puddled/dry soils. In recent years there is a serious concern about the availability of water for rice production due to sharp decrease in water table. It has been reported that 2 M ha of fully irrigated and 13 M ha of partially irrigated lands in Asia during wet season experience physical water scarcity and 22 Mha of irrigated lands in the dry season would face economic water scarcity by 2025 (Ali *et al.* 2014). These facts lead to shift from transplanting to broadcasting in many Asian countries including India.

In the recent years, rice is raised by manual broadcasting or line seeding of dry paddy seeds or pre-germinated paddy seeds and transplanting seedlings. Direct seeding of rice achieves early establishment of crop and more profit in areas with assured water supply by utilizing short duration modern varieties and cost-efficient herbicides. In this method, paddy seeds are not uniformly distributed and as a result, the lower yield and labour cost and other inputs for weeding and control of diseases and pests are very high. In addition, the principal disadvantage of traditional manual broadcasting method is the non-uniform distribution of seeds and very high seed rate. Thus, it result in non-optimal use of resources, which will increase labour, and other inputs cost. Furthermore, it requires experienced manpower to broadcast pre-germinated paddy seeds uniformly. The broadcasting of paddy seeds by mechanical methods can achieve uniform distribution of paddy seeds at recommended seed rate than traditional manual broadcasting.

Under these circumstances, a project entitled **"Development and Testing of a Power operated Pre-Germinated Paddy Seed Broadcaster"** was undertaken at Kelappaji College of Agricultural Engineering and Technology (KCAET), Tavanur, Kerala with the following objectives.

1. To study the engineering properties of pre-germinated paddy seeds.
2. To develop a power operated pre-germinated paddy seed broadcaster.
3. To test and evaluate the performance of a power operated pre-germinated paddy seed broadcaster.

REVIEW OF LITERATURE

CHAPTER II

2. REVIEW OF LITERATURE

This chapter provides a comprehensive review of research work carried out by various researchers related to the cultivation methods of paddy, physical and engineering properties of paddy seed, development of various seed and fertilizer broadcasters, different types of seed metering mechanisms which are adapted in broadcasters and operational parameters which affects the broadcaster performance.

2.1 PHYSICAL AND ENGINEERING PROPERTIES OF RICE

Physical and engineering properties of agricultural products are important in many problems associated with the design of machines and the analysis of the product behaviour during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting and drying (Irtwange and Igbeka, 2002). The physical properties such as moisture content, size and shape, bulk density, true density, porosity, angle of repose, coefficient of friction, surface area of dry and pre-germinated paddy seeds, as reported by different researcher are reviewed and presented here.

2.1.1 Dry paddy seeds

Physical and engineering properties of dry paddy seeds are discussed in the following sections.

2.1.1.1 Moisture content

Varnamkhasti et al. (2007) conducted a study to find out physical properties of raw paddy. In this study, physical properties of raw paddy were found out at 10% (w.b.) moisture content. Zareiforoush et al. (2009) conducted a study to determine the effect of moisture content on physical properties of two different paddy cultivars at five moisture content levels of 8 %, 11 %, 14 %, 18 % and 21% (db.).

2.1.1.2 Size and shape

Varnamkhasti et al. (2007) conducted a study to find out physical properties of raw paddy. It was found that the average grain length, width and thickness were

8.54 mm, 2.47 mm and 1.83 mm, respectively while the equivalent mean diameter, surface area and volume were 3.4 mm, 32.58 mm^2 and 21.06 mm^3, respectively.

Zareiforoush et al. (2009) found that in case of Alikazemi cultivar the average length, width, thickness, equivalent diameter and surface area increased from 9.83 mm to 10.05 mm, 2.65 mm to 2.76 mm, 1.92 mm to 2.01 mm, 3.72 mm to 3.85 mm, 39.37 mm^2 to 42.12 mm^2 respectively as the moisture content increased from 8 to 21% (db.). The corresponding values increased from 10.20 mm to 10.25 mm, 2.31 mm to 2.40 mm, 1.85 mm to 1.92 mm, 3.53 mm to 3.63 mm, 36.87 mm^2 to 38.61 mm^2, respectively, for Hashemi cultivar.

Jouki and Khazaei (2012) studied some physical and mechanical properties of rice at 12% moisture content (db). The results revealed that the average length, width, thickness and equivalent diameter of the rice grains were, 7.43 mm, 2.75 mm, 2.53 mm and 3.48 mm, respectively.

Suwanpayak et al. (2016) have conducted a study to determine some physical and mechanical properties of upland rice at 4.16% of moisture content (wb). This study results showed that the average values of length, width, thickness and equivalent diameter were 10.95±0.18 mm, 3.40±0.06 and 2.14±0.03 mm and 4.38±0.12 mm respectively.

2.1.1.3 Bulk density

Varnamkhasti et al. (2007) conducted a study to find out physical properties of raw paddy. In this study, the average bulk density of raw paddy was 471.16 kg m^{-3}. Jouki and Khazaei (2012) studied some physical and mechanical properties of rice at 12% moisture content (db). The results showed that the average value of bulk density was 541 kg m^{-3}.

2.1.1.4 True density

Varnamkhasti et al. (2007) studied, average true density of raw paddy was 1193.38 kg m^{-3}. Jouki and Khazaei (2012) studied some physical and mechanical properties of rice at 12% moisture content (db). It was found that the average value of true density was 1108.98 kg m^{-3}.

2.1.1.5 Porosity

Varnamkhasti et al. (2007) carried out the study, the average porosity of raw paddy was 60.37%.Jouki and Khazaei (2012) studied the porosity of at 12% moisture content (db). The results showed that the average value of porosity for rice was 46%.

2.1.1.6 Angle of repose

Varnamkhasti et al. (2007) studied, the average value of angle of repose for emptying was 35.83^{o}. Zareiforoush et al. (2009) found that in case of Alikazemi cultivar the average value of angle of repose increased from 35.67^{o} to 41.23^{o}, as the moisture content increased from 8 % to 21% (db). The corresponding value of angle of repose for above moisture content was increased from 38.27^{o} to 44.37^{o} for Hashemi cultivar. Jouki and Khazaei (2012) studied angle of repose of rice at 12% moisture content (db). The results revealed that the average value of angle of repose for rice was 34^{o}.

2.1.1.7 Static coefficient of friction

Varnamkhasti et al. (2007) found, that the average value of static coefficient of friction for raw paddy on different sliding surfaces varied from 0.2186 on glass sheet to 0.4279 on plywood. Zareiforoush et al. (2009) found that in case of Alikazemi cultivar the average value of the static coefficient of friction of grains increased linearly against three various surfaces, namely, glass (0.3168-0.4369), galvanized iron sheet (0.4179-0.4965), and plywood (0.4394-0.5264) as the moisture content increased from 8 % to 21% (db). The corresponding values of static coefficient of friction increased from 0.3577 to 0.4650, 0.4629 to 0.5082 and 0.4857 to 0.5452 respectively for Hashemi cultivar against above three sliding surfaces.

Jouki and Khazaei (2012) studied some physical and mechanical properties of rice at 12% moisture content (db). The results revealed that the average values of static coefficient of friction were 0.4835, 0.4061, and 0.3670 for wood, galvanized iron and glass surfaces respectively. The higher friction coefficient values were observed on wood surface and the lowest on steel surface.

2.1.2 Pre-germinated paddy seeds

The physical and engineering properties of pre-germinated paddy seeds are discussed in the following sections.

2.1.2.1 Moisture content

Dabbaghi et al. (2013) reported that the moisture content of pre-germinated paddy seeds of three different shape varieties of Hashemi (long grain), Binam (medium) and Hasani (short grain). The results showed that the average value of moisture content for pre-germinated paddy of Hashemi, Binam and Hasani varieties was 46.92%, 48.17% and 47.36%, respectively.

2.1.2.2 Size and shape

Dabbaghi et al. (2013) reported that the size of pre-germinated paddy seeds of three different shape varieties of Hashemi (long grain), Binam (medium) and Hasani (short grain) different rice varieties. The results showed that the average value of length for pre-germinated paddy of Hashemi, Binam and Hasani was 9.87 mm, 9.18 mm, 8.95 mm respectively, whereas the mean values of width and thickness for Hashemi, Binam and Hasani were 2.41 mm, 5.56 mm, 2.71 mm and 2.01 mm, 2.46 mm, 2.13 mm respectively.

2.1.2.3 Bulk density

Dabbaghi et al. (2013) reported that the bulk density of pre-germinated paddy seeds of three different shape varieties of Hashemi (long grain), Binam (medium) and Hasani (short grain) different rice varieties. The results revealed that the value of bulk density for Hasani variety (527.70-544.02 kg m^{-3}) was higher than those of Hashemi (432.2-460.38 kg m^{-3}) and Binam (528.96-537.12 kg m^{-3}).

2.1.2.4 True density

Dabbaghi et al. (2013) reported that the true density of pre-germinated paddy seeds of three different shape varieties of Hashemi (long grain), Binam (medium) and Hasani (short grain) different rice varieties. The results showed that the true density of Hashemi, Binam and Hasani were obtained 1243 kg m^{-3}, 1326 kg m^{-3} and 1346 kg m^{-3}, respectively.

2.1.2.5 Porosity

Dabbaghi et al. (2013) reported that the porosity of pre-germinated paddy seeds of three different shape varieties of Hashemi (long grain), Binam (medium) and Hasani (short grain). The results showed that the value of porosity for Hashemi (63.9%) was more than Binam (59.8%) and Hasani (60.9%).

2.1.2.6 Angle of repose

Dabbaghi et al. (2013) reported that the angle of repose of pre-germinated paddy seeds of three different shape varieties of Hashemi (long grain), Binam (medium) and Hasani (short grain) different rice varieties. The results revealed the average value of angle of repose for Hasani was about 48.31^{o} and those of Binam and Hashemi were measured 45.7^{o} and 42.4^{o}.

2.1.2.7 Static coefficient of friction

Dabbaghi et al. (2013) reported that the static coefficient of friction of pre-germinated paddy seeds of three different shape varieties of Hashemi (long grain), Binam (medium) and Hasani (short grain) different rice varieties against five different sliding surfaces such as galvanized iron, glass, iron sheet, plywood and plastic. The results revealed that the mean values of static coefficient of friction for Hashemi variety against as galvanized iron, glass, iron sheet, plywood and plastic were 0.321, 0.317, 0.395, 0.424 and 0.437 respectively. For Binam variety the mean values of static coefficient of friction against galvanized iron, glass, iron sheet, plywood and plastic were 0.309, 0.264, 0.412, 0.457 and 0.42 respectively and for Hasani variety the mean values of static coefficient of friction against galvanized iron, glass, iron sheet, plywood and plastic were 0.298, 0.264, 0.441, 0.487 and 0.392, respectively.

2.1.2.8 Surface area

Dabbaghi et al. (2013) reported that the surface area of pre-germinated paddy seeds of three different shape varieties of Hashemi (long grain), Binam (medium) and Hasani (short grain) different rice varieties. The results showed that the average value of surface area for Hashemi, Binam and Hasani varieties was obtained in the range of 34.22-44.67 mm^2, 34.77-44.74 mm^2 and 39.6-65.12 mm^2, respectively.

2.2 DEVELOPMENT OF VARIOUS SEED BROADCASTER

Ziauddin and Roy (1998) designed, developed and tested a low-cost seed-cum-fertilizer distributor for broadcasting seeds and fertilizer in the field. The seeds and fertilizer discharged by the gravity from a tank on a rotor. A hand-operated rotor distributed the seeds and fertilizer uniformly. The broadcasting unit was carried on the shoulder of an operator during operation. The uniformity coefficient of distribution of traditional manual broadcasting system varied from 30% to 43% depending up on the labour skills. Whereas the average uniformity coefficient of distribution of this distributor was about 82.32%, 80.43% and 85.66% for the fine urea, granular urea and wheat, respectively.

Tajuddin (1989) designed, developed and tested a hand rotary-broadcasting device for broadcasting seeds, fertilizers and granular insecticides in the laboratory and field. The uniformity co-efficient of distribution was determined by broadcasting urea and compared with that of the hand broadcasting process. The field coverage rate of this device for spreading urea was 1.26 ha hr^{-1} in paddy field. The unit had a weight of 3.6 kg and cost of 55 US$. The average uniformity coefficient of distribution achieved by the device was 50 %.

Awulu et al. (2014) developed and evaluated a manually operated seed broadcaster for broadcasting paddy, guinea corn, and soya bean seeds. The seed holding capacity of this device was 7068.6 cm^3 and the net weight of the device was 6.25 kg. Broken efficiency of the device was 2.7 %, 8.3 % and 10 % for soya bean, paddy and guinea corn respectively while discharge efficiency was 91.7 %, 92 % and 97.5 % for paddy, guinea corn and soya bean respectively. Grain breakage efficiency of grains increased with decrease in the size of seeds broadcasted and vice-versa. Discharge efficiency was increased with increase in the size of seeds broadcasted.

Ziauddin and Khan (2001) designed and developed manually operated seed-fertilizer distributor to broadcast seeds, fertilizers and granular insecticides in the field. Experiments were conducted for determination of uniformity co-efficient of distribution (UCD), field capacity of the machine and application rate of the seeds (lentil, black gram & wheat) and fertilizers (fine urea and TSP). This simple mechanical device weighed 6.0 kg and was designed to carry on the shoulder of an operator during operation. They found that normally UCD of traditional hand broadcasting system ranged from 40 % to 70 % depending upon the operator's skill. The average UCD of this device at a beater speed of 700 rpm for fine urea, TSP, wheat, lentil and black gram were found to be 97.75 %, 93.5 %, 88.75 %, 97.21 % and 96.25 %, respectively. The average effective field capacity of the device was 2.26 ha hr^{-1}, whereas it was about 0.32 ha hr^{-1} only in case of traditional hand broadcasting method.

Tawfik and Khater (2009) designed and tested performance of twin disc fertilizer spreader in new reclaimed areas in Eastern Qantara. The broadcaster was operated by tractor PTO. The obtained results showed that the lower value of coefficient of variation (C.V) and higher value of correlation (R^2) were achieved at spinner speed of 52.3 rad s^{-1} (500 rpm) without overlapping condition. Also, result showed that higher degree of uniformity and correlation between factors were achieved at 42.8% overlap and at effective swath width of 11.0 m.

El-Sharabasy et al. (2007) developed and evaluated a small self-propelled machine for spreading seeds and granular fertilizers. It consists of two hoppers, twin disc contra-rotating and transmission system to transmit the rotating motion from the machine engine to the rotating discs. This machine was evaluated to find out the optimum operating parameters for spreading both seeds and granular fertilizers. The developed machine was evaluated for two different materials of paddy seeds and granular fertilizer (super phosphate), four disc speeds of 350, 450, 550 and 650, rpm at four machine forward speeds of 4, 5, 6 and 7 km h^{-1} and four gate openings area of 6, 12, 18 and 24 cm^2 respectively. The results showed that the lower coefficient of variation (C.V.) of 16.28 % and 19.16 % and higher coefficient of uniformity of 83.72 % and 80.84 % were achieved at disc linear speed of 6.12 m s^{-1} and 7.48 m $s^{-1}$and gate opening of 12 and 18 cm^2 for spreading paddy and fertilizer, respectively. The fuel and energy consumed at the machine forward speeds of 5 km h^{-1} and 7 km h^{-1} and gate opening area of 12 v and 18 cm^2 were 3.59 l h^{-1} and 0.98 kW.h fed^{-1} as well as 2.28 l h^{-1} and 0.55 kW.h fed^{-1} for spreading paddy and fertilizer, respectively.

2.3 MODELLING OF CENTRIFUGAL BROADCASTER

Patterson and Reece (1962) investigated the motion of spherical particles on a spinner disc with a near-centre fed neglecting particle bounce off the spinner vanes. They developed analytical models for on-spinner particle motion and found reasonable agreement between their models and experimental measurements of the radial and total velocities of steel ball bearings leaving the spinner plate as well as the angle between where particles are dropped and where they leave the spinner plate.

Aphale et.al, (2003) conducted experimental and analytical study to investigate particles trajectories on and off spinner spreader. They used sixteen different granular fertilizers and the experimental data and showed that spinner trajectories generally lie between the analytical models for the pure rolling and pure sliding condition using a sliding friction coefficient of 0.5.

Hofstee (1995) utilized an ultrasonic transducer to determine the velocity and direction of particles leaving a spinner spreader. He found that the friction coefficient between a particle and the spinner plate and vane were significant variable. However, obtaining representative values of coefficient of friction for these variable for using in on-spinner models was difficult.

Dintwa et al. (2004) reported the calibration of simulation input parameters using a ‘landing area’, which represented the collective effect of the various particle interactions during movement along the vane and disc. They assumed that the discrepancies between simulation and measured spread patterns were mostly owing to particle interactions. It was identified that the most important parameters that affected the ‘landing area’ such as the mass flow rate, the disc radius, disc rotational speed, orifice radial dimensions, vane pitch, and the calibration curves for the individual parameters. They reported that the model, which considered particle interaction, improves simulation results and requires fewer calibrations.

Rahmato and Abdi (2013) studied motion analysis of teff seed particle on a rotating cone shaped disc. The basic equations of motion for a single teff seed particle was derived. They made analysis and directly applied to the flow of teff seeds on a spinning disc spreader. Equations of motion were developed for cone shaped disc and for the pitched type vane spreader. These equations of motion formed parts of the basis of MATLAB-SIMULINK model for spinning disc spreader with equation of motion through the air (off-disc) model. They considered different initial conditions (physical properties of teff seed) and also varying different machine parameters such as cone angle, pitch angle, and rotational speed of disc for analysing the motion of the single teff seed particle using MATLAB-SIMULINK simulation program.

Morad et al. (2002) developed a simulation model of the spinning disc performance of the broadcaster fertilizers. They found that the experimental results as well as the simulation model results reveal that the predicting operational parameters (feed radius of 75 mm, spinner radius of 250 mm and spinner rotating speed of 480 rpm) improve the uniformity of fertilizer distribution.

2.4 RICE ESTABLISHMENT METHODS

The paddy is established using dry seed, pre-germinated seed and seedlings. The most suitable planting technique depends on locality, soil type, and crop ecosystem. Rice can be broadcasted by hand, dibbled, and drilled in lines using a machine in both wet and dry soils. Rice seedlings can be planted manually, either in rows or randomly, or by rice transplanting machines. Direct seeded rice tend to mature faster than transplanted rice and often face more competition from weeds.

Saha and Bharti, (2010) reported that rice establishment methods have a considerable impact on rice growth, especially the seedling development and rice canopy structure establishment etc.

2.4.1 Dry seeding

Ho and Romli. (2000) found that direct seeding method reduced labour requirement and decreased the crop duration by 7-10 days and with higher yields compared to transplanted rice. Direct seeding method required only 34% of total labour requirement and saved 29% of the total cost compared to transplanting method.

Balasubramanian and Hill. (2002) reported that direct seeding of rice achieves early establishment of crop and more profit in areas with assured water supply by utilizing short duration modern varieties and cost-efficient herbicides.

2.4.2 Pre-germinated seeding/ wet seeding

In many irrigated and more reliable rain fed areas, pre-germinated paddy seeds are broadcasted into 2 to 5 cm of standing water in puddled paddy field. Seeding rates vary from 80 to 120 kg ha^{-1} and one person can broadcast one ha day^{-1}. Standing water levels are normally allowed to recede after seeding and irrigation is not given to seeded rice till seedlings are 1-2 leaf stage. If the soil surface dries too quickly, then flash flooding of the fields is required. For this system to work effectively, fields must be level and should have good drainage system. Gap filling and seedling rearrangement is required within 15-20 days after establishment. Weeds are controlled with 21 days after establishment especially if a pre-emergent herbicide are not sprayed. Pre-germinated herbicides are very effective for crop establishment, if there is a shortage of labour during planting, time and thus weeds can be managed and water can be controlled(Anon., 2015).

De Datta and Nantasomsaran. (1991) reported that direct wet-seeding contributed to early establishment of the first crop which contributed to increase cropping intensity because it eliminated the time for seedling raising.

Yoshida. (1981) reported that wet seeded rice starts tillering earlier than transplanted rice because its growth proceeds without the setback caused by uprooting injury to the root of seedlings

2.5 RICE SEEDING AND PLANTING TECHNIQUES

2.5.1 Broadcasting methods

In many rainfed and submerged condition, dry seeds are manually broadcasted onto the soil surface and then incorporated by ploughing or harrowing while the soil is still under dry condition. However, in deep water or recession rice areas, the pre-germinated seeds are not incorporated in soil after broadcasting and germination occurs following rain or rising water levels. This is a very inefficient way to establish a rice crop with a lot of seeds lost to birds and rodents and also heavy competition from weeds. The seeding rates are normally very high as 150-250 kg ha^{-1}, and yields are obtained generally quite low at 1-1.5 t ha^{-1} (Anon., 2015).

2.5.2 Broadcasting of seedlings

In some irrigation areas especially in China, 12-15 days old seedlings are broadcasted into standing water. This is done manually or by machine. The seedlings are established in bubble trays with sand or loam soils at seeding rate of 30-40 kg ha^{-1} (Anon., 2015).

2.5.3 Dry land seeding machine

In many parts of the world, rice is now sown using a seed drill. It is important to match the furrow opener to the soil type and residue levels and also have some means of closing the furrow after the seeding. A smooth, level seedbed is necessary to ensure that seeds are not planted at depths greater than 10 to 15 mm**.** Seeding rates of 60-80 kg ha^{-1} should be sufficient to give the desired plant stand. Most seed drills can plant at 20-25 cm row spacing. A good plant stand of 35 to 40 plants established per meter of drilled row after permanent water is applied to the field. A benefit of drill seeding is that fertilizer can be applied at the same time as the seed. Both manual and mechanical weeding is much easier in machine-drilled crops than in broadcast crops. Seed drills have many different types of furrow openers, which are designed for different soil types and crop residues (Anon., 2015).

2.5.4 Wet land seeding machine

Wet seeding machines are seed drills that can sow or drill seeds into wet and puddled soils. The field surface must be level and seed bed of even depth. These drills meter and deliver pre-germinated or dry seed, into a groove or furrow which is then covered by a small amount of sand or fine soil. Fertilizer can also be applied at the time of planting operation. This machine takes advantage of soil puddling but can only be used on tractors which have narrow steel wheels. Water must be added to the field as soon as possible after seeding (Anon., 2015).

