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EDITORIAL

The war between Russia and Ukraine has been going on for over a year and shows no signs of abating. This war has had a huge impact on many countries. Ukraine and Russia export a lot of food to Africa. This war has greatly reduced these exports and has caused food shortages. As a result, the number of hungry people in African countries is increasing due to food shortages. African countries that depend on food imports from Russia and Ukraine want this war to stop somehow, and they are trying to figure out how to stop it. The leaders of African countries will surely visit Russia and Ukraine and talk about how to stop the war in the future. Throughout history, man has developed science and technology, and industry has used them to do many good things for mankind. But science and technology, if used wrongly, can become a weapon of war. For example, nuclear power, which uses nuclear fission reactions, for example, is spreading around the world. However, the experience of Hiroshima and Nagasaki in Japan has taught us that it is sometimes difficult for human beings to use these "technologies" correctly.

Africa will soon have the largest population in the world, overtaking Asia, which currently has the largest population in the region. Therefore, the most important policy is to strengthen food production and agriculture. The spread of agricultural machinery is essential. The question is how to promote agricultural mechanization in Africa. All people involved in agricultural machinery around the world should think together about how to promote agricultural mechanization in Africa. Agriculture is a way for man to harmonize with the earth's life system and agricultural mechanization is indispensable for the improvement of agriculture.

Africa is a very large region with different climatic conditions, different soil conditions and different plant conditions. The continent is very diverse, for example, a desert spreads in northern area such as Egypt, and areas of heavy rainfall are located in the central part of the continent. Therefore, the mechanization of agriculture in Africa will require different kinds of agricultural machinery to help farmers to do the right work for the region and for crops, rather than simply applying the same methods.

Most agricultural work has been done by human labor, but from now on, mechanization of agriculture must be promoted. Agricultural mechanization needs to be diversified.

When I visited Tanzania last year, I visited rice fields that had been established with Japanese aid. The area was equipped with combine harvesters and other agricultural machinery provided by Japan free of charge, but all the combine harvesters were broken and not in use. In other words, there was no one in the area who could repair the combines. This means that to promote agricultural mechanization in Africa, it is necessary to educate and train local people who understand agricultural machinery. Africa will have the largest population in the world in the coming years, and agricultural machinery is in a great need for the region. Let us all work together to promote it.

Yoshisuke Kishida
Chief Editor
July, 2023

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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Examining Regional Differences in Agricultural Machinery Sector Productivity Using Data Envelopment Analysis (DEA)

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Abstract

This study analyzed regional differences in productivity of agricultural machinery sector using data envelopment analysis (DEA) approach. In this research, we identify areas with high productivity in agricultural machinery based on data envelopment analysis method. The data source was a database in the National Statistics Office of Iran (Agricultural Time Series Database). Concerning the performance approach in this study, data envelopment analysis should be used with regarding to input-based process. In order to analyze data from DEA method with input-based approach, different provinces of Iran were selected as the decision making unit in a particular crop year. The efficiency of provincial centers has been evaluated during 2013 and 2016. Based on the results, the centers with performance index of 1 deemed as efficient centers. These centers having high technical performance include Ardebil, Hamedan, Jiroft, Kurdistan, Ilam and Isfahan. Other provincial centers have been technically inadequate or efficient Pareto Kopman.

Keywords: Agricultural Machinery Productivity, Data Envelopment Analysis, Technical Performance, Pareto Kopman Efficiency.

Introduction

It is important to efficiently utilize agricultural machinery as an important factor in development of any country in the agricultural sector. In the last two decades, there has been a great deal of changes in the content and quality of global markets; the move towards regionalization and globalization of markets has accelerated; in parallel, the pivotal period has come to an end and the period of production is based on efficiency and quality. It is in the process of formation (Ardal et al., 2011). Crop producers aim to optimize their use of machinery and avoid wasting valuable resources, using their agricultural machinery to suit their needs and abilities.

Regarding to the important role of the mechanization as an essential and basic stimulus for the development of agriculture, it meets the diverse needs of both producers and consumers on the other hand (both inside and outside of the country), (Amon, 2013). Apart from the fact that the manufacturers are utilizing machinery, the company is also focusing on improving the efficiency of our province and the countries provinces. One of the main features of this transformation is the growth of production. This research will try to identify the outputs and inputs of using the machineries the country provinces in terms of efficiency in using agricultural machinery and discussing the optimal use. Although the agriculture section has the main role is employment.it has minor role in national production. According to tis, farmers outcon is low in the above category and they don't have enough qualification to produce more in our country, according to lock of water resources. We can't plant most are as to produce more. So, the only way to increase productivity is to regard the machinery efficiency. If we follow this trend, the amount if harvest will increase. Therefore, formers involvements increase duet productivity to achieve this goal forming equipment must be provided enough.

Theoretical Foundations

Based on studies by Bahaian and Najafi (2017) the third generation is based on the ideas generated by the media. Indicates a median score based on the mean score, with a mean score based on the mean score View article View with a menu, a menu of basic ideas. In terms of the number of mouse clicks, the maximum spacing is 1.72 times the average spike: With the highest average fruit juice prices, the average monthly consumption is 1.26 times. Research by Madame Madani (2016), who provided some information on human capital. In order to evaluate the situation using the tractor in Kerman province required data includes acreage number and balance of machines used in agriculture, costs and revenues using the tractor, working hours based on different types of farming activities, go to Statements or interviews with beneficiaries. These statistics measure the horsepower per hectare, level of mechanization internal rate of return and net present value of investment in the purchase and use two types of tractor units in 20131 Romania is used. Eventually, it turned out that the top 10 percent of the company had an interest rate of 84% on their corporate group. The current results also showed that the average yields were approximately 0.37 and 1.24, respectively.

Nasabian and Shahriar (2013) in a study relating to determine economic efficiency of agricultural production units showed that all wheat production units in Khorasan province have low economic efficiency, which is related to their low technical efficiency. This means that by using a specific input, producers cannot access the maximum profit and thus the resources are not used efficiently. Shajri and Barikani's study (2008) was conducted to determine the economic efficiency of agricultural production cooperatives and the factors affecting their economic efficiency. The results of estimating the profit function of agricultural production cooperatives in Fasa, Firozabad, Marvdasht and Eglid show that the amount of initial and current capital of the cooperatives of agricultural production and the cost of all their activities are directly related to the marginal profit. Also, the results of economic efficiency distribution of agricultural production cooperatives of the mentioned cities show that their average economic efficiency is 0.741. The study results of the factors affecting the economic efficiency of agricultural production cooperatives in these cities show that the level of education of the CEO, the number of activities of the agricultural cooperatives (activity variety), the distance of the agricultural cooperatives from the city center and their

Table 1 Performance evaluation of centers in 2016

DMU No.	RTS	∑λ	Input-oriented CRS efficiency	DMU Name	Bench marks
1	East Azarbaijan	1.00000	1.000	Constant	1.000
2	Western Azerbaijan	0.67406	3.620	Decreasing	0.002
3	Ardebil	1.00000	1.000	Constant	1.000
4	Esfahan	0.49311	0.601	Increasing	0.256
5	Ilam	0.81628	0.441	Increasing	0.006
6	Bushehr	0.29078	0.957	Increasing	0.000
7	Tehran	0.81700	15.387	Decreasing	6.359
8	Chahar Mahal Bakhtiari	0.68188	0.494	Increasing	0.362
9	Khorasan	0.78225	0.439	Increasing	0.000
10	Khuzestan	1.00000	1.000	Constant	1.000
11	Zanjan	0.78620	1.984	Decreasing	0.351
12	Semnan	0.69334	1.348	Decreasing	0.236
13	Sistan and Baluchestan	0.51765	4.050	Decreasing	0.619
14	Fars	0.49504	1.122	Decreasing	0.010
15	Qazvin	1.00000	1.000	Constant	1.000
16	Qom	0.66492	0.076	Increasing	0.000
17	Kurdistan	0.73801	14.973	Decreasing	8.920
18	Kerman	1.00000	1.000	Constant	1.000
19	Kermanshah	1.00000	1.000	Constant	1.000
20	Golestan	1.00000	1.000	Constant	1.000
21	Gilan	0.83694	2.244	Decreasing	0.291
22	Lorestan	1.00000	1.000	Constant	1.000
23	Mazandaran	0.80238	4.372	Decreasing	0.003
24	Central	0.56604	8.746	Decreasing	0.112
25	Hormozgan	1.00000	1.000	Constant	1.000
26	Hamedan	1.00000	1.000	Constant	1.000
27	Yazd	1.00000	1.000	Constant	1.000
28	Mantagh jiroft v kerman	1.00000	1.000	Constant	1.000

location. Co-operative company in Firozabad city (compared to Eqlid, Marvdasht and Fasa cities) has a positive effect on economic efficiency, type of government management (as opposed to autonomous management) and duration of activity of agricultural production cooperative company and being located in Fasa city (Compared to Eglid and Marvdasht cities) and the location of the cooperative The city Eghlid (to the city MARVDASHT) has negative impact on the economic efficiency of agricultural production cooperatives in the province.

Mahdavi and Rezaei (2010) Comparative analysis of technical efficiency studies of Iranian agricultural sectors, one of the most important issues in development process in any country, especially developing countries like Iranian this technique, optimal use of production factors in production is meant. In production process. According to the results, the average technical efficiency was 68.51% for the whole agricultural sector and 78.56%, 67.45% and 59.54% for the various sectors such as agriculture, horticulture and poultry, respectively, the is statistics show a potential increase in Iranian agriculture. Production is up to 32% by using the same factors of production and can be increased significantly by considering the factors that contribute to increasing technical efficiency.

The study by Luimi and Abbasi (2003) shows that the mechanization level in the north of Ahvaz is 1.1 hp. Despite the relative desirability of this level, the degree of mechanization was low for the most of appropriate technology operations, and most of the tractor farmers. They use only primary and secondary daily soil for routine operations. On the other hand, the qualitative status of the area mechanization, including user skill, machine management and support services, wheat respect to calculated parameters such as low tractor productivity (about 40%), high harvest loss (about 9.4%), and poor training of machine users have no balance with the level of mechanization of the area. Consequently, in order to increase the efficiency of agricultural machinery in the region, along with paying attention to the training of the mechanization of its various operations. Suitable machines and equipment must be provided.

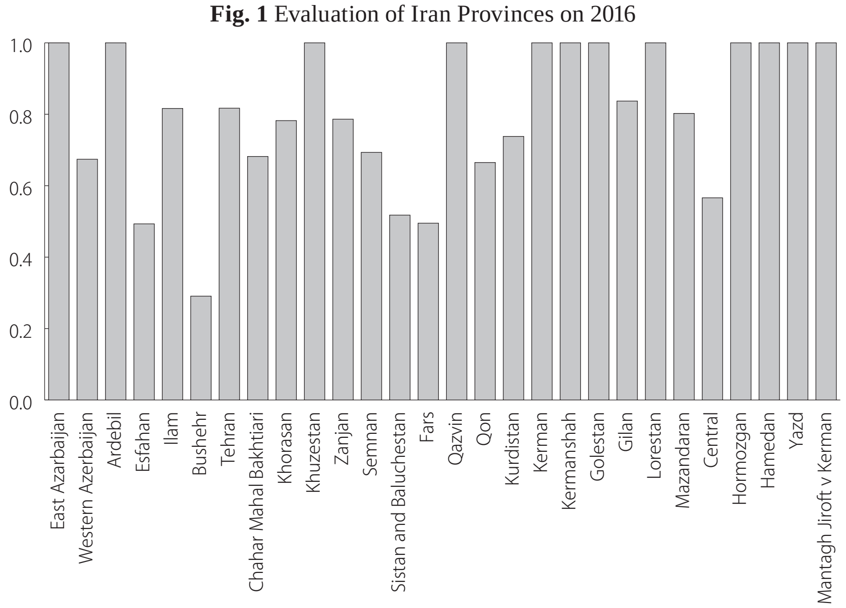
However, given the low degree of innovation and adoption of new technology in the local farming-based system, besides training and extension classes, and showing sample farms, encouraging and supporting mechanized service companies should be done to provide more machines and equipment. The results of the Sarbazi and his colleagues study (2013) showed that the mechanized level in this study was about 0.96 hp which indicates a deficiency in the tractor power of the area to reach the normal level of one hp per hectare, the government has to add 2009 horsepower to tractor power in the area.

Saeedi Rad et al. (2017) study of the technical and economic evaluation of the performance of PAW combines showed that the tertiary combines had the highest field capacity (0.48 ha/h) and the lowest yield (64.9%). Compared to the other two combines; the highest return (74.68%) belongs to the two-row combine. The lowest weight percent remaining on the calf (7.87%) is seen at a speed of 1.2 km/h. The results of economic evaluation and comparison three-row combine with two double row combine show that the three-row and two-row combine also have less return on investment (3.29 years) than the other two combines.

The main purpose of the research was to analyze the regional differences in agricultural machinery sector productivity using Data Envelopment Analysis (DEA) approach. For this the two objectives were found:

a. Examining the provincial centers of productive efficiency by using of agricultural machinery with the Data Envelopment Analysis (DEA) approach.2
b. Assessment and Comparison of Provincial Centers according to and Efficiency in Using Agricultural Machinery with Data Envelopment Analysis (DEA) Approach.

Fig. 1 Evaluation of Iran Provinces on 2016



Research Method

3.1 Definitions

Productivity: A concept that assesses the cost of resources spent a goal achievement. Thus, comparing the outputs with the inputs determines the efficiency.

Data Envelopment Analysis: One of the most effective tools in this field is data envelopment 7 analyses, which is used as a non-parametric method to calculate the efficiency of making units. The use of data envelopment analysis techniques is rapidly increasing today and is being used in the evaluation of various organizations and industries such as banking industry, post office, hospitals, training centers, power plants, refineries and so on.

Making Decision Unit: The decision-making unit is an organizational unit with a separate structure that is managed by a person named chief or officer.

The purpose of this study was to analyze regional differences in agricultural machinery sector productivity using data envelopment analysis (DEA) approach. In this research, the researcher seeks to identify productive areas in the field of agricultural machinery productivity based on data envelopment analysis method, so this research is an applied one because after the research completion, its findings can be used in the research community. The current study is a descriptive-case one in terms of data collection. Duet above explanations, the type of research is a descriptive-case one.

A library study is used to examine the dimensions of the problem according to available books and articles. According to productivity trend, using data envelopment technique must be preferred. The making decision units are diverse provinces in a harvest period. (Agricultural and employment is used to collect data base).

3.2 CCR-DEA Model

Consider a set of decision units whose number is n. Also suppose that each (j = 1, 2,..., n) DMU_j uses m input or X_{ij} source (i = 1, 2,..., m) and s sits your output. Outputs are Y_{rj} (r = 1, 2,..., s). The CCR relative model is defined as follows.

$$\text{Max } h_0 = \frac{\sum_r \mu_r y_{r0}}{\sum_i \vartheta_i x_{i0}} \qquad (1)$$

In equation (1) the decision variant are μ_r and ϑ_i and their coefficients are X_{i0} and Y_{r0}, respectively. Finally, the fractional planning model for evaluating the performance of making decision units is written as follows.

$$\text{Max } h_0 = \frac{\sum_{r=1}^{s} \mu_r y_{r0}}{\sum_{i=1}^{m} \vartheta_i y_{i0}}$$
$$\text{s.t. } \frac{\sum_{r=1}^{s} \mu_r y_{rj}}{\sum_{i=1}^{m} \vartheta_i y_{ij}} \leq 1 \quad j = 1, 2,..., n \qquad (2)$$
$$\mu_r, \vartheta i \geq 0 \quad \forall \text{ r, i}$$

The above fractional programming model was first used by Charnes et al. (1978) and is called CCR. In this model a fractional planning model is used to evaluate each DMU so that the objective function of this model is to maximize the ratio.

$$\text{Max } \sum_{r=1}^{s} \mu_r y_{r0}$$
$$\text{s.t. } \sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} \vartheta_i y_{ij} \leq 0 \qquad (3)$$
$$j = 1, 2,..., n$$
$$\sum_{i=1}^{m} \vartheta_i x_{i0} = 1 \qquad (4)$$
$$\mu_r, \vartheta_i \geq 0 \quad \forall \text{ r, i}$$

In fact, the fractional programming model answer (3) is the same as the linear programming model answer (4). Model (4) is an input-oriented model. Because by enlarging by considering the input value as one, it enlarge the value of the linear equation of the outputs. In

Table 2 Effective evaluation of centers in 2017

DMU No.	RTS	∑λ	Input-oriented CRS efficiency	DMU Name	Bench marks
1	East Azarbaijan	0.86328	0.984	Increasing	0.000
2	Western Azerbaijan	0.29889	0.426	Increasing	0.000
3	Ardebil	1.00000	1.000	Constant	1.000
4	Esfahan	1.00000	1.000	Constant	1.000
5	Ilam	1.00000	1.000	Constant	1.000
6	Bushehr	0.96419	0.451	Increasing	0.036
7	Tehran	1.00000	1.000	Constant	1.000
8	Chahar Mahal Bakhtiari	0.57577	0.283	Increasing	0.045
9	Khorasan	0.44514	0.404	Increasing	0.007
10	Khuzestan	0.21919	1.092	Decreasing	0.000
11	Zanjan	0.68484	3.871	Decreasing	0.300
12	Semnan	0.65245	0.781	Increasing	0.022
13	Sistan and Baluchestan	0.17180	2.061	Decreasing	0.226
14	Fars	0.59414	0.504	Increasing	0.050
15	Qazvin	1.00000	1.000	Constant	1.000
16	Qom	0.52722	1.181	Decreasing	0.073
17	Kurdistan	1.00000	1.000	Constant	1.000
18	Kerman	0.30273	2.926	Decreasing	0.039
19	Kermanshah	1.00000	1.000	Constant	1.000
20	Golestan	1.00000	1.000	Constant	1.000
21	Gilan	0.67506	4.433	Decreasing	0.584
22	Lorestan	0.97124	4.014	Decreasing	2.167
23	Mazandaran	1.00000	1.000	Constant	1.000
24	Central	1.00000	1.000	Constant	1.000
25	Hormozgan	0.37072	0.228	Increasing	0.074
26	Hamedan	1.00000	1.000	Constant	1.000
27	Yazd	0.61821	7.224	Decreasing	3.443
28	Mantagh jiroft v kerman	1.00000	1.000	Constant	1.000

most cases number of communities is greater than the number of performance indicators (including inputs and outputs). Solving the Dual Model Number 3 makes it easier to linear programming problem, so Dual Model Number (4) can be shown as following.

$$\theta^* = \mathrm{Min}\ \theta$$
$$\text{s.t.} \sum_{j=1}^{n} x_{ij} y_{rj} \lambda_j \leq \theta x_{i0} \quad i = 1, 2, ..., m$$
$$\text{s.t.} \sum_{j=1}^{n} y_{rj} \lambda_j \geq y_{r0} \quad r = 1, 2, ..., s$$
$$\lambda_j \geq 0 \quad j = 1, 2, ..., n \qquad (5)$$

The optimal values are always less than or equal to one. If the optimal value is equal to one in the DMU0 will be an efficient unit and if the optimal value is less than one, the DMU0 will be ineffective. The optimal value represents the performance value of DMU0 and DMU0 can be a part of the making decision units.

In model (5) there are definite values for the input and output constraints and their values are calculated as follows.

$$s_i^- = \theta^* x_{i0} - \sum_{j=1}^{n} x_{ij} \lambda_j \quad i = 1, 2, ..., m$$
$$s_r^+ = \sum_{j=1}^{n} y_{rj} \lambda_j - y_{r0} \quad r = 1, 2, ..., s \qquad (6)$$

In relation (6), we show the values and the helping variants of the input and output respectively. Using the concepts of helping variants we have the following DEA model. In the following model, model (5) is first implemented and the optimal values are obtained and inserted in the following model, then the following model is solved.

$$\mathrm{Max} \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+$$
$$\sum_{j=1}^{n} x_{ij} \lambda_j + s_i^- = \theta^* x_{i0} \quad i = 1, 2, ..., m$$
$$\sum_{j=1}^{n} y_{rj} \lambda_j - s_r^+ = y_{r0} \quad i = 1, 2, ..., s \qquad (7)$$

Using Model (7) we define the efficiency of making decision units as follows.

The DMU0 function has high efficient (in 100% efficient). If $s_i^- = s_r^+ = 0_r^+ = 0, \theta = 1$

In this case, DMU0 is efficient for Pareto-Copman.

The DMU0 function inefficient if $s_i^- \# 0$ or $\theta^* = 1$ or $s_r^+ \neq 0$ for some i and r. In this case DMU0 is Farrell's efficient.

DMU0 is ineffective if $\theta^* < 1$.

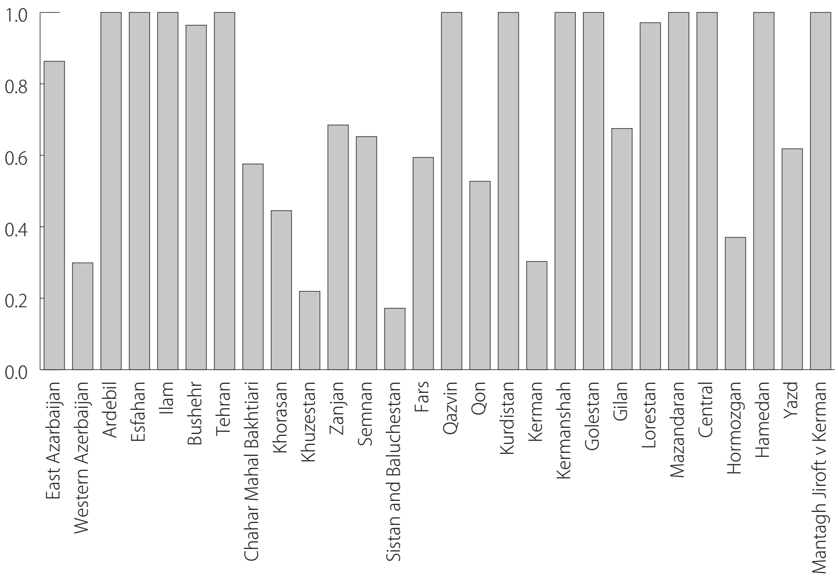
It should be noted that the value indicates technical, radial or relative efficiency. According to the above definitions, the following concepts are defined in data envelopment analysis.

If $\theta^* = 1$, DMU0 is technically efficient, and if $\theta^* < 1$, then DMU0 is technically ineffective.

If $\theta^* = 1$ and $s_i^- \neq 0$ / or $s_r^+ \neq 0$ is for indri DMU0 is technically efficient, but this unit has mixed inefficiencies.

If $\theta^* < 1$ and $s_i^- \neq 0$ (or) $s_r^+ \neq 0$ for some i's and r's, then DMU0 is both technically inefficient and mixed inefficient.

Fig. 2 Evaluation of Iran Provinces on 2017



Statistical Findings of the Study

The findings of the research are reported in the following tables based on statistical data on agricultural machinery sector productivity across provincial centers.

Based on the results of the centers which performance index is 1, the centers are efficient. These centers are technically efficient.

On the other hand, since all helping variants relating to inputs and outputs are zero after solving the model, these centers are either Pareto-Kopman efficient or efficient. The above chart compares these centers. The centers being more efficient have tendency to 1.Also since for the other $\theta^* < 1$, these centers are technically inefficient the input or output other centers also have compound on the other hand

When one of these covariant is more than zero the center is mixed technical efficient. According to this fact that some centers have the values of co variants as zero, they are Pareto kopman technical efficient to their inputs (s_i^-) and outputs (s_r^+) are zero after solving the model, the Pareto Kopman technique is efficient.

Due to findings, the centers which performance index is 1 are efficient centers. These centers technical performance. Ardebil, Hamedan, Jiroft, Kurdistan, Ilam and Isfahan have been effective this year.

On the other hand, since all co variants relating to inputs and outputs are zero above solving the model, these centers are either Pareto-Kopman efficient or efficient. The chart compares these centers. The centers that are more efficient have high tendency to 1 in compulsion with other centers. In addition, since for the other $\theta^* < 1$, these centers are technically inefficient, on the other hand, when solving the model, at least one of the input or output covariant is zero, so these other centers are mixed inefficiencies. Since the centers that have the index of covariant relating to their inputs (s_i^-) and outputs (s_r^+) are zero after solving the model, the Pareto Kopman technique is efficient .Due to this fact that the centers with input covariants (s_i^-) and output ones (s_r^+) valued as zero they are technical and parto kopman efficient.

Conclusion

The purpose of this study was to analyze regional differences in productivity of agricultural machinery sector using Data Envelopment Analysis (DEA) approach. Provincial centers efficiency assessment of agricultural machinery sector is based on their inputs (type of machinery, time of use and energy consumption in terms of fuel and employment, costs, water and area cultivated). We have examined the power of these provinces in terms of production and production efficiency. Findings of the study indicate that different centers have significant differences in production efficiency. Based on the results, the centers with their performance index 1 were efficient. These centers are technically efficient. Ardebil, Hamedan, Jiroft, Kurdistan, Ilam and Isfahan have been effective this year.

According to the results, it is suggested that: Provinces that have been more efficient in the field of agricultural machinery productivity should allocate their production based on the principle of absolute and relative profit or increase the percent aye of cultivated area. The provinces that have been ineffective in producing should r evaluate their efficiency in the different agricultural machinery sector, and change machinery, educate the use of machinery and type of machinery. The provinces need assess their production inputs and outputs independently to improve their production strengths based on production in different time duration.

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■■

Development and Evaluation of Tractor Operated Cassava Stake Cutter Planter

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Abstract

In India, the cultivation of cassava is mainly done in states of Kerala, Tamil Nadu, Andhra Pradesh, Nagaland, Meghalaya, and Assam; Tamil Nadu stands first both in area and production, and followed by Kerala and Andhra Pradesh. The total area under tapioca in India is 216.66 thousand ha and production is about 7,319.13 thousand metric tonnes. At present planting is done manually. The planting is done by women laborers by placing stakes in the ploughed and ridged soil. This tedious process requires around 20 man days/ha. The farmers contract the entire planting operation, which leads to increased cost of cultivation. If suitable system is developed for easy planting, they can get considerably higher price and profit. Currently very few planters are available in India hence, to eliminate the above problem, development of a cassava planter was attempted. To optimize the design of cassava stake cutter, an experimental cassava stake cutter was developed with main components viz., Hopper, Cutting blade, and Motor. The experimental cassava stake cutter was tested for its performance and was found working satisfactorily. An experimental cassava stake planter was developed to optimize the speed of counter rotating rollers for planting the cassava stakes. The test results indicated that the best planting was obtained at roller speeds of 400 rpm and 360 rpm and the highest number of stems per minute was 80. Similarly, the lowest number of stems per minute was 50 stems at speed of 190 rpm. Based on the optimized parameters, a tractor operated single row cassava stake cutter planter was developed and evaluated under laboratory and field conditions. From the laboratory trials the highest number of stakes per minute of 62 was obtained with the planting wheel speed of 1,421 rpm and cutting blade speed of 38 rpm and damage percentage of 34.7 was recorded. The average length of stake cut was recorded as 160 mm and the average diameter of the stake was measured as 31 mm. The effective field capacity of the developed planter is 0.18 ha h^{-1}.

Keywords: Cassava planter, stake cutter, cutter planter

Introduction

According to FAO classification, root and tuber crops form staple diet for three per cent of the global population. Cassava is mostly used for human consumption in the African continent and in the South America. Industrial utilization of cassava is prominent in Thailand, Indonesia, Vietnam, India in the form of starch, sago, dried chips, flour etc. In India, the cultivation of cassava is mainly done in Kerala, Tamil Nadu, Andhra Pradesh, Nagaland, Meghalaya, and Assam. Tamil Nadu stands first both in area and production, followed by Kerala and Andhra Pradesh. The total area under tapioca in India is 216.66 thousand ha and the production is about 7,319.13 thousand metric tonnes. It is a crop of food security in Kerala. By virtue of its diversified uses, it has become an important commercial crop in the agricultural economy of states like Tamil Nadu and Andhra Pradesh.

Cassava is also an important cash crop, especially in the state of Tamil Nadu where about 61% of total cultivation under cassava is located; it is the raw material used for the industrial production of starch and sago and caters to the needs of 1,300 starch and sago factories, providing employment to 0.4-0.5 million people

(Byju et al., 2010; Anon., 2012).

Cassava yields in India are by far the highest in the world, however in terms of cassava production in Asia, India comes third with a total production of 9.6 MMT after Indonesia (22 MMT) and Thailand (30.08 MMT). The reason for this disparity is due to the high production costs as a result of unavailability or high cost of labour. Consequently, the cost per tonne of cassava produced is still fairly high, making it difficult for India to compete in the world market (Howeler, 2012). For the past three decades, India's cassava production has not seen much significant change, however yield continues to increase significantly, chiefly due to the use of improved cassava varieties (Howeler, 2012). If this trend continues for the next decade, it is envisaged that labour constraints will be shifted from land preparation to harvesting as is been experienced in most cassava growing regions of Africa.

Cassava is normally planted using stem cuttings, also called "stakes". The stems are normally cut when the mother plant is 8-12 months old. Stakes derived from the lower and middle part of the stem have significantly higher germination rates than those derived from the upper part of the stem (George et al., 2001), and 150-200 mm stakes have higher germination than shorter stakes of 50-100 mm length (**Fig. 1**).

Planting Method

If the soil is loose and friable, stakes can be planted vertically by pushing the lower part of the stake about 50 mm length into the soil. When the soil is well prepared and friable, planting vertically is faster than planting horizontally, but care should be taken that the eyes or buds on the stakes face upward.

Cutting is at an angle, which makes it easy to insert the stake into the soil, but the Centro International de Agricultural Tropical (CIAT) recommends horizontal cutting because a slanted cut increases tissue exposure and dehydration (Sinthuprama, 1980).

Helio (1980) explained the cassava stems preparation for planting in Brazil.

A circular saw powered by an electric, gasoline or diesel motor was used to cut the stems into 200 mm length, and placed them in plastic boxes for use as the planting material for a Sans planter. Akhir and Sukra (2002) reported about a cassava stems cutting machine in Malaysia. The stems are cut by seven circular saws attached on the horizontal cutting shaft, which was operated by an electric motor. The conveyer chain with pegs was used to convey the cassava stems to the cutting unit. It can cut up to 3,300 stakes h^{-1}. Guzel and Zeren (1990) studied the theory of free cutting and its application for cotton stalk cutting. The results indicated that when cutting height was 100 or 150 mm and diameter of stalk ranged between 10 and 25 mm, energy consumption of blades were from 240 to 289 kg-m. Also, maximum and minimum velocities for blade varied from 46.97 to 51.87 and 33.67 to 36.52 ms^{-1} respectively.

Fig. 1 Cassava stakes for planting

A cassava stem cutting unit was developed to generate the design data for its use on a prototype of a cassava planter (Lungkapin et al., 2007). It consisted of a 255 mm circular saw blade, cam mechanism, bottom plate, electric motor (0.75 kW) to operate saw blade and a motor (0.37 kW). The cassava stems were fed manually into a feeding chute for free fall on to the bottom plate, and then these were cut by the circular saw operated by an electric motor. Cutting capacity depended on cam shaft speed. At 50 rpm cam shaft speed, minimum cutting capacity was found to be 5,034 stakes per hour (40,272 stakes day^{-1}) with 83.91% cutting efficiency. The stems were undamaged when operated at these conditions and showed satisfactory germination performance.

At present planting is done by manually. The planting is done by women labours by placing stakes in the ploughed and ridged soil. This process requires around 20 man days ha^{-1} and is a tedious work. The farmers contract the entire planting operation and this leads to increased cost of cultivation. If suitable system is developed for ease in planting, the farmers may get considerably higher price and profit. Currently very few planters are available in India hence, to eliminate the above problem development of cassava planter was attempted.

Material and Methods

The farmers cultivate cassava for edible and industrial purposes. The edible varieties are Sree Visakham, Sree Sathya, Sree Jaya, Sree Vijaya, Sree Rekha and Sree Prabha. For industrial purpose, the available varieties are H-97, H-165, H-226, Sree Harsha, etc.

Development of Laboratory Model Cassava Stake Cutter and Planter

Cassava Stake Cutter

The experimental cassava stake cutter was developed (**Figs. 2** and **3**) with the following components:

a. Hopper
b. Cutting blade
c. Motor

Hopper

This unit consists of two hopper, one is feeding hopper another one is delivery hopper. The feeding hopper is made of mild sheet. It is trapezoidal in shape. Delivery hopper is round in shape with diameter of 80 mm.

Fig. 2 CAD drawing of experimental stake cutter

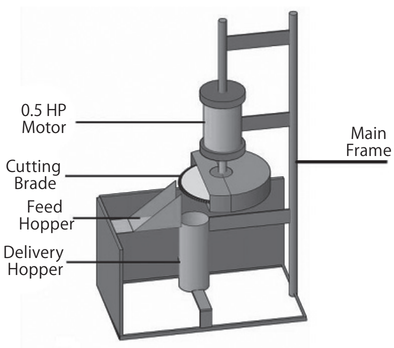


Fig. 3 Operational view of experimental cassava stake cutter

Cutting Blade

Cutting blade is made of mild steel. Diameter of cutting blade is 200 mm. It is used to cut the cassava stem in constant speed.

Motor

A 0.5 hp motor was used for cutting the cassava stems. The cutting blade is rotated with the help of motor.

Experimental Cassava Stake Planter

The Hopper

This unit consists of two hoppers one is a feeding hopper, another one is a delivery hopper (**Fig. 4**). This feeding hopper is made of MS with the dimensions 300 × 300 × 300 mm, which is trapezoidal in shape. At the base of the hopper a 5 mm diameter opening is provided and then below the feeding hopper, two numbers of counter rotating rubber rollers are placed. The variable speed motor gives the power to rotating rollers. Below the rollers, the delivery hopper is attached with funnel shape.

Worm Gears

The drive gear contains 60 TPI (teeth per inch) 12.5 mm diameter gear and driven gear contains 20 TPI- 5 mm diameter gear. The drive gear directly connected to the variable speed motor with help of universal joint. The drive and driven gear ratio is 1:3.

Rubber Rollers

It is made up of rubber with the following dimensions (15 × 5 mm) and the gap between these rollers is adjusted. The rollers are counter rotating.

Power Drive

Power drive is used to control or adjust the speed of the rollers. The rollers will be rotated in the speed range of 0-400 rpm.

The performance of stem cutting unit was analyzed with different circular saws, cam shaft speeds and cutting shaft speeds.

The following indicators were used to evaluate the performance of the developed cutting unit: in terms of cutting capacity, cutting efficiency, stem damage, power requirement, specific energy consumption and percentage of germination.

Their details are as follows:

a) Cutting capacity (stakes/h)

$C_p = s / t$

Where, s = number of stakes, t = time (h)

b) Cutting efficiency (%)

$E_f = (C_p$ / Theoretical cutting capacity) × 100

The theoretical cutting capacity was estimated to be twice the cam shaft speed.

c) Percentage of damaged stakes (%)

$= (D / s) \times 100$

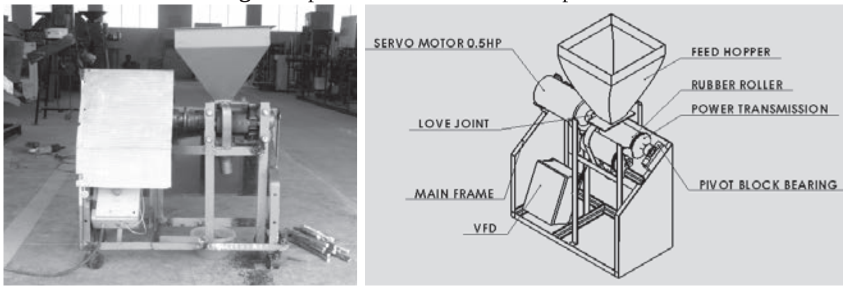
Where, D = Number of damaged stakes after cutting

All kinds of broken stakes (excluding rough cut-face) were considered to be damaged stakes.

Development of Tractor Operated Cassava Planter

A Prototype Tractor operated single row cassava stake cutting and planting equipment was developed at CIAE, RC, Coimbatore (**Fig. 5**). The developed unit consists of main frame, stake cutting system, stake planting mechanism, transmission

Fig. 4 Experimental Cassava stake planter



system and ridger.

Main Frame Assembly

The main frame of size 1500 × 790 mm is made of 75 × 50 mm MS rectangular tube with tractor hitching set up. A platform size of 785 × 400 made up of 50 × 50 mm MS square tube. Above the platform an operator seat is provided for seating an operator to feed the cassava stem in a height of 460 mm from the platform.

Ridger

The double disk ridger has two 560 mm diameter flat coulter disks mounted on bearing hubs. The two disk hubs are attached to a rigid, angled axle. The disks had an included angle of about 15° and had a single contact point. The disk contact point is such that the disk gap is diverging for the arc of the disk that is in the soil. The trajectory of the unplanted billet is forward of the disk axle. Both the discs were placed opposite to each other. The distance between the discs can be adjusted by sliding the shank to alter the ridge width. A ridging shaper was attached the back side of the ridge to smoothen the ridge. The designed height of ridge is 150-170 mm top width is 300 mm and the bottom width is 500 mm, which may slightly vary depending on the soil condition.

Hopper

Two numbers of hopper size 860 × 405 × 450 mm made of MS sheet, were fixed in the both sides of platform to keep the cassava whole stem as a feeding material.

Cutting Assembly

The cutting assembly consists of two sets of counter rotating shafts of diameter 65 mm. Around the periphery two or four number of blades size 100 × 50 × 10 m were fitted at equal distance in between the rubber shafts of diameter 65 mm was placed to hold the stem firmly to facilitate the cutting action and preventing the damage to the stake. The number of blades can be changed to get optimum stake length of size 200-240 mm. The rotary blades gets drive from the PTO of tractor through suitable gear transmission.

The cassava stem is manually fed through a chopper box that cuts the whole stem of cassava into stakes approximately 200-240 mm in length. The chopper box has sharp knives mounted on rotary drums to cut and feed the stakes. The twin drums are gear-driven and are synchronized such that the knives overlap and cleanly cut the cassava stem. Two stakes are produced for each rotation of the drum, and the pitch circle diameter of the drum is about twice the billet length (800 mm). Rubber feed rollers ensure positive feed of the cane stalk through the chopper box with minimal rind damage. As the chopper box is driven from the PTO drive, this metering system produces very uniform stake spacing when used by trained operator.

Planting Mechanism

The counter rotating rubber wheels of diameter 170 mm are fabricated and fitted below the cutting assembly to push the cut stakes in to the ridge with force. The funnel tubes fitted above the planting mechanism and below the cutting assembly guide the cut stakes to enter in to the counter rotating wheel assembly directly without any diversion. Below the planting wheels, a channel like provision is made to guide the pushed stake to enter into the soil on top of the ridge directly in vertical position.

Fig. 5 Tractor operated cassava planter

Transmission System

The power transmission arrangement for cutting assembly and planting mechanism arranged accordingly to get power from the tractor PTO. By changing the suitable gears speed of cutting mechanism and speed planting mechanism can be changed.

Tail Wheel

A spring loaded disc of diameter 410 mm made of 4 mm thick MS

Table 1 Technical specification

Sl. No.	Speed (%)	Setts/minute
1	Over all dimension (L × B × D), mm	1810 × 1730 × 1250
2	Weight, kg	344
3	Ridger	disc type
4	No of discs	2
5	Disc size(dia)	560 mm
6	Number of rows	one
7	Cutting mechanism	counter rotating shafts with rectangular blades
8	Planting mehansim	counter rotating planting wheel
9	Drive	PTO drive

Table 2 Experimental data for optimization roller speed for planting

Sl. No.	Speed (%)	RPM	Setts/minute			Setts/minute
			1	2	3	
1	50	190	64	56	65	61.66[aa]
2	60	240	56	61	66	61[aa]
3	70	290	70	69	71	70[bb]
4	80	320	70	69	71	70[bb]
5	90	360	82	78	80	80[cc]
6	100	400	78	82	79	79.66[cc]

Fig. 6 Relationship between Engine speed and stake damage

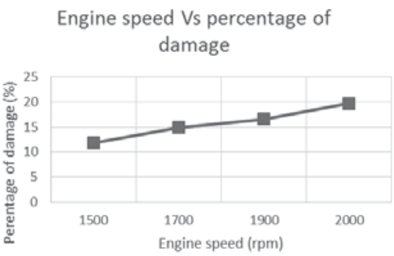


Fig. 7 Operational view of tractor operated cassava planter

Fig. 8 View of planted field

Table 3 Laboratory evaluation data of cassava planter

Sl. No.	Parameters	Engine speed, rpm			
		1,500	1,700	1,900	2,000
1	Cutting blade speed, rpm	29.9	33.5	36.4	38
2	Planter speed, rpm	1,093.6	1,185.6	1,329.6	1,421
3	No of Stakes min^{-1}	49	54	57.3	62
4	Damage, %	11.83	14.9	16.6	19.76
5	Cutting capacity, stakes h^{-1}	2,940	3,240	3,438	3,720
6	Cutting efficiency , %	0.81	0.80	0.78	0.81

sheet is provided to guide the planter and counter balance the stability of the planter.

Results and Discussion

Performance evaluation of the experimental cassava stake planter using cassava stems of different varieties was carried out. The experimental data for optimization of roller speed for number of setts planted per time is given in **Table 2**.

The test results indicate that the best planting was obtained at roller speed of 400 rpm and 360 rpm and the highest number of stems per minute was 80. Similarly, the lowest number of stems per minute was 50 stems in the speed of 190 rpm. Damage to the stems was not observed when operated at these conditions.

Laboratory Evaluation of Prototype Cassava Planter

Laboratory evaluation data are furnished in **Table 3**.

From the **Table 3** it was inferred that the cutting capacity increased with increase in engine speed, the highest cutting capacity of 3,720 stakes per hour recorded for engine speed of 2,000 rpm and the lowest cutting capacity of 2,940 stakes per hour recorded for engine speed of 1,500 rpm. The cutting efficiency was almost similar to all the speeds. The average cutting efficiency is 81%. The damage percentage of stakes also increased with increasing the speed. The lowest damage of 11.83% recorded for engine speed 1,500 rpm and the highest damage of 19.76% was recorded for 2,000 rpm (**Fig. 6**).

Evaluation of Prototype Under Field Condition

The operational view of the planter is shown in **Fig. 7** and the stakes planted are shown in **Fig. 8**. **Table 4** shows the results obtained during the field evaluation of the prototype cassava planter. Data presented for each trial is the average of three repetitions. For example, if the desired size of the stake is 200 mm, and the prototype is adjusted to produce stakes with this length, the result of the uniformity in size parameter indicates the efficiency of the machine to produce and plant stakes with the intended size.

Planting Depth

The average values of planting depth were measured as 63.7 and 20 mm for planter with two and four blades respectively (**Table 4**). From this data it was found that the planter with two blades is closer to the recommended depth of planning of 50 mm.

Mean Spacing

The mean value of the stake spacing of each stake planted row was

Table 4 Field performance data comparison for two and four blades

Sl. No.	Parameters	Four blades	Two blades
1	Plant spacing, mm	209.3	440.6
2	Depth of planting, mm	20.0	63.7
3	Stack length, mm	129	243.2
4	No of Nodes	6	13

Table 5 Overall performance data

Sl. No.	Parameters	Value
1	Uniformity in spacing, %	87.77
2	Uniformity in depth of planting, %	84.89
3	Missing, %	7.8
4	Effective field capacity, ha h^{-1}	0.18
5	Field efficiency, %	85
6	Fuel consumption, lh^{-1}	3.0
7	Tractor forward speed , km h^{-1}	2.0

recorded as 440.6 mm and 209.3 mm for planter with two and four blades respectively (**Table 4**). The mean spacing of cassava stake planted with two blade is very closer to the recommend spacing of 450 mm.

Stake Length

The average values of stake length were recorded as 243.2 and 129 mm for planter with two and four blades respectively (**Table 4**). From this data it was found that the planter with two blades is closer to the recommended stake length of 200 mm.

No of Nodes

The average number of nodes were recorded as 130 and 60 mm for planter with two and four blades respectively (**Table 4**). From this data it was found that the planter with two blades is closer to the recommended number of nodes of 10.

The overall performance data of cassava planter is summarized in **Table 5**.

Conclusions

The test results indicated that the best planting was obtained at roller speed of 400 rpm and 360 rpm and the highest number of stems per minute was 80. Similarly, the lowest number of stems per minute was 50 stems at speed of 190 rpm. From the laboratory trials the highest number of stakes per minute of 62 was obtained with the planting wheel speed of 1,421 rpm and cutting blade speed of 38 rpm, and corresponded to damage percentage of 34.7. The average length of stake cut was recorded as 240 mm and the average diameter of the stake was measured as 31 mm. The effective field capacity of the planter is 0.18 ha h^{-1}.

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Manufacture and Evaluation of a Solar Dryer for Aromatic Plants

by

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Abstract

This investigation was oriented to the design, manufacture and evaluation of a solar dryer for aromatic plants. For the fulfillment of the proposed objectives, appropriate theoretical-methodological bases referring to the subject were established and the pertinent computer tools were used. Amongst the main results obtained, it was evident that the theoretical foundations proposed made it possible to establish the design parameters of a solar dryer for aromatic plants. Using the SolidWorks computer tool, the developed prototype was designed. The manufactured solar dryer was evaluated using 0.8 kg of bay leaves. During the process, a weight loss of 25% and a moisture reduction rate of 4.34% / h were obtained and changes in the main physical and organoleptic properties of the bay leaves were shown. Thermodynamically, a total heat flow of 23.86 kW and a thermal efficiency of 37.4% were achieved, which demonstrated that the developed prototype has adequate efficiency. From the economic point of view, a specific cost was reached to dry one kilogram of bay leaves of 37.25 peso/kg and an operating cost of 1.49 peso/h.

Introduction

Currently, 10 to 40% of the harvested products never reach consumers. That occurs mainly in developing countries due to the decomposition and contamination of the produce (Esper and Muhlbauer, 1998).

There is a diverse range of post-harvest technologies applied to the preservation of perishable foods. However, in spite of being one of the oldest methods, the drying is still one of the most practical methods to extend the shelf life of the product and guaranteeing the physical, chemical and nutritional properties of foods (Balladin and Headley, 1999).

Drying is an expensive process, which represents between 35 and 40% of the total production cost. Amongst the drying processes currently applied are industrial drying methods, solar drying and the combination of both as a way to reduce energy consumption and improve product quality (Sagar and Suresh, 2010).

Since industrial dryers are not available to most small farmers, the use of low-cost and non-polluting alternative and renewable energy increases the economic viability of the process by reducing its application costs (Curcio et al., 2008; Purohit et al., 2006; Tshewang, 2005). Solar dryers are an alternative to drying in developing countries, where outdoor drying is the most widely used conservation method by small farmers (Purohit et al., 2006).

Taking into account that a high percentage of these farmers do not have access to the electricity network and the use of energy from fossil fuels has not been feasible due to costs, an effective alternative for drying their products is the use of renewable energy.

Various types of small-scale solar dryers have been developed and evaluated with their implementation in tropical and subtropical regions (Esper and Muhlbauer, 1998).

There are economic, social, environmental and cultural factors that are relevant in the design of drying technologies. For small-scale agricultural producers, only those activities and investments that significantly increase their incomes are significant, either directly by reducing costs or by increasing productivity. Therefore, unless solar drying systems offer exceptionally attractive benefits compared to outdoor drying or other drying systems, it will not be possible, in practice, to improve their acceptance (Purohit et al., 2006).

Under these circumstances, it is necessary to know and improve the current process of solar drying of agricultural products, and thus, reduce post-harvest losses, increase the quality of products, increase the efficiency of the process and achieve greater acceptance by farmers (Sagar and Suresh, 2010).

In 2006, world imports of aromatic plants recorded operations of more than $ 1.06 billion USD, a figure that reveals an inter-annual increase between 7% and 44% during the five-year period under study.

The United States, Germany and Japan consolidated as the main consumers of these products. The US market allocated an amount of 188 million USD to import these products, a value that represented an increase of 9% compared to 2005. In the specific case of Germany, it accumulated purchases of 128 million USD and a five-year increase of 63%. The Japanese market, became the third destination for world imports of aromatic plants and, despite having experienced a slight decrease of 3% in 2006 compared to the amounts imported in 2005, its purchases during the period 2002-2006 ranged from 90 million USD to 100 million USD. It is important to note that there is a divergence in the destinations of imports, with Europe, Asia and North America as the main buyers of aromatic plants.

Within the post-harvest process, drying is the most important step and it helps to achieve product quality, since the commercialization and conservation conditions will depend on it. It is considered as optimum result to bring the fresh material to 10% moisture content. The requirements for drying preparation are very high and, if they are not met or are not carried out at the right time, there is a danger of losing a large amount of active ingredients. The speed of drying, temperatures and air circulation are factors that determine good drying. The objective is to provide a product with a minimum percentage of moisture content in its tissues, which preserves color and aroma. Optimum drying temperatures vary in different species, although in general they range from 21° to 27°C (Fretes, 2010).

Due to the importance of post-harvest management, specifically the drying of aromatic plants, it is necessary to carry out research that allow designing and manufacturing a solar drying for aromatic plants.

Material and Methods

Theoretical-Methodological Bases for Determining the Physical Properties of Aromatic Plants

Knowing the physical properties of aromatic plants constitutes vital information in engineering, to adapt and operate machines, to design and build storage structures, to establish adequate transport systems, to design solar dryers, to perform quality analysis and to control processes involved in post-harvest handling. These properties include height, density, mass, moisture content and weight loss or mass variation.

Moisture content is an index of product quality that can be expressed on a moisture basis or on a dry basis, as shown in expression (1). It is also possible to determine this parameter using a humidity meter (Klaassen, 1983; Sato, 1994; Ohshita, 1995).

$$M_{wb} = W / (W_a - W) \times 100; \% \quad (1)$$

Where, W: Water content, kg; W_a: mass of product after drying process, kg.

The degree of humidity of aromatic plants is measured for one hour to observe the change in moisture content; this is called the rate of reduction of humidity per hour, which can be determined by the expression (2):

$$M_m = (M_i - M_a) / to; \ \%/h \quad (2)$$

Where, M_a: Moisture content after drying process, %; M_i: Moisture content before drying process, %; to: Operation time, h.

Loss of weight or variation of mass is the difference in mass of aromatic plants before drying with respect to it after being heat treated, it varies upwards during the drying process and directly influences in its duration, determined by means of the expression (3) (Thompson, 1985).

$$P_p = (W_b - W_a) / W_b \times 100; \% \quad (3)$$

Where, P_p: Loss of weight, %; W_b: mass before drying process, kg; W_a: mass after drying process, kg.

The mass of the product after drying can be determined using a balance, if this measuring instrument is not available, then the mass of the product after drying can be determined using expression (4):

$$W_a = [W_b \times (100 - M_a)] / (100 - M_i); \text{kg} \quad (4)$$

In the specific case of determining the size of the leaves of aromatic plants, a sample of 50 leaves is randomly selected. The thickness is measured with the use of a micrometer with an accuracy of ± 0.001 mm or minimum diameter. In the case of the mean and larger diameters, thickness is determined using a Vernier with an accuracy of ± 0.01; these measurements are made before and after the drying process.

For the determination of the volumetric density of the leaves of aromatic plants, a sample with a mass of 1 kg is selected. It is compressed in a test tube until the interstitial spaces are minimized. At the end of compression, the volume occupied by the leaves is observed. To obtain the volumetric density, the mass is divided by the volume it occupies.

Theoretical-Methodological Bases for the Design of Solar Dryers for Aromatic Plants

Drying is generally accomplished by applying heat to a substance with a certain percentage of moisture. It is very important to know the drying behavior, as well as the conditions and properties of the solid, because, based on them, the dryer can be designed according to the required needs. The study of drying also includes a set of problems such as geometries, fluid mechanics, heat and mass transfer, etc.

Bases for Calculating the Structural Resistance of Solar Dryers for Aromatic Plants

For the calculation of structural resistance of drying installations and other elements of agricultural machines and installations, the foundations defined by Feodosiev (1980), Stiopin (1985) were considered. In the specific case of solar drying installations, the resistance of the trays that support the material to be dried must be determined, as well as the structure of the dryer under study, which is determined through the safety factor (SDS) and of the stresses resulting from the third resistance hypothesis (Von Mises) using the SolidWorks®2017 computer system.

Bases for the Design of the Drying Chamber

For the design of the drying chamber, the volume of product to be processed (V) must be known, which can be determined by the volumetric density of the product. In the specific case of aromatic plants, the average volumetric density is 200 kg/m^3, so that the volume can be determined using the following expression:

$$V = W / \rho, \ m^3 \quad (5)$$

Where, W: mass of product, kg; ρ: volumetric density of product, kg/m^3.

The volume of the drying chamber (V_{cs}) must be four times the volume of the product, so that this is determined by the expression:

$$V_{cs} = 4 \times V, \ m^3 \quad (6)$$

Bases for the Design of the Product Placement Trays to be Processed

For determination of size of the trays, what is stated by Aparicio et al. (2011) is considered, which establish that the separation between trays should be approximately 2 inches or 4 cm high.

With the knowledge of the volume of the drying chamber and the product to be processed, it is possible to determine the volume of the trays (V_b), which in turn makes it possible to determine the number of trays required. The size of the trays must be considered in order to guarantee an easy loading and unloading operation of the drying installation.

Bases for the Design of the Solar Collector in Drying Installations

According to Montero (2005) for the design of solar collectors, efficient materials are normally selected to increase the outlet temperature of the air stream and, at the same time, to reduce the heat lost by the surfaces, that is, insulating materials. Aluminum, copper or galvanized steel, usually painted non-reflective black, is normally chosen for the absorbent plate and the plate can be smooth, corrugated or V-shaped. For the cover, transparent plastics with good mechanical properties (methacrylate, polycarbonate, polyethylene, etc.) and for the walls, the materials can be very diverse, but they must be insulators such as glass wool, rock wool or similar, and wood to give solidity.

The efficiency of the solar collector is a relevant parameter to check the correct operation of the dryer. A common value for natural convection is about 40-60%, being higher for forced convection with adequate airflow.

The collector efficiency is defined as the ratio between the heat power that is transmitted to the fluid stream, and the power that reaches the solar collector in the form of solar energy.

$$\eta = Q_u / (I_t \times A_c) \quad (7)$$

Where, Q_u: Heat that absorbs the air current from entering the collector until it leaves the collector, W, I_t: Total radiation on the inclined surface of the collector in W/m^2, A_c: Collection area in m^2.

$$Q_u = m_a \times C_{pa} \times (T_{fo} - T_{fi}); \ W \quad (8)$$

Where, m_a: is the mass flow of air, kg/s; C_{pa}: is the specific heat of the air, J/kg °C; T_{fo}: the air outlet temperature in the collector, °C; T_{fi}: inlet air temperature in the collector, °C.

For the measurement of the mass flow of air, a PROVA-AVM-05 anemometer is used, which offers the value of air speed. The ambient temperature is measured with three thermometers with a scale from 0 to 50°C and ± 0.1°C degree of precision, one of them placed on the surface of the layer of leaves, another one at the bottom of it and the third one in the solar collector. To determine the magnitudes of the cross-sectional area of the humid air outlet and the total area of the collector and walls of the drying installation, a tape measure of 5 m and a degree of precision of ± 1 mm is used. The thickness of the wall of the collector and walls of the prototype is determined with a vernier of ± 0.01 mm.

To support the efficiency of the solar collector, the foundations stated by Uriol (2016) regarding the determination of the energy balance for polyethylene roofs are considered, where the following hypotheses are considered:

a) There is no temperature gradient across the thickness of the cover and absorbent plate.
b) The system is perfectly insulated, there are no air leaks.
c) The heat capacities of the cover, absorbent plate and insulation are negligible.

Theoretical-Methodological Bases for the Determination of Heat Transfer in Solar Dryers of Aromatic Plants

To establish the fundamentals of heat transfer in drying installations, the criteria recognized by Faires and Simmang (1978), Geankoplis (1998) and Cengel (2002) are considered.

To dry a solid two fundamental and simultaneous processes take place:

a) Heat transmission to evaporate the liquid.
b) Mass transfer in internal humidity and evaporated liquid.

Heat transfer is defined as energy in transit due to a temperature difference, that is, whenever there is a temperature difference between different bodies, a heat transfer must occur. Heat can be transferred from one body to another through three ways. These are conduction, convection, and radiation.

Theoretical-Methodological Bases for the Functional Evaluation of the Aromatic Plant Drying Installation

For the functional evaluation of a drying installation, general behaviors have been established (Roa and Ortega, 2011), that is why it is very important to analyze and define the parameters that are taken into account when designing them.

Parameters to Evaluate during the Drying Process

Drying aromatic plants decreases the amount of moisture to pre-established levels. The required decrease in humidity ΔM serves as the basis for determining the amount of water that will be evaporated.

$$\Delta M = (M_i - M_f) / (100 - M_f) \times 100; \% \quad (9)$$

Where, ΔM: moisture content reduction, %; M_i: Initial moisture content, %; M_f: final moisture content, %

So the mass of water to be evaporated is:

$$W = (W_s \times \Delta M) / (100 - \Delta M); \% \quad (10)$$

Where, ΔW_{H2O}: mass of water to evaporate, kg; W_s: mass of dry matter at the end of the process, kg.

Theoretical Bases for Economic Analysis

In order to determine the profitability of the manufactured prototype, the bases were established to determine the operating costs.