2.6 MECHANICAL TRANSPLANTER

In Asia, many types of transplanters are used to establish rice crops. Transplanters are manufactured in China, Japan, Korea and Taiwan with varying levels of complexity. Rice transplanters range in size from one-row to two-row, walk-behind models to eight-row, riding type models. The seed bed must be well prepared for machine transplanting. The seed bed needs to be level and should have sufficient bearing strength to support the machine and transplant the seedlings. Most mechanical transplanters place seedlings in rows of 20-30 cm row spacing. The intra-row spacing between seedlings depends on the ground speed and speed of transplanting fingers (Anon., 2015).

Mechanical transplanters can transplant mat type rice seedlings at uniform depth and spacing. Mechanically established seedlings produce more number of tillers (16.8 tillers hill^{-1}) when compared to hand transplanted rice (Singh and Vatsa, 2006).

Singh and Rao (2010) reported about characteristics of transplanted rice such as plant height and root weight due to optimum planting features machines transplanters.

2.7 EFFECT OF DESIGN PARAMETERS ON PERFORMANCE OF CENTRIFUGAL BROADCASTER

Sayedahmed (1989) reported that the spinner with diameter of 500 mm was suitable for feed rates ranged from 8 to 12 kg min^{-1}, which gave better uniformity of distribution than 400 mm. He added that the C-shaped blades and C-curved blades tended to make the spreading performance look better. The difference between these two types of blades and L shape seemed to be due to the different amounts of materials bouncing in or out the spinner disc.

Morad (1990) reported that the distribution pattern width and uniformity of fertilizer distribution are clearly affected by the spreader speed. Increasing the spreader speed leads to increase the distribution width and improves uniformity of distribution, but on the other hand low discharge rate of fertilizer was observed. The spreader disc speed of (540 rpm) was considered the optimum to produce the best performance. He added that the spreader blade pitch affects significantly on the distribution width and the uniformity of distribution. The results indicated that the forward pitched blade +15 degree increased the distribution width and improved the uniformity of distribution in comparison to the backward pitched blade.

Metwali (1995) reported that the spinner speed of about 540 rpm gave the highest values of effective field capacity, lowest cost of production and gave the best distribution pattern hence, gives more swath width. Kamel et al. (2002) reported that Using C- shaped curved blades, the coefficient of variation was varied from about 51.05 to 38.04 % for spinner speed of 540 rpm and -10^0 blade angle without wind protection. For spiral curved shaped blades the coefficient of variation varied from 42.70 to 32.93 % under similar conditions.

Wilhoit *et al*. (1992) assessed the features of a centrifugal broadcaster in relation to broadcasting organic materials on the farm. They found that for bigger sized materials the uniformity of distribution was higher than the smaller materials. Pettersen *et al*. (1991) studied centrifugal broadcasters and concluded that broadcasting pattern was changed due to changing the size of broadcasted particles of fertilizers.

Parish (2002) and Yildirim and Kara (2003) found that the uniformity of broadcasting decreased as the flow rate increased. Parish (2002) reported that the fertilizer flow rate has an important effect on the broadcasting pattern, especially at low rate settings and that there were slight changes at high rate settings.

Olieslagers *et al*. (1996) concluded that broadcasting pattern was changed by some parameters such as the position of outlet gate and the rotary speed of spinning disk. Changing the flow rate of poured materials on spinning disk by variable-rate broadcasters, the uniformity was quite different from the desirable value.

2.8 ECONOMICS OF DIFFERENT CROP ESTABLISHMENT METHODS

Sanjay *et al*. (2006) stated that line transplanting showed significantly higher gross income Rs.31, 158 ha^{-1} compared to drum seeding 30, 829 Rs ha^{-1} and broadcasted rice 22, 032 Rs ha^{-1}. Hugar *et al*., (2009) concluded that significantly higher net returns of 37, 086 Rs ha^{-1} and higher B: C ratio about 2.03 observed under SRI method, when compared to aerobic and conventional method of rice establishment

Kumar (2015) reported that SRI machine planting proved to be the most profitable treatment in terms of net income and benefit cost ratio. The maximum net income 40765 Rs ha^{-1} and 39473 Rs ha^{-1} and return per rupee Rs.2.90 and Rs.2.84were recorded highest in SRI machine planting. Higher net returns are because of higher grain yield, consequently resulting better return for every rupee invested on cost of cultivation. The lowest returns are fetched from wet seeding which was the result of lowest grain yield under this treatment.

Bhardwaj et al. (2018) Cost of cultivation for mechanically transplanted and conventionally transplanted rice was 25648.13 Rs ha^{-1} and 25409.58 Rs ha^{-1}, respectively. Whereas rice grown by broadcasting of either sprouted or dry seeds had equal cost of cultivation i.e. 20534.60 Rs ha^{-1}. Establishment of rice with the help of drum seeder required cultivation cost of 21096.89 Rs ha^{-1}. Rice establishment methods under puddled soil had a significant impact on gross return. The gross return of conventionally transplanted was 71114 Rs ha^{-1}, drum seeded was 70390.50 Rs ha^{-1} and mechanically transplanted rice was 64492.50 Rs ha^{-1} were on par with one another. However, rice established by conventional transplanting and drum seeding of sprouted seeds had significant edge over broadcasting of either sprouted (60304.00 Rs ha^{-1}) or dry seeds (59313.00 Rs ha^{-1}). The agriculture practices involving lower cost of production and giving higher net return and benefit: cost ratio are preferred for adoption. Direct seeding of sprouted seeds by drum seeder (49293.61 Rs ha^{-1}) being on par with conventional transplanting (45704.42 Rs ha^{-1}) in net return had significant edge by 23.9, 26.9 and 27.1% over broadcasting of sprouted seeds, mechanical transplanting and broadcasting of dry seeds, respectively. The benefit : cost ratio (2.34) under drum seeded rice was higher than all other methods of rice establishment and had significant edge by 20.6, 23.8, 30 and 55% over broadcasting of sprouted seeds, broadcasting of dry seeds, conventional transplanting, and mechanical transplanting, respectively.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

3.1 ENGINEERING PROPERTIES OF PADDY

The engineering properties of pre-germinated paddy, especially physical and frictional properties are important factors to determine the design parameters of an efficient mechanical centrifugal broadcaster.

3.1.1 Physical properties of dry and pre-germinated paddy

The physical properties of dry and pre-germinated paddy seeds that affects the design of centrifugal broadcaster are moisture content, size dimensions, bulk density, true density, coefficient of friction that are directly affects the design of broadcaster hopper, agitator, and other components of broadcaster are determined in the this study((Irtwange and Igbeka, 2002)). The methods followed to determine these properties are discussed below.

3.1.1.1 Moisture content

In this study, both dry and pre-germinated paddy seeds of two local varieties, namely Uma and Jyothi were used for the study. The paddy seeds were cleaned to remove all foreign matters and broken seeds. In order to prepare the pre-germinated paddy seeds, the unfilled seeds separated from the filled seeds by using solution of water. The filled paddy seeds soaked into fresh water for 48 hours, and then samples were poured into separate polyethylene bags and at temperature ranged between 27^{o}C-30°C for starting the germination process. Before starting a test, the required quantity of pre-germinated seeds was taken out and allowed to warm up to room temperature. The initial moisture content of paddy was determined by oven drying at 103^{o}C for 48 (Minaei et al., 2007). The initial moisture content of the paddy seeds in percent on dry basis was determined by the following formula.

$$MC(\%) = \frac{(W_i - W_d)}{W_d} \times 100 \qquad \ldots(3.1)$$

Where,

MC = Moisture content of dry/pre-germinated paddy seeds

W_i = Initial weight of dry/pre-germinated paddy seeds

W_d = Dry weight of dry/pre-germinated paddy seeds.

3.1.1.2 Size and shape

To determine the axial dimensions viz., length 'l', width 'b' and thickness 't', 100 grains were randomly picked and their three linear dimensions were measured using travelling microscope and corresponding readings were noted down. The equivalent diameter 'D_p' considering a prolate spheroid shape for a rice grain, was calculated through the following expression (Reddy and Chakraverty, 2004). The equivalent diameter of paddy seeds was calculated by the following equation.

$$D_p = \left[4L\left(\frac{W+T}{4}\right)^2\right]^{1/3} \quad \ldots(3.2)$$

The geometric mean diameter 'D_g' is the product of the three axial dimensions. The geometric mean diameter of the grain were calculated by using the following relationships (Dursun and Dursun, 2005).

$$D_g=(LWT)^{1/3} \quad \ldots(3.4)$$

The Sphericity 'Φ' defined as the ratio or the surface area of sphere having the same volume as that of the grain to the surface area of grain, was determined as (Reddy and Chakraverty, 2004). The sphericity of paddy seeds was calculated by the following expression.

$$\Phi = \frac{(LWT)^{1/3}}{L} \quad \ldots(3.5)$$

Where,

L = Length of grain, mm

W = Width of grain , mm

T = thickness of the grain, mm

Grain surface area was calculated using (Jain and Bal, 1997). The surface area of paddy seeds was calculated by the following expression.

$$S = \frac{\pi B L^2}{(2L - B)} \quad ...(3.6)$$

Where,

$$B = \sqrt{WT} \quad ...(3.7)$$

R_a was calculated by Nimkar and Chattopadhyay (2001).

$$R_a = \frac{W}{L} \quad ...(3.8)$$

Where,

R_a = Aspect ratio

S = Surface area of the grain, mm^2

L = Length of grain, mm

W = Width of grain, mm

3.1.1.3 Bulk and true densities

The bulk density of dry and pre-germinated paddy seeds, 'ρ_b' was determined by filling a cylindrical container of 500 ml volume with the grains a height of 150 mm at a constant rate. The seeds were not compacted in any way. The container was weighted using a digital balance reading to 0.01 g. Bulk density was calculated from the ratio of seeds mass in the container to its volume (Sacilik et al., 2003). This measurement was repeated five times. The true density, 'ρ_t' defined as the ratio between the mass of paddy grains and the true volume of the grains, was determined using the toluene (C_7H_8) displacement method. Toluene was used instead of water because it is absorbed by kernels to a lesser extent. The volume of toluene displaced was found by immersing a weighted quantity of paddy grains in the measured toluene (Sacilik et al., 2003).

$$\rho_b = \left(\frac{M}{V}\right) \quad ...(3.9)$$

$$V_t = \frac{\text{Mass of displaced toluene,(kg)}}{\text{Density of toluene,(kg m}^{-3})} \qquad \text{…(3.10)}$$

$$\rho_t = \left(\frac{M_a}{V_t}\right) \qquad \text{…(3.11)}$$

Where,

ρ_b = Bulk density, kg m^{-3}

ρ_t = True density, kg m^{-3}

M= Mass of dry/pre-germinated paddy seeds in container, kg

M_a= Mass of dry/pre-germinated paddy seeds in air, kg

V= Volume of container, m^3

V_t= True volume of dry/pre-germinated paddy seeds, m^3

3.1.1.4 Porosity

The porosity *'ε'* defined as the percentage of void space in the bulk grain which is not occupied by the grain was calculated from the following relationship (Sacilik et al., 2003). The following expression was used for calculating the porosity

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \qquad \text{…(3.12)}$$

Where,

ε = Porosity, %

3.1.1.5 Angle of repose

The angle of repose is the angle with the horizontal at which the paddy seeds form heap (cone) when poured. For the determining the angle of repose of the pre-germinated paddy, a tube (inner diameter 106 mm and height 220 mm) was kept vertically on a horizontal crystal glass floor and filled with the sample. Tapping during filling was done to obtain uniform packing and to minimize the wall effect, if any. The tube was slowly raised above the glass floor so that whole material could slide and form a conical heap. The height above the floor '*H'* and the diameter of the heap '*D'* at its base were measured with the help of a measuring scale and the angle of repose of the paddy 'θ' was computed using the following expression (Jha, 1999). The angle of repose was calculated by using following expression

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \quad \ldots(3.13)$$

Where,

θ = Angle of repose, degrees

H = Height of the grain heap, mm

D = diameter of the heap, mm

3.1.1.6 Static coefficient of friction

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

Coefficient of friction, $\mu = \frac{F}{W}$ …(3.14)

Where,

μ = Coefficient of friction

F = frictional force, kg

W = Normal force, Kg

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

3.2 WORKING PRINCIPLE OF A CENTRIFUGAL BROADCASTER

The principle of a centrifugal broadcaster is for spreading out the paddy seeds by the centrifugal force of spinning rotor disc. The traditional centrifugal fertilizer broadcasting machine is used for spreading fertilizer uniformly in the fields. Usually 2 to 6 vanes are arranged on the disc. The shape of the vane is either straight or radial. The shape of the vane effects on the uniform distribution of seeds. A centrifugal broadcaster is widely used for applying cereals seeds and granular fertilizers. The centrifugal broadcaster throws more seeds towards right hand side of line of travel when spinning rotates clockwise direction that is towards right hand side of the operator, hence it results in skewness. The broadcaster throws the seeds up to a distance of 3 to 4 meter along the line of travel.

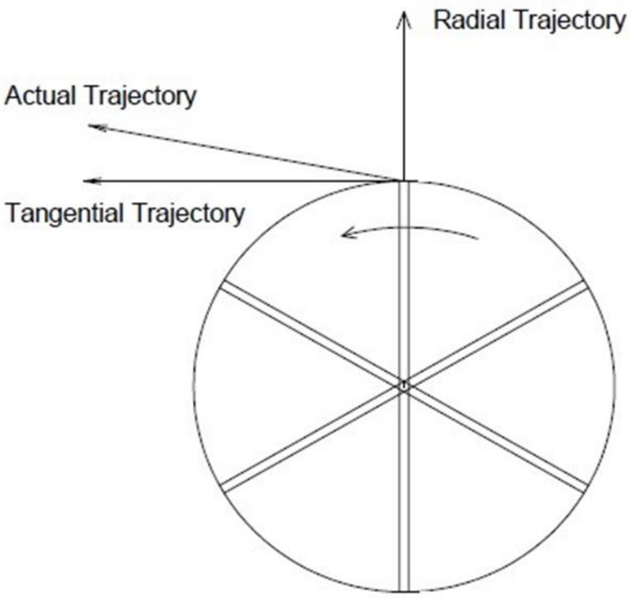

Fig. 3.1 Typical trajectory of a paddy seeds leaving a broadcaster spinning disc rotor.

The spinner disc broadcaster has a rotating rotor with vanes riveted to the rotor disc surface. The paddy seeds discharged on to the spinner rotor is thrown on to the ground after colliding with the rotating disc vanes. The paddy seeds generally slide out along the vanes of the spinning rotor disc until they are discharged. Thus, the weight and coefficient of friction of the paddy seeds on the spinning rotor disc material has a major effect paddy seeds to move from the drop point to the edge of the spinning rotor disc. For a given drop point, the longer the paddy seeds stays on the spinning rotor disc, the further the paddy seeds trajectory will be angled in the direction of rotation.

As the paddy seeds leave the disc vane and fly through the air to the ground. Paddy seeds moves in a direction that is more tangential to the spinning rotor disc (Fig. 3.1). The exact angle of the trajectory will depend on spinning rotor disc configuration, spinning disc speed, spinning rotor surface, paddy seeds characteristics and relative humidity.

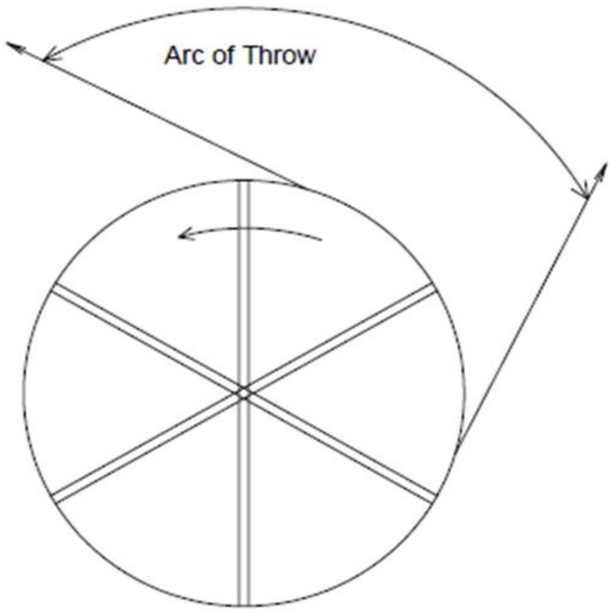

Fig. 3.2 Trajectory of paddy seeds leaving broadcaster spinning rotor disc in an arc.

Paddy seeds tend to leave the spinning rotor disc in an arc rather than all of the seeds following the same trajectory (Fig. 3.2). Also, variations in size and shape of the paddy seeds will cause some to leave the disc vane sooner than others. This phenomenon is desirable. In order to broadcast paddy seeds over a reasonably wide area, it is necessary to discharge the paddy seeds in an arc. The main advantage of the spinner broadcaster is that it can distribute granular materials or fertilizers uniformly over large area (Parish., 1996).

3.3 DETAILS OF A MOTORISED CENTRIFUGAL BROADCASTER

A prototype of power operated pre-germinated paddy seed broadcaster was developed and constructed whose details are discussed below:

3.3.1 Constructional details of power operated pre-germinated paddy seed broadcaster

The prototype of a power operated pre-germinated paddy seed broadcaster consists of a hopper, bevel gears, bearings, spinning disc, battery, DC motor, seed gate opening and shaft.

3.3.1.1 Modification of centrifugal broadcaster

A manual cranking fertiliser broadcaster was modified to a motorised centrifugal broadcaster prototype to broadcast dry and pre-germinated paddy seeds. The constructional details and modifications made are discussed below

3.3.1.2 Power transmission system

Power transmission system consists of DC motor, shafts and a pair of bevel gear. The DC motor has 75 watts capacity and attached with speed controller. Bevel gear converts the horizontal rotational motion (motor shaft) into vertical rotational motion (spinning disc shaft). The speed ratio of bevel gear system is 1:13, which means that when motor shaft turns one revolution then spinner disc shaft turns 13 revolution. The power transmitted from DC motor to spinning disc with help of bevel gear and shafts. The DC motor has two speeds 160 rpm and 220 rpm. The DC motor is driven 12 volts battery.

3.3.1.3 Agitator cum feed rate regulator

Metering mechanism consists of agitator and adjustable slider. The Paddy seed discharge rate depends upon the size of outlet opening of hopper. The seed outlet opening size of hopper can be adjusted by using adjustable slider. The slider is located between base of the hopper and spinning disc plate. The agitator is provided to prevent blockage of seeds at the opening of hopper. It is mounted on the spinning disc shaft and rotates to prevent the blocking of paddy at the seed outlet opening. Thus it facilitates a uniform and continuous discharge of paddy seeds from hopper to the spinning disc plate. Also, the agitator maintains a trouble free and smooth flow of paddy seeds from hopper. The paddy seeds are thus moved from hopper by gravity.

3.3.1.4 Spinning rotor disc and vanes

Paddy seeds which pass through hopper orifice are discharged on a 230 mm diameter spinning disc made of aluminium sheet metal having 5 mm thickness. It has six straight vanes are fitted on the disc. The length of each vane is 105 mm, and height 15 mm made of 5 mm thick aluminium sheet. Spinning disc rotor is placed below the hopper. The spinning disc rotor operated at two output speeds 160 rpm and 220 rpm. Vanes are provided on the spinning disc to assist in better spreading of paddy seeds over the fields. Paddy seeds are thrown by the action of centrifugal force of the spinning disc.

3.3.1.5 Battery

A 12 volt battery was used as a power source for operating the broadcaster. It is placed at the bottom of the broadcaster hopper base securely. It should be charged frequently before taking to field for broadcasting paddy seed. It should be kept away from water, grease and dust. The both terminals should be kept clean.

3.3.1.6 Hopper

The vertical cylindrical shaped hopper is designed to store paddy seeds for smooth and continuous flow of paddy seeds to conical bottom orifice. The hopper is made aluminium sheet. The total capacity of hopper is 13 litres. The hopper has 310 mm length, 230 mm diameter and 1 mm thickness. The hopper has frustum shaped truncated cone at the bottom, with an orifice.

3.3.1.7. Shoulder carrying belt

The seed broadcaster was carried in front of the operator by a cloth belt saddled on both shoulders. The belt was provided with clamps for fixing belt to the broadcaster. It helps in carrying and operation of broadcaster by the operator easily.

(a)

(b)

Plate 1 Centrifugal broadcaster

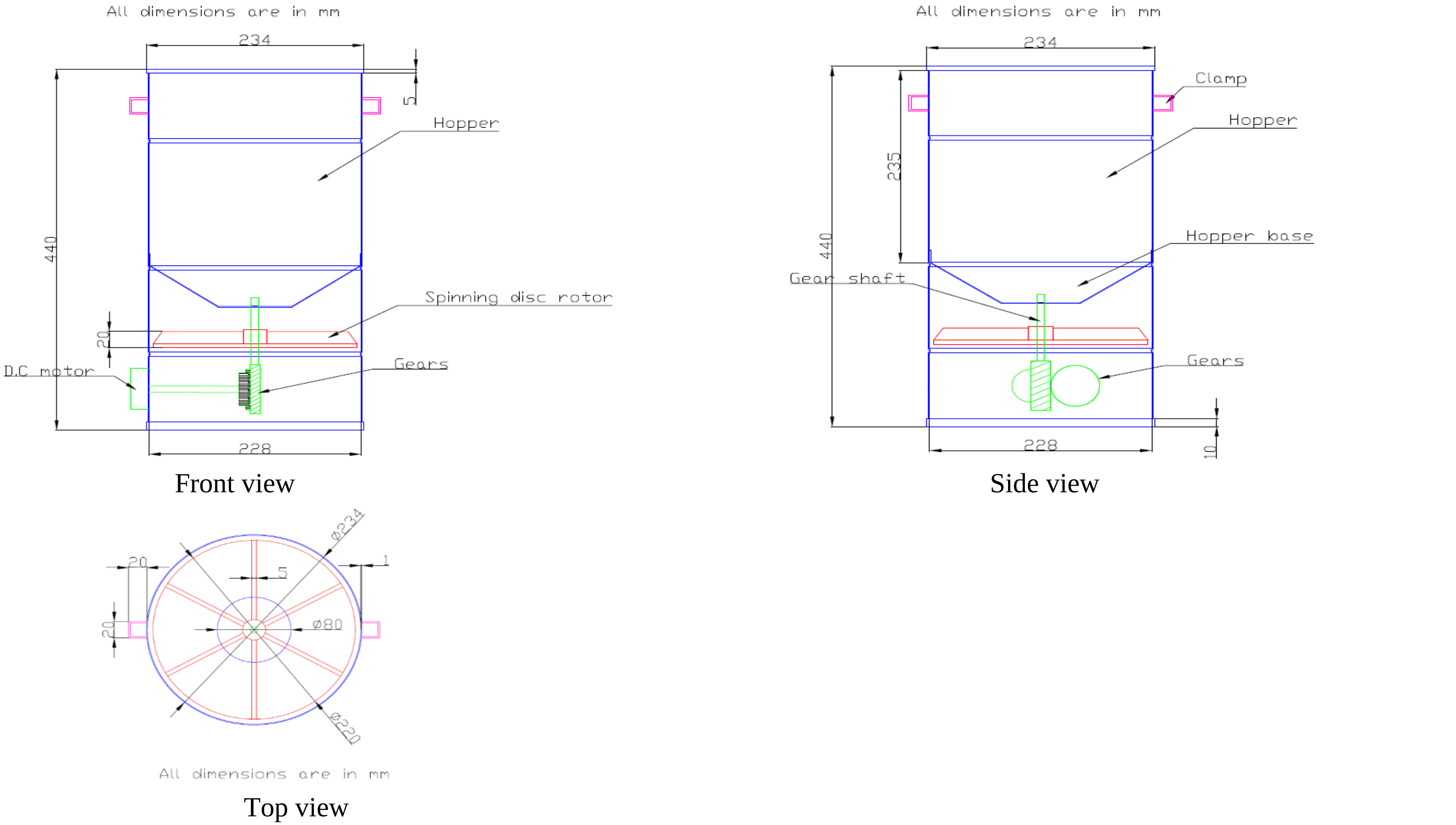

Fig. 3.3 Orthographic view of centrifugal broadcaster

3.4 CENTRIFUGAL BROADCASTER OPERATING CHARACTERISTICS

Centrifugal seed broadcaster, spread seeds in a wide pattern that tapers off at the edges. This tapering is beneficial because it reduces the minor errors in swath width. Centrifugal seeds broadcaster patterns take several shapes as shown in figures 3.4 and 3.5.