Bases for Determining the Operating Cost of the Prototype

For the determination of the operating cost (C_{exp}), the determination of the fixed costs (C_f) and variable costs (C_v) of the prototype is required and the sum of these costs allow determining the operating cost (Iglesias, 2002; Hunt, 1983; Iglesias et al., 1999). That is to say:

$$C_{exp} = \sum_{i=1}^{n} C_{fi} + \sum_{i=1}^{n} C_{vi}; \text{peso/h} \quad (11)$$

Specific costs (C_{esp}). The specific costs define the cost in peso for each unit of work carried out. That is, the existing relationship of the operating cost in peso/h, between the productivity (P_{inst}) in t/ h, for the prototype is determined by:

$$C_{esp} = C_{exp} / P_{inst}; \text{peso/t} \quad (12)$$

The productivity of the drying installation is obtained from the relationship between the amount of water removed in the process and the time required to reach the adequate humidity for storage or further processing (t_o).

$$P_{inst} = W / t_o; \text{kg/h} \quad (13)$$

Table 1 Results of the heat flow obtained in the component parts of the proposed drying system.

Materials	Q, kW				Area, m²	Thermal Efficiency, %
	Conduction	Radiation	Convection	Total		
Drying Chamber	15.00	0.19	-0.060	15.13	1.63	37.4
Collector	8.35	0.11	-0.033	8.43	0.89	
Total	23.35	0.30	-0.093	23.56	2.52	

Results and Discussion

Design and Manufacturing of the Prototype for the Solar Drying of Aromatic Plants

The designed and manufactured solar dryer for aromatic plants (**Fig. 1**) has a solar collector whose geometric dimensions are 1500 × 500 × 96 mm and a drying chamber whose geometric dimensions are 1000 × 500 × 400 mm. It is based on the operating principle of raising temperatures both in the solar collector and inside the drying chamber and achieving adequate air extraction as essentials to increase the efficiency of the drying process. On the other hand, the structural resistance calculations were carried out to guarantee that the prototype supports the loads to which it is subjected and the maximum deformations that it can withstand when the trays are full of leaves of aromatic plants.

With the purpose of evaluating the structural resistance of the

Fig. 1 Solar dryer of aromatic plants developed in research

Table 2 Bay leaf size behavior before and after the drying process

Average orthogonal dimensions, mm	Bay Leaves (Before drying)	Bay Leaves (After drying)	Difference, mm
Long (L), mm	66.54	64.35	2.19
Width (a), mm	35.94	32.94	3.00
Thickness (es), mm	0.36	0.29	0.07
Diameters			
Geometric mean diameter (D_g), mm	9.51	8.20	1.31
Arithmetic mean diameter (D_a), mm	34.28	30.31	3.97

Table 3 Behavior of the loss of moisture and mass of the bay leaves during the drying process

Initial Mass, kg	Final Mass, kg	Initial Moisture Content, %	Final Moisture Content, %	Amount of water removed, kg
0.8	0.6	35	13.13	0.2
Weight loss , %		Moisture reduction rate, %/h		
25		4.34		

prototype, the maximum stresses, displacement and unitary deformation to which it is subjected were determined. For this, the SolidWorks®2017 computer system was used, which, using finite elements, considers the criteria by Von Misses.

To determine these values, a mass of 10 kg was taken as a reference, considering the volumetric capacity of the trays located in the prototype's drying chamber, which have a volume of 0.007 m^3.

As it is seen in **Fig. 2a**, the maximum displacement is obtained between the upper limit of the polyethylene collector and the lower edge of the drying chamber, reaching a value of 2.3 mm, observing that the limit displacements are at the centric points. In **Fig. 2b**, it is observed that the unitary deformation reaches a value of 9.69×10^{-4}. In **Fig. 2c** it is shown that the maximum tension obtained is 1.5×10^7 Pa, at the base of the drying chamber, which when compared to the maximum allowable stress of the material, demonstrates the structural resistance of the prototype.

Energy Transfer in the Proposed Drying Installation

In **Table 1**, the behavior of the heat flows that respond to each of the energy transfer mechanisms can be seen. These results are of great importance due to the characteristics that this type of system must have. It must achieve higher temperatures than those of the environment to carry out an efficient drying process, without damaging the physiological quality of the product to be dried. The heat flow results were determined separately for the drying chamber and the solar collector.

From the results of each heat transfer mechanism, the total heat flow of the developed drying installation was determined, which amounts to 23.56 kW. That shows that the proposed design works as an installation of drying. From these values and the value of the average incident solar radiation in Cuba, that is 5 kW/m^2.day, the thermal efficiency of the prototype was determined. It reached a value of 37.4% and means the percentage of solar energy that is used by the system, favorable to carry out the solar drying process of bay leaves. These results validate the thermodynamic principles on which the prototype was designed.

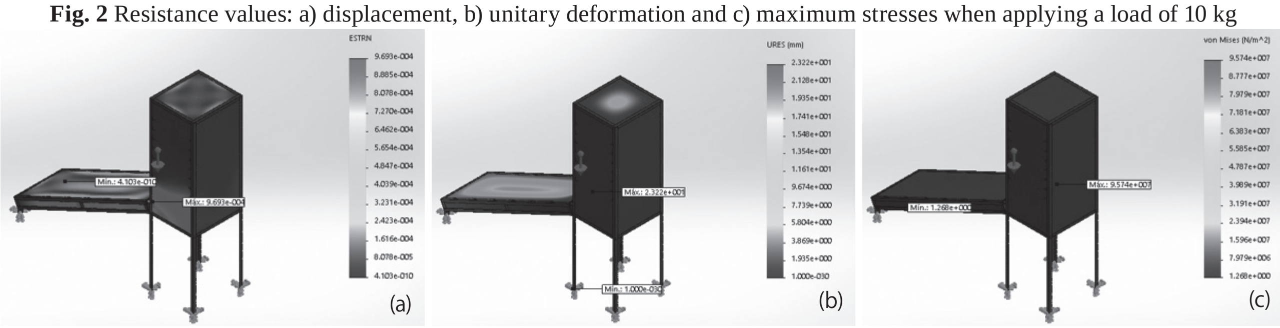
Determination of the Main Physical Properties of Bay Leaves

In order to increase the productivity and efficiency of the drying process, a solar dryer for aromatic plants was developed, which was designed, manufactured and evaluated in areas of the Agricultural Mechanization Center (CEMA) of the Agrarian University of Havana.

For the evaluation process, a sample of freshly harvested (undried) bay leaves was taken from "La Joya" farmhouse. The sample had an initial mass of 0.8 kg and the behavior of its physical properties, before and after the aforementioned process was determined. Size, moisture content and final mass of the product before and after drying were determined (**Tables 2** and **3**).

As it can be seen in **Table 2**, with the performance of the solar drying process, the values of the orthogonal dimensions and, correspondingly,

Fig. 2 Resistance values: a) displacement, b) unitary deformation and c) maximum stresses when applying a load of 10 kg



the diameters are reduced, because of the shrinking of the leaves. This confirms that the drying process influences directly on these properties.

To achieve a better understanding of the results shown in **Table 2** and appreciate the influence of the drying, images of the leaves were taken before and after that process (**Fig. 3**).

As it can be seen in the previous figure, the leaves, before being subjected to the drying process, had an intense green coloration and, after the drying process, they took on an opaque green color with a tendency to brown.

Another observed property was the texture; before the drying process, the leaves had a marked elasticity (they did not fracture easily) and after drying, they fractured easily. That demonstrates the relationship between moisture content and texture.

The influence of the drying process on the loss of moisture and mass was determined from the relationship between the moisture content and the initial and final mass of the sample analyzed (**Table 3**).

Functional Evaluation of the Drying Installation for Aromatic Plants

In order to analyze the drying process of the bay leaves, the kinematics of it was determined inside the drying chamber, that is, the decrease in moisture content was observed as a function of the operating time (**Fig. 4**).

As evidenced in **Fig. 4**, to achieve the reduction of the moisture content from 35% to 13.13%, for a sample of bay leaves with an initial mass of 0.8 kg, only 5 h of operating time was required, linearly reducing the moisture content of the analyzed sample. This efficiency in the drying process is given by the values of weight loss or mass variation and the rate of moisture content reduction (**Table 3**).

In addition to these results, the efficiency of the installation was also validated with the values of the vaporization rate and the productivity achieved, which were 0.02 kg/h and 0.04 kg of water removed/h, respectively.

Table 4 Economic costs per hour of operation of the prototype

Costs	Drying process
Depreciation cost (C_d), peso/h	0.04
Fuel-lubricant cost (C_{cl}), peso/h	0
Electricity cost (C_{el}) peso/h	0
Maintenance-repair cost (C_{mr}), peso/h	0.003
Cost in salary (C_s), peso/h	1.45
Operation Costs (C_{exp}), peso/h	1.49
Specific cost (C_{esp}), peso/kg	37.25

To evaluate the operation of the prototype, the temperature inside the drying chamber was monitored and its behavior can be seen in **Fig. 5**.

As it is observed in the **Fig. 5**, the minimum difference between the temperature obtained inside the dryer and the ambient temperature, was obtained after placing the samples inside the installation (at the beginning of the drying process). A difference of 1.2 °C was observed. However, when the drying process stabilized, a maximum difference was reached between the temperature obtained inside the dryer and the ambient temperature of 12.1 °C. This difference was obtained at the third hour (13:38 h) after the drying process started.

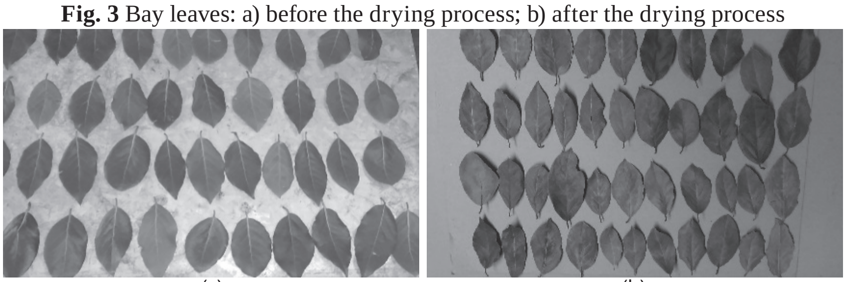
In general, during the entire drying process, an average temperature increase of 7.48 °C was achieved, which gradually increased, without appreciating thermal collapses, an aspect that reveals the functionality of the installation designed.

Economic Analysis

In order to carry out an in-depth economic analysis with respect to the prototype developed, the operating costs of the prototype during the process were determined, which are represented in the **Table 4**.

The cost in salary is based on the current minimum wage in the country, as well as the amount of work done in hours. The costs in fuels and lubricants are nil since the manufactured prototype does not require fossil fuel, or lubricants for its operation. The depreciation cost reaches a value of 0.04 peso/h, with the initial price of the prototype being 536.71 peso, considering an annual depreciation percentage of 12% and an annual load of 180 days working 8 hours. The cost in maintenance and repair only considers the replacement of the polyethylene cover, which must be replaced annually. The specific or required cost to dry one kilogram of bay leaves is 37.29 peso/kg. To obtain these values, the productivity achieved by the prototype was considered, which was 0.04 kg/h, for a mean moisture

Fig. 3 Bay leaves: a) before the drying process; b) after the drying process



(a) (b)

content reduction rate of 4.34%/h.

Conclusions

a) The proposed theoretical-methodological foundations made it possible to manufacture and evaluate a solar dryer for aromatic plants.
b) With the use of the developed solar dryer, a weight loss of 25% and a rate of moisture reduction of 4.34%/h were achieved, showing variations in the main physical and organoleptic properties of the bay leaves.
c) Using the SolidWorks 2017 computer tool, the structural resistance analysis of the developed prototype was performed, observing that it resists the loads to which it will be subjected.
d) The total heat flow of the proposed aromatic plant solar dryer amounts to 23.86 kW, reaching a thermal efficiency of 37.4%, which shows that the prototype developed has adequate efficiency. The economic analysis shows that the developed prototype is feasible for small-scale agricultural producers dedicated to the production of aromatic plants.

Recommendations

a) Introduce the prototype developed in productive areas for the production of aromatic plants.
b) Carry out other investigations using other aromatic and medicinal plant varieties, where the maximum capacity of the facility is used.
c) Carry out research aimed at analyzing the quality of the products processed in the proposed installation, as well as the behavior of the active ingredients and essential oils.

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Fig. 4 Kinematics of drying bay leaves

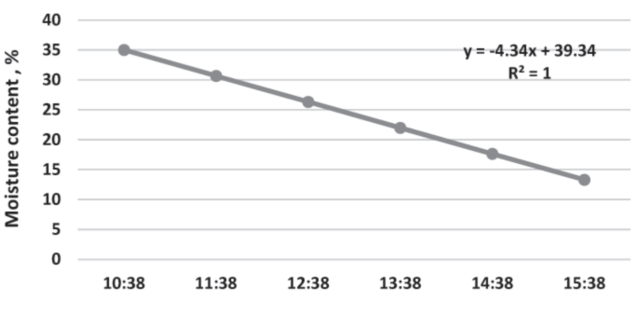
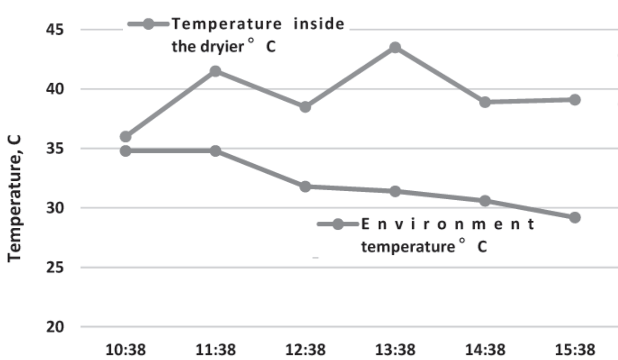


Fig. 5 Behavior of temperature outside (ambient) and inside the dryer



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Design and Development of a Tractor-drawn Liquid Fertilizer Applicator

by

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Abstract

This study was carried out to design and develop a tractor operated liquid fertilizer applicator, which could place liquid fertilizer inside soil simultaneously with seed. The liquid fertilizer selected was Urea Ammonium Nitrate. A liquid fertilizer metering system was developed that comprised a piston pump, control valve, distributor and conduit pipes. The piston pump was operated by tractor power take-off. The metering system was calibrated for nitrogen basal dose application. There was approximately 30-33% increase in flow rate with an increase in pressure from 0 to 1 kg-cm^{-2}, whereas, there was only 6-10% increase in flow rate when pressure changed from 1 to 2 kg-cm^{-2}. For a flow rate range of 11.1-17.96 l min^{-1}, the required pump speed ranged between 245-421 revolutions per minute. A shovel type furrow opener was modified to conduit the fertilizer into soil. Modified shovel furrow openers were able to place liquid fertilizer inside the soil at a depth of 3-4 cm below the wheat seed. The prototype liquid fertilizer applicator had an average draft requirement of 3.2 kN at full tank load (300 liters). The average slip of applicator was 6.23%. The average field capacity and field efficiency were 0.23 ha.h^{-1} and 72% respectively for continuous operation of the applicator at an average speed of 1.78 km.h^{-1}.

Keywords: applicator, tractor, liquid fertilizer, wheat, Urea Ammonium Nitrate

Introduction

Granular fertilizers are widely used in the crop production system. In global fertilizer demand, Nitrogenous fertilizer has the major share (60%) compared with phosphoric (22%) and potassic (18%) fertilizer (FAO, 2017). Among Nitrogenous fertilizer, urea commands a worldwide market share of 58 percent (Anonymous, 2017). However, Urea has a major disadvantage in terms of losses of N through volatilization, if it is not incorporated into the soil soon after application (Chen et al., 2016). Injection of liquid fertilizer into the soil can reduce nutrient loss through volatilization, reduce surface runoff pollution, and increase plant uptake of nutrients. Application of aqueous urea at root zone depth enhanced plant growth performance parameters in addition to better germination (Kant, 2008)). Due to the limitations of prilled urea, liquid fertilizers are popular in foreign countries viz. USA, European Union, Australia and many more (Anonymous, 2017 and Isherwood, 2003).

The most widely used nitrogen-based liquid fertilizer in these countries is Urea Ammonium Nitrate (UAN), which is an aqueous solution of urea and ammonium nitrate. UAN solutions are commonly injected into the soil beneath the surface, sprayed onto the soil surface, dribbled as a band onto the surface, added to irrigation water, or sprayed onto plant leaves as a source of foliar nutrition (IPNI, 2019). UAN contains nitrogen (N) between 28-32%. The NO^{3-} portion (25% of the total N) is immediately available for plant uptake. The NH^{4+} fraction (25% of the total N) can also be assimilated directly by most plants but is rapidly oxidized by soil bacteria to form NO^{3-} (nitrate). Soil enzymes hydrolyze the remaining urea portion (50% of the total N) to form NH^{4+}, which subsequently transforms to NO^{3-} in moist soil conditions.

It is easier to calibrate equipment to uniformly apply UAN via liquid applicators as compared to other types of fertilizer materials (Leikam, 2012). It is also easier to accurately regulate the desired rates of crop nutrients with liquid application equipment as compared to granular fertilizer. Urea Ammonium Nitrate (UAN) accounts for 5% of the total fertilizer consumption in the world (Anonymous, 2017). However, the shift of fertilizer consumption pattern from prilled urea to UAN is increasing and contributed 28% of the fertilizer demand in the United States of America and 12% in European Union (Anonymous, 2017). However, in India, 84% of the total fertilizer consumption is in the form of prilled urea. In India, way back in the 1970s, a public sector company developed a liquid fertilizer 'Ankur' that was found to be a good source of Nitrogen for wheat (Singh and Aggrawal, 2012). In spite of a number of benefits of liquid fertilizers for manufacturers' as well for farmers, the use of liquid fertilizers did not pick up in India due to lack of appropriate liquid fertilizer application technology. The non-availability of scientific data on application methodology and yield benefits of UAN and the lack of necessary proper storage and transport facilities for UAN among farmers hindered the popularization of liquid fertilizer (UAN) in the country.

Application of liquid fertilizer alongside the seed needs a precise and proper method to avoid contact of seed with liquid fertilizer. The precise placement of fertilizer and seed is critical for the efficient use of fertilizer and for enhanced plant growth. Fertilizer placed in high concentrations next to the seeds can result in toxic effects to the seedlings. If the concentration of fertilizer is too high close to the developing seedling, germination and emergence can be adversely affected. If seed and fertilizer are separated appropriately, fertilizer banded vertically below or laterally at some depth below the seed can efficiently provide nutrients to the seedling and without any damage to the roots. Simultaneous placement of seed and liquid fertilizer requires the development of a liquid fertilizer application system that can facilitate the differential depth application of seed and liquid fertilizer for proper seed emergence and root establishment.

Keeping the above points in view, a tractor-drawn liquid fertilizer applicator prototype, which could place the fertilizer inside soil was designed and developed.

Material and Methods

For the development of liquid fertilizer (i.e. UAN) application system, optimum placement depth of liquid fertilizer in the soil, furrow opener design and appropriate liquid fertilizer metering system are of critical importance. It was recommended to keep a vertical gap of at least 2 and 3 cm between seed and UAN with dilution ratio (UAN: Water) of 1:10 and 1:5 respectively while sowing wheat (Sundaram et al., 2017). For the design of furrow opener, type, size and material need to be given due consideration. In contrast to granular fertilizer, the liquid fertilizer metering can be either gravity fed or pressurized. The pressurized metering system although better in performance as compared to gravity fed, demands an optimum operating pressure and efficient liquid distribution system.

Urea Ammonium Nitrate fertilizer was provided by the National Fertilizer Limited, Nangal, India.

Design of Various Components of Liquid Fertilizer Applicator

Different components of liquid fertilizer applicator viz. furrow opener, liquid fertilizer metering system, power transmission system for the pump, seed hopper and liquid fertilizer tank were designed and fabricated.

Furrow Opener

Furrow opener is the most critical components in the design of liquid fertilizer applicator as it has to make a furrow as well as help in placing liquid fertilizer below the seed. Shovel type furrow openers were selected as they are the most common type of furrow openers used in conventional tillage (Chaudhuri, 2001). Due to the corrosiveness of UAN liquid fertilizer towards mild steel (Cahoon, 2002), it was decided to use narrow Poly Vinyl Chloride (PVC) tubes for the conduit of liquid fertilizer in order to avoid contact between UAN and the furrow opener surface. A groove of cross-section 7 × 7 mm was made in the lower front shank to fit the selected delivery pipe for liquid fertilizer. For placement of seed, the boot of the conventional seed drill was modified by split opening the lower part into two halves and shaping it with the help of hammer in the form of small furrow opener (**Fig. 1 a** & **b**).

Design of Shank of Furrow Opener

Shank is the straight part of the furrow opener that bears the load received at the lower part of furrow opener.

Draft force exerted on furrow opener was calculated using formula (Kepner et al., 1987):

$D = k_0 \times W \times d$ (1)

Where,

D = draft, N

k_0 = specific soil resistance, $N.mm^{-2}$ = 0.0147 N/mm^2 was selected for medium soil (Varshney et al., 2000), for calculation of draft it is taken as 5 times the value of normal soil (Sharma and Mukesh, 2008)

W = Width of furrow opener, mm

d = Maximum depth of operation, mm

Assuming, W = 25 mm, d = 120 mm as liquid fertilizer had to be placed at appropriate depth in the soil and $k_0 = 0.0147 \times 5 = 0.0735$ $N.mm^{-2}$ and substituting in equation 1

$D = 0.0735 \times 25 \times 120$ N = 220.5 N

Taking factor of safety as 3,

Total draft acting on a single furrow opener = 220.5 × 3 = 661.5 N

Total draft acting on nine furrow openers = 661.5 × 9 = 5.953 kN

Considering shank as a cantilever beam, the maximum bending moment was calculated as

Bending moment (M), N-mm = Draft (N) × Length of shank (mm) = 661.5 × 500 N-mm = 330.75 KN-mm (2)

Section modulus (z) of the shank was computed by

$z = I / y$ (3)

Where,

I = Moment of inertia of the rectangular section, mm^4

y = Distance from the natural axis to the point at which stress is determined, cm

Also, from the classical flexural formula

$\sigma = My / I$ (4)

Where,

σ = Bending stress, Nmm^{-2}

M = Bending moment, N-mm

y = Distance from the natural axis to the point at which stress is determined, mm

I = Moment of inertia of the rectangular section, mm^4

Allowable bending stress of mild steel = 70 Nmm^{-2}

Taking factor of safety = 2, (factor of safety for mild steel is taken as 1.5 to 2), (A.S.M.E.)

Design bending stress = Allowable bending stress x-factor of safety = 70 × 2 = 140 Nmm^{-2}

From equation 3 and 4,

$z = M / \sigma = (330.75 \times 1000) / 140$ mm^3 = 2362.5 mm^3

The most assumed ratio of the thickness (b) to the width (h) of the shank, b:h = 1:3 to 1:4[14].

Assuming, b:h = 1:3 and h = 3b

From equation 4,

$z = I / y$

Moment of inertia of rectangular section, $I = (b \times h^3) / 12$

Distance from the natural axis to the point at which stress is determined, $y = h / 2$

Hence, $z = (b \times h^2) / 6 = 2362.5$

$[b \times (3b)^2] / 6 = 2362.5$

$b^3 = (2362.5 \times 6) / 9$

b = 11.63 mm

The adjacent thickness available for Mild Steel iron flat was 15 mm

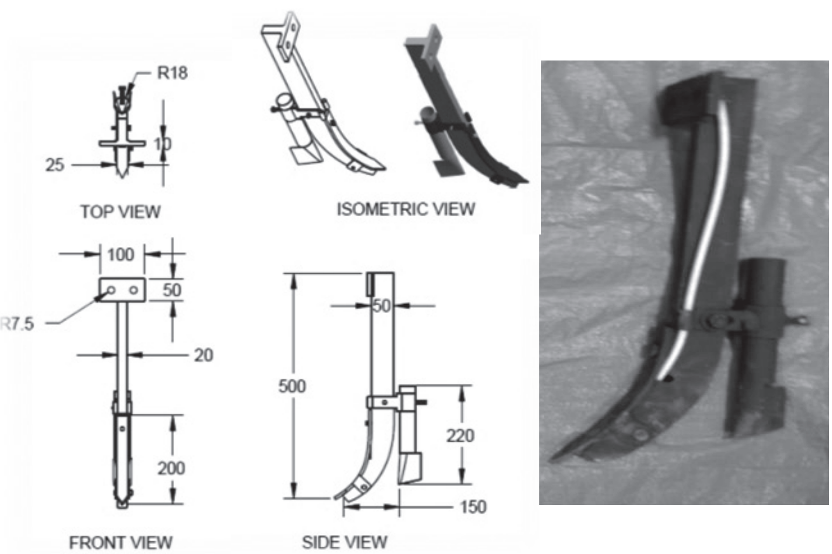
Therefore, width of shank = 3 × b = 3 × 15 = 45 mm

Hence, an MS flat of 15 × 45 mm was found to be sufficient to bear the bending moment caused by to the draft force on furrow opener. The nearest available flat of 20 mm × 50 mm was selected for designing shank of furrow opener.

Liquid Fertilizer Metering System

To avoid over-fertilization and under fertilization, liquid fertilizer should be distributed uniformly among different delivery tubes for uniform on field application. A circular distributor made of nylon was designed and developed (**Fig. 2**). It had a simple design with a central inlet opening into a disc-shaped chamber. To maintain uniform pressure and uniformity of flow, the volume of the inside chamber of the distributor was kept as minimum as possible. Nine holes were drilled around the periphery of the distributor at a spacing of 10 mm and each

Fig. 1 Shovel type furrow opener



(a) Different Views and major dimensions (b) Prototype furrow opener hole was screwed. The discharge from each pipe was measured and used for the analysis of flow uniformity and calibration (**Fig. 3**).

Design of Distributor

From the geometry (**Fig. 2**),

Inner perimeter of the chamber = (diameter of connector x no. of connectors) + (Space among two connector x no. of connectors) = 8 × 9 + 10 × 9 = 162 mm

Inner Diameter of Chamber = Perimeter / π = 162 / π = 52

Keeping the thickness as 10 mm,

Outer diameter of the chamber = Inner diameter of chamber + thickness = 52 + 2 × 10 = 72 mm

The UAN applicator was to be operated by a commonly available 40-45 hp tractor. Different moving components of the machine were supplied power from the tractor. A piston pump was used to pump liquid fertilizer and deliver it from the fertilizer tank to the distributor.

A suitable power transmission system was designed and fabricated for this purpose. The rpm of PTO varied as the engine speed varied. The tractor had to be operated in the field at a speed ranging from 1.5-2.0 km.h^{-1}. A relationship between engine rpm with PTO rpm as well as the linear speed of tractor was established (**Fig. 4**). The tractor was operated in lower first gear in the tilled filled which had a soil moisture content of 12 ± 2% (db). The engine speed was changed to different levels by changing the location of hand accelerator of the tractor. The PTO rpm was measured by contact type tachometer.

Experimental Set Up for Calibration of Liquid Fertilizer Metering System

An experimental set-up was fabricated for calibration of liquid fertilizer metering system with the provisions of varying (a) input rpm to the piston pump, and (b) pressure variations for different discharge levels. The experimental set up included one storage tank, a piston pump for supplying liquid fertilizer, a distributor, a pressure regulating valve, a ball valve to control liquid flow, connecting pipes, and power transmission system (**Fig. 3**). The power transmission system included a three-phase motor for driving pulley of the pump and a variable frequency drive (VFD) for controlling the rpm of the motor. Change in frequency by 0.1 Hz caused a corresponding increase/decrease of induction motor rpm by three units. The variation in the discharge of the pump was obtained by varying the speed of the pump. The study was conducted for discharge rate and discharge uniformity at different pump rpm and input pressure, **Table 1**.

Fig. 2 Different views of liquid fertilizer distributor

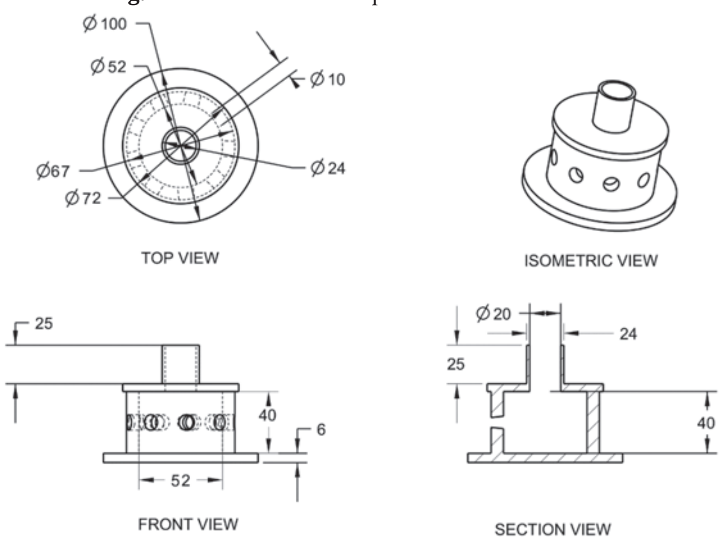
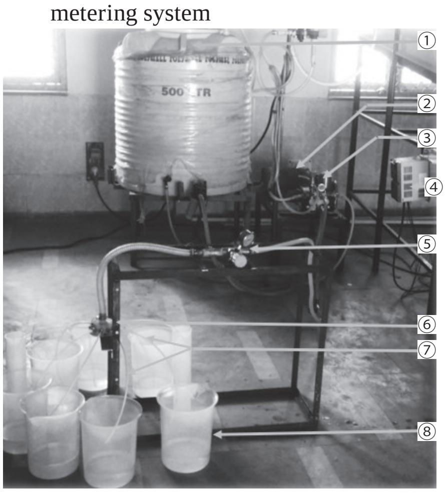


Fig. 3 Experimental set up for evaluation of liquid fertilizer metering system



①Fertilizer tank
②Motor
③Motor with pump
④Variable speed drive
⑤Pressure relief valve
⑥Liquid distributor
⑦RO pipes
⑧Collection units

Fig. 4 Relationship among engine speed, PTO speed and forward speed of tractor

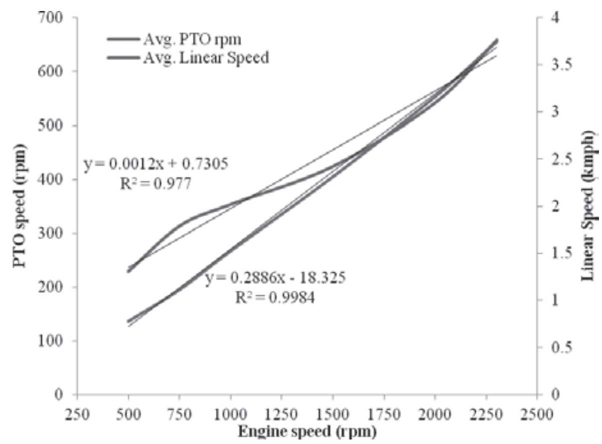


Table 1 Experimental plan for calibration of the liquid fertilizer metering system

Variables	Levels	Details	Measured parameter
Pump rpm	11	225, 255, 300, 330, 374, 420, 450, 525, 600, 675 and 750	a. Flow rate through different pipes, l min^{-1}
Pressure, k gm^{-2}	3	0, 1 and 2	b. Distribution uniformity among pipe flow rates

The estimated UAN requirement was 340 and 170 l ha^{-1} at 100 and 50% basal dose of nitrogen in wheat. UAN was diluted with water in the ratio of 1:10, 1:12.5 and 1:20 for applying 100%, 80% and 50% basal doses of Nitrogen, respectively. The range of pump rpm for the study was selected based on the rpm of power take-off (PTO) of the tractor as the UAN applicator metering system was to be operated by PTO. At rated rpm of the tractor engine, the rpm of PTO was 540 ± 10. Hence, an operating range of 225-750 rpm was selected. Eleven selected rpm levels of pump were selected (**Table 1**). The selected pressure levels for the study were 0, 1 and 2 kg-cm^{-2}. During the experimentation, the tank was filled with water. Initially, the frequency of VFD was kept at 15 Hz, which gave a motor rpm of 450. The discharge from each delivery pipes was collected in a plastic container of 5 litre capacity and measured using a measuring cylinder. The frequency was changed through VFD in increasing order from 15-50 Hz to get the required pump revolution. The discharge from each pipe was measured and based on these observations flow uniformity analysis was carried out.

Statistical Znalysis of Discharge Data

The discharge data thus, obtained from the experiments on performance evaluation of liquid fertilizer metering system was formatted in MS EXCEL package and the Coefficient of Variation (C.V) of the average data was calculated to find the uniformity of distribution.

Seed Hopper

A trapezoidal seed hopper most commonly used in seed cum fertilizer drill was used for fabrication of UAN applicator. The bottom of the box was flat and rounded at the corners. The inclined guiding plates were fitted at the base to help the movement of seed towards the inlet opening of the metering device. Due to the placement of fertilizer tank in the front part of the machine, the seed hopper was positioned 150 mm behind the frame and 900 mm above the ground.

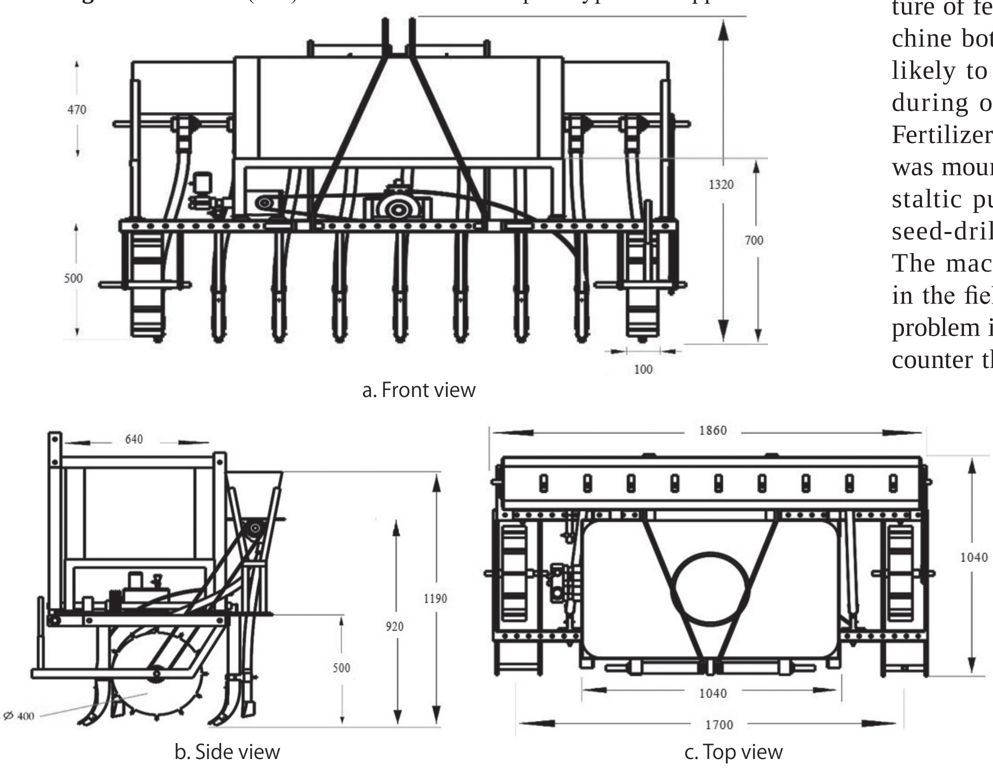
Seed Metering Mechanism

Fluted roller type seed metering mechanism was selected for metering of wheat seed. The rate of seeding with the fluted roller was controlled by changing the exposure length of the fluted roller to the seed.

Liquid Fertilizer Tank

Liquid fertilizer tank of appropriate size and shape was required for UAN solution. Due to the liquid nature of fertilizer, balance of the machine both lateral and vertical was likely to be disturbed particularly during operation of the machine. Fertilizer tank of 500 litre capacity was mounted at the rear of the peristaltic pumping based aqua-ferti-seed-drill (Dey and Mani, 2004). The machine during its operation in the field faced serious instability problem in the vertical direction. To counter the challenge in the present design of the experimental setup, a tank of 300 litre capacity was mounted on a platform made of angle iron of size 40 × 40 × 4 mm. The platform was supported by the main frame of the applicator. The size of the tank was 1040 × 620 × 465 mm.

Fig. 5 Dimensions (mm) and different views of prototype UAN applicator



a. Front view

b. Side view

c. Top view

Fabrication of UAN Applicator

Based on the selected designed values of different components of UAN applicator, a prototype was fabricated. The dimension of the prototype is presented in **Fig. 5** (**a**, **b** & **c**). The complete machine with various components is shown in **Fig. 6** (**a** & **b**).

Field Evaluation of Developed UAN Applicator

The field experiments for the performance evaluation of the tractor operated UAN applicator designed and developed after laboratory testing, was carried out in the experimental farm of IARI, New Delhi during the period November to April 2017-18.

The important indicators of machine performance i.e. draft, slip, field capacity and field efficiency were calculated using the following data observed in the field.

a) Time taken to cover a given area
b) Actual depth of placement of seed
c) Speed of operation

Draft of the Developed Prototype UAN Applicator

Draft is the horizontal force required to pull the machine by a tractor. The draft requirement of the UAN applicator was measured by the rolling method as given by RNAM (RNAM, 1995). A hydraulic dynamometer of capacity 1200 kg was attached to the front of the tractor to which the unit was hitched. The auxiliary tractor pulled the applicator mounted tractor (in neutral gear) while the implement was in the operating condition. The draft was recorded as well as the time taken to cover selected travel length of 20 m. The experiment was repeated trice and the average draft was computed. The difference between the readings indicated the draft requirement for the applicator.

Ground Wheel Slip Measurement

When the tractor tires rotate faster than the ground speed of the tractor, slip happens. As a result, less than 60% to 70% of the power that a tractor engine develops is used to pull an implement through the soil. For efficient operation, optimum wheel slip is required. The distance covered in five revolutions of the ground wheel covered by the UAN applicator was recorded for calculating the wheel slip using the following expression (RNAM, 1995).

Slippage (%) = $[(d_u - d_g) / d_u] \times 100$

Where,

d_u = actual distance traveled by ground wheel at no load, m

d_g = actual distance traveled by the ground wheel at load, m

Field Capacity and Field Efficiency

The theoretical field capacity is the rate of field coverage that would be obtained if the applicator was operating continuously without interruptions like turning at the ends and filling of the hopper. The effective field capacity is the actual average rate of coverage including the time lost in filling hopper and turning at the end of rows (Kepner et al., 1987).

Theoretical field capacity = $(W \times S) / 10$, $ha.h^{-1}$

Where,

W = width of coverage, m

S = Speed of operation, $km.h^{-1}$

Field efficiency is the ratio of effective field capacity to the theoretical field capacity as shown below.

$E_f = (FCe / FCt) \times 100$

Where,

E_f: Field efficiency, %

FCe: Effective field capacity, $ha.h^{-1}$

FCt: Theoretical field capacity, $ha.h^{-1}$

Results

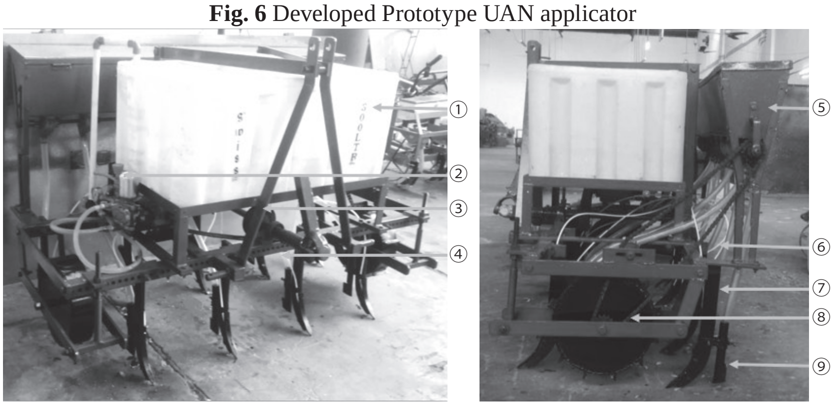
Calibration of Fertilizer Metering Unit of the Applicator

The flow rate of the pump had to commensurate with the liquid fertilizer requirement in the field. The liquid fertilizer requirement for different basal doses of N application was ascertained. The required UAN flow rate in totality as well as for individual delivery pipe at 100% basal dose of N was determined through the experimental setup. At a tractor forward speed of 1.23, 1.5 and 2 km/h, the required flow rate for 100% basal dose of Nitrogen (@ 120 kg/ha) was 11.1, 13.5 and 17.96 l min^{-1}, respectively. The pump was operated by the motor at different speeds controlled through a variable frequency drive (VFD).

Effect of Pump Speed and Line Pressures on the Pump Flow Rate

In general, the flow rate from the pump increased as the line pressure and the pump speed increased, **Fig. 7**. There was approximately 30-

Fig. 6 Developed Prototype UAN applicator



a) Front view b) Rear view

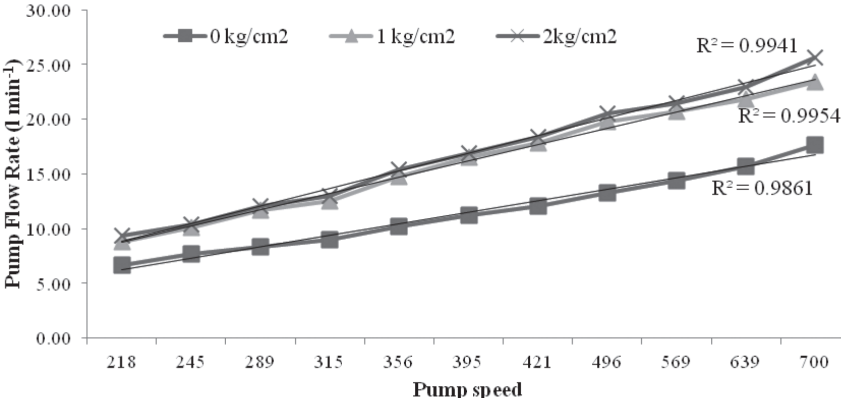
①Fertilizer tank, ②Piston pump, ③Pulley, ④⑥Fertilizer tube, ⑤Seed box, ⑦Furrow opener, ⑧Ground wheel, ⑨Seed boot opener

Table 2 Mean flow rate and distribution uniformity among delivery pipes at different line pressure and pump speed

Pump speed	Line Pressure					
	0 kg cm^{-2}		1 kg cm^{-2}		2 kg cm^{-2}	
	Mean Flow rate through each pipe (l min^{-1}) Mean ± SE_m	Distribution Uniformity among pipes (%)	Mean Flow rate through each pipe (l min^{-1}) Mean ± SE_m	Distribution Uniformity among pipes (%)	Mean Flow rate through each pipe (l min^{-1}) Mean ± SE_m	Distribution Uniformity among pipes (%)
218	0.74 ± 0.020	97.3	0.97 ± 0.011	98.9	1.04 ± 0.038	96.3
245	0.85 ± 0.020	97.7	1.13 ± 0.056	95.0	1.15 ± 0.027	97.6
289	0.92 ± 0.021	97.8	1.30 ± 0.043	96.7	1.34 ± 0.097	92.8
315	1.01 ± 0.034	96.7	1.40 ± 0.037	97.4	1.44 ± 0.005	96.5
356	1.13 ± 0.032	97.2	1.65 ± 0.025	98.5	1.71 ± 0.015	99.1
395	1.23 ± 0.016	98.7	1.83 ± 0.014	99.3	1.88 ± 0.063	96.6
421	1.35 ± 0.019	98.6	1.98 ± 0.008	99.6	2.05 ± 0.056	97.3
496	1.48 ± 0.027	98.2	2.21 ± 0.011	99.5	2.28 ± 0.037	98.4
569	1.62 ± 0.024	98.5	2.31 ± 0.018	99.2	2.38 ± 0.027	98.9
639	1.74 ± 0.016	99.1	2.42 ± 0.012	99.5	2.55 ± 0.062	97.5
700	1.97 ± 0.022	98.9	2.60 ± 0.062	97.6	2.85 ± 0.039	98.6

33% increase in flow rate with an increase in pressure from 0 to 1 kg-cm^{-2} whereas there was only 6-10% increase in flow rates when pressure changed from 1 to 2 kg-cm^{-2}. The flow rate varied linearly ($R^2 > 0.98$) with pump speed at selected pressure levels. For a flow rate range of 11.1-17.96 l min^{-1}, the required pump speed was ranged between 245-421 rpm. However, these flow rates could be achieved by different combinations of line pressure and pump speed. As the line pressure increased the flow rate of pump increased, but, at a decreasing rate. The flow rate varied linearly ($R^2 > 0.98$) with pump speed at the selected pressure levels (**Fig. 7**). For different basal doses of nitrogen different flow rate is required. The calibration helped in choosing the required pump rpm for different flow rates.

Fig. 7 Pump Flow rate affected by speed and line pressure



Effect of Pump Speed and Line Pressure on Distribution Uniformity of Flow Rates

The flow rates of liquid fertilizer through each delivery pipe were recorded and analyzed for their uniformity distribution. A uniform flow rate by different tubes led to higher uniformity coefficient and uniform nitrogen placement. The distribution uniformity was in the range of 96.7-99.1%, 96.7-99.5% and 92.8-99.1% at pressure levels of 0, 1 and 2 kg.cm^{-2}, respectively at different pump speeds, **Table 2**. The observations on the evaluation of the liquid fertilizer pumping system at different operational parameters revealed a significant effect of pressure and speed on flow rate.

Fabrication of Prototype UAN Applicator

The prototype UAN applicator was fabricated with the design values obtained during the experiment. The specification of the developed UAN applicator is described in **Table 3**.

Performance Parameter of Prototype Liquid Fertilizer Applicator

The machine performance of liquid fertilizer applicator was studied by determining draft, slip, field capacity and field efficiency. The average soil moisture content during field evaluation was 9.5% (wb). The average draft requirement of the applicator at full tank load (300 l) was 3.2 kN. The average slip was 6.23%. The average field capacity of 0.23 ha h^{-1} was obtained for continuous operation of the applicator at an average speed of 1.78 km h^{-1}. A field efficiency of 72% was observed which was in the permissible range of 60-80% for seed drill (Kepner et al., 1987). The refilling of fertilizer tank was a major cause for time lost in the field. No repairs, breakdown and adjustment of components during the operation were observed. Seeds were placed in the recommended range of seed depth of 30-50 cm and the average depth of placement was observed as 42 mm.

Conclusions

The prototype UAN applicator was developed with the provision to simultaneously place seed as well as liquid fertilizer. The machine consisted of three subunits- fertilizer metering system, furrow openers, and seeding unit. The fertilizer metering system included piston pump, control valve, liquid fertilizer distributor unit and delivery pipes. The pump was operated by the power take-off a unit of the tractor. The required flow rate of pump suitable for applying 100% basal dose application of nitrogen was in the range of 11.1-17.96 $l.min^{-1}$ attained at a pump rotational speed of 245 to 421 revolutions per minute. The applicator was able to simultaneously place both liquid fertilizer as well as seed at desired differential depth.

Acknowledgments

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Table 3 Specifications of prototype UAN applicator

S. No.	Items	Values
A	**Over all dimensions (L × B × H), mm**	1800 × 1420 × 1080
B	**Seed metering**	
I	Type of seed metering mechanism	Fluted roller
II	Hopper size, mm	1700 × 260 × 260
C	**Liquid metering**	
I	PVC Tank (L × B × H), mm	1040 × 620 × 465
II	Pump (Piston)	34 l min^{-1}@950 rpm
III	Pressure relief valve	1-7 bar
IV	Rotary distributor	
	Inside chamber diameter, mm	52
	Outer Diameter, mm	67
	No. of holes at periphery	9
	Hole dia. at periphery, mm	10
	Delivery pipes diameter (inner), mm	4
D	**Ground wheel**	
I	Type	Spike toothed wheel
II	Effective diameter of ground wheel, mm	360
III	Number of spikes	12
	Spike (Length × Height × Thickness)	100 × 25.5 × 5
E	**Furrow opener**	
I	Number of furrow openers	9
II	Type of furrow opener	Shovel type
III	Groove size (fertilizer tube), mm	7 × 7
F	**Power transmission**	
	Pulley diameter (PTO shaft), mm	152.40
	Pulley diameter (Pump), mm	63.50
G	**Weight of UAN applicator**	
	Tank full of UAN, kg	565
	Empty tank, kg	265

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- **University Merit Scholarship Award** in Post Graduation during 1984-1986.
- **National Merit Scholarship Award (ICAR)** in graduation during 1979-1983.

Design and Development of Chilli Planter for Direct Sowing of Seeds

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Abstract

India is the largest producer of chilli contributing 40% of world's production. Despite of its varied use in daily life, still the chilli farmers lack suitable machinery for their agricultural operations. Hence, this research on design and development of chilli planter for direct sowing of seeds was undertaken as direct sowing of seeds helps in obtaining increased plant densities with reduced labour and planting costs to improve the yields. Three metering mechanisms, namely, horizontal edge drop metering, roller type metering and cup type metering mechanisms were selected and their designs were modified based upon physical properties to suit for chilli seeds. All these mechanisms were tested for their performance under laboratory conditions to find the best suitable device for chilli seeds. Based up on the laboratory results, the development of chilli planter for direct sowing of seeds was carried out using a cup type metering mechanism. Performance of the planter under field conditions was evaluated and the planter was found to function effectively under field conditions by placing the seeds at a mean seed spacing of 27 cm has been obtained. The Missing Index of the planter vared from 6.06 to 15.15%. The draft of the planter varied from 50 to 159 kg as the depth of operation changed from 2.3 to 5.4 cm at varying speed of operation from 1.5 to 2.5 km/h. The wheel slippage of the tractor was found to be 4.38 to 7.31% as the depth of operation varied from 2.3-5.4 cm respectively. Average values of theoretical and actual field capacities were reported as 0.27 and 0.18 ha/h and field efficiency of 65-71% was recorded. The total cost of operation of the developed chilli planter is found to be Rs. 287.78/h.

Keywords: chilli, planter, metering mechanism, cup type metering mechanism

Introduction

Sowing operation is one of the most important cultural practices associated with crop production. Increase in the crop yield, cropping reliability, cropping frequency and crop returns all depend on the uniform and timely establishment of optimum plant populations. India being the largest producer of chilli contributing 40% of world's production and despite its varied use in our daily life we lack suitable machinery for their agricultural operations. Rising in nurseries and transplanting in fields have increased the demand for labour in chilli production thus increasing the cost of cultivation (Goudappa, 2012). Even by transplanting method, multiple types of machinery are required for sowing i.e., for sowing the seeds in nurseries and transplanting seedlings into the fields. One solution for this problem might be changing the method of sowing from transplanting to direct sowing. Leskovar and Cantliffe (1993) found that direct-seeded plants maintained a more-balanced root, stem, leaf, and fruit dry matter partitioning than transplants and direct sowing practice helped in increasing the plant densities with reduced labour and planting costs to improve the yields.

Chilli is a fruit of the plant Capsicum annuum that come from the genus capsicum belonging to the family of Solanaceae. Capsicum is derived from the Greek word ‘Kapsimo’ means “To Bite”. Chilli (*Capsicum annuum* L.,) is an important spice as well as commercial crop available in either green or as dried red fruits. Chillies are believed to have their origin in the region of tropical America. Chillies usually require warm and humid climate for growth and they usually grow in wide range of soils where loamy soils are good under irrigated conditions and black soils under rainfed conditions. In India, chilli yields two crops per year i.e., they are cultivated as both Rabi and Kharif crops with a production period of about 4-5 months.

The farm power availability on Indian farms has seen a considerable rise from 0.295 kW/ha in 1971-72 to 2.02 kW/ha in 2016-17 because of considerable decline in the use of animal and human power in the fields but the overall level of mechanisation is still less than 50%, as compared to 90% in developed countries.

Shambu and Thakur (2019) evaluated the performance of seed drill that sows jute and mustard seeds manually. They found that length and breadth of jute seed was to be little higher than mustard seed hence the metering device was developed in such a way that the dispensing hole for jute was made little longer than that of mustard. Singh et al. (2017) developed and evaluated the performance of single row manual/bullock drawn multi crop planter suitable for hilly regions to sow the seeds like wheat, maize, soya bean, lentil, peas, mustard and millets using cell type seed metering mechanism with 4 different sizes of cells on the roller for seed metering and fluted roller for fertilizer metering.

Reddy et al. (2012) evaluated the performance of different seed metering mechanisms under simulated conditions. The inclined plate metering mechanism with elongated shape and 6 number of cells on the plate and horizontal plate metering mechanism in circular shape with 24 number of cells on the plate were tested on the laboratory test rig of sticky belt method.

Ahmadi et al. (2008) modified the conventional seed drill in such a way that it can be used as a precision seed drill for planting small seeds, oilseed rape in particular. They found that the effect of forward speed on seed rate of oil seed rape in the modified roller was found to be not similar to that of conventional roller. Gaikwad and Sirohi (2007) developed a precision plug tray seeder, using indigenous materials and off-the-shelf available standard components. This prototype pneumatic seeder was fabricated and tested for its performance for sowing capsicum and tomato seeds in plug trays and concluded that the use of graded and coated seeds was necessary to achieve a higher percentage of sowing singles. Wanjura and Hudspeth (1968) studied the seed metering and seed pattern characteristics of horizontal edge drop planter for dispersing cotton seed. Considering the past research work, need for planter for sowing of chilli seeds, importance of direct sowing for reducing cost inputs and technological sophistication that offers minimum labour requirement and provides high density cropping system that is comparable with the traditional transplanting system research work on design and developing of a chilli planter for direct sowing of seeds was adopted.

Material and Methods

2.1 Design and Development of Chilli Planter

The entire work of design and development of chilli planter is done in following stages:

a) Determination of physical properties of the chilli seeds for designing the components
b) Design of components based on physical properties of seeds
c) Laboratory testing of selected seed metering mechanisms
d) Development of planter with the best suited metering mechanism
e) Evaluation of the developed chilli planter

2.2 Determination of Physical Properties of the Chilli Seeds

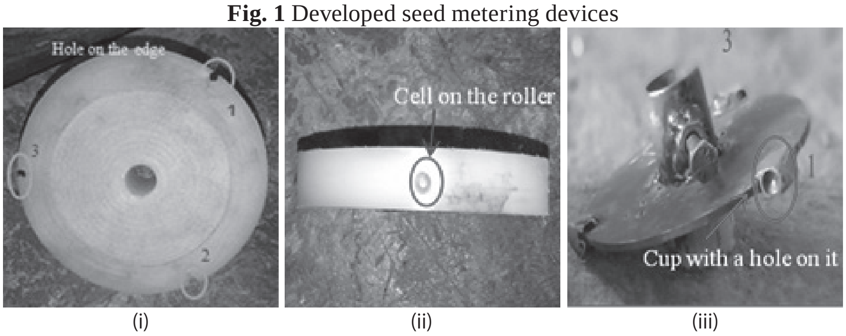
The physical properties were determined for efficient design of planter components to work effectively with good accuracy in the field. Accordingly the seed properties such as size, sphericity, geometric mean diameter, surface area, angle of repose, thousand kernel weight, co-efficient of static friction and bulk density of chilli seeds were calculated and based on those results the components of chilli planter were developed (Mohsenin, 1970).

2.3 Design Components of Chilli Planter

2.3.1. Seed Metering Device

Considering the ease of operation of metering device and cost of operation three types of metering devices namely horizontal edge drop metering type, roller type metering device and cup type metering

Fig. 1 Developed seed metering devices



(i) (ii) (iii)

Table 1 Specifications for developed seed metering devices

Particular	Horizontal seed metering device	Roller type seed metering device	Cup type seed metering device
Material used for construction	Nylon (Plastic) (Nylon 66 A125, Mold surface Temperature 90°C, Elastic modulus 2690 MPa)	Nylon (Plastic) (Nylon 66 A125, Mold surface Temperature 90°C, Elastic modulus 2690 MPa)	Mild steel (Yield Strength: 275 MPa Tensile Strength: 475 MPa)
Diameter of the seed metering device	10 cm	10 cm	10 cm
Number of cells on the seed metering device	3	3	3
Salient Features	The plate was developed in such a way that it is having 1 cm thickness at the centre of the plate and made tapered toward the edges such that it is having a thickness of 1 mm.	The size of hole on the roller is based upon the axial dimensions of the seed.	3 cups were developed from square rod 8 × 8 × 8 mm with hole of size 5 mm in diameter on one side of the rod and tapered on the other side i.e. to the shape of a truncate so that seeds won't stay upon the surface during operation.

devices were selected and modified accordingly to meter the chilli seeds as they are light in weight and small in size. The number of cells to be facilitated on the seed metering device and the diameter of the seed metering device was calculated.

Number of cells on the seed metering plate, $n = (\pi \times D_g) / (i \times x)$

Where,

D_g = Diameter of the ground wheel, cm

i = Gear ratio to be maintained (1:1)

x = required seed to seed spacing, cm

Diameter of the seed metering device, $d_r = V_r / (\pi \times N_r)$

Where, V_r = peripheral velocity of the seed metering device, m/s; N_r = rpm of the roller, rpm

By using these dimensions the selected metering devices were developed and the specifications of the metering devices were given in the **Table 1**.

2.3.2. Design of Seed Box

Seed box is designed in such a way that it can hold adequate quantity of seed, shape of the box should freely pick and meter the seed from the box and deliver it to the seed outlet, must permit easy loading and unloading of the material.

Volume of seed box, $V_b = 1.1 \times V_s$

Where, V_s = Volume of the seed, cm

Volume of the seed, $V_s = W_s / \gamma_s$

Where, γ_s = Bulk density of the seed, g/cm^3, ω_s = Weight of the seeds, g

Volume of the seed, $V_b = 1.1 \times (W_s / \gamma_s)$

By considering the amount of seed the box has to carry and it's suitability to seed metering device, the shape of seed boxes were chosen and the specification of the Developed seed boxes were given in the **Table 2**.