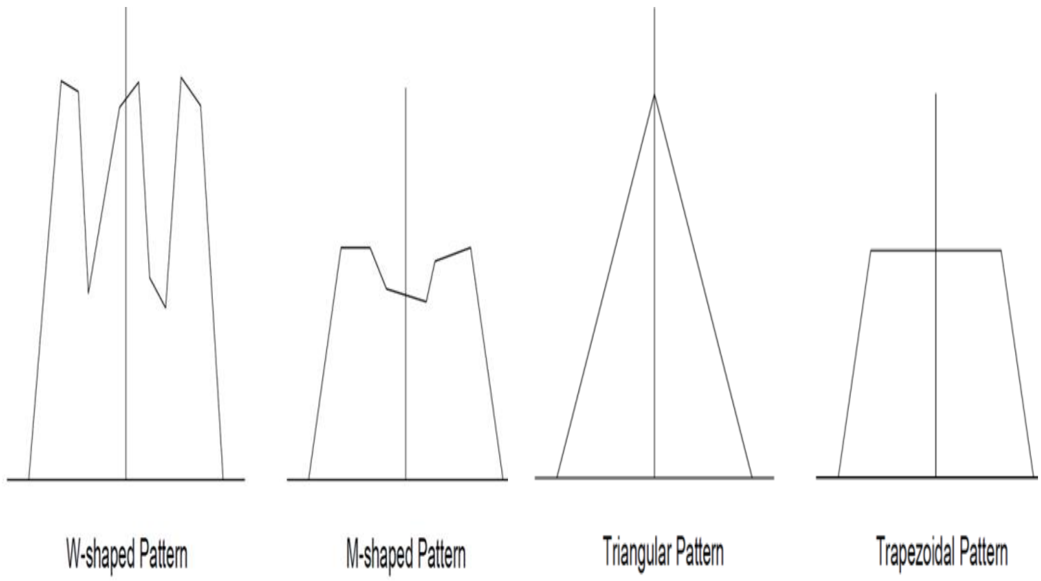

Fig. 3.4 problem patterns **Fig. 3.5 Trapezoidal and triangular broadcaster patterns**

Trapezoidal and triangular patterns (Fig. 3.5) are most effective because (if centered) they can provide a uniform application when properly overlapped. The patterns shown in Figure 3.4 are common, but they create problems. Patterns that are M-shaped or W-shaped typically require a double overlap and may not be uniform even then. Skewed patterns result in uneven application even when overlapped (Parish., 1996)

Operating pattern affects the performance of centrifugal seed broadcaster. In this study back-and-forth pattern was selected. This pattern results in the right side of the pattern overlapping with the right side of the adjacent pattern Fig. 3.6 and 3.7. The most observed pattern is trapezoidal pattern and this type of pattern gives better results compared to other type of pattern (Parish., 1996).

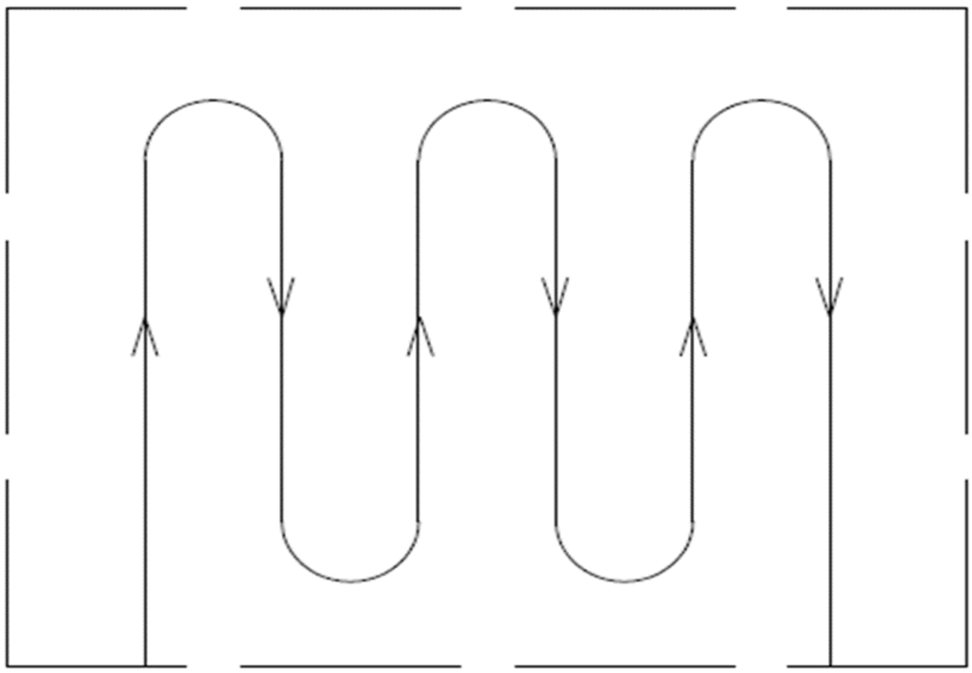

Fig. 3.6 Progressive or back-and-forth mode of operation

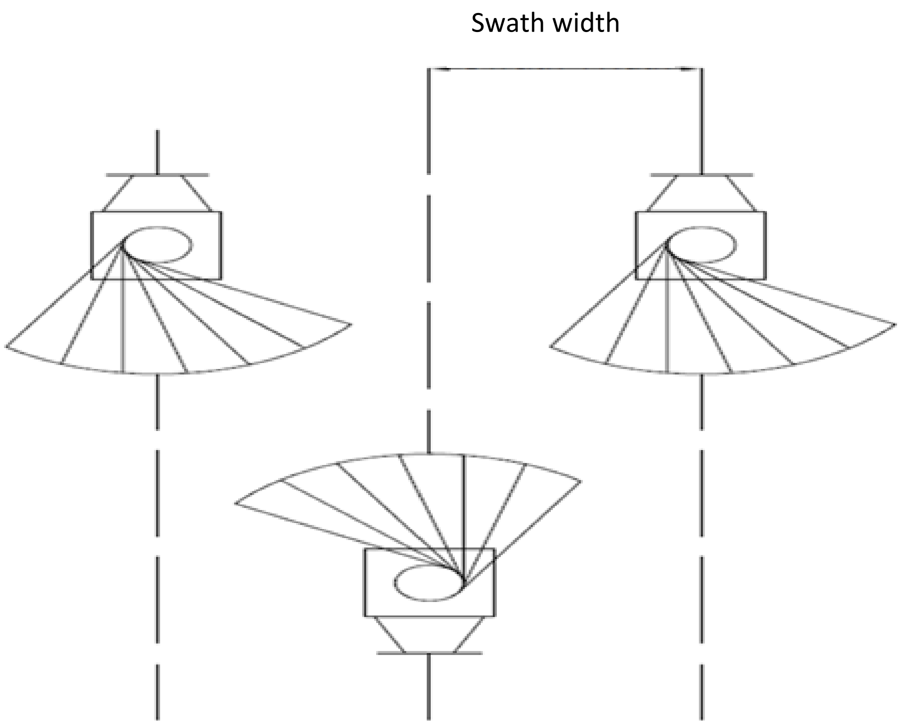

Fig. 3.7 Right-on-right, left-on-left overlapping with back-and-forth mode of operation

3.5 WORKING PRINCIPLE OF CENTRIFUGAL BROADCASTER

A centrifugal broadcaster works on the principle of centrifugal force. Paddy seed flows from hopper to spinning disc from there seeds thrown on the paddy field surface by the action of centrifugal force. The rotating spinning disc develops centrifugal force and this force acts on paddy seeds to be thrown tangentially along the disc periphery. The tangentially thrown paddy seeds are uniformly distributed on the paddy field surface.

3.6 TESTING OF A MOTORIZED CENTRIFUGAL BROADCASTER

The developed prototype of power operated pre-germinated and dry paddy seed broadcaster was tested for evaluating performance in the laboratory. The tests were conducted at Kelappaji Collage of Agricultural Engineering and Technology, Tavanur campus. The testing floor was divided into square checks of one meter size. According to ASAE S341.3 (ASAE Standards, 2006), experiments were performed at slope of 2% (quite horizontal grounds, in this research). For getting proper results, broadcasting started 3 meter before the broad casting square checks starts and finished for 10 m for travel length. The broadcaster hopper is filled during the time of test. Tests were conducted with the broadcaster hopper filled up to the level of 50% to 75% of capacity as per ASAE S341.3. Standards. The broadcasting was carried out and weight of paddy seeds per meter square checks were collected and weighed. The centrifugal broadcaster was operated for a period sufficient enough to attain continues flow of seeds. Measuring devices and instruments used for measurements were measuring tape, wooden frame, plastic bags, dry paddy seeds, colour chalk, multi-meter, stop watch and electronic balance. The following parameters were observed during the test to evaluate the performance of centrifugal broadcaster.

3.6.1 Walking speed

Walking speed of the operator was measured from the time required for the operator to travel the distance of 10 m in the test floor. Three average readings were taken after testing of the centrifugal broadcaster.

3.6.2 Swath width

Swath width of the centrifugal broadcaster was measured perpendicular to the direction of travel according to the ASAE 341.2 Standards. Total swat width was measured with few paddy seeds present in the square checks.

3.6.3 Quantity of paddy seeds

The Quantity of seeds distributed in each square checks along the traverse width was measured by selecting random rows. This measurement was in sequence with respective location of each square checks. For each treatment, two random rows were selected and average value of paddy seeds collected from square checks boxes were weighed to determine application rate.

3.7 PERFORMANCE PARAMETERS FOR EVALUATION OF CENTRIFUGAL BROADCASTER

Performance evaluation was conducted for 8 treatments with combinations of spinning rotor disc speed, quantity of paddy seeds filled in hopper and hopper outlet opening size. The two factorial experimental design with 2 levels of spinning rotor disc speed, quantity of paddy seeds and hopper outlet opening size is given in Table 3.1.

Table 3.1 Experimental design of power operated centrifugal broadcaster.

Sl. No.	Experimental design	Rotor speed, Rpm	Quantity of paddy seeds, kg	Hopper outlet opening, cm^2
1	Q1S1O1	160	1.5	4.9
2	Q1S1O2	160	1.5	3.7
3	Q1S2O1	220	1.5	4.9
4	Q1S2O2	220	1.5	3.7
5	Q2S1O1	160	3	4.9
6	Q2S1O2	160	3	3.7
7	Q2S2O1	220	3	4.9
8	Q2S2O2	220	3	3.7

3.7.1 Testing parameters of centrifugal broadcaster

Independent variables

i. Rotor speed (S_1 and S_2)
ii. Quantity of paddy seeds filled in hopper (Q_1 and Q_2)
iii. Hopper outlet opening size (O_1 and O_2)

Dependent variables

i. Application rate
ii. Swath width and effective swath width
iii. Skewness ratio
iv. Coefficient of variation
v. Uniformity coefficient of distribution
vi. Effective field capacity

3.7.2 Performance evaluation of centrifugal broadcaster.

The performance parameters of a centrifugal paddy seed broadcaster was evaluated for application rate, swath width and effective swath width, skewness ratio, coefficient of variation, uniformity coefficient of distribution, and field capacity were calculated by the following calculations.

3.7.2.1 Application rate

The application rate of paddy seed was calculated using the following relationship (Ziauddin and Roy, 1998).

$$A = \frac{D}{FC_{eff}} \qquad \ldots(3.15)$$

Where,

A = Application rate of the paddy seed in kg ha^{-1}

FC_{eff} = Effective field capacity of the centrifugal broadcaster in ha hr^{-1}

D = Discharge rate of paddy seed in kg hr^{-1}.

3.7.2.2 Swath width and effective swath width

Swath width measurement was done by measuring the distance between outer most seeds collected from square checks on either side of the centre line along the transverse direction. Swath width and effective swath width measurement was done by pattern of broadcaster. The graph was drawn for the values of swath width in X-axis with respect to application rate in the Y-axis. The centrifugal seed broadcaster pattern gives estimate of the effective swath width. To estimate the swath width spread pattern, a horizontal line was drawn through the spread pattern about where it gives the recommended seed rate (of the centre section) (Fig.3.8). Further second horizontal line at 50% recommended seed rate was drawn. In the next step vertical lines were draw down from the points where the half rate line intersects the spread pattern line edges. The distance between the two vertical lines is the approximate effective swath width. The vertical lines represent the overlap points from adjacent patterns at the selected swath width. If the pattern is skewed, one vertical line may be further from the centre than the other.

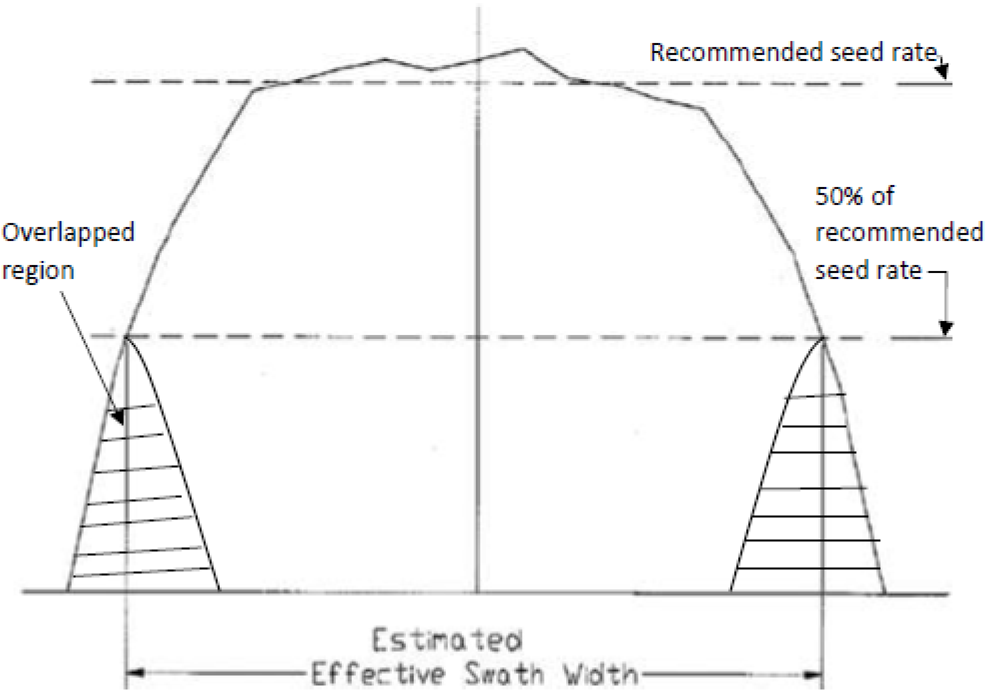

Fig. 3.8 Estimating swath width from a graph.

This is done by listing the data from the individual square checks for the centre swath and then adding in the amounts at each point for assumed adjacent (identical) travel interval width that overlap with respect to initial line of travel. Depending on the proposed operating mode, you will need to add left-on-left, right-on-right or left-on-right, right-on-left. For evaluating the performance for any interval width of over laps with respect to initial line of travel. Enough overlap patterns must be considered such that all data points from overlapping passes falling between the overlap points on the line of travel are taken into account for 50% of the recommended application rate. All points beyond that will be a repeat of the points between the overlap points and thus are superfluous for this exercise. The spread Patten for overlaps can be constructed with the help of single spread pattern data, to determine application rate and swath width. (Parish., 1996).

3.7.2.3 Skewness ratio (S):

Skewness ratio was calculated by using the following equation (Tawfik and Khater, 2009).

$$S = \frac{R_Z}{L_Z} \times 100 \qquad \dots(3.16)$$

Where,

S = Skewness ratio (%)

L_z = Mass of paddy seed collected from the left side, Kg

R_z = Mass of paddy seed collected from right side, Kg.

3.7.2.4 Coefficient of variation

Coefficient of variation is a measure of the overall uniformity of the pattern. The lower the CV implies that the spread Patten of broadcaster is uniform. If the application rate is exactly the same all the way across the overlapped pattern, the CV would be 0%. A CV value of 10% or less is generally considered acceptable for any broadcasting situation. For centrifugal broadcaster parameters and forward speeds are adjusted to obtain a minimum value of CV (Parish., 1996).

Coefficient of variation (C.V.):

The coefficient of variation was calculated as follows (ASAES341.3, 2006):

$$\delta = \sqrt{\frac{\sum(X_i - X_a)^2}{n-1}} \qquad \ldots(3.17)$$

Where,

δ = Standard deviation

X_i = weight of paddy seed in each one meter square box, kg

X_a = Recommended paddy seed rate (100 kg ha^{-1})

n = Number of checks

$$CV = \frac{\delta}{Xa} \times 100 \qquad \ldots(3.18)$$

3.7.2.5 Uniformity coefficient of distribution (UCD)

Uniformity coefficient developed by Christiansen in 1942 is stated below:

$$CU(UCD) = 100 \times \left(1.0 - \frac{\sum X}{n.m}\right) \qquad \ldots(3.19)$$

$$CU(UCD) = 100 \times \left(1.0 - \frac{\sum |Z - m|}{\sum Z}\right) \qquad \ldots(3.20)$$

Where,

CU(UCD) = Uniformity coefficient of distribution developed by Christiansen (%)

Z=The amount of paddy seeds in each container while testing uniformity (kg)

X=|z-m|= The total absolute value of deviations from desired seed rate of paddy measured in all accumulation containers (kg)

m=Recommended seed rate (kg ha^{-1})

n =The number of seed collecting checks

3.7.2.6 Effective field capacity

The effective field capacity of broadcaster was calculated by using following expression:

$$\text{Theortical field capacity} = \frac{\text{Effective swath width(W)} \times \text{walking Speed(S)}}{10} \quad ..(3.21)$$

$$\text{Effective field capacity} = \frac{\text{Theoretical field capacity} \times \text{Field efficiency}(E_f)}{100} \quad ..(3.22)$$

Where,

S = Travel speed, km h^{-1}

W = Effective swath width, m

E_f = Field efficiency, (%)

3.8 Cost of operation

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

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

This chapter gives the performance details of a battery operated manual centrifugal broadcaster. The centrifugal broadcaster was tested for two levels of rotor speed, orifice openings and quantity of material in the cylindrical container. The test performances of the centrifugal broadcaster for the above variables at two levels were studied using the seed material and the results are given in sections below.

4.1 ENGINEERING PROPERTIES OF PADDY SEED

Engineering properties of paddy seeds are very important parameters for designing centrifugal broadcaster. All engineering properties of paddy seeds were studied in the laboratory. The main engineering properties are bulk density, true density, angle of repose, coefficient of friction, porosity etc., are discussed below. The following sections gives the result about the engineering and physical properties of Uma and Jyothi varieties of paddy seeds.

4.1.1 Physical properties of dry paddy seed

4.1.1.1 Moisture content

The moisture content of Uma and Jyothi varieties of dry paddy seeds were determined as explained in section 3.1.1.1. The moisture content of Uma and Jyothi varieties were found to be 11 % and 12 % respectively.

4.1.1.2 Size and shape

Size and shape of paddy seeds were determined as explained in section 3.1.1.2. The major, intermediate, and thickness dimensions of Uma and Jyothi varieties of dry paddy seeds were measured. The average dimensions of Uma and Jyothi varieties of dry paddy seeds are given in Table 4.1. The mean linear dimensions of randomly selected dry paddy seeds of Uma variety have a major axis (length) 7.62$\pm$0.92 mm; intermediate axis (width) 3.15$\pm$0.32 mm; minor axis (thickness) 2.98$\pm$0.62 mm; equivalent diameter 4.17$\pm$0.32 mm; geometric mean diameter 4.17±0.32 mm; sphericity 0.552±0.042 %; surface area 46.204±0.053 mm^2; aspect ratio 0.425±0.047.

Table 4.1 Physical dimensions of dry paddy seeds

Sl. No.	Dimensions	Uma	Jyothi
		Mean ± SD, mm	
1	Length (mm)	7.62±0.92	8.34±0.83
2	Width (mm)	3.15±0.32	3.02±0.36
3	Thickness (mm)	2.98±0.62	2.82±0.58
4	Equivalent diameter (mm)	4.17±0.32	4.14±0.29
5	Geometric mean diameter (mm)	4.17±0.27	4.14±0.25
6	Sphericity (%)	0.552±0.042	0.506±0.036
7	Surface area (mm^2)	46.204±0.053	47.053±0.055
8	Aspect ratio	0.425±0.047	0.372±0.051

Similarly, the mean linear dimensions of randomly selected dry paddy seeds of Jyothi variety have a major axis (length) 8.34±0.83 mm; intermediate axis (width) 3.02±0.36 mm; minor axis (thickness) 2.82±0.58 mm; equivalent diameter 4.14±0.29 mm; geometric mean diameter 4.14±0.29 mm; sphericity 0.506±0.036 %; surface area 47.053±0.055 mm^2; aspect ratio 0.372±0.051.