2.3.3 Testing of Developed metering devices under laboratory

All the selected seed metering devices were tested for their performance on the sticky belt setup established at the laboratory maintaining a constant speed ratio of 1:1 to evaluate the performance parameters of the metering devices such as seed to seed spacing, missing index, and multiple index.

a. Seed to Seed Spacing

The distance between two consecutive seeds was measured by a steel rule and the results were noted. The spacing was measured at different locations and an average value is noted.

b. Missing Index

The Missing Index is the percentage of spacing greater than 1.5 times the theoretical spacing. Missing rate is determined by the following equation.

Missing Index, % = (n/m) × 100

Where, n = number of seeds missing during pickup by metering wheel into seed tube; m = number of seed should be dropped by the metering wheel if there is no missing of seeds.

c. Multiple Index

The Multiple Index is the percentage of spacing that are less than or equal to half of theoretical spacing. Multiple index is determined by the following equation.

Multiple Index, % = (p/m) × 100

Where, p = number of times multiple dropping of seeds occurred

Fig. 2 Developed seed metering devices

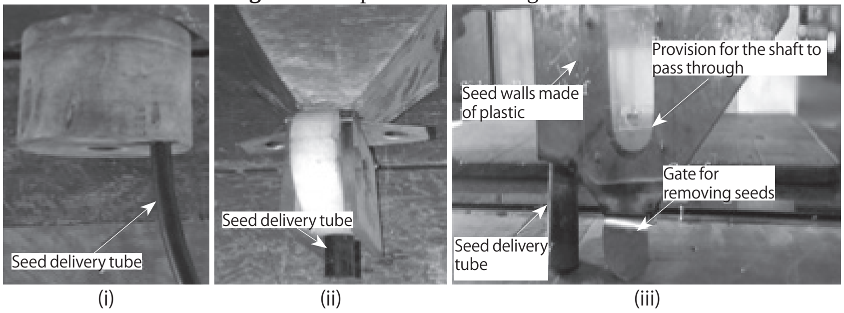


Table 2 Specifications for developed seed boxes

Parameter	Horizontal edge drop metering	Roller type metering	Cup type seed metering
Material used for construction	Soft Wood (Guava Wood)	Galvanised iron sheet (Garde:SS301, Thickness: 2 mm)	Galvanised iron sheet (Garde: SS301, Thickness: 2 mm)
Shape of the box	Cylindrical	Pyramid truncated at the top	Frustum of a pyramid (developed)
Dimensions of the seed box	Height: 12 cm Diameter of box: 10.1 cm	Top: 15 × 12 × 15 Bottom: 5.5 × 2.5 × 5 cm	Total Length: 30 cm Width: 6 cm Height: 14 cm
Salient Features	2 holes are provided at the base of the box, one of 2.54 cm in diameter for the passage of the shaft through it so that power transmission to the seed metering plate is done and the other of 1 cm in diameter to act as an outlet for seed metered to which seed tube is attached.	A seed metering house is attached to the seed box in which, the metering roller rotates in housing and developed in such a way that the roller can be removed by loosening one side of screws of the plate and the seed delivery tube is in turn attached.	A seed gate is provided at the bottom of the box for providing feasibility to remove the seed out of the box

from the delivery tube; m = number of seed dropped by the metering wheel if there are no multiple seed

2.4. Testing and Evaluation of the Developed Planter

2.4.1 Testing for Seed Rate

The developed planter was tested for seed rate by collecting seeds when the seed hopper was loaded with half of its capacity and the drive wheel was rotated 50 times in raised position.

Seed rate (kg/ ha) was calculated by using the equation given below.

Seed rate (kg/ha) = Total amount of seed collected (W_s) / Area covered for 50 revolutions

Area covered by the planter in 50 revolutions is calculated as:

Area covered for 50 revlitions m^2 $= (\pi \times D \times N) \times W$

Where, D = diameter of the ground wheel, cm; N = number of revolutions of ground wheel = 50 revolutions; W = working width of planter, cm

2.4.2 Field Evaluation of Developed Chilli Planter

An 18 hp, Mistubishi Shakti MT 180D 2WD tractor with the developed planter was evaluated in a black soil of plot size 20 × 20 m under field conditions. The field performance parameters such as draft requirement, depth of operation, missing index, multiple index, theoretical field capacity, effective field capacity, field efficiency, wheel slip and fuel consumption were evaluated by standard procedures in the field.

2.5 Economics of the Developed Chilli Planter for Direct Sowing of Seeds

By using straight line method the fixed and variable costs of chilli planter were calculated by undertaking certain assumptions when necessary. This cost was compared with the cost of chilli planting with the cost of operation by traditions methods. (Investigations were done about the cost of sowing for chilli crop from different farmers and research articles and the cost of transplanting operation was assumed to be a minimum of Rs. 4,500 per hectare which was very less than the original cost)

Table 3 Physical properties of the chilli seeds

Particular	Value
Length, mm	3.817 ± 0.03
Width, mm	3.114 ± 0.03
Thickness, mm	0.729 ± 0.07
Sphericity, %	0.538 ± 0.04
Geometric mean diameter, mm	2.05 ± 0.02
Surface area, mm^2	13.22 ± 0.04
Bulk density, g/cm^3	64.5 ± 0.024
Coefficient of static friction, Galvanized iron	0.490 ± 0.03
Coefficient of static friction, wood	0.785 ± 0.02
Coefficient of friction, glass	0.557 ± 0.01
Angle of repose, degrees	28.21 ± 0.01
Thousand kernel weight, g	5.346 ± 0.01

Results and Discussion

3.1 Physical Characteristics of the Chilli Seeds

The physical properties of the chilli seeds were measured and the average values are tabulated as below (**Table 3**).

3.2 Development of Chilli Planter

Before developing a chilli planter suitable to the mini-tractor, CAD drawings drawn in CATIA software were used for fabrication of the machine. Three seed metering mechanisms namely edge drop metering mechanism, roller type metering mechanism and cup type metering mechanism were selected and suitable seed boxes for each metering mechanism were developed and all the three metering mechanism were tested in the laboratory. Of all the three cup type metering was found to be effective and a planter for chilli for direct sowing of seeds based on the cup type metering mechanism was developed. The developed chilli planter has been presented in **Fig. 3**. The specifications of the developed planter are given in **Table 4**.

3.3 Laboratory Testing of Selected Metering Mechanisms

All the three selected seed metering devices namely horizontal edge drop metering device, roller type metering device and cup type seed metering device were tested individually for their performance parameters namely seed spacing (seed to seed spacing), missing Index and multiple index. The comparative performance of all seed metering devices were as shown in **Figs. 4-6** respectively, and remarks are as mentioned in **Table 5**.

3.4 Selection of Seed Metering Device

Based upon comparison of laboratory test results, Cup type metering device at 25 rpm was found to maintain optimum spacing and negligible amount of missing and multiple index.

3.5 Laboratory Testing of the Developed Chilli Planter

The amount seed required to sow the seeds with the developed chilli planter in one hectare area is found to be 0.5 kg/ha. The inspection for seed damage has been done visually and no such damage has been found.

3.6 Evaluation of Chilli Planter Under Field Conditions

3.6.1 Measurement of Wheel Slippage

The wheel slip was found to be varied from 4.38-7.31%. It was found that during different depths at constant forward speed of the planter, the wheel slip was increased while increasing the depth of operation. The reasons for increasing the wheel slip while increasing the speed maybe due to increase in draft force of the planter.

3.6.2 Seed Spacing

The seed spacing was decreased from 28 to 26.5 cm as the speed of operation increased from 1.5 to 2.5 km/h. The decrease in seed spacing of the tractor is attributed to increase in wheel slip of the tractor

Table 4 Specifications of the developed chilli planter

Parameter	Details
Overall height, mm	450
Overall length, mm	1400
Overall width, mm	650
Metering mechanism	Cup type
Number of rows	3
Seed to seed spacing	30
Row to row spacing	45
Type	Fully mounted

3.6.3 Missing Index

The seed missing index under field condition fount to vary from 6.06 to 15.15 % as the speed varied from 1.5 to 2.5 km/h. The increase in the miss index might be due to increasing wheel slippage of the ground wheel.

3.6.4 Theoretical and Effective Field Capacity

Theoretical field capacity found to vary from 0.20 to 0.34 ha/h with an average value of 0.27 ha/h and effective field capacity found to vary from 0.14 to 0.22 ha/h with an average value of 0.18 ha/h, as the change in speed of operation from 1.5 to 2.5 km/h. The field capac-

Fig. 3 Developed chilli planter for direct sowing of seeds

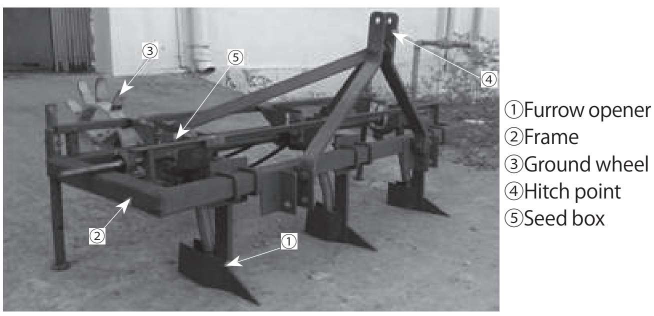


Fig. 4 Effect of number of revolutions on spacing of different metering devices

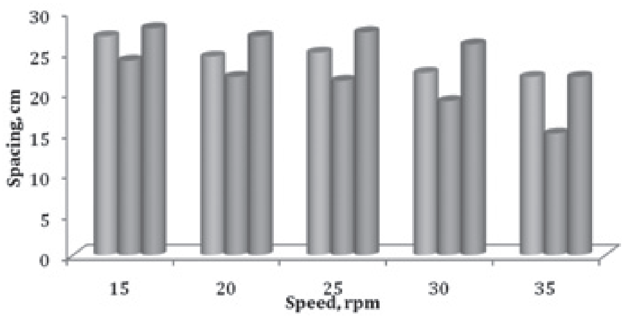


Fig. 5 Effect of number of revolutions on Miss Index of different metering devices

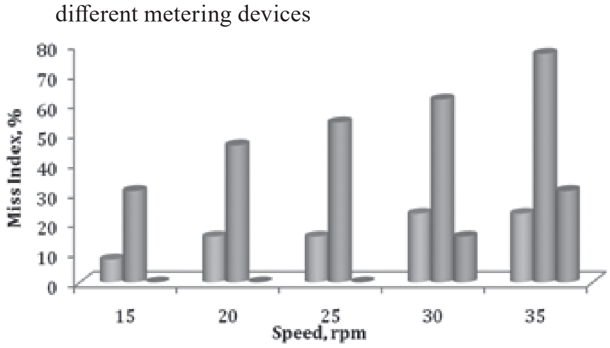


Fig. 6 Effect of number of revolutions on Multiple index of different metering devices

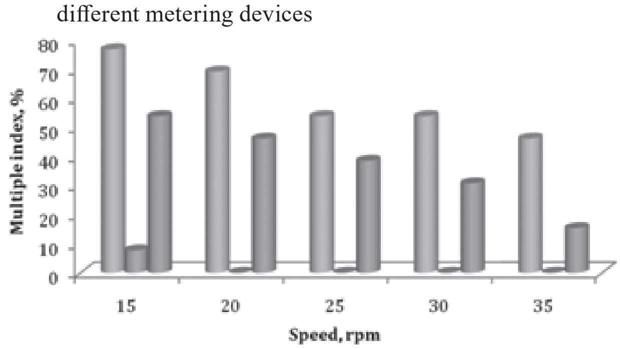


Table 5 Summary of comparative performance seed metering devices

Parameter	Horizontal edge drop metering	Roller type metering	Cup type seed metering
Mean spacing	Chilli seeds were found to be getting into the clearance provided for rotation of the metering device in the seed box.	The seeds were unable transfer onto the metering device as they were getting overlapped in the seed box.	The optimum placement of seeds can be attributed to placement of cups on the seed metering device and good pick up and dropping capabilities of the developed cup type seed metering device.
Missing Index	As the revolutions were increased, the metering device is unable to drop the seed into the seed delivery tube in such a short span of time.	The seed were getting jammed and there was no free flow of the seeds from the seed box to metering device	Negligible at most times as the metering device has picked the seed with good precision.
Multiple Index	The seeds were found to be getting into the clearance provided between the box and the metering device and getting dropped into the tube along with the metered seed in the cell.	Negligible at most times as the metering device has dropped the seed with precision.	Seeds were found to be overlapped on the metering device and getting dropped along with the seed that has been picked up in the cup.

ity was increased with increase the speed of operation due to increase in rated time of operation. The field efficiency seen to vary from 71.42 to 65.71 % as the change in speed of operation from 1.5 to 2.5 km/h.

3.7 Economics of the Developed Planter

The economics of the developed planter was done taking the cost of the prime mover and the considering an annual use of the planter as 200 h/year. The cost of operation per ha is found to be Rs. 1,598.77. The cost of operation was comparatively very less when compared with the traditional transplanting method and cost saving of about 64.48% may be achieved with the developed chilli planter.

Conclusions

A research work on design and development of a chilli planter for direct sowing of seeds was undertaken. Accordingly, three metering mechanisms viz., horizontal edge drop metering, roller type metering and cup type metering mechanisms were selected and their design was modified according to the requirement based on the physical properties of the seeds. Based upon the laboratory tests it was found that cup type metering mechanism functioned well and hence, the chilli planter with the cup type metering mechanism was developed and evaluated for its performance under laboratory and field conditions.

With the developed planter mean seed spacing of 27 cm has been obtained as the speed of operation increased from 1.5 to 2.5 km/h. The wheel slippage of the tractor was found to be 4.38-7.31% as the depth of operation varied from 2.3-5.4 cm. Average values of theoretical and actual field capacities were reported as 0.27 and 0.18 ha/h at a varying speed of 1.5-2.5 km/h. Field efficiency of 65-71% was recorded and found to be declined as the speed of operation increases from 1.5-2.5 km/h. Economics of the chilli planter was evaluated and cost of operation was found to be Rs. 1,598.77/ha and is found to be comparatively very less with the traditional method of planting chilli.

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Design and Development of a Defluffing Machine for Dinanath Grass Seeds (*Pennisetum Pedicellatum*)

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Abstract

Dinanath is an important range grass of India, seeds of which are lighter, fluffy and hairy in nature. Traditionally, separation of nucleus seeds from fluffy *dinanath* grass seeds is cumbersome and time consuming. Hence, a defluffing machine consisting of feeding chute, feed rollers, serrated cylinder assembly, grading unit and power transmission unit was designed and developed considering the physical properties of the *dinanath* grass seed and evaluated for its performance. The mean values of seed dimensions (length × width × thickness) for fluffy seed and nucleus seed were computed as 6.20 × 2.77 × 1.83 mm and 2.89 × 1.10 × 0.82 mm, respectively. The average bulk densities of fluffy and nucleus seeds were 7.65 kg/m^3 and 613.63 kg/m^3 respectively. The machine performance like defluffing capacity (4.9 kg/h), defluffing efficiency (92.1%) and nucleus seed recovery (22.82%) were evaluated at 7.0% moisture content and 545 rpm of serrated cylinder speed. The machine saved 76% processing cost as compared to traditional manual defluffing. Drastic reduction (99.7%) in volume of fluffy seed could be achieved after defluffing.

Keywords: *Dinanath*, Nucleus Seed, Defluffing Capacity, Defluffing Efficiency

Introduction

Grasses are the best propagating material for marginal and uncultivable wastelands, forest and rangelands, but non-availability of quality seed in sufficient quantities is one of the reasons to obstacle the green fodder production. Availability of good quality seed is only 25-30% in cultivated fodder and < 10% in range grasses and legumes in India (Anonymous 2011). Among annual range grasses, *dinanath* (*Pennisetum pedicellatum*) is an important fodder species, because of high early vigor, adaptability to very poor soils and high productivity with minimal input. However, during seed production in huge quantities, the lightweight small seed enclosed in voluminous fluff leads to difficulties in precise sowing in the field. Reducing the volume and extracting nucleus seed (true seed or naked seed) for precise sowing is the requirement for large scale adoption of the *dinanath* grass. The nucleus seed is easy to mix in the soil during sowing by broadcasting. If awns and other appendages are removed, it is better to embed the seed with pelleting technology to ensure their firm establishment in the field. Authors like Linnet (1977) and Loch (1993) have extensively covered the principles, practices of pasture seed processing followed in different countries. Maity et al. (2017) worked on layered pelleting of nucleus seed of *dinanath* grass with soil and observed highest germination of 91%. Each spikelet (fluff) contains 2 to 3 nucleus seeds, separation of which is difficult due to their minute size. Defluffing (removal of fluff and hairs from fluffy seeds) is an important post-harvest operation in grass seed processing. Traditionally, defluffing of fluffy *dinanath* grass seeds is done manually by beating the harvested and dried crop to separate nucleus seed. This process is time consuming, labor intensive and recovered nucleus seed includes foreign materials and damaged seed.

Various size reduction processes have been reported for many grass seeds depending upon their ultimate use. Hammer milling of the seed of seca stylo (Stylosanthes scabra) was done to reduce the hard seed content (Hopkinson and Paton, 1993). It dehulled 52% of seeds and when light materials aspired off it reduced bulk weight by about 20 percent. Loch (1993) experimented for dehulling in Chloris gayana using horizontal cone-shaped polishing chamber. The seed was rubbed against the surrounding mesh screen (0.83 mm apertures) by nylon brushes rotating at 945 rpm and 50-70% of the caryopsis was extracted from the surrounding husks. Arude et al. (2018) developed a spike cylinder type single locking cotton feeder cum cleaner for double roller gin and observed 15 to 20% increase in the output with improved fibre quality. Very little information is available about defluffing of fluffy grass seeds. Thus, developing machine for the separation of fluff of *dinanath* grass seeds is essential for getting nucleus seed for effective fodder production. This study, therefore, presents the design, development and evaluation of the defluffing machine for *dinanath* grass seeds.

Material and Methods

The study was undertaken at Indian Council of Agricultural Research (ICAR) - Indian Grassland and Fodder Research Institute (IGFRI), Jhansi, India. The required physical properties of *dinanath* grass (variety BD-II) seeds for developing the prototype of defluffing machine were determined. The moisture content was determined by heated air oven method at 105 ± 3 °C for 24 h (AOAC, 1980). Length, width, thickness, arithmetic mean diameter, geometric mean diameter, sphericity, surface area, volume, bulk density and 1000 seed mass were determined using the relationship given by Dursun and Dursun, 2005 and Singh et al., 2016. The average size of fluffy *dinanath* seeds and nucleus seeds of *dinanath* were determined by randomly selecting 100 seeds and were measured using a digital vernier caliper (Mitutoyo Corporation, Japan; Model No: CD-12'' C; least count 0.01 mm). Thousand seed mass was determined by picking the sample of thousand seeds randomly from the lot and the mass of each sample were measured on a precision electronic balance having accuracy of 0.01 g. Bulk density of seeds was measured using AOAC method, in which a 500 ml cylinder was filled with *dinanath* seeds to 15 cm of height and calculated as the ratio between the seed weight and the volume of the cylinder.

Design and Development of Defluffing Machine

The defluffing machine (DM) consisted of: serrated cylinder (SC) assembly; feeding chute (FC); feeding rollers (FR); grading unit (GU); and power transmission unit (PTU). The detailed design procedures are stated in following sections.

Serrated Cylinder Assembly: The SC was made of wood (360 mm φ, 580 mm long) with serrated iron teeth at equal distances on its outer periphery. SC was mounted on the rotating shaft fixed on angle iron frame and powered by 0.75 kW electric motor through belt pulley drive mechanism. SC speed of the DM was decided through trial runs on the existing cotton batting machine which is used for quilt making. The operating cylinder speed of the cotton batting machine was found in the range of 400-800 rpm depending upon the load during operation. Based on this, a speed of 600 rpm was selected for designing the cylinder speed of DM. The SC was covered with upper casing and perforated lower casing. On inner surface of the upper casing, sand paper was fixed. Concave clearance and sieve size were decided on the basis of size of *dinanath* grass seeds.

Feeding Chute: Size of FC was decided based on the bulk density of fluffy *dinanath* seed. Feeding chute was placed tangential to the feeding rollers to facilitate the feeding of fluffy grass seed.

Feeding Roller: Two feeding rollers each of 60 mm φ, 615 mm long were provided in FC. Power from main shaft of SC was transmitted to the upper feeding roller through chain sprocket system which was placed in opposite side of main pulley. Lower FR was connected to upper FR through meshed gear mechanism.

Grading Unit: A grading unit comprised of a sieve at the top and a MS tray at the bottom was attached below the SC assembly with the provision of crank shaft and belt pulley system to provide reciprocating action to the sieves.

Belt and Pulley System: Size of pulleys and the lengths (L) of belts used in the design of the machine were determined using the equation (1) and (2) respectively (Khurmi and Gupta, 2007).

$$N_1D_1 = N_2D_2 \quad (1)$$

Where, N_1 is speed of drive (motor) pulley (rpm); N_2 is speed of driven (SC) pulley (rpm); D_1 is diameter of drive pulley (mm); D_2 is diameter of driven pulley (mm).

$$L = \frac{\pi}{2}(D + d) + 2C + \frac{(D + d)^2}{4C} \quad (2)$$

Where, C is distance between drive and driven pulleys (mm); D is diameter of drive pulley (mm) and, d is diameters of the driven pulleys (mm).

Ergonomic Consideration: Ergonomic considerations were used in the design for safety of the worker. The length of the feeding chute was kept 950 mm as per IS: 9020-2002. Height of the machine was kept 950 mm as per average waist height (natural indentation) of the worker for better comfort work. The machine consisted of all safety guards over power transmission system.

The conceptual design and drawing of DM was prepared with the help of PTC Creo Parametric 3.0-2014 software and fabricated. The front, back, top and isometric views of the designs of defluffing machine are given in **Fig. 1** and the views of fabricated machine are shown in **Fig. 2**.

Testing Procedure of Defluffing Machine

The prototype of DM was tested for defluffing of fluffy *dinanath* grass seeds (**Fig. 3**). Experiments were conducted by taking 9 samples each of 500g of feed mass of fluffy *dinanath* grass seeds at three levels of moisture content (7.0%, 9.0%, 11.0%) using Randomized Block Design (RBD) having 3 replications.

On start of the motor, the SC along with FR start rotating and GU start moving to and fro. The bunch of fluffy seed was fed in the FC and the seed materials were slightly pushed towards FR by a person. Simultaneously, the SC pulled the mass through the gap between the iron teeth and the upper casing. The experimentation on the machine was started after 2 minute of start when steady state of inflow and out flow of the materials occurs. The rotational speed of cylinder was 545 rpm during operation. The defluffed nucleus (true) seeds along with the separated hairs and powdery dust particles passed through the openings of the upper screen of the GU and dropped down on the bottom tray during the reciprocating motion of the grading assembly. The time taken in defluffing the selected mass of the fluffy seeds were measured by using a quartz stop watch and the samples retained on the top sieve and bottom tray of GU were collected separately. The top screen of the GU contains the seed cover materials such as hairs and appendages without the true seed and few non defluffed seeds. Further, separation of nucleus seed, dust particles and bigger chaffs from the mixture of seeds retained on the bottom tray of GU was done separately using two square opening test sieves of sizes 1.18 mm and 0.60 mm. The material retained on 0.6 mm sieve was the desired nucleus seed.

Fig. 1 Front, back, top and isometric views of the CAD design of defluffing machine

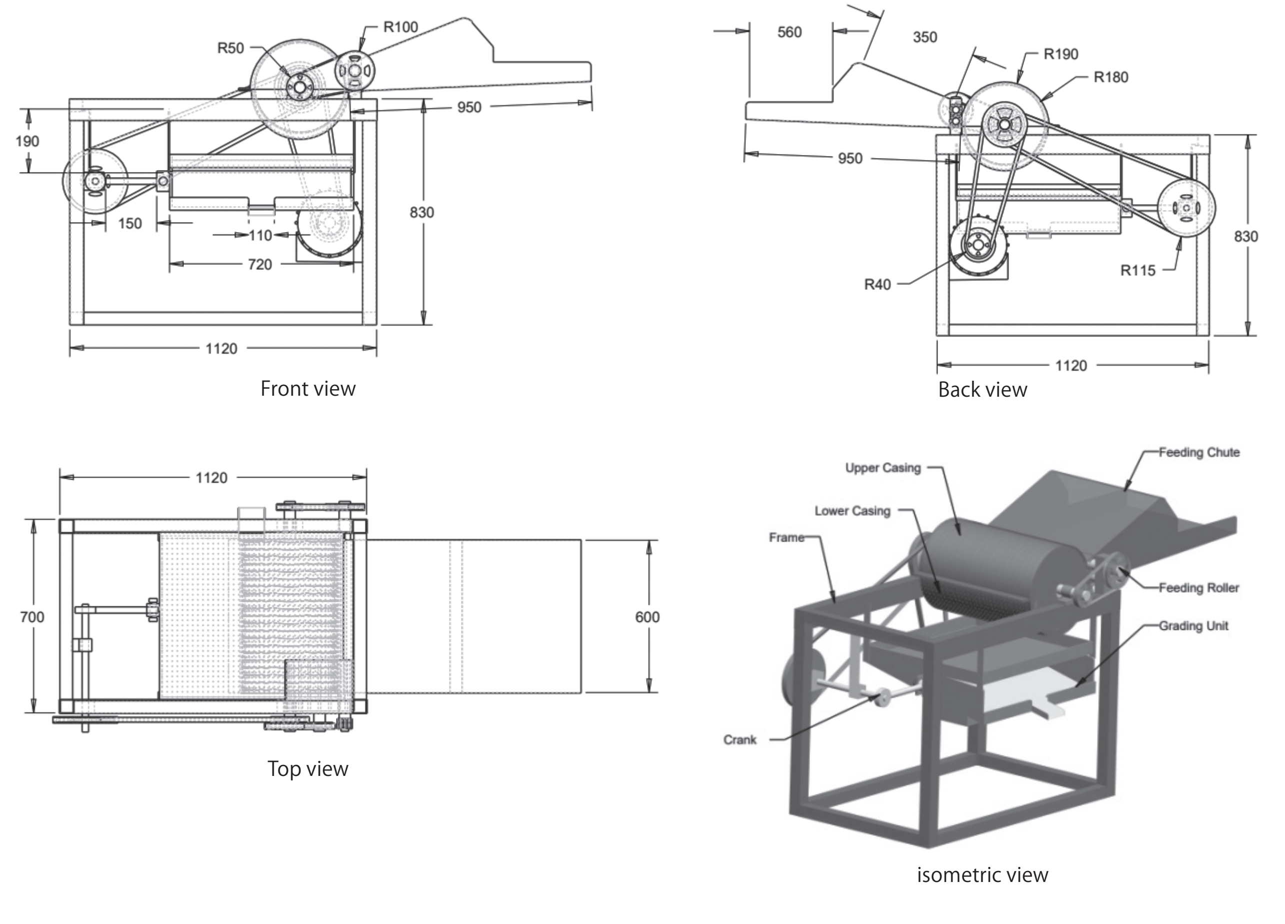


Table 1 Physical properties of fluffy and nucleus seeds of dinanath grass at 9% moisture content

Properties	Mean value for fluffy seeds	Mean value for nucleus seeds
Length (L), mm	6.20 ± 0.97	2.44 ± 0.21
Width (W), mm	2.77 ± 0.67	0.82 ± 0.13
Thickness (T), mm	1.83 ± 0.66	0.58 ± 0.11
Arithmetic mean dia. (D_a), mm	3.60 ± 0.53	1.28 ± 0.12
Geometric mean dia. (D_g), mm	3.11 ± 0.58	1.05 ± 0.12
Sphericity, %	50.57 ± 9.56	43.01 ± 4.32
Surface area (A_s), mm^2	31.41 ± 12.29	3.49 ± 0.82
Volume (V), mm^3	10.97 ± 7.27	6.62 ± 3.02
1000- seed mass, g	0.819 ± 0.03	0.478 ± 0.01
Bulk density (ρ_b), $kg.m^{-3}$	7.65 ± 0.24	613.63 ± 10.66

Computation of the Performance Parameters

The formula used in computing the defluffing capacity, defluffing efficiency and the percent nucleus seed recovery are stated as follows:

Defluffing capacity, D_c

It is the ratio of mass of fluffy seed fed to the defluffing time. Defluffing capacity (kg/h) was estimated as:

$$D_c(kg/h) = \frac{F / 1000}{D_t / 60} = \frac{3F}{50D_t} \quad (3)$$

where, F is mass of fed seed sample (g) and, Dt is time of defluffing (min).

Traditional method of defluffing of *dinanath* seeds (**Fig. 4**) includes drying of harvested crop followed by beating manually with wooden stick (1 to 2 m length) on threshing floor and sieving. This process has less defluffing output (6 kg per day/ woman).

Defluffing efficiency, D_e

It is the ratio of mass of defluffed seed to the total mass of fed seed sample expressed in percentage. Preliminary tests on prototype indicated that the material passed through top sieve of GU and retained on bottom plate of GU do not have any fluffy seed. Chances of non defluffed seeds were only on the samples retained on the top screen. Therefore, the De was calculated using 5 g random sample from the material retained on the top screen of grading unit and following formula was derived to calculate the D_e.

$$D_e(\%) = (\text{Mass of defluffed seed} \times 100) / (\text{Total mass of fed seed}) = (1 - (\text{Mass of non defluffed seed}) / (\text{Total mass of fed seed}) \times 100 = [1 - (M_{ND} \times M_t) / 5F] \times 100 \quad (4)$$

Where, F is mass of fed seed sample (g); M_{ND} is mass of non defluffed seed from 5 g random sample taken from top screen (g) and, M_t is mass retained on top screen of grading unit (g).

Nucleus seed recovery, M_n

It is the ratio of quantity of nucleus seed obtained from sieving of the mixture retained on bottom tray of GU to the mass of fed seed sample expressed as a percentage and is given as

$$M_n (\%) = (\text{Mass fraction retained on 0.6 mm sieve} \times 100) / (\text{Total mass of fed seed}) = (M_f / F) \times 100 \quad (5)$$

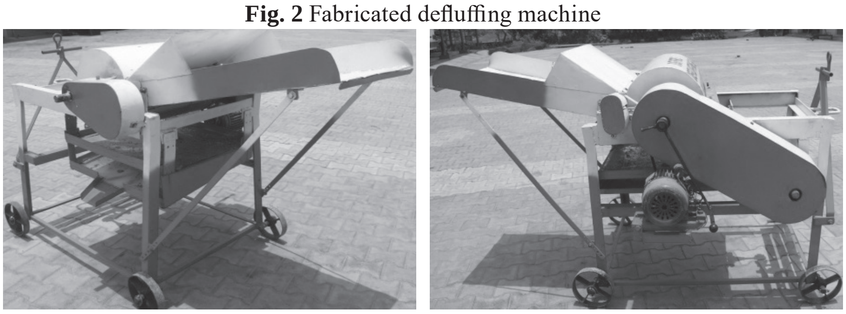
Results and Discussion

The mean values of physical properties of both fluffy and nucleus *dinanath* seeds were determined for designing the machine as shown in **Table 1**. The mean values of seed dimensions (L × W × T) for fluffy seed and nucleus seed were 6.20 × 2.77 × 1.83 mm and 2.44 × 0.82 × 0.58 mm respectively. Similarly, D_a and D_g for fluffy seeds were 3.6 mm, 3.11 mm respectively and for nucleus seeds, the respective values were 1.28 mm and 1.05 mm. D_g value was found more than that of its width and thickness. The sizes of fluffy and nucleus seed were taken into considerations to design the concave clearance, sieve sizes of lower casing and GU. Ten millime-

Fig. 3 Defluffing machine in operation

Fig. 4 Traditional method of defluffing

Fig. 2 Fabricated defluffing machine



ters concave clearance was selected considering the maximum length of fluffy seed (6.20 + 0.97 mm) in view of one thin layer of fluffy material lodged onto the rotating SC while in operation, whereas 2.6 mm round sieve size of lower casing was taken so that all the material which are crushed passed through it on GU. Similarly, 1.8 mm round opening sieve was selected for the top screen of GU so that the nucleus seeds and smaller dust particles pass through the openings of top sieve.

The mean value of sphericity for fluffy and nucleus seeds were 50.57 and 43.01 respectively. According to Dutta et al. (1988), seeds having sphericity less than 0.70 may not be considered spherical. The mean value of ρb of fluffy and naked seeds were 7.65 kg/m^3 and 613.63 kg/m^3. This indicates that the ρb of nucleus seed was 80.21 times the ρb of fluffy seeds. Data on ρb was used for the design of size of FC. Similarly, the mean values of V of fluffy seed and nucleus seeds were 10.97 mm^3 and 6.62 mm^3 respectively. Average 1000 seed mass of fluffy and nucleus seeds were 0.819 g and 0.478 g respectively. Based on the physical properties of *dinanath* grass seeds and design considerations, the specifications of prototype were developed which are shown in **Table 2**.

Performance Evaluation

The prototype was evaluated for defluffing of *dinanath* grass seeds and M_n, D_c and D_e were measured. The operating speed of SC was 545 rpm. The data were analyzed using generalized linear model (GLM) procedure of SAS (V-9.3) to assess the suitability of the machine. The experimental results on performance parameters are presented in **Table 3**. ANOVA was conducted for M_n, D_c and D_e, which are also presented in **Table 3**.

The ANOVA data shows high F value (1140.1) for M_n at 1% level of significance. The linear effect of M_c was highly significant on M_n. Similarly, F values of 36.35 and 14.52 were observed for D_c and D_e at 5% level of significance, therefore, the effect of M_c on D_c and D_e were highly significant. Results

Table 2 Specifications of the defluffing machine

Items	Specification
Main Frame	1) Dimension: 1120 × 700 × 950 mm 2) Material: angle iron (45 × 45 mm)
FC	1) Dimension: 950 mm length, 600 mm breadth 2) Material: MS sheet, 18 gauge
SC Assembly	1) Wooden cylinder: 360 mm φ × 580 mm long with serrated iron teeth on periphery; Cylinder shaft diameter: 30 mm φ; 2) Upper casing: 380 mm φ; Lower casing: 380 mm φ, 2.6 mm round sieve; 3) Abrasive material on inner surface of the upper casing: sand paper (0.5 m^2); 4) Clearance between upper casing and SC: 10 mm
FR	1) Feed roller: 2 (Nos.); 60 mm φ, 615 mm long; 2) Feed roller shaft: 20 mm φ
GU	1) Dimension: 730 mm length × 600 mm width × 360 mm front height and 285 mm back height; 2) Vertical gap between top sieve and bottom plate: 150 mm; 3) Inclination of bottom plate: 10 degree; 4) Top sieve: 1.8 mm round opening and a MS tray at the bottom
PTU	1) Electric motor: 0.75 kW, single phase A.C. motor (1440 RPM). 2) V-Belt and pulley system: (i) between motor pulley and SC pulley; (ii) between SC pulley and GU pulley 3) Chain and sprocket system between SC shaft and FR shaft 4) Cam shaft and belt pulley attachment: between GU and SC

Table 3 Recovery of nucleus seed, defluffing capacity and defluffing efficiency for fluffy *dinanath* seeds

F (g)	M_c (% wb)	M_t (g)	M_b (g)	Mass fractions through sieves			M_{ND} (g)	D_t (min)	Performance parameters		
				Retained on 1.18 mm sieve	Retained on 0.60 mm sieve	Passed through 0.60 mm			M_n (%)	D_c (kg/h)	D_e (%)
	7.0	295.20	203.80	55.20	114.10	34.00	0.6690	6.12	22.82^a	4.90^a	92.10^a
500	9.0	310.51	187.48	62.32	98.40	25.86	0.9170	7.18	19.68^b	4.18^b	88.63^a
	11.0	325.40	172.50	49.71	78.55	44.24	1.4981	10.0	15.71^c	3.02^c	80.50^b
						Coefficient of variation (CV)			0.669	4.798	2.214
						Critical difference (CD)			0.294	0.439	4.370
						Mean sum of square (MSE)			0.017	0.037	3.716
						F value			1140	36.35	14.52
						Level of significance (p-value)			< 0.01	< 0.05	< 0.05

a, b, c: the letters at superscript indicate whether the treatment means are at par or different.

M_c = Moisture content of fed seed sample; M_t = Mass retained on top screen of GU; M_b = Mass retained on bottom plate of GU indicated that the defluffing at 7.0% M_c and 545 rpm produced highest capacity of 4.9 kg/h and defluffing at 11.0% M_c with the same speed produced the lowest D_c of 3.02 kg/h. Increased D_c at 7.0% M_c was the result of more dryness of the fluffy seed. The results of D_e of the machine as presented in **Table 3** indicates that the highest value of D_e was 92.10% at 7.0% M_c which was at par to the seed having 9.0% M_c because the critical difference (CD = 4.370) is more than the difference of average values of D_e at 7.0% M_c and 9.0% M_c. The lowest values of D_e was 80.5% at 11.0% M_c which is significantly different. This agreed with the result of an earlier study by Simonyan and Oni (2001), where decrease in M_c of unthreshed grains resulted to an increase in threshing efficiency. Kamble et al. (2003) conducted the study of pearl millet thresher and got the reduced threshing efficiency with increase of Mc because high moisture content increased the plasticity of the grain. Bansal and Lohan (2009) obtained higher threshing efficiency at lower M_c during threshing of seed crops. Kushwaha et al. (2005) developed an okra seed extractor and evaluated at different Mc from which they got the result as extracting efficiency was decreased with increase of M_c.

Fulani et al. (2013) resulted that higher threshing efficiency observed at lower M_c in case of cowpea. The M_n decreased from 22.82% to 15.71% with increase in M_c from 7.0% to 11.0%. The quantity of nucleus seed obtained from 500 g fluffy seed was 22.82% at 7% M_c. This shows 77.2% decrease in bulk weight and 99.7% reduction in bulk volume of fluffy seeds after defluffing in the form of nucleus seed. This will be helpful in easy handling, transportation and storage. Vijay et al. (2018) conducted study on traditional cotton batting machine for defluffing of *dinanath* grass seed and got 5.6% M_n. They also observed 94% decrease in mass and 98% reduction in V of nucleus seed as compared to fluffy seed.

Cost Economics

Cost of defluffing using the prototype of machine was determined considering the fixed cost and variable cost of the machine (Dabhi and Davara, 2017). It was compared with traditional manual defluffing cost. Total cost was considered as the sum of fixed and variable costs. Following assumptions were made:

a) Life of machine, year: 10
b) Total working days per year: 150
c) Total working hours per day: 8
d) Depreciation cost of defluffing machine, Rs./y: 10% of initial cost
e) Rate of interest on capital investment per year, %: 12
f) Housing, insurance and other expenditures, Rs./y: 1% of initial cost
g) Repair and maintenance cost, Rs./y: 5% of initial cost
h) Capacity of defluffing machine: 4 kg/h
i) Labour charges, Rs./day: 400/-
j) Electricity charges @ Rs. 6 per unit: 0.75 kW × 8 h × 6 = Rs. 36/day

Details of the cost analysis are given in Table 4. Machine defluffing cost was Rs. 16.05 per kg, while traditional defluffing cost was Rs. 66.66 per kg considering manual defluffing @ 6 kg/day. The saving of cost was 75.92% of traditional manual defluffing cost. The main aim of defluffing was justified with cost saving and also in labour saving for the farmers.

Table 4 Comparative cost of defluffing operation

Parameters	Values
A. Fixed Costs	
(1) Depreciation cost of defluffing machine, Rs./h, (D) = (Initial cost − final cost) / (Life of machine × working, h/yr)	4.05
(2) Interest on the machine cost, Rs./h, (I) = (Average cost of machine × rate of interest) / (working, h/yr)	2.97
(3) Housing, insurance and other expenditures, Rs./h, (H) = (Initial cost × 0.01) / (working, h/yr)	0.45
(4) Total fixed cost, Rs./h	7.47
B. Variable Costs	
(1) R = Repair and maintenance cost, Rs./h = (Initial cost × 0.05) / (working, h/yr)	2.25
(2) W = Wages, Rs//h = (Labour charge per day) / (working, h/day)	50.00
(3) E = Electricity Charge, Rs./h = (kW of motor) × (unit rate of electricity)	4.50
(4) Total variable cost, Rs./h	56.75
C. Total defluffing cost (A + B), Rs. /h	64.22
D. Defluffing cost of the machine, Rs./kg = (Total defluffing cost, Rs./h) / (defluffing capacity, kg/h)	16.05
E. Defluffing cost by traditional method, Rs./kg = (Labor charges, Rs./day) / (manual capacity of defluffing, kg/day)	66.66

Conclusions

From the above results, it could be concluded that the designed and developed defluffing machine based on physical properties of *dinanath* grass seeds and design considerations, resulted in highest defluffing capacity (4.9 kg/h), defluffing efficiency (92.1%) and nucleus seed recovery (22.82%) at 7.0% moisture content. The lowest defluffing capacity of 3.02 kg/h and defluffing efficiency of 80.5% were recorded at 11.0% moisture content. The capacity of the defluffing machine was compared with manual defluffing of fluffy *dinanath* seeds and it was observed that the defluffing machine could save 76% cost of defluffing as compared to the manual defluffing. The mean value of seed dimensions (L × W × T) for fluffy seed and nucleus seed were 6.20 × 2.77 × 1.83 mm and 2.89 × 1.10 × 0.82 mm respectively. Similarly, the mean values of bulk densities of fluffy and nucleus seeds were 7.65 kg/m3 and 613.63 kg/m^3 respectively. Transportation cost of voluminous fluffy seeds may be reduced drastically as its volume reduced up to 99.7% after defluffing in the form of nucleus seed. The defluffed *dinanath* seeds, not only aid in easy storage and transportation but also in sowing either through broadcasting or pelleting. The defluffing machine may also provide an opportunity to defluff other grass seeds of similar nature.

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Techno-Economic Assessment of Happy Seeder Technology

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Abstract

The present study was conducted in district Ludhiana (L_1) and Moga (L_2) of state Punjab, India on happy seeder for sowing of wheat crop under rice wheat cropping system. Assessment of field performance of happy seeder technology was observed with the economic worth from the angle of custom hiring operator or the progressive farmer. The performance evaluation was done on the basis of dependent parameters such as fuel consumption, actual field capacity and field efficiency by selecting three different gears 1st, 2nd and 3rd low. Actual field capacity, field efficiency was maximum and fuel and energy consumption was minimum for 2nd gear for both L_1 and L_2. Economic analysis showed that the total operating cost of happy seeder system was Rs. 2,900.98 per ha and break-even point was 70.93 ha/y with the actual payback period of 2.68 years. The results from present study showed that happy seeder is a promising technology for adoption.

Keywords: Break-even point, Cost, Energy consumption, Field capacity, Happy seeder, Payback period.

Introduction

Rice-wheat cultivation in the Punjab state is highly mechanized and about 90 percent of paddy area is harvested by the combine harvesters which generates heavy straw load i.e. up to 6 tonnes per ha. Thus in total out of 20 million tonnes of paddy straw is produced after mechanical paddy harvesting, 15 million tonnes is burnt annually by farmers for timely and convenient sowing of next crop. The reasons for this stubble burning are due to its ease, economical and rapid means for get rid of paddy straw. However, this practice of burning posing long-standing concerns both on and off-farm (Singh et al., 2008). The burning of paddy straw also results in deterioration of soil health due to loss of plant nutrients, organic carbon of the soil, micro flora and fauna. As per estimates 25 percent of nitrogen, 50 percent sulphur and 75 per cent Potassium remained in the straw are lost through such burning thus costing more than Rs. 200 crores at the prevailing prices (Sidhu et al., 2007). As in the state more than 60% of the population lives in the rice growing areas so they are directly exposed to air pollution due to burning of stubbles (Kumar and Kumar, 2010). This burning practice results in production of enormous quantity of fine particulate matter and other noxious gases in the atmosphere which causes acute asthmatic, lung disease, cardio vascular problems etc. in elderly people and children. The stubble burning practice also contributes significantly to greenhouse gas emissions (Gujral et al., 2010). The presence of fog during winters further escalates the problem by trapping pollutants and hampering their dispersal and the thick clouds of smoke engulf roads, causing an increase in the number of accident, blocking or slowing down traffic etc. (Milham et al., 2011). In order to address the above issues in the state, number of crop residue management technologies have been invented, modified and demonstrated by researchers/scientists at the farmers' fields. Among the various paddy straw management technologies, happy seeder technology had a major breakthrough due to its exponential expansion in the past two years. It is one of the promising technology which is getting popularity among the farmers. Research finding reveal that, sowing of wheat with happy seeder technology the farmer can save time 5.38 h, fuel 16.03 liters and money Rs. 3,250/- per ha over the conventional practice (Singh et al., 2013). Farmers are adopting this technology for sowing of wheat crop in their own combine harvested paddy field and also using this machine on custom hiring purposes for sowing wheat crop in other farmers. In view of this farmers are purchasing this machine but under the current scenario where farmers of the state are in debt and maximum number of farmers comes under the category of small and marginal farmer, there is a need to study the optimal economic utilization of happy seeder technology. Therefore, the objective of this study is to evaluate the techno-economic worth or viability of happy seeder technology.

Materials and Methods

The field performance happy seeder was evaluated at farmers' fields for sowing of wheat in super SMS fitted combine harvested paddy field in the district Ludhiana (L_1) situated at the 30°56′ N latitude and 75°52′ E longitude and district Moga (L_2) stretches between 30°48′ N latitude and 75°08′ E longitude of state Punjab, India. The study was conducted during first week of November, 2018 and the soil of the experimental field at the location L_1 and L_2 was loamy. The climate was sunshine and the temperature range was 25-33 °C. The happy seeder technology implemented in the study is described below:

Happy Seeder Technology

In a single operation, happy seeder, drill the seed of wheat into a combine harvested paddy field by managing only that part of straw which is coming just in front of furrow openers. It consists of a rotor for managing the paddy residues and a zero till-drill for sowing of wheat. Flail type straight blades are mounted on the straw management rotor which cuts the standing stubbles/loose straw coming in front of the sowing tine and clean each tine twice in one rotation of rotor for proper placement of seed in the soil. The flails push the residues as surface much between the seeded rows. Flails are wings made up of mild steel and attached to the shaft called flail shaft. The shaft with flails is placed ahead of the furrow openers. Power to the flail shaft is fed through the power take off (PTO) drive of tractor. The optimal efficiency of the happy seeder is largely depends upon the efficient working of flails (Singh et al., 2018). Stationary view of happy seeder and flail and furrow opener is shown in **Figs. 1** and **2**. General specifications of happy seeder machine are given in **Table 1**. Happy seeder machine used in the present study had the press wheel attachment i.e. a wheel attached between two adjacent furrow openers to press the chopped straw, thrown by the flails of happy seeder. Pre-requisite for smooth operation of the happy seeder is uniform distribution of loose straw. For this purpose super SMS attachment is used which is installed at the rear side of the combine harvester which chop and evenly distribute the paddy straw coming out from the combine. The operational view of happy seeder and Super SMS is shown in **Figs. 3** and **4**.

Table 1 General specifications of happy seeder machine

Sl. No	Parameter	Value
1	No. of tines	10
2	No. of blades	20
3	Overall width (mm)	2,225
4	Power requirement (hp)	50
5	Tine spacing	225 mm
6	Weight (kg)	700
7	Seed and fertilizer mechanism	Fluted Roller
8	Type of furrow opener	Inverted T type
9	Rotor rpm	1,400 rpm at 540 rpm of tractor PTO

Experimental Procedure for Field Performance Assessment

For conducting the experiment, three farmers from locations L_1 and L_2 were selected, each having 1.2 ha area from same village. The area was divided into three equal parts, each having area of 0.4 ha. The machine was operated on each divided part with selected gear having particular forward speed. The same procedure was followed for the other two farmer's field. The power source used for the study purpose at each location was of 55 hp double clutch tractor. The machine was operated for sowing of wheat crop on the farmer's field at different gears 1st low, 2nd low and 3rd low at two different location L_1 and L_2 and for each operation dependent variable such as, fuel consumption, theoretical field capacity, actual field capacity and field efficiency were record-

Fig. 1 Stationary view of happy seeder

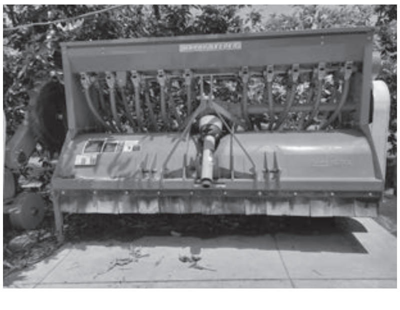
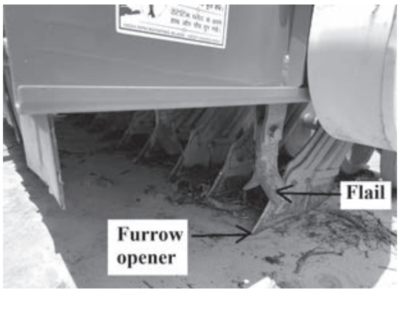


Fig. 2 Furrow opener and flail of happy seeder



ed. To calculate speed of operation at each gear, two poles were placed 35 m apart in the middle of test run. The speed was calculated from the time required for the machine to travel the distance of 35 m. The fuel consumption was determined by top-up level method in which the tank is filled to full capacity before and after the test. Amount of refilling after the test is the fuel consumption for the test (Malik et al., 2017). The procedure followed for the determination of other performance parameters are given below:

Actual Field Capacity (AFC)

Kepner et al. (1972) defined the effective field capacity as the actual average rate of coverage by the machine, based upon the total field time. It is impossible to operate machines continuously at their rate width of action, therefore their actual capacity is substantially less than the theoretical capacity (Hunt, 1979). The best way to determine the actual field capacity of a machine is to make an accurate check of the area actually covered (Siemens and Bowers, 1999).

Theoretical Field Capacity (TFC)

Theoretical field capacity is the maximum positive capacity obtained at a given speed, assuming the machine using its full width (Siemens and Bowers, 1999). It is the rate of field coverage of the implement (Kepner et al., 1972), based on 100% of time at rated speed and covering 100% of its rated width. Hunt (1979), suggested the following equation for theoretical field capacity calculation

$$TFC\left(\frac{ha}{h}\right) = \frac{W \times S}{10}$$

where,
W = Working width, m
S = Speed of operation, km/h

Field Efficiency (FE)

Field efficiency is defined as the ratio between the productivity capacity of a machine under field conditions and the theoretical maximum productivity (ASAE, 2000). It is a measure of the effective work done by a machine in ratio form between actual work done and what could be achieved under ideal conditions (Torres and Villegas, 1993). Kepner et al., (1972), Hunt (1979) and Siemens and Bowers (1999), defined machine field efficiency as the ratio of actual field capacity to theoretical field capacity, expressed in %,

$$FE\ (\%) = \frac{AFC}{TFC}$$

where,
AFC = Actual field capacity, ha/h
TFC = Theoretical field capacity, ha/h

Energy Consumption Calculation

The energy consumption for operating happy seeder technology at L_1 and L_2 was calculated from the sum of energy consumed by human, fuel, machine and tractor component. Proper energy equivalents (*Ee*) were used to account for each components and the values of the energy equivalent for human, fuel, machine and tractor component are 1.96 MJ/h, 56.31 MJ/l, 62.7 MJ/kg and 64.8 MJ/kg (Singh and Mittal, 1992; Singh et al., 2002; Gundogmus, 2006). The following relations were used to determine energy consumption (MJ/ha) from human, fuel and machinery component for operating happy seeder machine (Sidhu et al. 2015):

1. Human energy (MJ/ha) = [(No. of labor used × time (h) / Area (ha)] × *Ee*, (MJ/h)
2. Machine energy (MJ/ha) = [(Machine weight (kg)) / (Machine wear out life (h) × AFC, ha/h)] × *Ee* (MJ/kg)
3. Fuel energy (MJ/ha) = [Fuel consumption (l/h) / AFC (ha/h)] × *Ee* (MJ/l)

The energy consumption in each group of inputs was calculated from the multiplication of the amount of the input consumption and its energy equivalent per unit (extracted from scientific sources). The energy in MJ/ha is converted to kWh/ha by using the conversion factor of 3.6. The significance ($p = 0.05$) of the difference between the actual field capacity, fuel consumption and field efficiency of happy seeder for L_1 and L_2 at selected gears was determined by using the SPSS (version 26) statistical software.

Economic Worth Assessment

For the economic worth assessment, machinery (Tractor + Happy seeder) operation cost which consists of (a) fixed cost - depreciation, interest on invest, taxes, insurance and housing; (b) variable cost - labour, fuel, oil, repair and maintenance, were calculated. The detail of various types of cost involve and economic indicator parameter is given as below:

Fixed Cost

Fixed cost is defined as one, which does not change when level of output alters (i.e., it applies to a resource that is fixed in quantity). The straight-line method is the simplest for calculating depreciation

Fig. 3 Operational view of happy seeder

Fig. 4 Operational view of Super SMS installed at the rear of combine harvester

and is normally used in budgeting, since the concern is usually only with the average annual cost of machine (Barnard and Nix, 1980). Therefore, in calculation of fixed cost, a straight-line depreciation is assumed and the following equation was used for calculating the annual depreciation:

$$D = \frac{P - S}{L}$$

where,

D = Depreciation, Rs./y

P = Purchase price of Machinery, Rs.

S = Salvage value of machinery, Rs.

L = Life of machinery, y.

The interest on investment is included in fixed cost estimation. Even if the investment money is not actually borrowed, a charge is made since that money cannot be used for some other interest paying enterprises. The rate of interest taken in present study was 12%. The following equation was used for calculating the interest on invest:

$$I = \frac{P + S}{2} \times i$$

where,

i = interest rate, decimal.

Variable Cost (VC)

The variable cost is one, which changes when the level of output alters. Variable cost depends on hourly labour cost, fuel, oil, repair and maintenance cost and the required working hours for each field operations. The cost of operator/labour was calculated as the labour rate in Rs/h. The fuel and oil cost was estimated from consumption rate and multiplied by their respective prices.

Operating Cost (OC)

Annual operating cost of machinery used in present study was divided into fixed cost and variable cost. All calculated fixed cost and variable cost was converted into Rs/ha (Rs/h) and then summation of fixed and variable cost had given OC in Rs/ha (Rs/h). The OC was calculated as follows:

OC, Rs./ha = Fixed cost + Variable cost

Break Even Point (BEP)

Many farmers do not choose or cannot afford to own all the machinery required in their farming operations. Often this is because of restricted capital, limited labour, and small size of land holdings or other reasons. For these farmers, the purchase of custom services is one method of obtaining the needed machinery services on the farm. To decide whether it is more economical to own machinery or to hire a customer operator, compare the fixed and variable costs of owning and operating the machinery to the total costs of custom service. The break-even point (Gutierrez and Dalsted, 2020) is found faster and more accurately with the following formula:

$$BEP = \frac{S}{(R - V)}$$

where,

F = annual fixed costs

V = variable costs per unit of operation

R = custom hiring charge/rent per unit

Payback Period

The payback refers to the time period within which the costs of investment can be covered by revenues. In other words, it is the length of time required for the stream of cash proceeds produced by an investment to equal the initial expenditure incurred. This can be computed by applying the following formula:

$$\text{Payback period (yr)} = \frac{\text{Investment (total initial, Rs.)}}{\text{Net benefit (Rs./yr)}}$$

Benefit-cost Ratio (BCR)

Benefit-cost ratio is the ratio of present worth of benefit stream to present worth of cost stream. The method of benefit-cost analysis is simple in principle. It follows the systematic approach used in selecting between economic investments alternatives (Gittinger, 1994) and is given by the equation below.

$$BCR = \frac{\sum \text{Present worth of benefit}}{\sum \text{Present worth of cost}}$$

The investment is said to be profitable when the BCR is greater than one. Depreciation and interest of investment are not included in the costs to prevent double accounting. Depreciation is accounted for by the inclusion of the investment cost while interest of investment is accounted for by the discount factor.

Utility Index

It is a direct indication of work machine contact hours. With an increase in the utility index the cost of operation and the non-operating hours decrease. This in turn, results

Table 2 Field performance data of the happy seeder

Gear	Replication	L_1				L_2			
		FC (l/h)	FC (l/h)	AFC (ha/h)	FE (%)	FC (l/h)	FC (l/h)	AFC (ha/h)	FE (%)
1st Low	R1	6.5	0.47	0.32	67.72	5.8	0.47	0.32	67.72
	R2	5.75	0.47	0.3	63.49	6.5	0.47	0.35	74.07
	R3	6	0.47	0.34	71.96	6.25	0.47	0.3	63.49
	Avg.	6.08	0.47	0.32	67.72	6.18	0.47	0.32	68.43
2nd Low	R1	5.5	0.68	0.42	62.22	5.5	0.68	0.41	60.74
	R2	5.3	0.68	0.4	59.26	5.75	0.68	0.4	59.26
	R3	6	0.68	0.44	65.19	5.25	0.68	0.41	60.74
	Avg.	5.60	0.68	0.42	62.22	5.50	0.68	0.407	60.25
3rd Low	R1	7.1	0.83	0.31	37.24	5.5	0.83	0.34	40.84
	R2	6.5	0.83	0.35	42.04	6.2	0.83	0.37	44.44
	R3	6.2	0.83	0.32	38.44	6.4	0.83	0.35	42.04
	Avg.	6.60	0.83	0.33	39.24	6.03	0.83	0.35	42.44

into a net increase in the total power available for farm work. Utility index (K) can be calculated as

K = (Number of actual working hours per year) / (Number of expected working hours per year)

Results and Discussion

Machine performance analysis

The fuel consumption, theoretical field capacity, actual field capacity, field efficiency obtained at three different gears 1st low, 2nd low and 3rd low corresponding to forward speeds 2.1, 3.0 and 3.7 km/h and two different locations L_1 and L_2 is given in **Table 2**. The maximum average actual field capacity and minimum fuel consumption was found to be 0.42 ha/h and 5.60 l/h at gear 2nd L for location L_1 and was 0.407 ha/h and 5.50 l/h for location L_2. Since, actual field capacity depends upon actual time and as the actual time observed in case of forward speed of 1st and 3rd low gear was more due to more hindrance created in the operation happy seeder at low and high speed because of machine choking with straw observe at these gears speed whereas smooth functioning of happy seeder was observe at gear 2nd low. The same reason can be stated for the minimum fuel consumption observed at gear 2nd low. The variations corresponding to location may be due to the varying field condition and operator skill. The field efficiency was maximum 67.72 and 68.43 % for location L_1 and L_2 at forward speed of 1st low due to the less speed which cause less theoretical field capacity and more time consumption which in term decrease the actual field capacity. The effect of changing gear at location L_1 and L_2 on fuel consumption, actual field capacity and field efficiency is given in shown in **Figs. 5**, **6** and **7**. The ANOVA test conducted showed that the gears affected the fuel consumption, actual field capacity and field efficiency significantly at 5 % level of significance. There is negative correlation between actual fuel consumption and fuel consumption, which is significant at 5 % level of significance (two tailed).