4.1.1.3 Bulk density

The bulk density of Uma and Jyothi varieties of dry paddy seeds were determined as explained in section 3.1.1.3 and results are given in Table 4.2. The bulk density of Uma and Jyothi varieties were found to be 560.24 kg m^{-3} and 530.18 kg m^{-3} respectively. The hopper capacity of centrifugal broadcaster depends upon bulk density of paddy seed.

4.1.1.4 True density

The true density of Uma and Jyothi varieties of dry paddy seeds were determined as explained in section 3.1.1.3 and results are given in Table 4.2. The true density of Uma and Jyothi varieties were found to be 1185 kg m^{-3} and 1005 kg m^{-3} respectively.

Table 4.2 Bulk density and true density of dry paddy seeds

Sl. No	Paddy Varieties	Bulk density	True density
		Mean ± SD (kg m^{-3})	
1	Uma	560.24±4.05	1185±40.15
2	Jyothi	530.18±3.55	1005±38.65

4.1.1.5 Porosity

The porosity of Uma and Jyothi varieties of dry paddy seeds were determined as explained in section 3.1.1.4 and results are given in Table 4.3. The porosity of Uma and Jyothi varieties were found to be 51.23% and 43.42% respectively.

Table 4.3 Porosity of dry paddy seeds

Sl. No	Varieties	Porosity Mean ± SD (%)
1	Uma	51.23±1.09
2	Jyothi	43.42±0.95

4.1.1.6 Angle of repose

The Angle of repose of Uma and Jyothi varieties of dry paddy seeds were determined as explained in section 3.1.1.5 and results are given in Table 4.4. The angle of repose of Uma and Jyothi varieties were found to be 36.25^0 and 30.52^0 respectively.

Table 4.4 Angle of repose of dry paddy seeds

Sl. No.	Varieties	Angle of repose Mean ± SD (degree)
1	Uma	36.25±0.43
2	Jyothi	30.52±0.38

4.1.1.7 Coefficient of friction

The static coefficient of friction of Uma and Jyothi varieties of dry paddy seeds were determined as explained in section 3.1.1.6 and results are given in Table 4.5. The static coefficient of friction was found against the three different surfaces namely aluminium, wood, and stainless steel.

Table 4.5 coefficient of friction of dry paddy seeds

Sl. No	Material surface	Uma	Jyothi
		Mean ± SD	
1	Aluminium	0.3664±0.13	0.3562±0.16
2	Wood	0.31±0.15	0.3186±0.18
3	Stainless steel	0.3523±0.09	0.3573±0.12

4.1.2 Physical properties of Pre-germinated paddy seed

4.1.2.1 Moisture content

The moisture content of Uma and Jyothi varieties of pre-germinated paddy seeds were determined as explained in section 3.1.1.1 and results are given in Table 4.6. The moisture content of Uma and Jyothi varieties were found to be 45% and 43% respectively. The hopper capacity of centrifugal broadcaster depends of upon bulk density of paddy seeds.

4.1.2.2 Size

The size and shape were determined as explained in section 3.1.1.2. The major, intermediate, and thickness dimensions of Uma and Jyothi varieties of pre-germinated paddy seeds were measured. The length, width, thickness and mean diameter were determined. The average dimensions of Uma and Jyothi varieties of pre-germinated paddy seeds are given in Table 4.6. The mean linear dimensions of randomly selected pre-germinated paddy seeds of Uma variety have a major axis (length) 7.67±1.07 mm; intermediate axis (width) 3.19±0.23 mm; minor axis (thickness) 3.04±0.33 mm; equivalent diameter 4.20±0.28 mm; geometric mean diameter 4.20±0.28 mm; sphericity 0.546±0.042 %; surface area 46.997±0.053 mm^2; aspect ratio 0.416±0.047. Similarly, the mean linear dimensions of randomly selected pre-germinated paddy seeds of Jyothi variety have a major axis (length) 8.35±1.16 mm; intermediate axis (width) 3.08±0.26 mm; minor axis (thickness) 2.86±0.44 mm; equivalent diameter 4.19±0.24 mm; geometric mean diameter 4.19±0.24 mm; sphericity 0.501±0.036 %; surface area 47.575±0.055 mm^2; aspect ratio 0.368±0.051.

Table 4.6 Physical dimensions of pre-germinated paddy seeds

Sl. No	Dimensions	Uma	Jyothi
		Mean $\pm$ SD, mm	
1	Length (mm)	7.67$\pm$1.07	8.35$\pm$1.16
2	Width (mm)	3.19$\pm$0.23	3.08$\pm$0.26
3	Thickness (mm)	3.04$\pm$0.33	2.86$\pm$0.44
4	Equivalent diameter (mm)	4.20$\pm$0.28	4.19$\pm$0.31
5	Geometric mean diameter (mm)	4.20$\pm$0.23	4.19$\pm$0.24
6	Sphericity (%)	0.546$\pm$0.042	0.501$\pm$0.036
7	Surface area (mm^2)	46.997$\pm$0.053	47.575$\pm$0.055
8	Aspect ratio	0.416$\pm$0.047	0.368$\pm$0.051

4.1.2.3 Bulk density

The bulk density of Uma and Jyothi varieties of pre-germinated paddy seeds were determined as explained in section 3.1.1.3 and results are given in Table 4.7. The bulk density of Uma and Jyothi varieties were found to be 583.34 kg m^{-3} and 552.11kg m^{-3} respectively. The hopper capacity of centrifugal broadcaster depends of upon bulk density of paddy seeds and also packing nature of pre-germinated paddy seeds.

4.1.2.4 True density

The true density of Uma and Jyothi varieties of pre-germinated paddy seeds were determined as explained in section 3.1.1.3 and results are given in Table 4.7. The true density of Uma and Jyothi varieties were found to be 1250 kg m^{-3} and 1020 kg m^{-3} respectively.

Table 4.7 Bulk density and true density of pre-germinated paddy seeds

Sl. No.	Varieties	Bulk density	True density
		Mean $\pm$ SD (kg m^{-3})	
1	Uma	583.34$\pm$3.02	1250$\pm$35.28
2	Jyothi	552.11$\pm$4.14	1020$\pm$32.13

4.1.2.5 Porosity

The porosity of Uma and Jyothi varieties of pre-germinated paddy seeds were determined as explained in section 3.1.1.4 and results are given in Table 4.8. The porosity of Uma and Jyothi varieties were found to be 53.33% and 45.53% respectively.

Table 4.8 Porosity of pre-germinated paddy seeds

Sl. No.	Varieties	Porosity Mean ± SD, %
1	Uma	53.33±1.13
2	Jyothi	45.53±1.02

4.1.2.6 Angle of repose

The Angle of repose of Uma and Jyothi varieties of pre-germinated paddy seeds were determined as explained in section 3.1.1.5 and results are given in Table 4.9. The angle of repose of Uma and Jyothi varieties were found to be 38.94^0 and 32.12^0 respectively. The angle of repose of paddy seeds determines the angle of cone shaped base of cylindrical hopper to facilitate free flow of seeds through the opening. This angle affects the flow of paddy seeds through hopper.

Table 4.9 Angle of repose of pre-germinated paddy seeds

Sl. No	Varieties	Angle of repose Mean ± SD, degree
1	Uma	38.94^0±0.35
2	Jyothi	32.12^0±0.31

4.1.2.7 Coefficient of friction

The static coefficient of friction of Uma and Jyothi varieties of pre-germinated paddy seeds were determined as explained in section 3.1.1.6 and results are given in Table 4.10. The static coefficient of friction was found against the three different surfaces namely aluminium, wood, and stainless steel. The coefficient of friction between hopper material and paddy seeds affects flow of paddy seeds from hopper to spinning rotor disc. If coefficient of friction between hopper material and paddy seed is less, then the paddy seeds can flow very easily and vice versa.

Table 4.10 Coefficient of friction of pre-germinated paddy seeds

Sl. No	Material surface	Uma	Jyothi
		Mean $\pm$ SD	
1	Aluminium	0.3664$\pm$0.16	0.3562$\pm$ 0.19
2	Wood	0.31$\pm$ 0.13	0.3186$\pm$ 0.17
3	Stainless steel	0.3523$\pm$ 0.10	0.3573$\pm$ 0.12

4.2 PERFORMANCE OF MOTORIZED CENTRIFUGAL SEED BROADCASTER

The testing and evaluation of a power operated pre-germinated paddy seed broadcaster was conducted as discussed in section 3.8. The testing of power operated pre-germinated paddy seed broadcaster was conducted for combinations of rotor disc speed, quantity of paddy seeds in hopper and size of orifice opening of hopper of the centrifugal broadcaster. The performance parameters such as effective swath width, application rate, uniformity coefficient of distribution, coefficient of variation, Skewness and effective field capacity were computed for single and multiple swath width. The performance of centrifugal broadcaster for different interval spacing laps of 3 m, 4 m, and 5 m were studied.

4.2.1 Performance of centrifugal broadcaster for single lap

The performance parameters, the application rate and swath width of seed distribution of a battery operated manual centrifugal broadcaster is given Table 1 to 4 of Appendix I. The application rate and swath width are discussed in subsequent sections.

4.2.1.1 Application rate for single lap

The application rate of paddy seeds for the different variables at two levels are given in Fig. 4.1 and in Table 1 to 4 of Appendix I. The maximum application rate of 149.02 kg ha^{-1} was observed for the treatment ‘Q2S2O1’, having 3 kg of material at a working rotor speed of 220 rpm and 4.9 cm^{2} orifice opening size. The minimum application rate of 0.14 kg ha^{-1} was observed for the treatment-'Q2S2O1', at 3 kg of paddy seeds, rotor working speed at 220 rpm having 4.9 cm^2 orifice opening. The maximum application rate of treatments 'Q2S1O2' Q2S1O1, Q1S2O2 and 'Q1S1O1' were 103.87 kg ha^{-1}, 102.65 kg ha^{-1}, 118.65 kg ha^{-1} and 112.8 kg ha^{-1} respectively and it is reasonably with in the range of about the recommended seed rate of 100 kg ha^{-1} (KAU) for the swath width for a single lap. However, the application rate for treatments 'Q1S2O1' and 'Q2S2O2' were slightly higher than the recommended paddy seed rate for manual broadcasting of low wet land paddy cultivation.

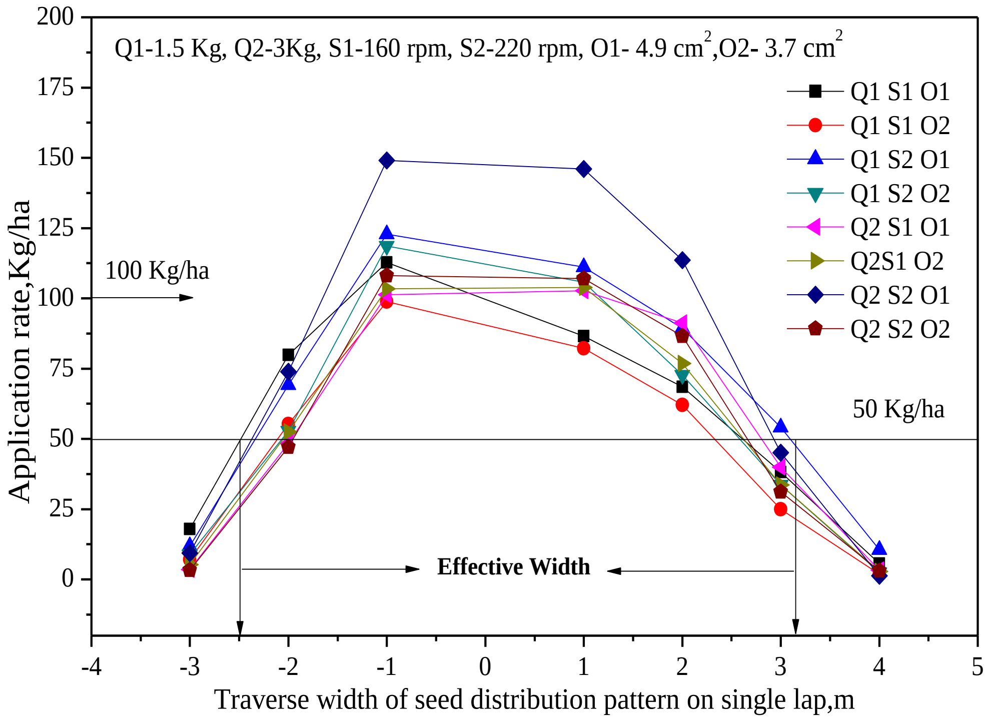

Fig. 4.1 Application rate of paddy seed distribution pattern along traverse width for single lap, (0) line of travel path, (-) LHS, (+) RHS

The desired paddy seed application rate was observed for lowest levels of the rotor speed and orifice opening size of the treatments studied for the two levels of seed quantity in the container drum. For higher level of rotor speed and orifice opening, the application rate exceeded the recommended seed rate for the single lap due to the increased rotor speed and higher volume of seed discharge through larger size opening of the cylindrical hopper. Moreover, the paddy seed rate distribution pattern trend follows the trapezoidal pattern for all the treatments, which is almost flat at the top.

4.2.1.2 Swath width for single lap

The seed distribution distance on either side of line of forward travel (0), the left hand side (-1,-2,-3) or right hand side (1, 2, 3, 4) is presented in Fig. 4.1. The effective swath width measurement was explained in the section 3.8.2.1. The effective spread width (Fig. 4.1) is determined by taking the point on the left and right side of the centreline where the application rate is half or most uniform application occurs (ASABE, 2006). The maximum width of seed distribution to the left hand side of forward travel was 3 m and while it was 4 m on the right side for all the treatments studied. However, the maximum effective swath width measured on left side 2.5 m for Q1S1O1 treatment and on right side was 3.2 m for the Q2S2O1 treatment respectively. For the minimum application rate of the treatment Q1S1O2, the effective swath width was 2.1 m on left hand side and 2.3 m on right hand side in the forward travel direction.

4.2.1.3 Coefficient of variation for single lap

The Uniformity coefficient of distribution along the swath width was analysed by the coefficient of variation. The coefficient of variation for the variables stuided at different levels is given Table-2 and 3 of Appendix I and in Fig. 4.2. The coefficient of variation between the treatments ranged from 57.15 to 70.96 % since the varaiations were due to variable levels and their combinations. However, with in the treatment, the quanitity of seeds dropped varied consideraly in rows on the left and right side of the line of forward travel because the rotor rotated in clockwise direction with respect to the travel and also, due to the orifice position with respect to the rotor axis. The centrifugal force in lifting and dropping the paddy seeds tangentially along disc periphery was aslo affected by the particle weight and physical charcteristics of the paddy grain. There was significant difference between the coefficient of variation for the application rate for differnet orifice size levels at various rotor speed and quantity of material in the seed container. For higher size opening ‘O1’ the coefficient of variation was in the range of 58.48% to 66.57%. This was due to the low rotor speed and higher volume of material in the seed container which led to insufficient centrifugal force developed to throw the material tangentially at higher discharge flow from the container. Similar trend was also observed for the quantity of the seed material in the cylinder container.

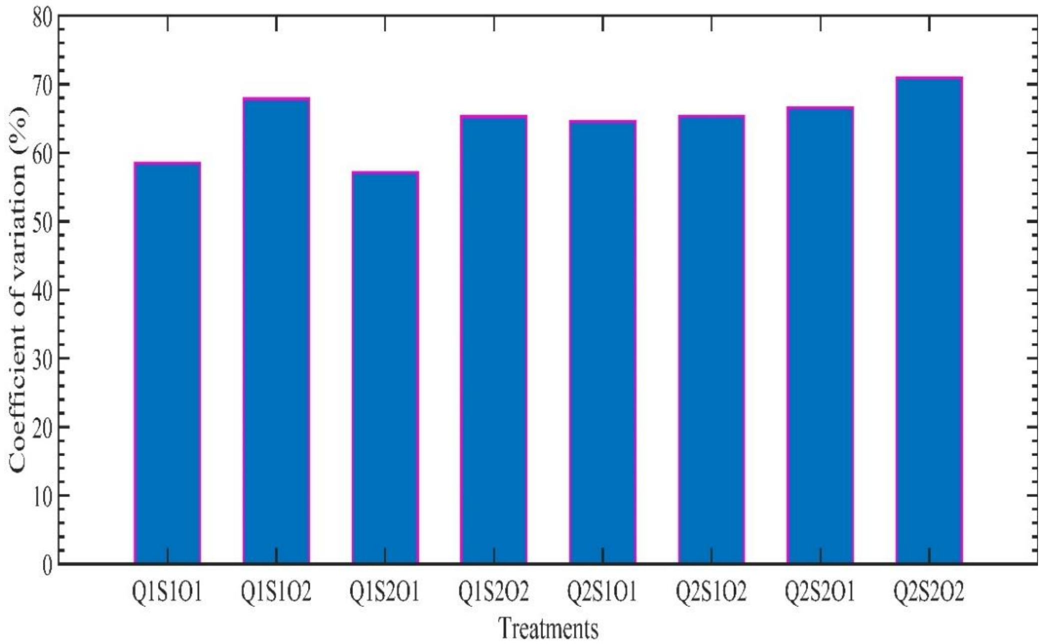

Fig. 4.2 Coefficient of variation in application rate for different treatment at various levels of quantity of material, rotor speed and orifice opening

However, it was observed that the coefficient of variation for smaller size of orifice opening was not significant and it ranged only from 65.27% to 70.96 % for the treatments at various levels of rotor speeds and quantity of material. This was due to very low quantity of seed material flowing through the smaller size orifice opening. The maximum Coefficient of variation 70.96% was observed for the treatment Q2S2O2 and minimum coefficient of variation 57.17% was observed for the treatment Q1S2O1.

4.2.1.4 Skewness

The Skewness for the treatments studied for varying levels of paddy seed material in the cylinder, rotor speeds and orifice opening sizes are given in Table 4 of Appendix I and is shown in Fig. 4.3. The Skewness is expressed as the mass of seed material on the left side of the travel path to the mass of seed material on the right side, which is expressed in percentage.

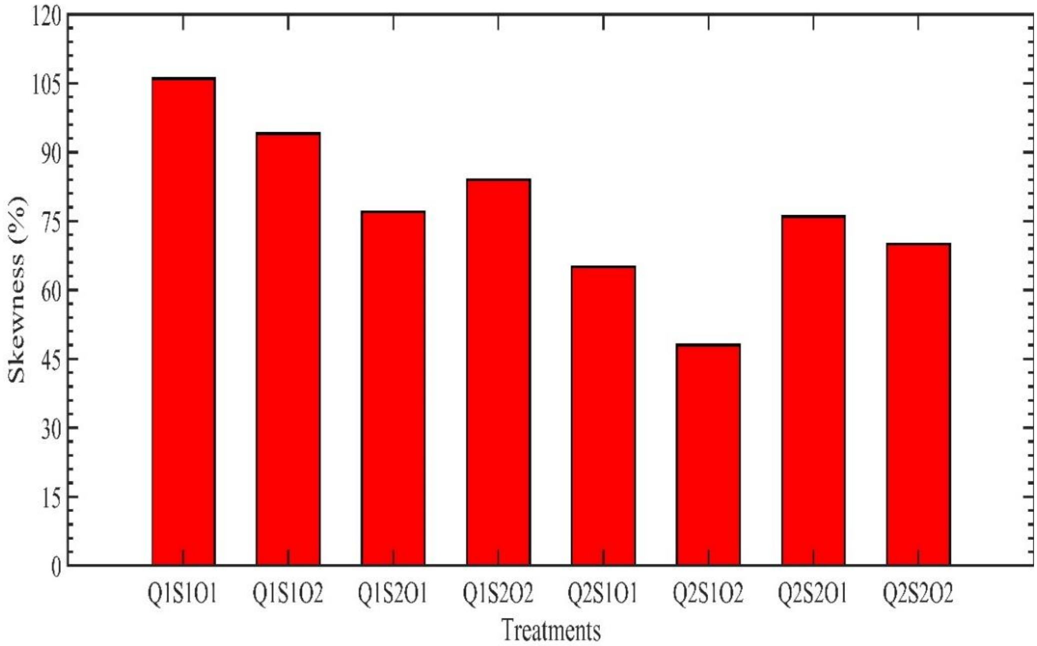

Fig. 4.3 Skewness for different treatment at various levels of quantity of material, rotor speed and orifice opening

The Skewness in percentage for all experimental treatments were below 100% except for the treatment 'Q1S1O1' which was above 100%. The higher Skewness % of treatment 'Q1S1O1' above 100% was due to the low speed of rotor and higher size of orifice opening as well as the physical properties of paddy seed material. The minimum and maximum Skewness were 106 and 48% observed for treatments Q1S1O1 and Q2S1O2 respectively. The low kinetic energy developed by the rotor disc was due to the low speed that resulted in throwing less quantity of seed material on right side of travel path due to the larger volume of material being discharged on the left hand side of the travel path. The higher percentage of Skewness indicated that the seed distribution on either sides of travel were almost equal quantity. The large orifice opening with lower rotor speed and higher volume of seed material resulted lower skewness percentage.

4.3 PERFORMANCE OF CENTRIFUGAL BROADCASTER FOR MULTIPLE OVERLAPS

The performance of centrifugal seed broadcaster for different spacing of 3 m to 5 m on return travel in opposite direction of forward travel is discussed here in this section. The application rate for 3m to 5m spacing in return travel, the coefficient of variation, uniformity of distribution and effective field capacity are discussed in the following sections.

4.3.1 Application rate for multiple overlaps

The application rate for different interval spacing of 3 m to 5 m for return travel in the opposite direction of forward travel is given Fig. 4.4 to 4.6 and the results computed are also presented in Table 5 to 13 in Appendix II. The application rate for 3m, 4m and 5m intervals spacing are respectively discussed subsequently.

4.3.1.1 Application rate for three meter spacing

The application rate for three meter spacing from the forward line of travel to return travel spacing is given Fig. 4.4 and results are presented in Tables from 5 to 7 in Appendix II. For a seed rate of 100 kg ha^{-1}, swath width obtained is 5 m as observed from the Fig. 4.4. The treatments Q1S1O1 and Q1S1O2 almost obtained uniform seed rate of 100 kg ha^{-1} for a swath width 5 m. However, the treatment Q1S2O2 distributed seeds slightly above 100 kg ha^{-1} for the same swath width compared to other treatments which distributed seeds above the desired seed rate for same swath width. For Q1S1O2, the seed rate ranged from 100.75 kg ha^{-1} to 124.2 kg ha^{-1}. The maximum seed rate 124.2 kg $ha^{-1}$was observed in middle of the swath width. The increase in seed rate in the middle of the swath width was 24.2% higher than the recommended seed rate. For Q2S1O2 the seed rate ranged from 106.31 to 153.78 kg ha^{-1} above the recommended seed rate of 100 kg ha^{-1}. At half seed rate the effective swath width obtained was 7m. Similarly also, for treatments Q1S2O2, the seed rate ranged from 52.88 kg ha^{-1} to 145.36 kg $ha^{-1}$for effective swath width of 7.0 m. All these treatments obtained a seed distribution pattern trapezoidal shape curve for the effective swath width.