Energy Consumption Analysis

The total energy consumption in operating happy seeder machine in different selected gears at L_1 and L_2 is shown in **Fig. 8**. It was observed that at both location L_1 and L_2, energy consumption was less for gear 2nd low gear as compared to 1st and 3rd low gear. This is due to less fuel consumption and more actual field capacity of machine at 2nd low gear. The energy consumption at L_1 and L_2 for 2nd low gear was 244.77 and 248.74 kWh/ha, whereas energy consumption for 1st and 3rd low gear at L_1 and L_2 were 344.72 and

Fig. 5 Effect of gear change on fuel consumption of happy seeder at location L_1 and L_2

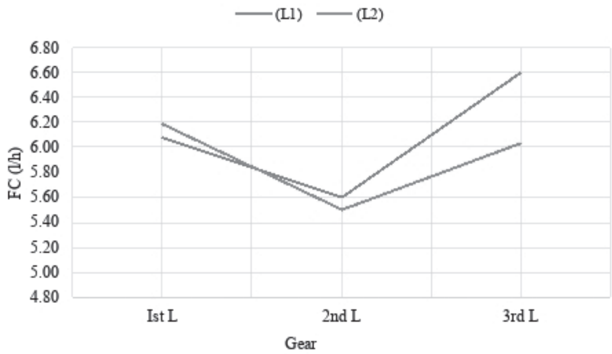


Fig. 6 Effect of gear change on actual field capacity of happy seeder at location L_1 and L_2

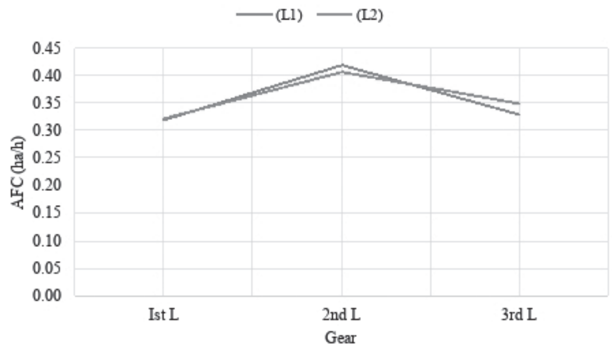


Fig. 7 Effect of gear change on field efficiency of happy seeder at location L_1 and L_2

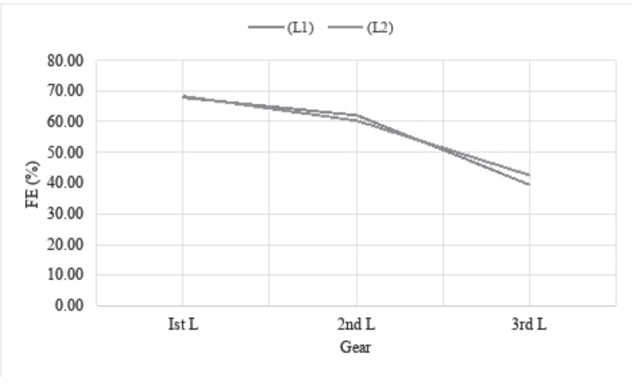
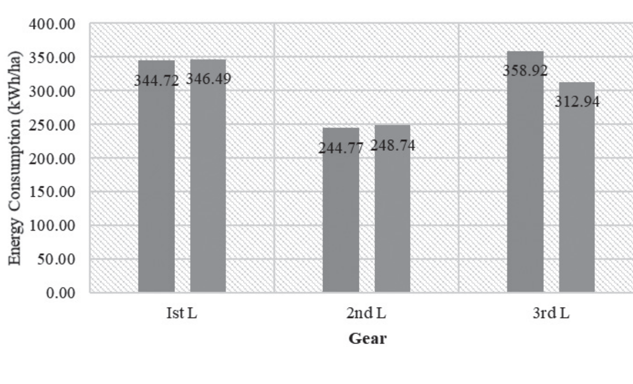


Fig. 9 Total energy consumption in operating happy seeder



346.49; 358.92 and 312.94 kWh/ha respectively. Among the all components, the maximum contribution in energy consumption was from fuel component in all the selected gears at both L_1 and L_2 location followed by machine, tractor and human energy consumption component. The least involvement of human energy component indicates the high status of mechanization in the study areas. The least fuel energy consumption was 208.56 and 211.37 kWh/ha for 2nd low gear at both L_1 and L_2 whereas for 1st and 3rd low gear the fuel energy consumption was 297.19 and 299.13; 312.83 and 269.48 kWh/ha at L_1 and L_2 respectively. The component wise energy consumption for each selected gear at L_1 and L_2 is shown in **Fig. 9** and the energy consumption detail for operating happy seeder machine is given in **Table 3**.

Table 3 Energy consumption for operating happy seeder

Location	Gear	Energy consumption (kWh/ha)				Total (kWh/ha)
		Machine	Human	Fuel	Tractor	
L_1	1st L	6.5	0.47	0.32	0.32	67.72
	2nd L	5.75	0.47	0.3	0.35	74.07
	3rd L	6	0.47	0.34	0.3	63.49
L_2	1st L	5.5	0.68	0.42	0.41	60.74
	2nd L	5.3	0.68	0.4	0.4	59.26
	3rd L	6	0.68	0.44	0.41	60.74

Cost Analysis

The economic analysis of using the happy seeder with tractor and various assumption made during the analysis is given in **Table 4**. The financial analysis was computed from the viewpoint of machine owner whether he is a custom hiring operator or a progressive farmer. Based on field data, the present total cost of operation and actual field capacity of the happy seeder machine were estimated as Rs. 2,900.98 per ha and 0.41 ha/h (average maximum actual field capacity of location L_1 and L_2) respectively. Fixed cost and variable cost for the machine operation were estimated Rs. 1,326.83 and 1,574.15 per ha respectively based on the average field data and collected through personal interview of custom-hire service providers. The rental charges of using happy seeder by a customer operator is Rs. 3,810/- per ha. The net benefit was comes out to be Rs. 909.02 per ha and considering 150 h annual use of happy seeder according to the custom operators and the net annual benefit or revenue was observed to be Rs. 55,905. The various itemized

Table 4 Economic analysis of machinery under study

Particulars	Assumption	(Happy Seeder)	Tractor
Purchase price (P), Rs.	-	150,000	700,000
Salvage (S) , Rs.	10 % of P	15,000	70,000
Life, year	-	6	10
Economic life, h	-	150	400
Depreciation, Rs./year	-	22,500	63,000
Interest cost, Rs./year	Rate of interest, 12%	9,900	46,200
Tax, insurance, shelter, Rs./year	2% of P	3,000	14,000
Fixed Cost, Rs/year (Rs./h)	-	35,400 (236)	123,200 (308)
Total fixed cost (FC), Rs./year (Rs./h)	-	158,600 (544)	
Repair & maintenance, Rs/h	5% of P/Avg/year	50	87.5
Fuel cost (5.94 l/h), Rs./h	@ Rs. 65/litre	0	360.75
Lubrication cost, Rs./h	20% of Fuel Cost	0	72.15
Labour Cost, Rs./h	-	37.5	37.5
Variable cost (VC), Rs./h	-	87.5	557.9
Total cost (TC), Rs./h	-	323.5	865.9
Operating cost, Rs./ha (Rs./h)	-	2,900.98 (1,189.4)	

Fig. 9 Energy consumption involvement of different component

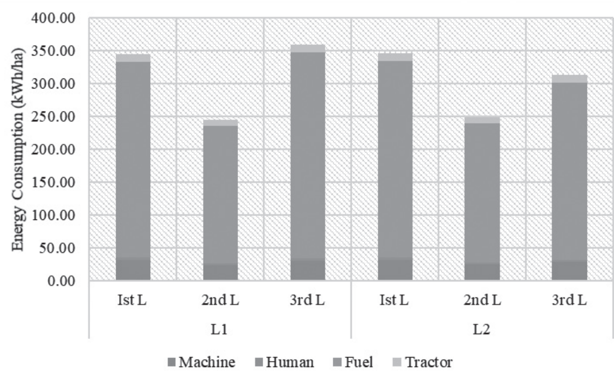


Fig. 10 Itemized cost per hour of operation

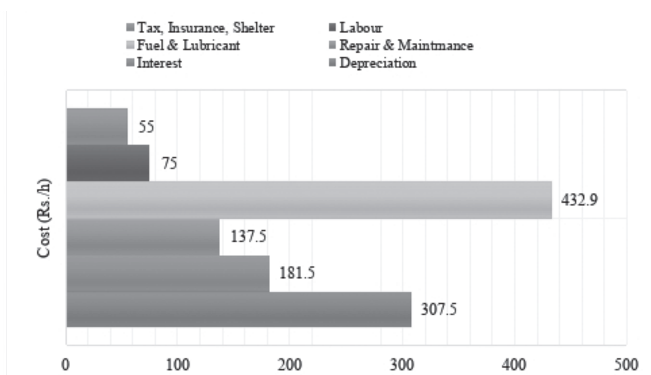


Table 5 Economic worth evaluation of happy seeder technology

Sl. No	Items	Value	Remarks
1	Actual field capacity, ha/h	0.41	Average of location L_1 and L_2
2	Rental charges, Rs./ha (Rs./h)	3,810 (1,562.1)	-
3	Net Benefit, Rs./ha (Rs./h)	909.02 (372.7)	-
4	Annual Benefit (Rs.)	55,905	-
5	Actual Payback period (year)	2.68	Less than economic life of machine (< 6 y)
6	Break-even point ha/year (h/year)	70.93 (173.01)	More than the actual covered area
7	Optimal benefit (Rs.)	64,480.83	-
8	Optimal Payback period (year)	2.33	Less than economic life of machine (< 6 y)
9	Benefit-cost ratio (BCR)	1.31	Greater than unity (> 1)
10	Utility index	0.87	Less than unity (< 1)

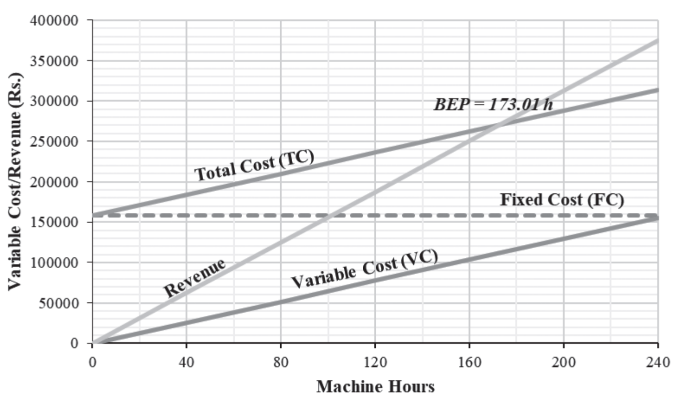
cost per hour is shown in **Fig. 10**.

Considering the capital cost involved in purchase of happy seeder and assumption made for economic analysis in this study, the break-even point comes out to be 70.93 ha per year or 173.01 h per year whereas actual use of machine is 150 h per year. Considering the actual annual use of machine the farmer or custom operator shall be able to recover his cost in 2.68 year (payback period). All the earnings after this period while using the same happy seeder machine will be his earning but if literally the farmer uses the machine optimally for 173.01 h per year (break-even point) then his payback period would be 2.33 years (**Fig. 11**). The both actual and optimal payback period of machine is less than the economic life (6 y) of the machine and also the benefit cost ratio is found to be 1.31, which is greater than unity, So, operating the machine on custom hiring and covering area around 70.93 ha per year is a acceptable profitable venture, although in current actual condition custom operator/progressive farmer covering operating 150 h is also acceptable but the payback period will increased. The utility index obtained was 0.87 which is less than unity which showed underutilization of machine from the point of optimal parameters. All the details of economic parameters is given in **Table 5**.

Conclusion

It is concluded that using the happy seeder technology is a profitable venture with the additional benefit of viable alternative to on farm paddy straw burning. In present study, techno-economic evaluation of happy seeder technology for sowing of wheat in combine harvested paddy field was done at two locations L_1 and L_2 with the economic analysis. Actual field capacity, field efficiency was maximum and fuel and energy consumption was minimum for 2nd low gear for both location. The total operating cost of system was Rs. 2,900.98 per ha and break-even point was 70.93 ha/y which was more than the actual use of machine per year with the actual payback period of 2.68 years, but the optimal payback period should be 2.33. The benefit-cost ratio of machine was found 1.31, which was profitable venture for a custom hiring operator.

Fig. 11 Economic use of happy seeder machine operation



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Design and Development of a Tractor Operated Bund Former for Mulched Field

by

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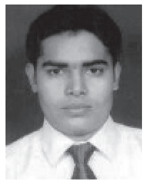

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Abstract

A tractor operated bund former was conceptualized, designed and CAD models were developed using Pro-E software before the actual development/fabrication. The machine was developed with integrating mainly three units such as mulcher, rotavator and bund forming unit based on design calculations. These respective units perform three operations, namely, mulch removing, soil pulverizing and bund forming on desired path simultaneously in one pass. The mulcher, rotavator and bund former was designed based on the amount of soil required to prepare the bund. The preliminary trials indicated that height and width of bund was obtained about 27 cm and 64 cm, which was more than desired values ≥ 20 cm and ≥ 60 cm, respectively. This machine is found to be an excellent and convenient option over existing bund forming technologies to be operated in the mulched field.

Introduction

Paddy is a major crop of Punjab (India) and covers about 3.06 million ha area with 20.07 MMT of paddy production. With this, straw production is also surplus accounting about 20.17 MMT (Anon. 2020a). Handling of this straw is cumbersome within the shorter window period (15-20 days) for sowing of wheat and subsequent bund making. There are two mechanized methods that includes *in-situ* and *ex-situ* management of paddy straw (Modi et al., 2020). The *in-situ* technique refers to incorporation or retaining (as a mulch) of paddy straw into soil or on soil surface whereas *ex-situ* technique refers to removal of paddy straw from the field. In *ex-situ* technique of paddy straw management, paddy straw is either removed or collected off from the harvested field. This can be done by machines like farm mulch collector, balers and head feed combines. The farm mulch collector removes loose straw and loads into trolley at the same time. While the bailing machine picks the loose straw from windrows and moulds it into a cylindrical shape or cube shape depending on type of baler used (Modi et al., 2020). *In-situ* incorporation improved decomposition of residues harvested with combines to early replenishment of nutrients in the soil. Incorporation also has optimistic influence on soil health parameters such as pH, increase in soil organic carbon content, rate of infiltration and water holding capacity which in turn improves fertility of soil (Gupta et al., 2004; Mandal et al., 2004; Sahai et al., 2011). About 1-2 irrigations are saved for preparing seedbed when straw is incorporated. The incorporating technique includes the operation of conventional straw chopping machinery followed by tillage machinery for straw mixing in the soil. The chopped straw can be mixed into the soil with reversible mould board plough or equipment like disc harrow, cultivator and plankers. The usual incorporating method is to use combination of straw chopper, reversible mould board plough followed by rotavator and planker. Another operation includes use of tractor mounted paddy straw chopper-cum-spreader which cuts, chops and spreads the straw simultaneously (Anon. 2017).

Therefore, the residue is uniformly distributed using the above *in-situ* method. But, the residue lying in field comes with a number of issues associated with it. One of those problems is hindrance in formation of bunds in the field as they cause the bunds made are broken after application of irrigation water. Bund making is a tillage operation intended for heaping up of tilled soil from two sides to form long stripes of mounds having furrows in between (Nkakini, 2014). Tractor operated bund formers are normally either disc or mould board type or forming board type. There is conventional practice of bund making, to remove the straw about (1.25 m width) manually, then using tillage machinery and finally operating forming board type bund former to make demarcations in fields. Whereas, disc type and mould board type bund formers make bunds directly in mulch field. These formed bunds are porous and oversized due to incorporation of paddy straw in it. It leads to breakage of bund and moreover higher application of irrigation water. These problems prevent desired bund formation and demands more labour for the entire process that can upsurge expenses. To eliminate these problems, such machine was required that can single handedly perform mulching, rotary tilling and bund making operation. The machine was required to assist forthcoming operations of Happy Seeder due to growing popularity of the same. Happy Seeder is one composite machine consisting of straw chopping unit and a sowing unit. This technology belongs to the *in-situ* method of retaining straw as mulch on the field. In Punjab, the area under Happy Seeder technology is 3,224 ha in 2018-19 (Mahal et al., 2019). As rice-wheat is water guzzling cropping system, judicious use of irrigation water has to be done in order to follow this cropping pattern. Thus, keeping in view need of farmers, design and development of tractor operated bund former was undertaken.

Material and Methods

Conceptual Design

The conceptualization of the machine involves following functional requirements:

a) The loose or standing paddy straw should be removed from soil surface on which rotavator is intended to work.

b) This straw-free soil surface should be well pulverized in which pulverization index ranged from 3-15 mm.

c) Trapezoidal shaped bund of height 150 mm and width about 600 mm should be formed with optimum compaction.

d) All these operations should be done at single pass of the machine.

Removing of paddy straw from in front intended operational area of bund former using mulcher and pulverizing the same soil surface by rotavator. During the forward travel of the machine, mulcher picks the straw, rotavator pulverizes the straw free soil and bund former makes the bund. The picked straw by mulcher was thrown in rear side on the prepared bund. The conceptual design of bund former is shown in **Fig. 1**.

Design of Tractor Operated Bund Former

Required Width of Rotavator

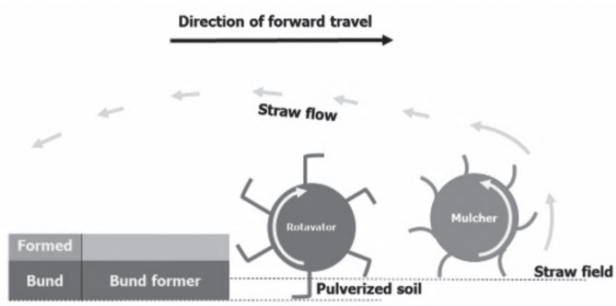
The operational width of cut required for the rotavator was based on required size of bund. The dimensions of the prepared bund in terms of top width (W_t), base width (W_b) and height of bund (H) were 250, 600 and 300 mm, respectively (Ryals, 1984; Xian-Jun and De-Ti, 2009).

Volume of soil (V_s) required for trapezoidal shaped bund per meter length (L) of travel was calculated as follows

$$V_s = 1/2 \times (W_t + W_b) \times H \times L \quad (1)$$

$$V_s = 1/2 \times (250 + 600) \times 300 \times 1000 = 127500000 \text{ mm}^3$$

Fig. 1 The conceptual design of tractor operated bund former



An allowance of 10% variation in the volume of soil required based on moisture content of soil

$V_s = 127500000 \times 1.10 = 140250000$ mm^3 (from Eqn. 1)

Then working width of rotavator (W) can be determined by considering the working depth of rotavator (R_d) as 115 mm (Bhambota et al., 2017).

$W = V_s / (R_d \times L) = 140250000 / (115 \times 1000) = 1220$ mm (2)

Thus, operational width of rotavator calculated as 1220 mm. Providing 2.5% allowance for accommodation the rotor shaft the width becomes

$W = 1220 \times 1.025 = 1250.5$ mm ≈ 1251 mm (from Eqn. 2)

The operational width of cut of rotavator was found to be 1251 mm. Similarly, paddy straw has to be removed from same width where the soil to be pulverized. Hence, the mulcher of same width as that of rotavator was selected.

Design of Mulcher

Power requirement of mulcher per tonne of mulch (P_{mt}) with effective width of 2.1 m for mulched conditions was 1.864 kWh/t (Kepner et al., 2005). According to Singh et al., (2011), Indian mulched field conditions have maximum 7.0 tonnes of straw load (S_l).

The power requirement of mulcher rotor (P_m) can be calculated as:

$P_m = P_{mt} \times S_l = 1.864 \times 7.0 = 13.048$ kWh (3)

Power requirement for mulcher with effective width of 1.25 m (60% power requirement based on width of mulcher) becomes

$P_m = P_r \times 0.60 = 13.048 \times 0.60 = 7.83$ kWh (from Eqn. 3)

Torque required for mulcher (T_m) can be calculated from the formula

$T_m = (P_m \times 60) / (2 \times \pi \times N)$ (Kepner et al., 2005) (4)

where,

N = Rotations of mulcher rotor, rpm

Mulcher has to remove the straw (without chopping) from its front side. The conventional mulcher had rotational speed of about 1500 rpm (Thakur et al., 2018). Thus, the speed for this rotor was kept about 26% lesser than the conventional rotor thus the mulcher rotor speed (N) was taken as 1100 rpm.

$T_m = (7.83 \times 1000 \times 60) / (2 \times \pi \times 1100) = 67.97$ Nm = 67360 Nmm (from Eqn. 4)

Also, the outer diameter of the mulcher rotor (d_o) can be calculated as

$d_o = \sqrt[3]{(T_m \times 16) / [\tau \times \pi \times (1 - k^4)]}$ (Sharma and Mukesh, 2018) (5)

where,

τ and k is allowable shear stress 42 MPa and ratio of inner to outer diameter as 0.5, respectively (Khurmi and Gupta, 2005)

Putting above values in Eqn. 5 it yields,

$d_o = \sqrt[3]{(67360 \times 16) / [42 \times \pi \times (1 - 0.5^4)]} = 20.5$ mm

Taking factor of safety (F_{s1}) taken as 6.0 (Sharma and Aggarwal, 2013) thus outer diameter of the mulcher rotor becomes

$d_o = 20.5 \times F_{s1} = 20.5 \times 6.0 = 123.0$ mm

The diameter of mulcher rotor was calculated to be 123.0 mm and the actual available rotor diameter was 168.0 mm thus design is safe.

Design of rotavator

In design of rotavator, it is necessary to calculate maximum peripheral force (Kp, kgf) on rotavator working blades set which can be calculated as follows:

$K_p = (75\ P_t\ \eta_t\ \eta_r) / u$ (Sharma and Mukesh, 2018) (6)

where,

P_t = tractor power, hp

u = rotavator tyne peripheral velocity, m/s (3.3 m/s) (Sharma and Mukesh, 2018)

η_t = tractor transmission efficiency (0.9 for concurrent revolution)

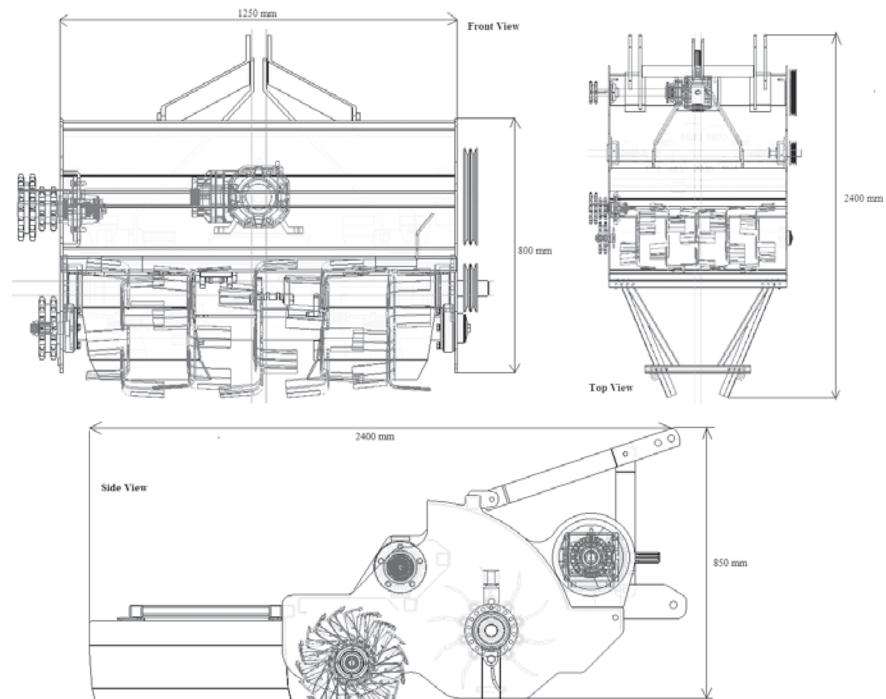
η_r = coefficient including a reserve of tractor power amounting to 0.7-0.8 (taken as 0.78)

To operate the rotavator required tractor power is 43.5 hp for width of cut about 1250 mm (Anon., 2002)

$K_p = (43.5 \times 75 \times 0.9 \times 0.78) / 3.3 = 694.02$ kgf (from Eqn. 6) (7)

Considering overload factor (C_p) for peak peripheral force as 1.5 for

Fig. 2 CAD drawings of tractor operated bund former



stone less soil (Sharma and Mukesh, 2018)

Therefore, design force (K_d) on rotary tyne is calculated as

$$K_d = C_p \times K_p = 1.5 \times 694.02 = 1041.03 \text{ kgf} \quad (8)$$

The radius of rotary tyne (R) was assumed as 22 cm (Sharma and Mukesh, 2018)

Thus, torque of rotavator shaft (Tr) can be calculated as

$$T_r = K_d \times R = 22902.66 \text{ kgf-cm} \quad (9)$$

Outer diameter of rotavator rotor shaft (d_{or}) in torsion can be calculated as

$$d_{or} = {}^3\sqrt{(Tr \times 16) / [\tau \times \pi \times (1 - k^4)]}$$

(Khurmi and Gupta, 2005) (10)

$$d_{or} = {}^3\sqrt{(223763.1 \times 16) / [42 \times \pi \times (1 - 0.5^4)]} = 30.94 \text{ mm}$$

Taking factor of safety (F_{s2}) taken as 2.5 thus outer diameter of the rotavator rotor becomes

$$d_o = 30.94 \times F_{s1} = 30.94 \times 2.5 = 77.35 \text{ mm}$$

The diameter of rotavator rotor shaft was calculated to be 77.35 mm and actual available rotor diameter was of 88.00 mm thus the design is safe.

Design of Gear Box Shaft

Power required at PTO (P_o) taking 87% of tractor power

$P_o = 50 \times 0.87 = 43.5$ hp ≈ 43 hp (as 50 hp tractor is capable to operate the machine properly)

Some transmission losses occur during transmission of power from P.T.O to gear box main shaft. The reason being number of mechanical components between both ends such as universal joint, gear box input shaft, gears and gearbox output or main shaft.

Power available at gearbox after universal joint (P_u) can be calculated as

$$P_u = 0.92 \times P_o = 0.92 \times 43.5 = 40.94 \text{ hp} \quad (11)$$

Power available at gear box main shaft (P_{gm}) can be calculated as taking 2.0% losses

$$P_{gm} = 0.98 \times P_u = 0.98 \times 40.94 = 40.12 \text{ hp} = 29.93 \text{ kW} \quad (12)$$

$$T_{gm} = (P_m \times 1000 \times 60) / (2 \times \pi \times N_m) = 529.27 \text{ Nm} \quad (13)$$

Where,

N_m = Speed of gear box main shaft, rpm

Backup torque (T_b) = 7% (minimum) (Anon., 2008)

$T_b = 529.27 \times 1.07 = 566.32$ Nm

$T_b = (\pi \times \tau_m \times d_g^3) / 16$ (τ_m and d_g is diameter of gear box main shaft and cold drawn mild steel shaft 50-80 MPa, respectively) (14)

$d_g = 33.03$ mm (from Eqn. 14)

Taking Factor of safety = 1.25 (Sharma and Aggarwal, 2013)

$d_g = 33.03 \times 1.25 = 41.28 \approx 41.3$ mm

The diameter of gear box main shaft was calculated to be 41.3 mm and actual available main shaft diameter was of 45 mm thus the design is safe.