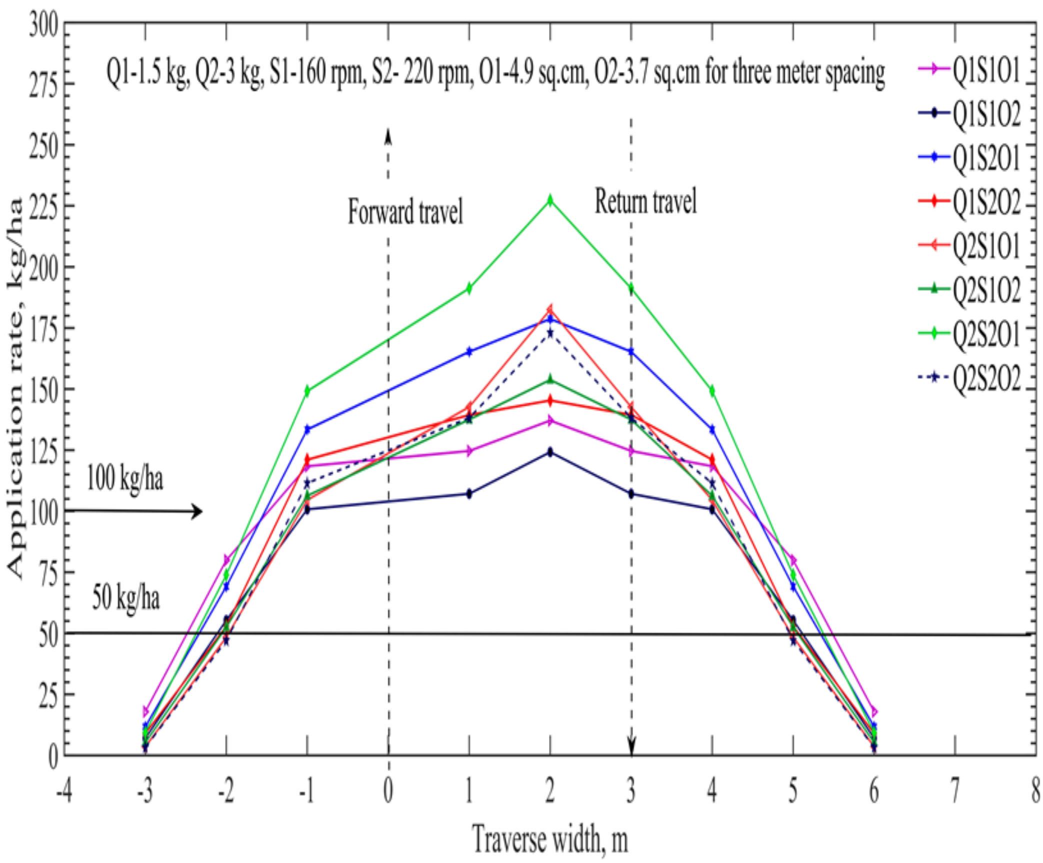

Fig. 4.4 Application rate of centrifugal broadcaster for return travel at three meter spacing with respect forward travel, (0)- forward travel line, (+3)- return travel line

4.3.1.2 Application rate for four meter spacing

The paddy seed application rate for four meter spacing from the forward line of travel to return travel spacing is given Fig. 4.5 and results are presented in Table 8 to 10 of Appendix II. For a seed rate of 100 kg ha^{-1}, the swath width obtained is 6 m as observed from the Fig. 4.5. The treatments Q1S1O1, Q2S1O2 and Q1S2O2 almost obtained uniform seed rate of 100 kg ha^{-1} for a swath width 6 m. However, the treatment Q2S2O1 distributed seeds slightly above 100 kg ha^{-1} for the same swath width compared to other treatments which distributed seeds above the desired seed rate for same swath width. The effective swath obtained for four meter spacing between forward and return travel was 6 m in most of the treatments.

The treatments Q1S1O1, Q1S1O2, Q1S2O2, Q2S1O2 and Q2S2O2 obtained a seed rate from 98.85 to 117.7 kg ha^{-1} for 6m effective swath width ranged. There was an increase in seed rate of about 6% to 18.65% from recommended seed rate of 100 kg ha^{-1} at the middle of two rows of the effective swath width in case of treatments Q1S1O1, Q1S2O2, Q2S1O2 and Q2S2O2. However for treatment Q1S1O2 the seed rate obtained ranged from 85.07 to 98.85 kg ha^{-1}. There was decrease in seeds rate in the range of 12.95% to 15.93% in the middle of four rows of the effective swath width for the treatment Q1S1O2. About 1.15% decrease was observed at the outer ends of the 6 m effective swath width from the recommended seed rate in case of Q1S1O2. For treatment Q2S1O2 the seed rate increase along traverse width for the effective swath width ranged from 3.46% to 10.52%. The variation in seed rate for the treatment Q1S2O2 and Q2S2O2 were not significant appreciably from the recommended seed rate.

4.3.1.3 Application rate for five meter spacing

The application rate for five meter spacing from the line of forward travel to return travel spacing is given Fig. 4.6 and results are presented in Tables 11 to 13 of Appendix II. For a seed rate of 100 kg ha^{-1}, the swath width obtained is 7 m as observed from the Fig. 4.6. The treatments Q1S2O1 and Q1S1O1 almost obtained uniform seed rate of 100 kg ha^{-1} for a swath width 7 m. However, the treatment Q1S2O1 distributed seeds slightly above 100 kg ha^{-1} for the same swath width compared to other treatments which distributed seeds above the desired seed rate for same swath width. The application width for all treatments a swath width of 7m. The application rate for Q1S2O1 and Q2S1O1, Q2S2O2 ranged from 122.85 to 62.38 kg ha^{-1}. For these treatment, the midway 2m width distributed seed rate ranging from 62.38 to 89.63 kg ha^{-1} for treatment Q2S2O2 compared to 80 to 94.5 kg ha^{-1} in case of Q2S1O1. However, for treatment Q1S2O1 the midway bandwidth of effective swath width has a seed rate distribution in the range of 99.32 to 108.20 kg ha^{-1}.

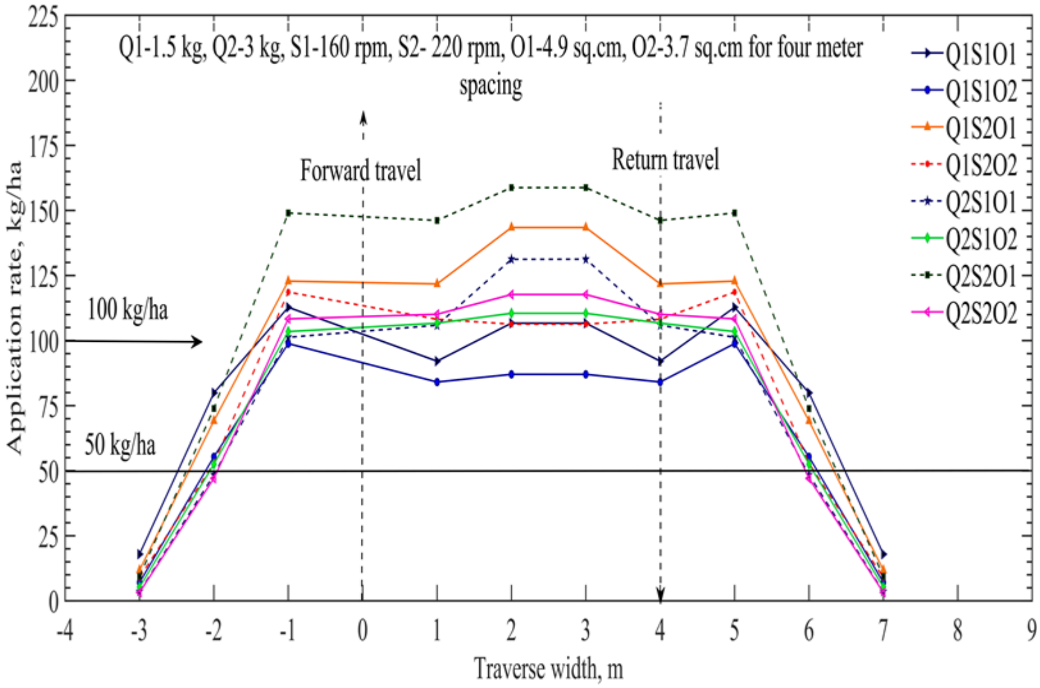

Fig. 4.5 Application rate of centrifugal broadcaster for return travel at four meter spacing with respect forward travel.

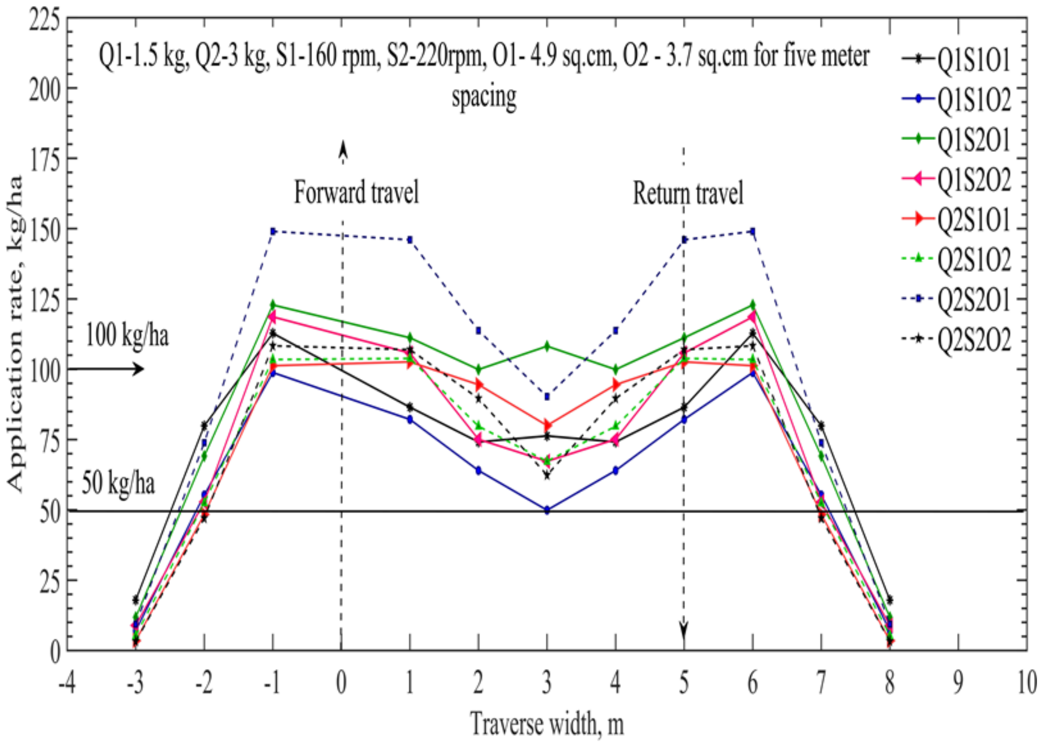

Fig. 4.6 Application rate of centrifugal broadcaster for return travel at five meter spacing with respect forward travel

For five meter spacing, it is observed that there was a decrease in seed rate distribution in the middle rows of the effective swath width for all treatments compared to 3 and 4 meter spacing. The outer two end rows of treatments Q1S2O1, Q2S1O1and Q2S2O2, there was an increase in seed distribution from 1.92% to 22.85%. The Q2S1O1 treatment almost obtained a seed distribution rate of 94.51 kg ha^{-1} to 102.65 kg ha^{-1} except in the mid width row which had a seed rate 80 kg ha^{-1}.

4.3.2 Coefficient of variation for multiple overlap

The coefficient of variation for different interval spacing of 3 m to 5 m for return travel in the opposite direction of forward travel is given in Fig. 4.7 To 4.10 and results computed are presented in Table 6, 9 and to 12 in Appendix II. The coefficient of variation for 3m, 4m and 5m intervals spacing are respectively discussed subsequently.

4.3.2.1 Coefficient of variation for three meter spacing

The coefficient of variation of application rate for the three meter spacing is given in Table 6 in Appendix II and variation of different treatments are also given in Fig. 4.7. The lowest coefficient of variation of 13.12% was observed for treatment Q1S1O2 for the effective swath width of 7.0 m. and the coefficient of variation for whole swath width was 52.39%. The coefficient of variation for treatment Q1S1O1 was 28.59% for the effective swath width and 46.83 % for the whole swath width. The maximum variation of 97.04 % was observed for treatment Q2S2O1 for the effective swath width and 83.26% for whole swath width. In case of treatment Q1S1O2, the coefficient of variation was least for the effective swath width which mean that the seeds are distributed uniformly over the entire effective swath width. However, the coefficient of variation for whole swath width was more than 50% due to the fact that the seed distributed at extreme banks where too low, at a rate of 7.05 kg ha^{-1}. The coefficient of variation of 46.83% which was lowest for the treatment Q1S1O1 for the whole swath width.

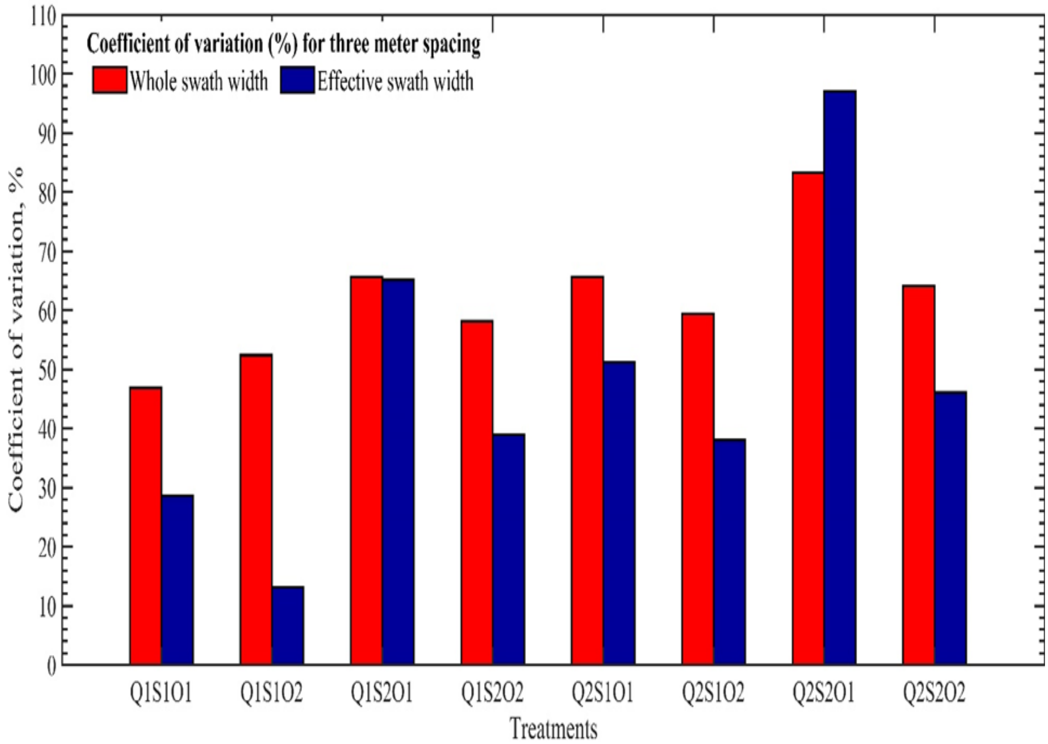

Fig. 4.7 Coefficient of variation of application rate for three meter spacing

4.3.2.2 Coefficient of variation for four meter spacing

The coefficient of variation of application rate for the four meter spacing is given in Table 9 in Appendix-II and variation of different treatments are also given in Fig. 4.8. The lowest coefficient of variation was observed for treatment Q2S1O2 for the effective swath width of 8.0 m. and the coefficient of variation for whole swath width was 50.32%. The coefficient of variation for treatment Q1S1O1 was 10.41% for the effective swath width and 40.57 % for the whole swath width. The maximum variation of 56.54% was observed for treatment Q2S2O1 for the effective swath width and 61.26% for whole swath width. In case of treatment Q2S1O2, the CV was least for the effective swath width which indicated that the paddy seeds were distributed uniformly over the entire effective swath width. However, the CV for whole swath width was more than 40.57% due to the very low quantity of paddy seeds distributed away from the line of travel. The values of coefficient of variation of treatments Q1S1O1, Q1S2O2, Q2 S1O2 and Q2S2O2 were 10.41%, 13.49%, 8.19% and 13.93% respectively.

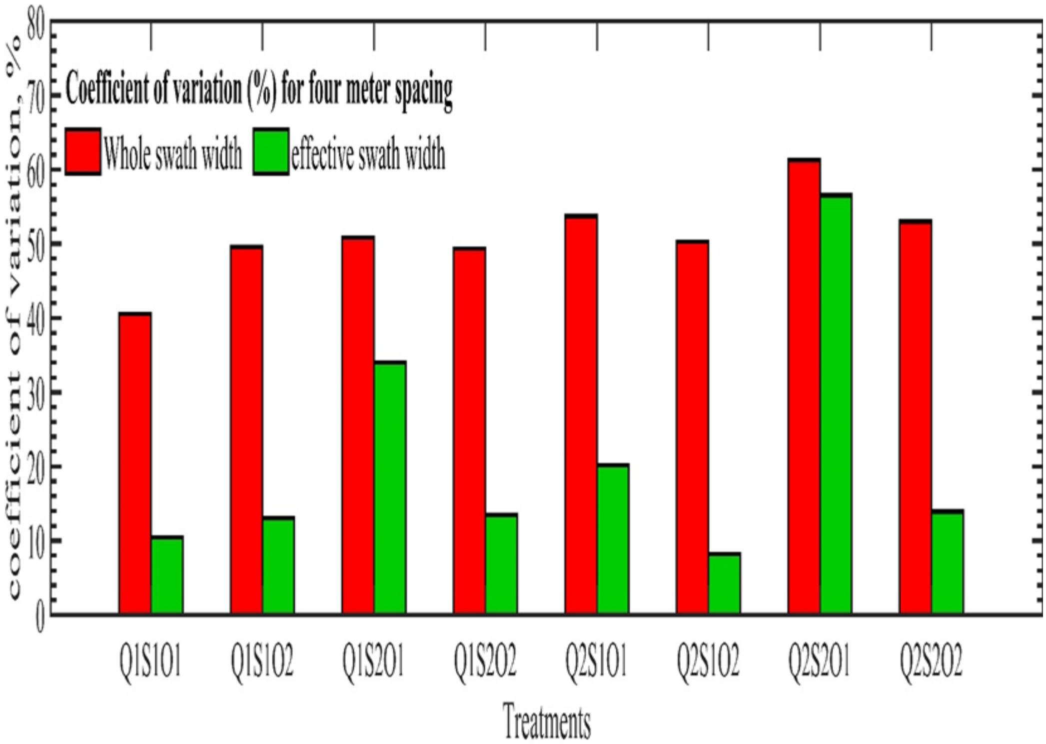

Fig. 4.8 Coefficient of variation of application rate for four meter spacing

4.3.2.3 Coefficient of variation for five meter spacing

The application rate for five meter spacing for right hand turn travel is given in Table 11 and 12 in Appendix II. The application rate of Q2S1O1 ranged from 102.65 kg ha^{-1} to 80 kg ha^{-1}. The standard deviation of application rate was 8.92 for the effective width from Table 11. But it was 49.41 kg ha^{-1} for whole swath width. The application rate for treatment Q1S2O1was lowest for five meter spacing ranging from 99.93 kg ha^{-1} to 122.5 kg ha^{-1} for effective swath width of 7 meter. The standard deviation of application rate for Q1S2O1 was 43.39 kg ha^{-1}. For five meter spacing as observed from Table 11. The standard deviation of application rate ranged between 8.92 kg ha^{-1} to 39.84 kg ha^{-1} which implied that for most of the treatment at five meter spacing the broadcaster was able deliver paddy seeds appreciably at uniform rate higher than the recommended seed rate. The coefficient of variation of application rate for the five meter spacing is given in Table 12 of Appendix-II and Fig. 4.9. The coefficient of variation for application rate ranged from 8.92% for Q2S2O1 15.07% of Q1S2O1 treatment. It was observed that the application width achieved for all treatment was about 7 m effective swath width. The application rate obtained at the centre portion of the 7 m effective swath width was 108.2 kg ha^{-1} which was 8.2% higher than 100 kg ha^{-1}. For all other treatments except Q1S2O1 there was decrease in application rate in the centre portion of the effective swath width.

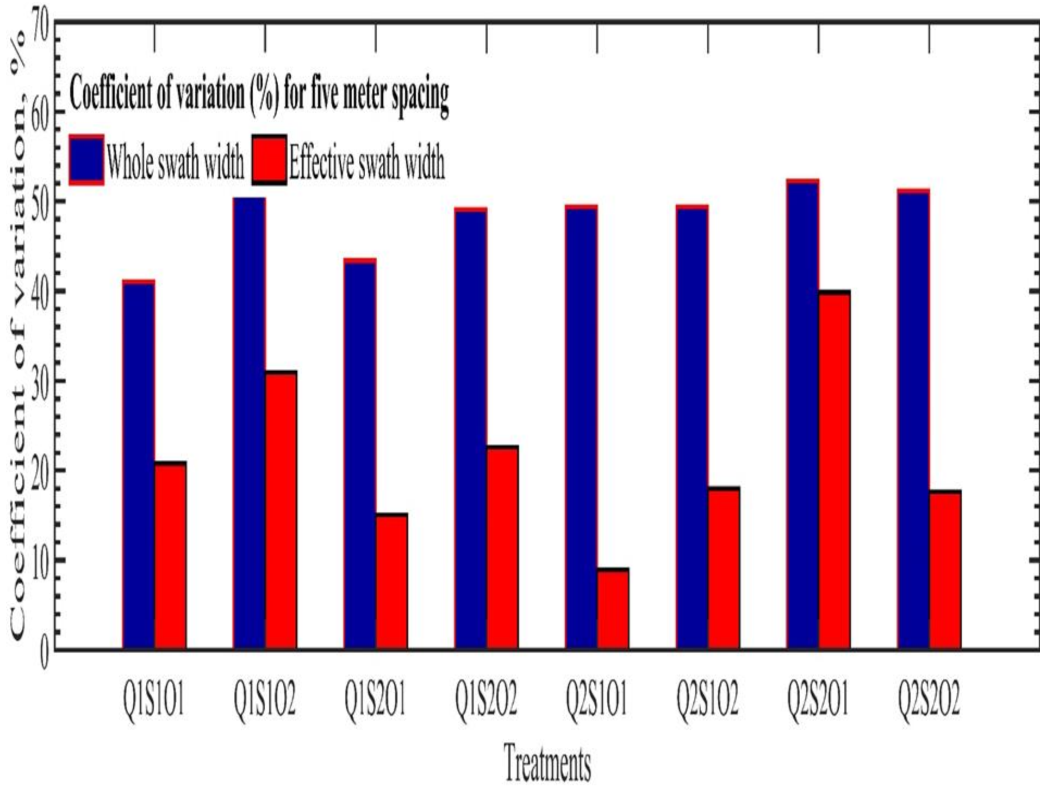

Fig. 4.9 Coefficient of variation of application rate for five meter spacing

4.3.3 Uniformity coefficient of distribution for different overlap spacing

The uniformity coefficient of distribution for different interval spacing of 3 m to 5 m for return travel in the opposite direction of forward travel is given Fig. 4.10 To 4.12 and the results computed are presented in Table 7, 10 and 13 in Appendix II. The uniformity coefficient of distribution for 3m, 4m and 5m intervals spacing are discussed below.

4.3.3.1 Uniformity coefficient of distribution for three meter spacing

The uniformity coefficient of distribution for three spacing is given in Table 7 in Appendix II and in Fig. 4.10. The uniformity coefficient of distribution of paddy seeds for the Q1S1O2 treatment was maximum for the effective swath width. The lowest was uniformity coefficient of distribution was observed for the treatment Q2S2O1 which was due to the large variation in application rate along the effective swath width and whole swath width for three meter spacing. For the Q1S2O1 treatment the uniformity coefficient of distribution of application rate differences were least between effective swath width and whole swath width as observe Table 7 and Fig. 4.10. Similarly the uniformity coefficient of distribution differences in application rate for effective swath width and whole swath width was lowest for the treatment Q1S1O1 but application rate for three meter was much higher than the recommended seed rate along transverse width.

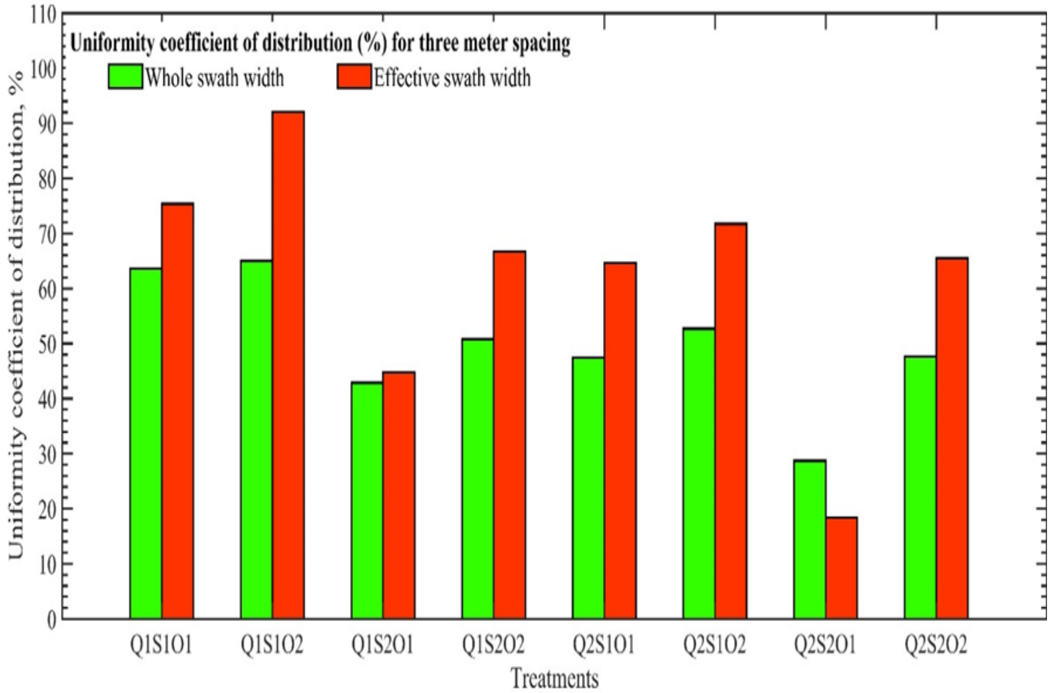

Fig. 4.10 Uniformity coefficient of distribution of application rate for three meter spacing

4.3.3.2 Uniformity coefficient of distribution for four meter spacing

The uniformity coefficient of distribution for three spacing is given in Table 10 in Appendix II and in Fig. 4.11. The uniformity coefficient of distribution of paddy seeds for the Q2S1O2 was maximum for the effective swath width. The lowest was uniformity coefficient of distribution was observed for the treatment

Q2S2O1 which was due to the large variation in application rate along the effective swath width and whole swath width. For Q2S2O1 treatment the uniformity coefficient of distribution of application rate differences were least between effective swath width and whole swath width as observe Table 10 and Fig. 4.11. Similarly the UCD differences in application rate for effective swath width and whole swath width was lowest for the treatment Q2S2O1 but application rate for three meter was much higher than the recommended seed rate along transverse width.

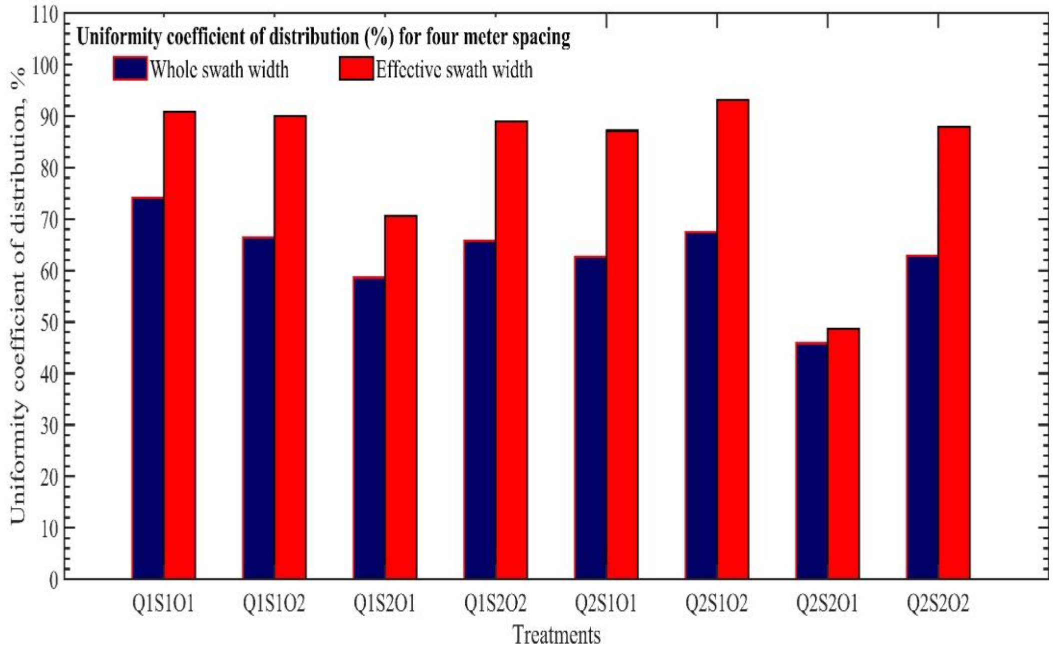

Fig. 4.11 Uniformity coefficient of distribution of application rate for four meter spacing

4.3.3.3 Uniformity coefficient of variation for five meter spacing

The uniformity coefficient of distribution of paddy seeds for five meter spacing is shown Table 13 in Appendix II and Fig. 4.10. It is observed from Fig. 4.10 that the uniformity coefficient of distribution for effective swath width and whole swath width did not vary much even though the application rate obtained for the treatment Q1S2O1 was much higher than the recommended rate along the traverse width. The maximum uniformity coefficient of 94.45% was obtained for treatment Q2S1O1 for the effective swath width and 69.55% for the whole swath width. It is observed that a fairly equal distribution of seeds were achieved for this treatment along the traverse width of effective swath width which resulted in high uniformity coefficient of distribution. However, for the whole swath width there was large variation in seed distribution at the extreme band ends which resulted in very low uniformity coefficient compared to effective swath width. For treatment Q1S2O1 a fairly uniform distribution of paddy seeds were observed along the traverse width for the effective swath width but with increase of 8 to 12% of seed rate above the recommended seed rate.

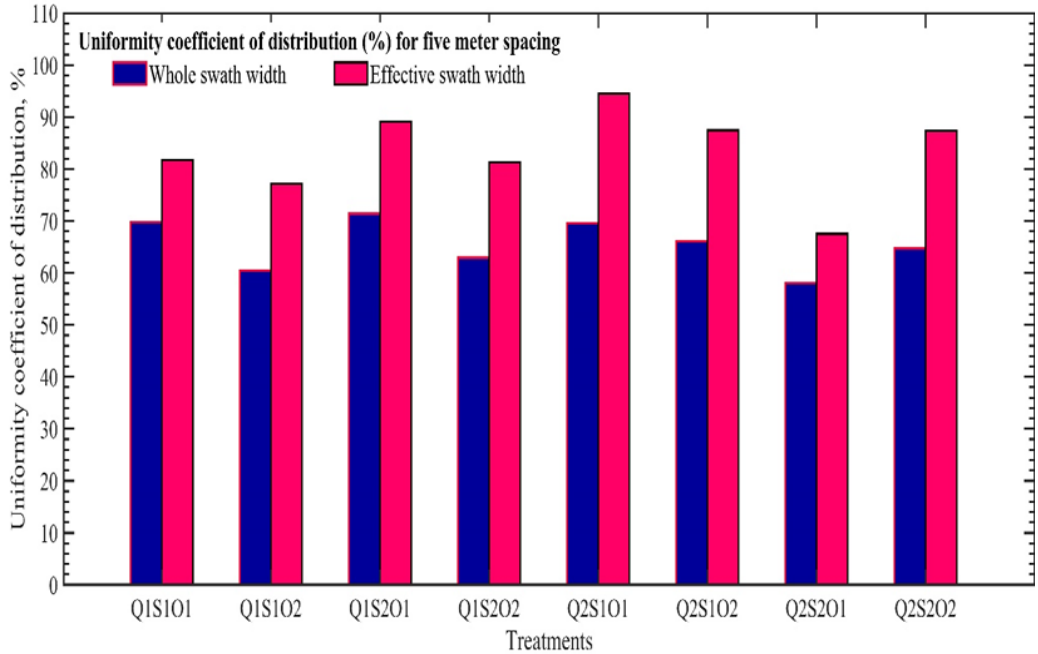

Fig. 4.12 Uniformity coefficient of distribution of application rate for five meter spacing

4.3.4 Field capacity

The mean field capacity of power operated paddy seed broadcaster was 0.68 ha hr^{-1} observed for three and five meter spacing with seven meter effective swath width and 65 % field efficiency. The filed capacity was 0.59 ha hr^{-1} observed for four meter spacing with six meter effective swat width and 65% field efficiency. The maximum mean effective field capacity was observed for three and five meter spacing and minimum mean field capacity was observed for four meter spacing. The field capacity of centrifugal broadcaster is given in Appendix III.

4.4 COST ECONOMICS OF BROADCASTER

The cost of operation of battery operated manual centrifugal broadcaster was analysed and presented in Appendix V. The cost of operation of centrifugal broadcaster is Rs 189.31 ha^{-1} and by manual broadcasting, it is Rs. 800 ha^{-1}. The cost and time saved compared to manual broadcasting was about 76.34% and 78.88%. The cost of battery operated broadcaster (Appendix IV) was Rs. 8850/-. The benefit cost was computed and it is 3.23:1.

CHAPTER V

SUMMARY AND CONCLUSION

Rice (Oryza sativa L.) is important leading food crop and it is widely cultivated in India. The farmers face many problems in paddy cultivation due to the lack of labour, timeliness of operations, improper management of inputs and considerable drudgery in work. Nevertheless, the mechanization of paddy cultivation has boosted higher productivity and reduced cost of production considerably. In this context, the present study was undertaken to develop and evaluate the performance of a manual battery operated pre-germinated broadcaster for sowing paddy.

The manual pre-germinated paddy seed broadcaster was fitted with a 12 V DC to the battery operate the broadcasting spinning disc and an agitator. The performance of the battery powered pre-germinated paddy seed broadcaster was tested with two levels of rotor disc speeds, two levels of quantity of paddy seeds and two levels of orifice opening for three-intervals of traverse spacing of 3 m, 4 m, and 5 m. The application rate and uniformity distribution per square meter with respect to the recommended seed rate of 100 kg ha^{-1}. The battery powered centrifugal broadcaster was tested and performance was evaluated for single and multiple passes for above factors.

The performance parameters studied were the application rate, coefficient of variation, skewness ratio and uniformity coefficient of distribution respectively. The maximum application rate of 149.02 kg ha^{-1} was observed for the treatment Q2S2O1 in single pass and minimum application rate of 0.14 kg ha^{-1} was observed for the treatment Q2S2O1 in single pass. In multiple pass, the maximum and minimum application rate of 182.52 kg ha^{-1} and 47.05 kg ha^{-1} were observed for the treatments Q2S1O1 and Q2S2O2 for three meter spacing of seven-meter effective swath width. The application rate was uniform for the four-meter spacing with a effective swath width of 6 m. The maximum skewness ratio was about 101% for the treatment Q1S1O1 and minimum was about 48% for the treatment Q2S1O2 was observed in single pass. The maximum coefficient of variation for the treatment

Q2S2O2 was 70.96 % and minimum coefficient of variation for the treatment Q1S2O1 was 57.15 % . The maximum uniformity coefficient of distribution was 54.19 % for the treatment Q1S1O1 and minimum uniformity coefficient of distribution was 43.33 % for the treatment Q2S2O2 in single pass. The minimum coefficient of variation for the treatments of 3 m, 4 m and 5 m spacing whose application rate was approximately equal to recommended seed rate were for the treatments Q1S1O2, Q2S1O2, and Q2S1O1 respectively. The maximum uniformity coefficient of distribution were 92.01%, 93.10% and 94.45% for treatments Q1S1O1, Q2S1O2, and Q2S1O1 respectively for 3 m, 4 m and 5 m spacing.

Among the treatments Q1S1O1, Q2S1O2 and Q2S1O1 were the best combinations of tested variables for the spacing intervals of 3 m, 4 m, and 5 m respectively. The treatment Q2S1O2 of 4 m spacing has the best application rate of 106.9 kg ha^{-1} and corresponding coefficient of variation of 8.19% and uniformity coefficient of variation 93.10% for an effective swath width of six meters. It satisfies the recommended seed rate because it has the lowest value coefficient of variation and uniformity coefficient of distribution compared to other two treatments mentioned above. Even though uniformity coefficient of distribution of treatment Q2S1O1 is higher than the treatment Q2S1O2, it is not recommendable due to lower application rate in the mid band portion of the effective swath width.

The centrifugal paddy seed broadcaster was operated at walking speed of 1.5 km ha^{-1}. The maximum average effective field capacity was about 0.68 ha hr^{-1} for the effective swath width of seven meter. The average effective field capacity for four meter was about 0.59 ha hr^{-1} for six-meter effective swath width. Among three different interval spacing, the application rate of four meter spacing with six-meter effective swath width was the best due to the seed application rate being nearest to the recommended rate.

The cost of paddy seed broadcasting using the battery powered centrifugal broadcaster was Rs. 189.31 ha^{-1} compared to Rs. 800 $ha^{-1}$for manual broadcasting. The percentage of cost and time saved by manually held and battery powered centrifugal broadcaster over manual broadcasting was about 76.34% and 78.88% with a benefit cost ratio of about 3.23:1. The development cost of power operated paddy seed broadcaster was about Rs. 8850/-.

From the performance evaluation test, it is concluded that the battery operated centrifugal paddy seed broadcaster can perform paddy seed broadcasting operation efficiently and economically.

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APPENDICES

APPENDIX I

Table 1 Application rate and standard deviation for single pass

Sl. No.	Treatments	Replications	Application rate for single pass, Kg ha^{-1}							Standard deviation (SD), kg ha^{-1}
			Left hand side(-)			Right hand side(+)				
			-3	**-2**	**-1**	**1**	**2**	**3**	**4**	
1	Q1 S1 O1	R1	18.4	75.3	117.2	88.9	66.9	45.8	6.2	58.48
		R2	17.5	84.5	108.4	84.1	70.2	30.5	5	
		Average	**17.95**	**79.9**	**112.8**	**86.5**	**68.55**	**38.15**	**5.6**	
2	Q1 S1 O2	R1	5.7	43.66	88.95	72.14	54.78	23.87	2.44	67.88
		R2	8.41	66.99	108.75	92.21	69.43	26.04	1.36	
		Average	**7.05**	**55.32**	**98.85**	**82.17**	**62.1**	**24.95**	**1.9**	
3	Q1 S2 O1	R1	10.58	61.83	120.41	108.48	78.65	53.97	11.12	57.15
		R2	13.02	76.48	125.29	113.9	100.07	54.24	10.03	
		Average	**11.79**	**69.16**	**122.85**	**111.19**	**89.36**	**54.1**	**10.57**	
4	Q1 S2 O2	R1	8.95	53.16	118.51	105.77	73.22	33.63	2.71	65.27
		R2	8.95	52.61	118.79	105.77	72.14	33.63	2.17	
		Average	**8.95**	**52.88**	**118.65**	**105.77**	**72.68**	**33.63**	**2.44**	
5	Q2 S1 O1	R1	4.07	45.29	91.12	93.29	83.26	35.8	4.07	64.57
		R2	2.98	51.53	111.46	112.01	99.26	44.21	2.44	
		Average	**3.53**	**48.41**	**101.29**	**102.65**	**91.26**	**40**	**3.25**	
6	Q2S1O2	R1	4.88	50.17	100.62	114.72	87.87	38.51	4.34	65.36
		R2	5.7	54.78	106.31	93.02	65.9	28.75	1.36	
		Average	**5.29**	**52.48**	**103.46**	**103.87**	**76.89**	**33.63**	**2.85**	
7	Q2 S2 O1	R1	10.31	69.43	128.82	133.97	108.21	48	0	66.57
		R2	8.41	78.38	169.23	158.11	119.06	42.31	0.27	
		Average	**9.36**	**73.9**	**149.02**	**146.04**	**113.63**	**45.15**	**0.14**	
8	Q2 S2 O2	R1	3.25	46.92	107.94	107.94	86.78	32	3.25	70.96
		R2	3.25	47.19	213.71	106.04	86.24	30.37	2.98	
		Average	**3.25**	**47.05**	**108.75**	**106.99**	**86.51**	**31.19**	**3.12**	

Table 2 Application rate and coefficient of variation for single pass

Sl. No.	Treatments	Replications	Application rate for single pass, Kg ha^{-1}							Coefficient of variation (CV), %
			Left hand side(-)			Right hand side(+)				
			-3	**-2**	**-1**	**1**	**2**	**3**	**4**	
1	Q1 S1 O1	R1	18.4	75.3	117.2	88.9	66.9	45.8	6.2	58.48
		R2	17.5	84.5	108.4	84.1	70.2	30.5	5	
		Average	**17.95**	**79.9**	**112.8**	**86.5**	**68.55**	**38.15**	**5.6**	
2	Q1 S1 O2	R1	5.7	43.66	88.95	72.14	54.78	23.87	2.44	67.88
		R2	8.41	66.99	108.75	92.21	69.43	26.04	1.36	
		Average	**7.05**	**55.32**	**98.85**	**82.17**	**62.1**	**24.95**	**1.9**	
3	Q1 S2 O1	R1	10.58	61.83	120.41	108.48	78.65	53.97	11.12	57.15
		R2	13.02	76.48	125.29	113.9	100.07	54.24	10.03	
		Average	**11.79**	**69.16**	**122.85**	**111.19**	**89.36**	**54.1**	**10.57**	
4	Q1 S2 O2	R1	8.95	53.16	118.51	105.77	73.22	33.63	2.71	65.27
		R2	8.95	52.61	118.79	105.77	72.14	33.63	2.17	
		Average	**8.95**	**52.88**	**118.65**	**105.77**	**72.68**	**33.63**	**2.44**	
5	Q2 S1 O1	R1	4.07	45.29	91.12	93.29	83.26	35.8	4.07	64.57
		R2	2.98	51.53	111.46	112.01	99.26	44.21	2.44	
		Average	**3.53**	**48.41**	**101.29**	**102.65**	**91.26**	**40**	**3.25**	
6	Q2S1O2	R1	4.88	50.17	100.62	114.72	87.87	38.51	4.34	65.36
		R2	5.7	54.78	106.31	93.02	65.9	28.75	1.36	
		Average	**5.29**	**52.48**	**103.46**	**103.87**	**76.89**	**33.63**	**2.85**	
7	Q2 S2 O1	R1	10.31	69.43	128.82	133.97	108.21	48	0	66.57
		R2	8.41	78.38	169.23	158.11	119.06	42.31	0.27	
		Average	**9.36**	**73.9**	**149.02**	**146.04**	**113.63**	**45.15**	**0.14**	
8	Q2 S2 O2	R1	3.25	46.92	107.94	107.94	86.78	32	3.25	70.96
		R2	3.25	47.19	213.71	106.04	86.24	30.37	2.98	
		Average	**3.25**	**47.05**	**108.75**	**106.99**	**86.51**	**31.19**	**3.12**	

Table 3 Application rate and uniformity coefficient of distribution for single pass

Sl. No.	Treatments	Replications	Application rate for single pass, kg ha^{-1}							Uniformity coefficient of distribution(UCD), %
			Left hand side(-)			Right hand side(+)				
			-3	**-2**	**-1**	**1**	**2**	**3**	**4**	
		R1	18.4	75.3	117.2	88.9	66.9	45.8	6.2	
1	Q1 S1 O1	R2	17.5	84.5	108.4	84.1	70.2	30.5	5	54.9
		Average	**17.95**	**79.9**	**112.8**	**86.5**	**68.55**	**38.15**	**5.6**	
		R1	5.7	43.66	88.95	72.14	54.78	23.87	2.44	
2	Q1 S1 O2	R2	8.41	66.99	108.75	92.21	69.43	26.04	1.36	47.48
		Average	**7.05**	**55.32**	**98.85**	**82.17**	**62.1**	**24.95**	**1.9**	
		R1	10.58	61.83	120.41	108.48	78.65	53.97	11.12	
3	Q1 S2 O1	R2	13.02	76.48	125.29	113.9	100.07	54.24	10.03	57.28
		Average	**11.79**	**69.16**	**122.85**	**111.19**	**89.36**	**54.1**	**10.57**	
		R1	8.95	53.16	118.51	105.77	73.22	33.63	2.71	
4	Q1 S2 O2	R2	8.95	52.61	118.79	105.77	72.14	33.63	2.17	49.45
		Average	**8.95**	**52.88**	**118.65**	**105.77**	**72.68**	**33.63**	**2.44**	
		R1	4.07	45.29	91.12	93.29	83.26	35.8	4.07	
5	Q2 S1 O1	R2	2.98	51.53	111.46	112.01	99.26	44.21	2.44	54.64
		Average	**3.53**	**48.41**	**101.29**	**102.65**	**91.26**	**40**	**3.25**	
		R1	4.88	50.17	100.62	114.72	87.87	38.51	4.34	
6	Q2S1O2	R2	5.7	54.78	106.31	93.02	65.9	28.75	1.36	51.97
		Average	**5.29**	**52.48**	**103.46**	**103.87**	**76.89**	**33.63**	**2.85**	
		R1	10.31	69.43	128.82	133.97	108.21	48	0	
7	Q2 S2 O1	R2	8.41	78.38	169.23	158.11	119.06	42.31	0.27	45.69
		Average	**9.36**	**73.9**	**149.02**	**146.04**	**113.63**	**45.15**	**0.14**	
		R1	3.25	46.92	107.94	107.94	86.78	32	3.25	
8	Q2 S2 O2	R2	3.25	47.19	213.71	106.04	86.24	30.37	2.98	43.33
		Average	**3.25**	**47.05**	**108.75**	**106.99**	**86.51**	**31.19**	**3.12**	

Table 4 Application rate and skewness ratio for single pass

Sl. No.	Treatments	Replications	Application rate for single pass, Kg ha^{-1}							Skewness Ratio, %
			Left hand side(-)			Right hand side(+)				
			-3	**-2**	**-1**	**1**	**2**	**3**	**4**	
1	Q1 S1 O1	R1	18.40	75.30	117.20	88.90	66.90	45.80	6.20	101
		R2	17.50	84.50	108.40	84.10	70.20	30.50	5.00	111
		Average	**17.95**	**79.90**	**112.80**	**86.50**	**68.55**	**38.15**	**5.60**	**106**
2	Q1 S1 O2	R1	5.70	43.66	88.95	72.14	54.78	23.87	2.44	90
		R2	8.41	66.99	108.75	92.21	69.43	26.04	1.36	97
		Average	**7.05**	**55.32**	**98.85**	**82.17**	**62.10**	**24.95**	**1.90**	**94**
3	Q1 S2 O1	R1	10.58	61.83	120.41	108.48	78.65	53.97	11.12	76
		R2	13.02	76.48	125.29	113.90	100.07	54.24	10.03	77
		Average	**11.79**	**69.16**	**122.85**	**111.19**	**89.36**	**54.10**	**10.57**	**77**
4	Q1 S2 O2	R1	8.95	53.16	118.51	105.77	73.22	33.63	2.71	84
		R2	8.95	52.61	118.79	105.77	72.14	33.63	2.17	84
		Average	**8.95**	**52.88**	**118.65**	**105.77**	**72.68**	**33.63**	**2.44**	**84**
5	Q2 S1 O1	R1	4.07	45.29	91.12	93.29	83.26	35.80	4.07	65
		R2	2.98	51.53	111.46	112.01	99.26	44.21	2.44	64
		Average	**3.53**	**48.41**	**101.29**	**102.65**	**91.26**	**40.00**	**3.25**	**65**
6	Q2S1O2	R1	4.88	50.17	100.62	114.72	87.87	38.51	4.34	47
		R2	5.70	54.78	106.31	93.02	65.90	28.75	1.36	49
		Average	**5.29**	**52.48**	**103.46**	**103.87**	**76.89**	**33.63**	**2.85**	**48**
7	Q2 S2 O1	R1	10.31	69.43	128.82	133.97	108.21	48.00	0.00	72
		R2	8.41	78.38	169.23	158.11	119.06	42.31	0.27	80
		Average	**9.36**	**73.90**	**149.02**	**146.04**	**113.63**	**45.15**	**0.14**	**76**
8	Q2 S2 O2	R1	3.25	46.92	107.94	107.94	86.78	32.00	3.25	69
		R2	3.25	47.19	108.75	106.04	86.24	30.37	2.98	71
		Average	**3.25**	**47.05**	**108.34**	**106.99**	**86.51**	**31.19**	**3.12**	**70**

APPENDIX II

Table 5 Application rate and standard deviation for three meter spacing

Sl. No.	Treatment	Travel Mode	Application rate for three meter spacing, Kg ha^{-1}									Standard deviation(SD), kg ha^{-1}	
			Left hand side (-)			Right hand side(+)							
			← Whole swath width, m →									Effective swath width	Whole swath width
				← Effective swath width, m →									
			-3	**-2**	**-1**	**1**	**2**	**3**	**4**	**5**	**6**		
1	Q1S1O1	Forward	17.95	79.90	112.80	86.50	68.55	38.15	5.60	0.00	0.00	28.59	46.83
		Return	0.00	0.00	5.60	38.15	68.55	86.50	112.80	79.90	17.95		
		Average	17.95	**79.90**	**118.40**	**124.65**	**137.10**	**124.65**	**118.40**	**79.90**	17.95		
2	Q1S1O2	Forward	7.05	55.32	98.85	82.17	62.10	24.95	1.90	0.00	0.00	13.12	52.39
		Return	0.00	0.00	1.90	24.95	62.10	82.17	98.85	55.32	7.05		
		Average	7.05	**55.32**	**100.75**	**107.12**	**124.20**	**107.12**	**100.75**	**55.32**	7.05		
3	Q1 S2 O1	Forward	11.79	69.16	122.85	111.19	89.36	54.10	10.57	0.00	0.00	65.11	65.59
		Return	0.00	0.00	10.57	54.10	89.36	111.19	122.85	69.16	11.79		
		Average	11.79	**69.16**	**133.42**	**165.29**	**178.72**	**165.29**	**133.42**	**69.16**	11.79		
4	Q1S2O2	Forward	8.95	52.88	118.65	105.77	72.68	33.63	2.44	0.00	0.00	38.90	58.17
		Return	0.00	0.00	2.44	33.63	72.68	105.77	118.65	52.88	8.95		
		Average	8.95	**52.88**	**121.09**	**139.40**	**145.36**	**139.40**	**121.09**	**52.88**	8.95		
5	Q2S1O1	Forward	3.53	48.41	101.29	102.65	91.26	40.00	3.25	0.00	0.00	51.21	65.60
		Return	0.00	0.00	3.25	40.00	91.26	102.65	101.29	48.41	3.53		
		Average	3.53	**48.41**	**104.54**	**142.65**	**182.52**	**142.65**	**104.54**	**48.41**	3.53		
6	Q2S1O2	Forward	5.29	52.48	103.46	103.87	76.89	33.63	2.85	0.00	0.00	38.03	59.41
		Return	0.00	0.00	2.85	33.63	76.89	103.87	103.46	52.48	5.29		
		Average	5.29	**52.48**	**106.31**	**137.50**	**153.78**	**137.50**	**106.31**	**52.48**	5.29		
7	Q2S2O1	Forward	9.36	73.90	149.02	146.04	113.63	45.15	0.14	0.00	0.00	97.04	83.26
		Return	0.00	0.00	0.14	45.15	113.63	146.04	149.04	73.90	9.36		
		Average	9.36	**73.90**	**149.16**	**191.19**	**227.26**	**191.19**	**149.18**	**73.90**	9.36		
8	Q2S2O2	Forward	3.25	47.05	108.34	106.99	86.51	31.19	3.12	0.00	0.00	46.13	64.07
		Return	0.00	0.00	3.12	31.19	86.51	106.99	108.34	47.05	3.25		
		Average	3.25	**47.05**	**111.46**	**138.18**	**173.02**	**138.18**	**111.46**	**47.05**	3.25		

Table 6 Application rate and coefficient of variation for three meter spacing

Sl. No.	Treatment	Travel Mode	Application rate for three meter spacing, Kg ha^{-1}									Coefficient of variation (CV), %	
			Left hand side (-)			Right hand side(+)							
			Whole swath width, m									Effective swath width	Whole swath width
				Effective swath width, m									
			-3	**-2**	**-1**	**1**	**2**	**3**	**4**	**5**	**6**		
1	Q1S1O1	Forward	17.95	79.90	112.80	86.50	68.55	38.15	5.60	0.00	0.00	28.59	46.83
		Return	0.00	0.00	5.60	38.15	68.55	86.50	112.80	79.90	17.95		
		Average	17.95	**79.90**	**118.40**	**124.65**	**137.10**	**124.65**	**118.40**	**79.90**	17.95		
2	Q1S1O2	Forward	7.05	55.32	98.85	82.17	62.10	24.95	1.90	0.00	0.00	13.12	52.39
		Return	0.00	0.00	1.90	24.95	62.10	82.17	98.85	55.32	7.05		
		Average	7.05	**55.32**	**100.75**	**107.12**	**124.20**	**107.12**	**100.75**	**55.32**	7.05		
3	Q1 S2 O1	Forward	11.79	69.16	122.85	111.19	89.36	54.10	10.57	0.00	0.00	65.11	65.59
		Return	0.00	0.00	10.57	54.10	89.36	111.19	122.85	69.16	11.79		
		Average	11.79	**69.16**	**133.42**	**165.29**	**178.72**	**165.29**	**133.42**	**69.16**	11.79		
4	Q1S2O2	Forward	8.95	52.88	118.65	105.77	72.68	33.63	2.44	0.00	0.00	38.90	58.17
		Return	0.00	0.00	2.44	33.63	72.68	105.77	118.65	52.88	8.95		
		Average	8.95	**52.88**	**121.09**	**139.40**	**145.36**	**139.40**	**121.09**	**52.88**	8.95		
5	Q2S1O1	Forward	3.53	48.41	101.29	102.65	91.26	40.00	3.25	0.00	0.00	51.21	65.60
		Return	0.00	0.00	3.25	40.00	91.26	102.65	101.29	48.41	3.53		
		Average	3.53	**48.41**	**104.54**	**142.65**	**182.52**	**142.65**	**104.54**	**48.41**	3.53		
6	Q2S1O2	Forward	5.29	52.48	103.46	103.87	76.89	33.63	2.85	0.00	0.00	38.03	59.41
		Return	0.00	0.00	2.85	33.63	76.89	103.87	103.46	52.48	5.29		
		Average	5.29	**52.48**	**106.31**	**137.50**	**153.78**	**137.50**	**106.31**	**52.48**	5.29		
7	Q2S2O1	Forward	9.36	73.90	149.02	146.04	113.63	45.15	0.14	0.00	0.00	97.04	83.26
		Return	0.00	0.00	0.14	45.15	113.63	146.04	149.04	73.90	9.36		
		Average	9.36	**73.90**	**149.16**	**191.19**	**227.26**	**191.19**	**149.18**	**73.90**	9.36		
8	Q2S2O2	Forward	3.25	47.05	108.34	106.99	86.51	31.19	3.12	0.00	0.00	46.13	64.07
		Return	0.00	0.00	3.12	31.19	86.51	106.99	108.34	47.05	3.25		
		Average	3.25	**47.05**	**111.46**	**138.18**	**173.02**	**138.18**	**111.46**	**47.05**	3.25		

Table 7 Application rate and uniformity coefficient of distribution for three meter spacing

Sl. No.	Treatment	Travel Mode	Application rate for three meter spacing, Kg ha^{-1}									Uniformity coefficient of distribution(UCD), %	
			Left hand side (-)			Right hand side(+)							
			←Whole swath width, m→										
				←Effective swath width, m→								Effective swath width	Whole swath width
			-3	**-2**	**-1**	**1**	**2**	**3**	**4**	**5**	**6**		
1	Q1S1O1	Forward	17.95	79.9	112.8	86.5	68.55	38.15	5.6	0	0	75.36	63.61
		Return	0	0	5.6	38.15	68.55	86.5	112.8	79.9	17.95		
		Average	17.95	**79.9**	**118.4**	**124.65**	**137.1**	**124.65**	**118.4**	**79.9**	17.95		
2	Q1S1O2	Forward	7.05	55.32	98.85	82.17	62.1	24.95	1.9	0	0	92.01	64.98
		Return	0	0	1.9	24.95	62.1	82.17	98.85	55.32	7.05		
		Average	7.05	**55.32**	**100.75**	**107.12**	**124.2**	**107.12**	**100.75**	**55.32**	7.05		
3	Q1 S2 O1	Forward	11.79	69.16	122.85	111.19	89.36	54.1	10.57	0	0	44.77	42.86
		Return	0	0	10.57	54.1	89.36	111.19	122.85	69.16	11.79		
		Average	11.79	**69.16**	**133.42**	**165.29**	**178.72**	**165.29**	**133.42**	**69.16**	11.79		
4	Q1S2O2	Forward	8.95	52.88	118.65	105.77	72.68	33.63	2.44	0	0	66.73	50.81
		Return	0	0	2.44	33.63	72.68	105.77	118.65	52.88	8.95		
		Average	8.95	**52.88**	**121.09**	**139.4**	**145.36**	**139.4**	**121.09**	**52.88**	8.95		
5	Q2S1O1	Forward	3.53	48.41	101.29	102.65	91.26	40.00	3.25	0	0	64.62	47.44
		Return	0	0	3.25	40	91.26	102.65	101.29	48.41	3.53		
		Average	3.53	**48.41**	**104.54**	**142.65**	**182.52**	**142.65**	**104.54**	**48.41**	3.53		
6	Q2S1O2	Forward	5.29	52.47	103.46	103.87	76.89	33.61	2.85	0	0	71.72	52.68
		Return	0	0	2.85	33.63	76.89	103.87	103.46	52.48	5.29		
		Average	5.29	**52.47**	**106.31**	**137.5**	**153.78**	**137.5**	**106.31**	**52.48**	5.29		
7	Q2S2O1	Forward	9.36	73.90	149.02	146.04	113.63	45.16	0.14	0	0	18.40	28.73
		Return	0	0	0.14	45.15	113.63	146.04	149.04	73.9	9.36		
		Average	9.36	**73.90**	**149.16**	**191.19**	**227.26**	**191.19**	**149.18**	**73.9**	9.36		
8	Q2S2O2	Forward	3.25	47.05	108.34	106.99	86.51	31.19	3.1188	0	0	65.54	47.59
		Return	0	0	3.12	31.19	86.51	106.99	108.34	47.05	3.25		
		Average	3.25	**47.05**	**111.46**	**138.18**	**173.02**	**138.18**	**111.46**	**47.05**	3.25		

Table 8 Application rate and standard deviation for four meter spacing

Sl. No.	Treatment	Travel Mode	Application rate for four meter spacing, Kg ha^{-1}										Standard deviation (SD), kg ha^{-1}	
			Left hand side (-)			Right hand side(+)								
			← Whole swath width, m →										Effective swath width	Whole swath width
					← Effective swath width, m →									
			3 -	**2 -**	**1 -**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		
1	Q1S1O1	Forward	17.95	79.90	112.80	86.50	68.55	38.15	5.60	0.00	0.00	0.00	10.41	40.57
		Return	0.00	0.00	0.00	5.60	38.15	68.55	86.50	112.80	79.90	17.95		
		Average	17.95	79.90	**112.80**	**92.10**	**106.70**	**106.70**	**92.10**	**112.80**	79.90	17.95		
2	Q1S1O2	Forward	7.05	55.32	98.85	82.17	62.10	24.95	1.90	0.00	0.00	0.00	13.00	49.57
		Return	0.00	0.00	0.00	1.90	24.95	62.10	82.17	98.85	55.32	7.05		
		Average	7.05	55.32	**98.85**	**84.07**	**87.05**	**87.05**	**84.07**	**98.85**	55.32	7.05		
3	Q1 S2 O1	Forward	11.79	69.16	122.85	111.19	89.36	54.10	10.57	0.00	0.00	0.00	33.97	50.81
		Return	0.00	0.00	0.00	10.57	54.10	89.36	111.19	122.85	69.16	11.79		
		Average	11.79	69.16	**122.85**	**121.76**	**143.46**	**143.46**	**121.76**	**122.85**	69.16	11.79		
4	Q1S2O2	Forward	8.95	52.88	118.65	105.77	72.68	33.63	2.44	0.00	0.00	0.00	13.49	49.36
		Return	0.00	0.00	0.00	2.44	33.63	72.68	105.77	118.65	52.88	8.95		
		Average	8.95	52.88	**118.65**	**108.21**	**106.31**	**106.31**	**108.21**	**118.65**	52.88	8.95		
5	Q2S1O1	Forward	3.53	48.41	101.29	102.65	91.26	40.00	3.25	0.00	0.00	0.00	20.14	53.71
		Return	0.00	0.00	0.00	3.25	40.00	91.26	102.65	101.29	48.41	3.53		
		Average	3.53	48.41	**101.29**	**105.90**	**131.26**	**131.26**	**105.90**	**101.29**	48.41	3.53		
6	Q2S1O2	Forward	5.29	52.48	103.46	103.87	76.89	33.63	2.85	0.00	0.00	0.00	8.19	50.32
		Return	0.00	0.00	0.00	2.85	33.63	76.89	103.87	103.46	52.48	5.29		
		Average	5.29	52.48	**103.46**	**106.72**	**110.52**	**110.52**	**106.72**	**103.46**	52.48	5.29		
7	Q2S2O1	Forward	9.36	73.90	149.02	146.04	113.63	45.15	0.14	0.00	0.00	0.00	56.54	61.26
		Return	0.00	0.00	0.00	0.14	45.15	113.63	146.04	149.04	73.90	9.36		
		Average	9.36	73.90	**149.02**	**146.18**	**158.78**	**158.78**	**146.18**	**149.04**	73.90	9.36		
8	Q2S2O2	Forward	3.25	47.05	108.34	106.99	86.51	31.19	3.12	0.00	0.00	0.00	13.93	53.02
		Return	0.00	0.00	0.00	3.12	31.19	86.51	106.99	108.34	47.05	3.25		
		Average	3.25	47.05	**108.34**	**110.11**	**117.70**	**117.70**	**110.11**	**108.34**	47.05	3.25		

Table 9 Application rate and coefficient of variation for four meter spacing

Sl. No.	Treatment	Travel Mode	Application rate for four meter spacing, Kg ha^{-1}										Coefficient of variation (CV), %	
			Left hand side (-)			Right hand side(+)								
			← Whole swath width, m →										Effective swath width	Whole swath width
					← Effective swath width, m →									
			3 -	**2 -**	**1 -**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		
1	Q1S1O1	Forward	17.95	79.90	112.80	86.50	68.55	38.15	5.60	0.00	0.00	0.00	10.41	40.57
		Return	0.00	0.00	0.00	5.60	38.15	68.55	86.50	112.80	79.90	17.95		
		Average	17.95	79.90	**112.80**	**92.10**	**106.70**	**106.70**	**92.10**	**112.80**	79.90	17.95		
2	Q1S1O2	Forward	7.05	55.32	98.85	82.17	62.10	24.95	1.90	0.00	0.00	0.00	13.00	49.57
		Return	0.00	0.00	0.00	1.90	24.95	62.10	82.17	98.85	55.32	7.05		
		Average	7.05	55.32	**98.85**	**84.07**	**87.05**	**87.05**	**84.07**	**98.85**	55.32	7.05		
3	Q1 S2 O1	Forward	11.79	69.16	122.85	111.19	89.36	54.10	10.57	0.00	0.00	0.00	33.97	50.81
		Return	0.00	0.00	0.00	10.57	54.10	89.36	111.19	122.85	69.16	11.79		
		Average	11.79	69.16	**122.85**	**121.76**	**143.46**	**143.46**	**121.76**	**122.85**	69.16	11.79		
4	Q1S2O2	Forward	8.95	52.88	118.65	105.77	72.68	33.63	2.44	0.00	0.00	0.00	13.49	49.36
		Return	0.00	0.00	0.00	2.44	33.63	72.68	105.77	118.65	52.88	8.95		
		Average	8.95	52.88	**118.65**	**108.21**	**106.31**	**106.31**	**108.21**	**118.65**	52.88	8.95		
5	Q2S1O1	Forward	3.53	48.41	101.29	102.65	91.26	40.00	3.25	0.00	0.00	0.00	20.14	53.71
		Return	0.00	0.00	0.00	3.25	40.00	91.26	102.65	101.29	48.41	3.53		
		Average	3.53	48.41	**101.29**	**105.90**	**131.26**	**131.26**	**105.90**	**101.29**	48.41	3.53		
6	Q2S1O2	Forward	5.29	52.48	103.46	103.87	76.89	33.63	2.85	0.00	0.00	0.00	8.19	50.32
		Return	0.00	0.00	0.00	2.85	33.63	76.89	103.87	103.46	52.48	5.29		
		Average	5.29	52.48	**103.46**	**106.72**	**110.52**	**110.52**	**106.72**	**103.46**	52.48	5.29		
7	Q2S2O1	Forward	9.36	73.90	149.02	146.04	113.63	45.15	0.14	0.00	0.00	0.00	56.54	61.26
		Return	0.00	0.00	0.00	0.14	45.15	113.63	146.04	149.04	73.90	9.36		
		Average	9.36	73.90	**149.02**	**146.18**	**158.78**	**158.78**	**146.18**	**149.04**	73.90	9.36		
8	Q2S2O2	Forward	3.25	47.05	108.34	106.99	86.51	31.19	3.12	0.00	0.00	0.00	13.93	53.02
		Return	0.00	0.00	0.00	3.12	31.19	86.51	106.99	108.34	47.05	3.25		
		Average	3.25	47.05	**108.34**	**110.11**	**117.70**	**117.70**	**110.11**	**108.34**	47.05	3.25		

Table 10 Application rate and uniformity coefficient of distribution for four meter spacing

Sl. No.	Treatment	Travel Mode	Application rate for four meter spacing, Kg ha^{-1}										Uniformity coefficient of distribution(UCD), %	
			Left hand side (-)											
			← Whole swath width, m →										Effective swath width	Effective swath width
					← Effective swath width, m →									
			3 -	2 -	1 -	1	2	3	4	5	6	7		
1	Q1S1O1	Forward	17.95	79.90	112.80	86.50	68.55	38.15	5.60	0.00	0.00	0.00	90.87	74.09
		Return	0.00	0.00	0.00	5.60	38.15	68.55	86.50	112.80	79.90	17.95		
		Average	17.95	79.90	**112.80**	**92.10**	**106.70**	**106.70**	**92.10**	**112.80**	79.90	17.95		
2	Q1S1O2	Forward	7.05	55.32	98.85	82.17	62.10	24.95	1.90	0.00	0.00	0.00	89.99	66.47
		Return	0.00	0.00	0.00	1.90	24.95	62.10	82.17	98.85	55.32	7.05		
		Average	7.05	55.32	**98.85**	**84.07**	**87.05**	**87.05**	**84.07**	**98.85**	55.32	7.05		
3	Q1 S2 O1	Forward	11.79	69.16	122.85	111.19	89.36	54.10	10.57	0.00	0.00	0.00	70.64	58.58
		Return	0.00	0.00	0.00	10.57	54.10	89.36	111.19	122.85	69.16	11.79		
		Average	11.79	69.16	**122.85**	**121.76**	**143.46**	**143.46**	**121.76**	**122.85**	69.16	11.79		
4	Q1S2O2	Forward	8.95	52.88	118.65	105.77	72.68	33.63	2.44	0.00	0.00	0.00	88.94	65.73
		Return	0.00	0.00	0.00	2.44	33.63	72.68	105.77	118.65	52.88	8.95		
		Average	8.95	52.88	**118.65**	**108.21**	**106.31**	**106.31**	**108.21**	**118.65**	52.88	8.95		
5	Q2S1O1	Forward	3.53	48.41	101.29	102.65	91.26	40.00	3.25	0.00	0.00	0.00	87.18	62.70
		Return	0.00	0.00	0.00	3.25	40.00	91.26	102.65	101.29	48.41	3.53		
		Average	3.53	48.41	**101.29**	**105.90**	**131.26**	**131.26**	**105.90**	**101.29**	48.41	3.53		
6	Q2S1O2	Forward	5.29	52.48	103.46	103.87	76.89	33.63	2.85	0.00	0.00	0.00	93.10	67.41
		Return	0.00	0.00	0.00	2.85	33.63	76.89	103.87	103.46	52.48	5.29		
		Average	5.29	52.48	**103.46**	**106.72**	**110.52**	**110.52**	**106.72**	**103.46**	52.48	5.29		
7	Q2S2O1	Forward	9.36	73.90	149.02	146.04	113.63	45.15	0.14	0.00	0.00	0.00	48.67	45.85
		Return	0.00	0.00	0.00	0.14	45.15	113.63	146.04	149.04	73.90	9.36		
		Average	9.36	73.90	**149.02**	**146.18**	**158.78**	**158.78**	**146.18**	**149.04**	73.90	9.36		
8	Q2S2O2	Forward	3.25	47.05	108.34	106.99	86.51	31.19	3.12	0.00	0.00	0.00	87.95	62.83
		Return	0.00	0.00	0.00	3.12	31.19	86.51	106.99	108.34	47.05	3.25		
		Average	3.25	47.05	**108.34**	**110.11**	**117.70**	**117.70**	**110.11**	**108.34**	47.05	3.25		

Table 11 Application rate and standard deviation for five meter spacing

Sl. No.	Treatment	Travel Mode	Application rate for five spacing, Kg ha-1											Standard deviation (SD), kg ha^{-1}	
			Left hand side (-)			Right hand side(+)								Effective swath width	Whole swath width
			← Whole swath width, m →												
					← Effective swath width, m →										
			3 -	**2 -**	**1 -**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**		
1	Q1S1O1	Forward	17.95	79.90	112.80	86.50	68.55	38.15	5.60	0.00	0.00	0.00	0.00	20.78	41.06
		Return	0.00	0.00	0.00	0.00	5.60	38.15	68.55	86.50	112.80	79.90	17.95		
		Average	17.95	79.90	**112.80**	**86.50**	**74.15**	**76.30**	**74.15**	**86.50**	**112.80**	79.90	17.95		
2	Q1S1O2	Forward	7.05	55.32	98.85	82.17	62.10	24.95	1.90	0.00	0.00	0.00	0.00	30.93	51.97
		Return	0.00	0.00	0.00	0.00	1.90	24.95	62.10	82.17	98.85	55.32	7.05		
		Average	7.05	55.32	**98.85**	**82.17**	**64.00**	**49.90**	**64.00**	**82.17**	**98.85**	55.32	7.05		
3	Q1 S2 O1	Forward	11.79	69.16	122.85	111.19	89.36	54.10	10.57	0.00	0.00	0.00	0.00	15.07	43.39
		Return	0.00	0.00	0.00	0.00	10.57	54.10	89.36	111.19	122.85	69.16	11.79		
		Average	11.79	69.16	**122.85**	**111.19**	**99.93**	**108.20**	**99.93**	**111.19**	**122.85**	69.16	11.79		
4	Q1S2O2	Forward	8.95	52.88	118.65	105.77	72.68	33.63	2.44	0.00	0.00	0.00	0.00	22.63	49.08
		Return	0.00	0.00	0.00	0.00	2.44	33.63	72.68	105.77	118.65	52.88	8.95		
		Average	8.95	52.88	**118.65**	**105.77**	**75.12**	**67.26**	**75.12**	**105.77**	**118.65**	52.88	8.95		
5	Q2S1O1	Forward	3.53	48.41	101.29	102.65	91.26	40.00	3.25	0.00	0.00	0.00	0.00	8.92	49.41
		Return	0.00	0.00	0.00	0.00	3.25	40.00	91.26	102.65	101.29	48.41	3.53		
		Average	3.53	48.41	**101.29**	**102.65**	**94.51**	**80.00**	**94.51**	**102.65**	**101.29**	48.41	3.53		
6	Q2S1O2	Forward	5.29	52.48	103.46	103.87	76.89	33.63	2.85	0.00	0.00	0.00	0.00	18.01	49.40
		Return	0.00	0.00	0.00	0.00	2.85	33.63	76.89	103.87	103.46	52.48	5.29		
		Average	5.29	52.48	**103.46**	**103.87**	**79.74**	**67.26**	**79.74**	**103.87**	**103.46**	52.48	5.29		
7	Q2S2O1	Forward	9.36	73.90	149.02	146.04	113.63	45.15	0.14	0.00	0.00	0.00	0.00	39.84	52.26
		Return	0.00	0.00	0.00	0.00	0.14	45.15	113.63	146.04	149.04	73.90	9.36		
		Average	9.36	73.90	**149.02**	**146.04**	**113.77**	**90.30**	**113.77**	**146.04**	**149.04**	73.90	9.36		
8	Q2S2O2	Forward	3.25	47.05	108.34	106.99	86.51	31.19	3.12	0.00	0.00	0.00	0.00	17.64	51.18
		Return	0.00	0.00	0.00	0.00	3.12	31.19	86.51	106.99	108.34	47.05	3.25		
		Average	3.25	47.05	**108.34**	**106.99**	**89.63**	**62.38**	**89.63**	**106.99**	**108.34**	47.05	3.25		

Table 12 Application rate and Coefficient of variation for five meter spacing

Sl. No.	Treatment	Travel Mode	Application rate for five spacing, Kg ha-1											Coefficient of variation (CV), %	
			Left hand side (-)			Right hand side(+)								Effective swath width	Whole swath width
			← Whole swath width, m →												
					← Effective swath width, m →										
			3 -	2 -	1 -	1	2	3	4	5	6	7	8		
1	Q1S1O1	Forward	17.95	79.90	112.80	86.50	68.55	38.15	5.60	0.00	0.00	0.00	0.00	20.78	41.06
		Return	0.00	0.00	0.00	0.00	5.60	38.15	68.55	86.50	112.80	79.90	17.95		
		Average	17.95	79.90	**112.80**	**86.50**	**74.15**	**76.30**	**74.15**	**86.50**	**112.80**	79.90	17.95		
2	Q1S1O2	Forward	7.05	55.32	98.85	82.17	62.10	24.95	1.90	0.00	0.00	0.00	0.00	30.93	51.97
		Return	0.00	0.00	0.00	0.00	1.90	24.95	62.10	82.17	98.85	55.32	7.05		
		Average	7.05	55.32	**98.85**	**82.17**	**64.00**	**49.90**	**64.00**	**82.17**	**98.85**	55.32	7.05		
3	Q1 S2 O1	Forward	11.79	69.16	122.85	111.19	89.36	54.10	10.57	0.00	0.00	0.00	0.00	15.07	43.39
		Return	0.00	0.00	0.00	0.00	10.57	54.10	89.36	111.19	122.85	69.16	11.79		
		Average	11.79	69.16	**122.85**	**111.19**	**99.93**	**108.20**	**99.93**	**111.19**	**122.85**	69.16	11.79		
4	Q1S2O2	Forward	8.95	52.88	118.65	105.77	72.68	33.63	2.44	0.00	0.00	0.00	0.00	22.63	49.08
		Return	0.00	0.00	0.00	0.00	2.44	33.63	72.68	105.77	118.65	52.88	8.95		
		Average	8.95	52.88	**118.65**	**105.77**	**75.12**	**67.26**	**75.12**	**105.77**	**118.65**	52.88	8.95		
5	Q2S1O1	Forward	3.53	48.41	101.29	102.65	91.26	40.00	3.25	0.00	0.00	0.00	0.00	8.92	49.41
		Return	0.00	0.00	0.00	0.00	3.25	40.00	91.26	102.65	101.29	48.41	3.53		
		Average	3.53	48.41	**101.29**	**102.65**	**94.51**	**80.00**	**94.51**	**102.65**	**101.29**	48.41	3.53		
6	Q2S1O2	Forward	5.29	52.48	103.46	103.87	76.89	33.63	2.85	0.00	0.00	0.00	0.00	18.01	49.40
		Return	0.00	0.00	0.00	0.00	2.85	33.63	76.89	103.87	103.46	52.48	5.29		
		Average	5.29	52.48	**103.46**	**103.87**	**79.74**	**67.26**	**79.74**	**103.87**	**103.46**	52.48	5.29		
7	Q2S2O1	Forward	9.36	73.90	149.02	146.04	113.63	45.15	0.14	0.00	0.00	0.00	0.00	39.84	52.26
		Return	0.00	0.00	0.00	0.00	0.14	45.15	113.63	146.04	149.04	73.90	9.36		
		Average	9.36	73.90	**149.02**	**146.04**	**113.77**	**90.30**	**113.77**	**146.04**	**149.04**	73.90	9.36		
8	Q2S2O2	Forward	3.25	47.05	108.34	106.99	86.51	31.19	3.12	0.00	0.00	0.00	0.00	17.64	51.18
		Return	0.00	0.00	0.00	0.00	3.12	31.19	86.51	106.99	108.34	47.05	3.25		
		Average	3.25	47.05	**108.34**	**106.99**	**89.63**	**62.38**	**89.63**	**106.99**	**108.34**	47.05	3.25		

Table 13 Application rate and uniformity coefficient of distribution for five meter spacing

Sl. No.	Treatment	Travel Mode	Application rate for five spacing, Kg ha-1											UCD, %	
			Left hand side (-)			Right hand side(+)								Effective swath width	Whole swath width
			← Whole swath width, m →												
					← Effective swath width, m →										
			3 -	2 -	1 -	1	2	3	4	5	6	7	8		
1	Q1S1O1	Forward	17.95	79.90	112.80	86.50	68.55	38.15	5.60	0.00	0.00	0.00	0.00	81.71	69.79
		Return	0.00	0.00	0.00	0.00	5.60	38.15	68.55	86.50	112.80	79.90	17.95		
		Average	17.95	79.90	**112.80**	**86.50**	**74.15**	**76.30**	**74.15**	**86.50**	**112.80**	79.90	17.95		
2	Q1S1O2	Forward	7.05	55.32	98.85	82.17	62.10	24.95	1.90	0.00	0.00	0.00	0.00	77.13	60.43
		Return	0.00	0.00	0.00	0.00	1.90	24.95	62.10	82.17	98.85	55.32	7.05		
		Average	7.05	55.32	**98.85**	**82.17**	**64.00**	**49.90**	**64.00**	**82.17**	**98.85**	55.32	7.05		
3	Q1 S2 O1	Forward	11.79	69.16	122.85	111.19	89.36	54.10	10.57	0.00	0.00	0.00	0.00	89.08	71.41
		Return	0.00	0.00	0.00	0.00	10.57	54.10	89.36	111.19	122.85	69.16	11.79		
		Average	11.79	69.16	**122.85**	**111.19**	**99.93**	**108.20**	**99.93**	**111.19**	**122.85**	69.16	11.79		
4	Q1S2O2	Forward	8.95	52.88	118.65	105.77	72.68	33.63	2.44	0.00	0.00	0.00	0.00	81.24	62.94
		Return	0.00	0.00	0.00	0.00	2.44	33.63	72.68	105.77	118.65	52.88	8.95		
		Average	8.95	52.88	**118.65**	**105.77**	**75.12**	**67.26**	**75.12**	**105.77**	**118.65**	52.88	8.95		
5	Q2S1O1	Forward	3.53	48.41	101.29	102.65	91.26	40.00	3.25	0.00	0.00	0.00	0.00	94.45	69.55
		Return	0.00	0.00	0.00	0.00	3.25	40.00	91.26	102.65	101.29	48.41	3.53		
		Average	3.53	48.41	**101.29**	**102.65**	**94.51**	**80.00**	**94.51**	**102.65**	**101.29**	48.41	3.53		
6	Q2S1O2	Forward	5.29	52.48	103.46	103.87	76.89	33.63	2.85	0.00	0.00	0.00	0.00	87.44	66.15
		Return	0.00	0.00	0.00	0.00	2.85	33.63	76.89	103.87	103.46	52.48	5.29		
		Average	5.29	52.48	**103.46**	**103.87**	**79.74**	**67.26**	**79.74**	**103.87**	**103.46**	52.48	5.29		
7	Q2S2O1	Forward	9.36	73.90	149.02	146.04	113.63	45.15	0.14	0.00	0.00	0.00	0.00	67.52	58.10
		Return	0.00	0.00	0.00	0.00	0.14	45.15	113.63	146.04	149.04	73.90	9.36		
		Average	9.36	73.90	**149.02**	**146.04**	**113.77**	**90.30**	**113.77**	**146.04**	**149.04**	73.90	9.36		
8	Q2S2O2	Forward	3.25	47.05	108.34	106.99	86.51	31.19	3.12	0.00	0.00	0.00	0.00	87.28	64.69
		Return	0.00	0.00	0.00	0.00	3.12	31.19	86.51	106.99	108.34	47.05	3.25		
		Average	3.25	47.05	**108.34**	**106.99**	**89.63**	**62.38**	**89.63**	**106.99**	**108.34**	47.05	3.25		

UCD = Uniformity coefficient of distribution, %

APPENDIX III

FIELD CAPACITY AND FIELD EFFICIENCY

$$\text{Theoretical field capacity}(\text{ha h}^{-1}) = \frac{\text{Effective swath width(m)} \times \text{walking Speed}(\text{km h}^{-1})}{10}$$

$$\text{Effective field capacity}(\text{ha } h^{-1}) = \frac{\text{Theoretical field capacity}(\text{ha } h^{-1}) \times \text{field efficiency}(\%)}{100}$$

a) For travelling speed of 1.5 km hr^{-1}, field efficiency of 65% and effective swath width of six meter for four meter spacing.

Theoretical field capacity = $\frac{6 \times 1.5}{10}$

= 0.90 ha hr^{-1}

Effective field capacity = $\frac{0.9 \times 65}{100}$

= 0.59 ha hr^{-1}

a) For travelling speed of 1.5 km hr^{-1}, field efficiency of 65% and effective swath width of seven meter for three and five meter spacing.

Theoretical field capacity = $\frac{7 \times 1.5}{10}$

= 1.05 ha hr^{-1}

Effective field capacity = $\frac{1.05 \times 65}{100}$

= 0.68 ha hr^{-1}

APPENDIX IV

Estimation of cost of the centrifugal broadcaster

<table>
<tr><th>Sl. No.</th><th colspan="2">Parts</th><th>Quantity, nos.</th><th>Specification</th><th>Weight, Kg</th><th>Cost, Rs.</th></tr>
<tr><td>1</td><td colspan="2">Broadcaster</td><td>1</td><td>13 litre</td><td>3.43</td><td>2000</td></tr>
<tr><td>2</td><td colspan="2">Battery</td><td>1</td><td>12 V, 4Ah</td><td>1.50</td><td>1300</td></tr>
<tr><td>3</td><td colspan="2">DC motor</td><td>1</td><td>12 V, 5Amps, 35 RPM and 50 RPM, 50W</td><td>1.35</td><td>2600</td></tr>
<tr><td>4</td><td colspan="2">Speed controller</td><td>1</td><td>PWM DC, 12 V, 5A (max.)</td><td>0.80</td><td>450</td></tr>
<tr><td rowspan="3">5</td><td rowspan="3">Others</td><td>Nuts and bolts</td><td>6</td><td>-</td><td>-</td><td>300</td></tr>
<tr><td>Welding rods</td><td>-</td><td>-</td><td>-</td><td>250</td></tr>
<tr><td>Paint</td><td>-</td><td>-</td><td>-</td><td>150</td></tr>
<tr><td colspan="3">Total cost</td><td colspan="2"></td><td colspan="2">7050</td></tr>
<tr><td colspan="3">Fabrication</td><td colspan="2"></td><td colspan="2">1800</td></tr>
<tr><td colspan="3">Total cost of broadcaster</td><td colspan="2"></td><td colspan="2">8850</td></tr>
</table>

APPENDIX V

Cost of operation of power operated pre-germinated paddy seed broadcaster

Cost of the broadcaster with accessories, C	=	Rs. 8850
Expected life, L	=	5 years
Annual operating hours, H	=	200
Annual interest, I	=	10%
Salvage value, S	=	10% of C = Rs. 885

i. Fixed cost

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

Where,

C = Total cost of machine

S = Salvage value 10% of C

H = Annual use in hours

Depreciation = $\frac{8850-885}{5 \times 200}$

= Rs.7.96 h^{-1}

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

Where,

i = % rate of interest per year

Interest = $\frac{8850+885}{2} \times \frac{10}{200} \times \frac{1}{100}$

= Rs.2.43 h^{-1}

Total fixed cost = a + b = Rs. 7.96 + 2.43 = Rs. 10.39 h^{-1}

ii) Variable cost

a) Repair and maintenance cost (3% of initial cost)

$$= \frac{8850}{200} \times \frac{3}{100}$$

= Rs1.33 h^{-1}

b) Battery charging cost (for every 4 hours)

To charge 12 V, 4Ah battery

i) Total Electricity used = $\frac{(4Ah)\times(12V)}{1000} = 0.048$ units

ii) Charging cost = 0.048(units) × 2.89 (Rs./unit)

= Rs. 0.138

= 0.138× 2 = Rs. 0.3

c) Operator wages (labours Rs. 800 per day of 8 hours)

$= \frac{800}{8}$ = Rs.100 h^{-1}

Total variable cost = a + b +c= 1.33+0.3+100 = Rs. 101.63 h^{-1}

Total operating cost of broadcaster = Fixed cost + Variable cost

= 10.39 + 101.63

= Rs. 112.02 h^{-1}

Theoretical field capacity of broadcaster = 0.90 ha h^{-1}

Actual field capacity of broadcaster = 0.59 ha h^{-1}

Field efficiency of broadcaster = 65 %

Time required to cover 1 ha, h = 1/AFC

= 1/0.59

= 1.69 h ha^{-1}

Cost of operation of broadcaster = 1.69 × 112.02 = Rs 189.31 ha^{-1}

Cost of operation of manual broadcasting

Labour requirement = 8 man h ha^{-1}

Cost of broadcasting Rs. 800 per labour = $\frac{8}{8} \times 800$

= Rs. 800 ha^{-1}

Cost saved over manual broadcasting = 800 – 189.31

= Rs.610.69 ha^{-1}

Cost saved over manual broadcasting (%) = $\frac{610.69}{800} \times 100$ =76.34%

Time saved over manual broadcasting = 8 – 1.69

= 6.31 ha h^{-1}

Time saved over manual broadcasting = $\frac{6.31}{8} \times 100$ = 78.88%

Benefit – cost – ratio

Benefit cost per hectare

= cost of manual broadcasting – cost of battery operated broadcaster

= Rs. 800 – 189.31

= Rs. 610.69

Therefore,

Benefit cost ratio = $\frac{\text{Benifit cost}}{\text{cost of bettery operated broadcaster}}$

Benefit cost ratio = $\frac{610.69}{189.31}$ = 3.23

ABSTRACT

DEVELOPMENT AND TESTING OF A POWER OPERATED PRE-GERMINATED PADDY SEED BROADCASTER

by

SREEDHARA B

(2016 - 18 - 013)

ABSTRACT OF THE THESIS

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Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

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

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ABSTRACT

Rice (Oryza sativa L.) is important leading food crop and it is widely cultivated in India. The farmers are facing problems due to lack of labour, time, inputs cost and also due to drudgery in work. Nevertheless, mechanization in paddy cultivation can boost higher productivity and considerably reduce the cost of production. Therefore, the present study was undertaken to develop and evaluate the performance of a battery operated pre-germinated broadcaster in paddy cultivation. The power operated pre-germinated paddy seed broadcaster was developed and tested based on the, engineering and physical properties of dry and pre-germinated paddy seeds.

The performance parameters of paddy seed broadcaster were the application rate, coefficient of variation, skewness ratio and uniformity coefficient of distribution. The maximum application rate of 149.02 kg ha^{-1} was observed for the treatment Q2S2O1 in single pass. The minimum application rate of 0.14 kg ha^{-1} was observed for the treatment Q2S2O1 in single pass. In multiple pass the maximum and minimum application rate of 182.52 kg ha^{-1} and 47.05 kg ha^{-1} were observed for the treatments Q2S1O1 and Q2S2O2 for three meter spacing of seven meter effective swath width. The maximum skewness ratio was about 101% for the treatment Q1S1O1 in single pass. The minimum skewness ratio observed was about 48% for the treatment Q2S1O2. The minimum coefficient of variation observed was about 57.15 % for the treatment Q1S2O1 in single pass. The minimum coefficient of variation of about 8.19% was observed for the treatment Q1S102 for four meter spacing application rate. The average effective field capacity and field efficiency for four meter was about 0.59 ha hr^{-1} and 65% for six-meter effective swath width at walking speed of 1.5 km ha^{-1}. The savings in cost and time for battery powered centrifugal broadcaster about 76.34% and 78.88% compared to manual broadcasting. From the performance evaluation test, it was concluded that the battery operated centrifugal paddy seed broadcaster can perform paddy seed broadcasting operation efficiently and economically.