Development of Tractor Operated Bund Former

The machine was developed based on above design calculations. Mainly three units namely mulcher, rotavator and bund former unit were developed. Initially, main frame was developed with overall dimensions of 1240 × 208 × 46 mm. The mulcher was used for straw removing and spreading it onto the prepared bund at rear. The conventional mulcher consisted of shaft, serrated gamma shaped flails, cover, output opening etc. The mulcher rotor equipped on bund former differs in some means as compared to conventional mulcher. The flat flail type blades without serrations were used instead of gamma blades. The developed mulcher unit had serrated gamma shaped flails arranged in a helical manner on the periphery of the rotor. Blade acts on standing stubble with impact action which can pick up the straw and throw out with centrifugal force. The blades were bent at an angle of 22° with its straight surface with sharped tip. The rotavator unit was assembly of hollow cylindrical rotor shaft, blades mounted on flange, bearings, straw outlet, side skid etc. A hollow cylindrical shaft was mounted with flanges on which blades were fixed at equal distance. Each flange had a set of six blades bolted with C shaped blades. The C type blades were selected due to their capability of better pulverization of soil and lesser power requirement. The overall length and outer diameter of shaft of rotavator was 1,350 and 66 mm, respectively. The bund forming plates are similar to rectangular type bund maker with plates tilted towards inwards from the rear end. This unit consisted of main frame, holding plates and a pair of rectan-

Fig. 3 Power transmission layout

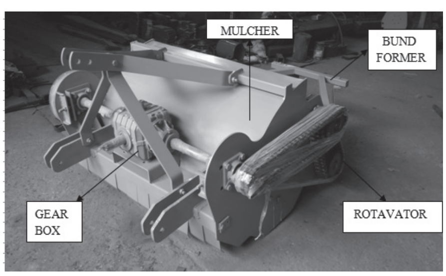
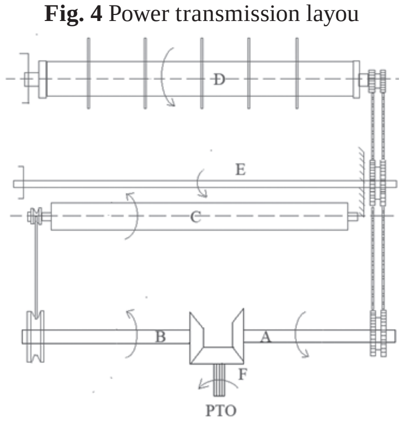


Fig. 4 Power transmission layou



A: Output shaft to rotavator, B: Output shaft to mulcher, C: Mulcher shaft, D: Rotavator shaft, E: Support shaft, F: Gear box shaft

Fig. 5 Working view of tractor operated bund former machine

gular plates on both sides. The plates had outward bends near the longer edges at equal distance from center of plates. There was great amount of thrust exerted on the plates due to soil conveyed by rotavator after pulverization. The rear most part of the machine was bund forming plates required to shape and compact the bund. A T-type double action gear box was procured from the local market. An appropriate pair of skid plates, chains and sprockets, pulleys and belts were selected for smooth working of the machine. The rest of components include gear box, belts, pulleys, chains, sprockets as shown in power transmission layout (**Fig. 3**). The suitable belt, pulley, chain and sprockets were selected according to the designed speed of the rotavator and mulcher unit. The specifications of developed tractor operated bund former are shown in **Table 1**.

Preliminary Trials of the Developed Prototype

Preliminary trial of the developed machine was carried out at Departmental Research Farm, PAU, Ludhiana in clay loam soil type. The developed prototype was evaluated for assessing of proper functioning of all the parts of the machine. The mulcher was observed to properly working as it removed straw uniformly. Moreover, there was no hindrance to tractor movement during bund formation. The performance of the machine was encouraging during the preliminary trails in the straw mulched field up to the straw load 6.5 t/ha. The height and width of bund was found about 27 cm and 64 cm, respectively. At a forward travel speed of 1.5 km/h the field capacity of the machine was 0.18 ha/h with field efficiency of 82%. The machine has potential to eradicate problems associated with irrigation, straw management and extra labour costs.

Table 1 Specifications of developed tractor operated bund former

Description of component	Specifications
Type of machine	Mounted with three point hitch
Power source, hp	PTO, 42.5
Mulcher unit	
Total No. of blades	10
Blade type	Flat
Diameter of shaft	168
Overall dimensions of mulcher unit, mm	1240 × 208 × 46
Flat partition flapper overall dimensions, mm	1219 × 609 × 7
Rotavator unit	
Type of blade	C
Total number of blade	30
Number of flanges	5
Number of blades on each flange	6
Diameter of shaft	88
Overall dimensions of rotavator unit, mm	1150 × 210 × 66
Bund forming unit	
Plate Type	Rectangular
No. of plates	2
Overall dimensions, mm	830 × 320 × 7
Gear box	
Ratio	1:1
Type	T, Single speed double action
Overall dimensions of the machine, mm	2400 × 1250 × 850
Weight, kg	675

Conclusions

The bund former machine can be used in other mulch conditions along with paddy mulch fields. The machine can also be used in no mulch conditions by disengaging the mulcher rotor. Farmers can use the machine to perform mulching, tilling and bund forming at the same time. Straw mulch was retained over the bund which played a role in conserving moisture and forming a protective cover for bund. There could be reduction in seepage of water through bunds due to decreased porosity of soil. Therefore, use of mulcher, rotavator and bund former combined proved to be a better option over the conventional bund making methods.

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Modification and Performance Evaluation of an Industrial Fodder Chopping Machine

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Abstract

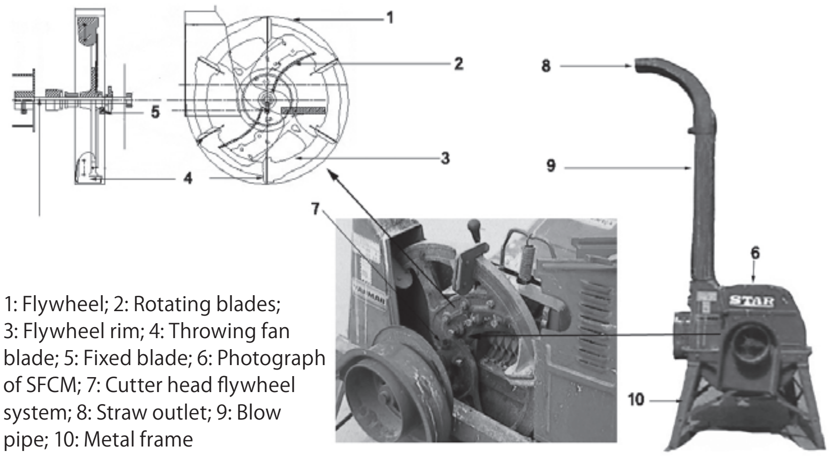
Star forage chopper machine (SFCM) was modified and tested to lower the power requirement and to improve forage cutting efficiency, and thereby to lower the environmental and health impacts by replacing diesel-based farm machines with electric powered machines. Power transmission assembly, rotating cutter head knives and straw outlet position were modified, and newly constructed feed rollers were added and positioned to control plant material to be chopped. The performance of SFCM was evaluated based on its ability to chop rice straw and cotton stalks under three different feed rates 0.8, 1.2 and 1.5 t/h, four different knife speed 78.6 (750), 91.1 (1,000), 115.2 (1,250) and 136.2 (1,500) m/s (rpm). Minimum cut lengths were 1.35 and 1.27 cm for rice straw that were achieved corresponding to the highest feed rate of 1.5 t/h with the maximum knife speed 136.2 m/s while using toothed blades and normal (flail) blades respectively. At higher feed rates, either power required to cut rice straw or cotton stalks increased with increasing knife speed under the two types of new knifes. Minimum power required to cut rice straw were 1.81 and 1.76 kW and were achieved at feeding rate of 0.8 t/h with knife speed of 78.6 m/s for toothed blades and normal (flail) blades, respectively. Rice straw and cotton stalks cutting efficiency decreased with increasing feeding rates, and increased with increasing knife speeds. Specific energy for cutting rice straw and cotton stalks decreased with increasing feeding rates and decreased also with increasing knife speeds.

Keywords: animal feed, crop residue, chopping power.

Introduction

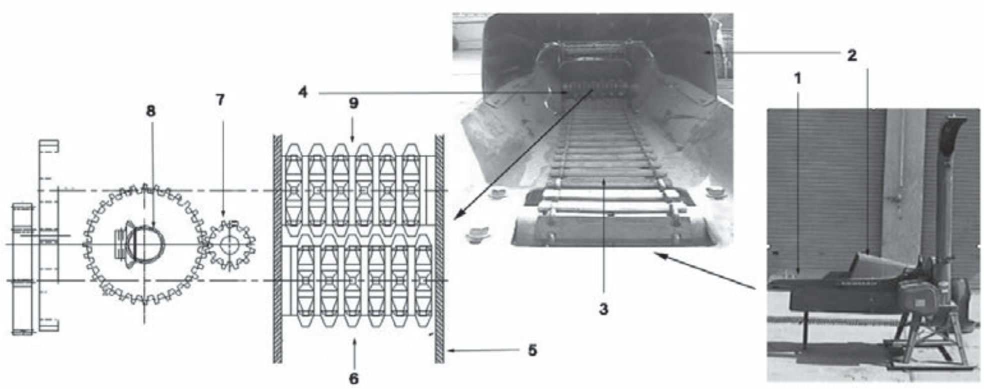
Agricultural residues are the most abundant biomass and animal feed resources in Egypt. Due to the size of agricultural production, a large volume of residues is generated from this sector each year, the total residue produced for all the selected residue types was estimated to be around 30 MMt/year. A large portion of these residues consists of those from cereals (67.6%), with wheat straw making up the largest share (37.7%), followed by maize stalk (16.6%) and rice straw (10.7%) [1]. About 52% of these agricultural residues are either not used effectively or are burnt directly in fields or in inefficient burners [2]. Chopping green fodder and forages is practiced for crop residues and fodder crops such as maize and sorghum and tall forages such as Napier grass. There are many different ways of chopping; by hand with a machete; by using a hand-operated chopper; an engine-driven chopper or an engine-driven chuff cutter. Both electric and petrol-driven motors are used widely to power mechanical choppers and chaff cutters too [3]. Chopping is a prerequisite for either use, and reducing the shearing force has been considered as one of the most effective approaches to save energy [4]. A feed chopper is mechanical device used to cut and properly processes the straw or hay into small pieces so as to mix it together and fed to cattle. This improves animal digestion and prevents animal from rejecting any part of their food. Also, it improves feed intake and thus might be a viable option to help cows cope with less nutrient-dense feeds [5, 6]. So, to increase the productivity and reduce the physical effort required for running the machine, improved and motorized machineries came into existence to support farmers and animal feed processors. Presently fodder cutting machines are electric driven as well as hand operated or engine driven [7]. Researchers [8] recommended using engine-driven feed choppers as they proved their effectiveness in terms of different chopping efficiency, output capacity and conservation of moisture and content in crop stalks. Engine-driven chopper has been developed by [9] for chopping of maize stalk and grass. The machine was designed with feed chopper, rotating drum with swinging knives, casing with fixed knives welded on it, a screen and stands as main components. The test result showed that the optimum drum speed and feed rate values for both maize stalk and grass were 1,200 rpm and 40 kg/h respectively. The average size reduction percentage using these optimum combinations was 92.0% and 79.5% for maize stalk and grass respectively. [10] conducted field experiments to evaluate the performance of a modified thresher machine for chopping two types of crop residues namely rice straw and cotton stalks. They concluded that the optimum operation conditions for cutting rice straw was at cutting rotor speed of 19.6 m/s, stalks moisture content of 10.45%, and using swinging knives and for cutting cotton stalks was at cutting rotor speed of 27.5 m/s, stalks moisture content of 8.37%, and using rotating knives. [11] constructed and evaluated a fodder-bales chopper in terms of chopping productivity and efficiency and required power. Results cleared that the maximum machine productivity values were 785.5 and 830.7 kg/h, the maximum required power values were 20.86 and 22.64 kW, and the maximum chopping efficiency values were 96.8 and 97.4% when the chopper used with wheat straw and rice straw bales respectively by using combined knives with hammers at drum speed of 1,040 rpm. Researchers [12] determined the optimum machine working conditions for making a good silage from fodder beet tubers using small local prototype forage chopper machine. The highest recorded actual capacity and machine efficiency were 3.412 Mg/h and 88.41% respectively. Also, minimum recorded total losses and energy required were 7.65%, 0.767 kWh/Mg respectively. From literature review, it is recommended

Fig. 1 Star forage chopper machine (SFCM)



1: Flywheel; 2: Rotating blades; 3: Flywheel rim; 4: Throwing fan blade; 5: Fixed blade; 6: Photograph of SFCM; 7: Cutter head flywheel system; 8: Straw outlet; 9: Blow pipe; 10: Metal frame

Fig. 2 Feeding system, movement mechanism and feeding drums



1: Inlet feeding trough; 2: Feeding gate; 3: Conveyor; 4: Feeding drums; 5: Guide plates; 6: Lower feed drum; 7: Spur gear; 8: Bevel gear; 9: Upper fee--d drum to work further to modify, promote and to adapt fodder choppers. Therefore, this research work was aimed at demonstrating and evaluate a modified engine driven feed chopper which is star forage chopper machine (SFCM) for reducing power requirement and to improve the cutting efficiency.

Material and Methods

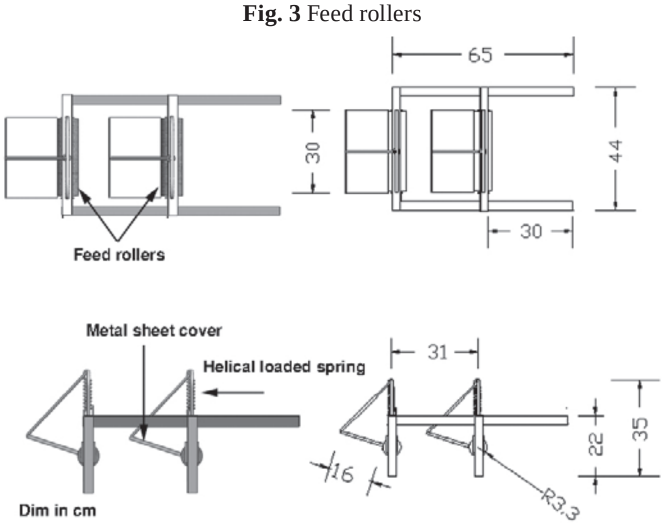
Star forage chopper machine (SFCM) was modified at private engineering workshop and tested at Rice Mechanization Research Center (RMRC), Meet El-Deeba, Kafr El-Sheikh Governorate, Egypt during 2018. The present research was carried out to upgrade SFCM that was used only for chopping maize stalks to be suitable for chopping more residual materials such as rice straw and cotton stalks with using electricity as the power source to run the modified SFCM.

2.1 Star Forage Chopper Machine (SFCM)

SFCM is a stationary flywheel chopper machine. The machine consists primarily of a feed chain, upper and lower feed rollers, a stationary lower blade, a cutter and a throwing fan. The straw is fed via the feed chain into the feed rollers, pressed and moved forward by them, then cut into pieces by the combination of upper and lower blades, and it is finally blown by the fan to the storage site or containers. The power is coming from the source (often a tractor) by flat belt to the plane pulley fixed on the main axial of the machine. The cutter head flywheel system consists of two types of knives; first type is rotating flat and logarithmic curved edge knife, where, two knives fixed on arms of the flywheel with 180° between each other and they rotate in clockwise direction. Second type is fixed flat and straight edge knife and only one knife is fitted at 4 cm down the level of the flywheel axis (**Fig. 1**). SFCM has flat pulley rotate by tractor as power source, so the machine rotate with one speed for cutting (770 rpm) with high slippage between belt and pulley and low power transmission efficiency. The overall dimensions of developed machine were 157 × 87.5 × 163 cm as length, width and height respectively.

SFCM's feeding system consists of; trough as feeding inlet for the material intended to be cut, the material slides on the floor by forward moving of conveyer; conveyor driven by pentagonal wheel; conveyer roll on the back of the trough; pentagonal wheel turned by chain and two sprockets to move the conveyor from back side to forward direction; powered feeding drums fixed in the entrance of the feeding gate. The feeding system movement is correlated to the cutting system movement with help of bevel and spur gears and quick coupling components under feeding gears ratio (**Fig. 2**).

Fig. 3 Feed rollers



2.2 Fodder Chopping Machine Modification

2.2.1 Feed Rollers

Feeding rollers are positioned and are adapted to control plant material to be chopped forward. Two-30 cm wide cylindrical feed rollers were used to gather, compress and advance the crop into the feeding drums. These feed rollers have adjustable clearance by moving vertically with help of helical loaded springs according to amount and volume to be fed into the hopper. A metal sheet cover was fixed in front of each roller to direct the feed to the feed rollers (**Fig. 3**).

2.2.2 Straw Outlet Position

Lower straw outlet position has been made to collect chopped material directly after cutting to shorten the distance and reduce the energy required to move chopped material though the blow pipe and the upper straw outlet (**Fig. 4**).

2.2.3 Rotating Cutter Head Knives

Two types of new knives, to guarantee the best possible chopping quality, replaced traditional curved rotating knives that are attached in the cutter head flywheel. The new knives are pressed out of steel strap. Longitudinal operating edges are sharpened with making one of them in form of triangular toothed blades, and the other as sharp flat edge blade for longer time cutting operation. Six openings is drilled out on the head of each knife for proper fixing. The finished product goes through thermal processing for enhancing its strength and wear resistance. New cutter head knives shape and specifications are listed in **Fig. 5** and **Table 1**.

2.2.4 Power Transmission Assembly

New power transmission assembly is done mechanically and made up based on an electric motor, belt, shaft and pulley. Tensioner is used to tighten the belt to make a better grip between the pulley and the belt. The electric motor is connected to pulleys of different sizes either driver or driven with belts. Electric motor (5 kW, 1,490 r.p.m) was installed with special chasse on machine chasse. By stacking pulleys (drive pulley and driven pulley) of two different diameters on top of one another, four different speed options created just by sliding the belt onto a different set of pulleys. Each set of pulleys is paired such that the belt length and the distance between the pulleys' pivots stay the same while the speed ratio changes (**Fig. 6**). Based on the used different pulleys' sizes, knife speeds were 78.6 (750), 91.1 (1,000), 115.2 (1,250) and 136.2 (1,500) m/s (r.p.m). The speed of the feed rolls has fixed relative speed to the cutter head. All modified parts, systems were adjusted properly, and the modified SFCM fixed on a frame with final dimensions of 157 × 87.5 × 193 cm as length, width and height respectively (**Fig. 7**).

Table 1 New cutter head knives specifications

Characteristic	value
Weight, kg	0.22
Number of mounting holes, N	6
Mounting holes diameter, cm	1.8
Thickness, cm	5
Length, cm	25
Width, cm	13
Blades	normal flail / toothed
Material	steel

2.3 Experiments, Study Variables and Measurement

Modified SFCM was evaluated against its ability to maintain the desirable residue cutting length, save the power and specific energy required, achieving better cutting efficiency and productivity with the ability to reduce the operating costs. Study variables were three feeding rates (0.8, 1.2 and 1.5 t/h), four different knife speed, 78.6 (750), 91.1 (1,000), 115.2 (1,250) and 136.2 (1,500) m/s (r.p.m), and two types of residual material (rice straw and cotton stalks) with two different knife; blades (normal flail and toothed blades). Moisture content and characteristics of used residual material were recorded and are presented in **Table 2**. Theoretical length of chopped residual material, power and specific energy required, cutting efficiency and productivity and operating costs for modified SFCM were calculated and recorded.

Results and Discussion

3.1 Effect of Feed Rate, Knife Speed and Type on Cut Length of Rice Straw and Cotton Stalks

Average cut lengths of rice straw and cotton stalks were measured and presented in **Fig 7**. At lower feeding rate (0.8 t/h), increasing knife speed from 78.6 to 136.2 m/s decreased rice straw cut length from 5 to 6 cm and from 5.9 to 4.8

Fig. 4 New straw outlet position

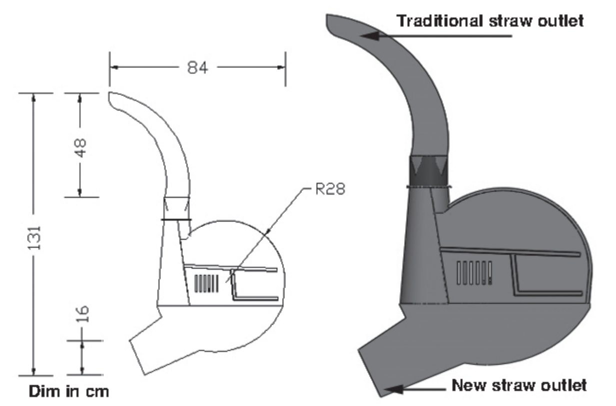


Fig. 5 New cutter head knives

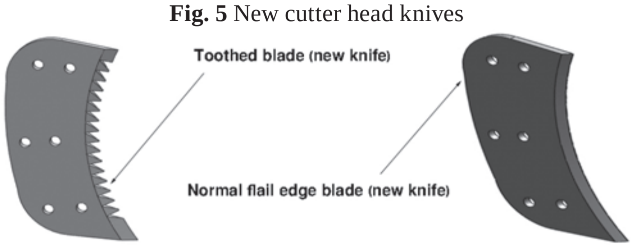


Fig. 6 New power transmission assembly

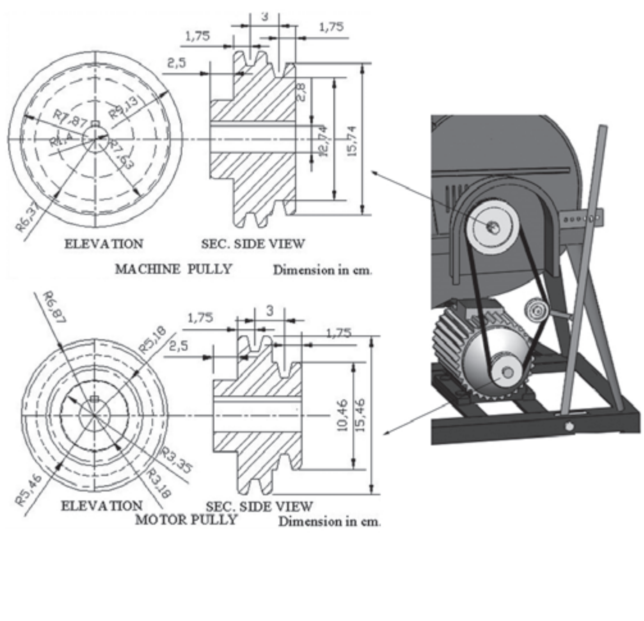


Table 2 Characteristics of used residual material

Characteristic	Cotton stalks	Rice straw
Stem original length, cm	From 90 to 170	Normal length from 85 to 100, after combine harvester from 35 to 45
Average stem diameter, cm	From 0.70 to 1.5	From 0.25 to 0.40
Mass of stalk, g	From 35 to 190	From 15 to 75
Moisture content, %	From 12.25 to 22	From 9 to 15.3
Tensile strength, MPa	12.54 to 30.12	From 30.20 to 50.47
Compressive strength, MPa	7 to 17	8.5 to 13
Bulk density, kg/m^3	165 to 190	165 to 220

cm with using toothed blades and normal (flail) blades respectively. While the length of cotton stalks reduced from 6.5 to 5.5 cm and from 6.2 to 5.4 cm with using toothed blades and normal (flail) blades respectively. Also at higher feed rates, cut length for rice straw and cotton stalks reduced with increasing knife speed under the two types of new knifes. Minimum cut lengths were 1.35 and 1.27 cm for rice straw and were achieved by using the highest feed rate of 1.5 t/h with the maximum of knife speed 136.2 m/s with using toothed blades and normal (flail) blades respectively. Similar cut lengths of cotton stalks were also obtained under same conditions, where, the cut lengths were 1.50 and 1.40 cm with using toothed blades and normal (flail) blades respectively (**Fig. 8**).

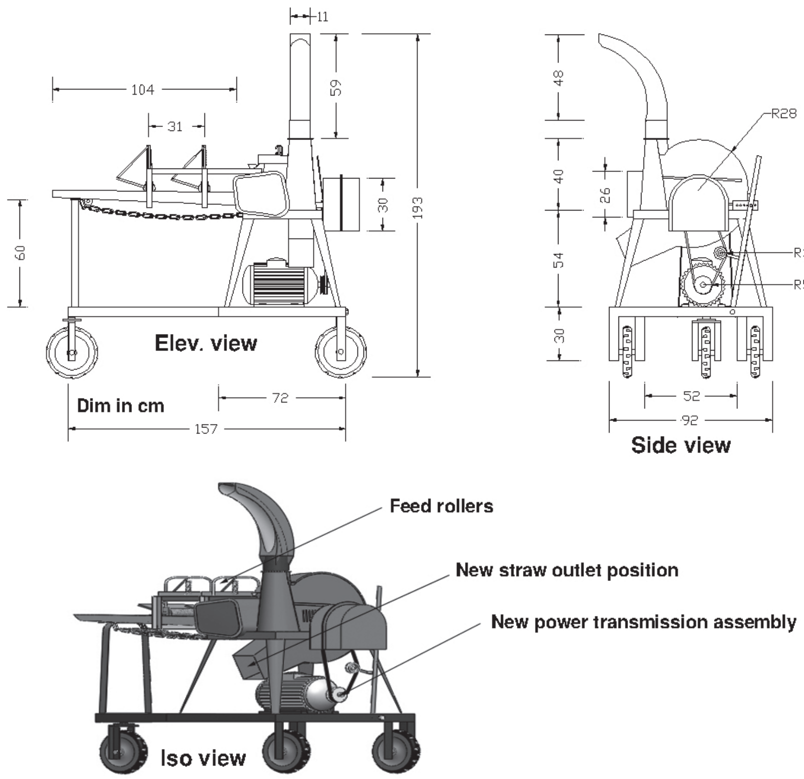
3.2 Effect of Feed Rate, Knife Speed and Type on Power Required for Cutting Rice Straw and Cotton Stalks

Increasing knife speed from 78.6 to 136.2 m/s increased the power required to cut rice straw residues from 1.81 to 2.64 kW and increased the power required to cut cotton stalks from 1.76 to 2.42 kW with using toothed blades and normal (flail) blades respectively at 0.8 t/h feeding rate. At higher feed rates, either power required to cut rice straw or cotton stalks increased with increasing knife speed under the two types of new knifes. Minimum power required to cut rice straw were 1.81 and 1.76 kW and were achieved by using the lowest feeding rate of 0.8 t/h with the lower knife speed of 78.6 m/s with using toothed blades and normal (flail) blades respectively. Minimum power required to cut cotton stalks were also obtained under same conditions, where, power required were 1.8 and 1.85 kW with using toothed blades and normal (flail) blades respectively (**Fig. 9**).

3.3 Effect of Feed Rate, Knife Speed and Type on Rice Straw and Cotton Stalks Cutting Efficiency and Specific Energy

Rice straw and cotton stalks cutting efficiency and calculated specific energy were calculated and listed in **Table 3**. Rice straw and cotton stalks cutting efficiency decreased with increasing feeding rates and increased with increasing knife speeds. Average rice straw and cotton stalks cutting efficiency decreased from 63% to 62% to 60.8% and from 72.6% to 71% to 70% with increasing the feeding rate from 0.8 to 1.2 to 1.5 t/h under 78.6 m/s knife speed and for toothed blades respectively. Similar data trend was obtained with using normal (flail) blades too. Specific energy required for cutting rice straw and cotton stalks decreased with increasing feeding rates and decreased also with increasing knife speeds. Average Specific energy required for cutting rice straw and cotton stalks decreased from 1.65 to 1.2 to 0.5 kWh/t and from 1.6 to 1.1 to 0.8 kWh/t with increasing the feeding rate from 0.8 to 1.2 to 1.5 t/h under 78.6 m/s knife speed and for toothed blades respectively.

Fig. 7 Modified SFCM and its final geometry.



Similar data trend was obtained with using normal (flail) blades too. Maximum value of cutting efficiency was 78.5% and was achieved during cotton stalk chopping by using the lowest feeding rate of 0.8 t/h with the highest knife speed of 136.2 m/s with using (flail) blades. Minimum value of specific energy was 0.3 kWh/t and was achieved by using the highest feeding rate of 1.5 t/h with the highest knife speed of 136.2 m/s with using toothed blades (**Table 3**).

Table 3 Rice straw and cotton stalks cutting efficiency and calculated specific energy

Feed rate, (t/h)	Knife speed, m/s	Toothed blades	Normal (flail) blades	Toothed blades	Normal (flail) blades
Cutting efficiency, %					
0.8	**78.6**	**63.0**	**66.5**	**72.6**	**74.5**
	91.1	64.8	68.2	73.9	75.8
	115.2	66.7	70.2	75.4	77.2
	136.2	67.9	72.2	76.9	78.5
1.2	**78.6**	**62.0**	**65.4**	**71.0**	**73.9**
	91.1	63.3	67.2	72.3	75.1
	115.2	64.8	69.1	74.0	76.6
	136.2	65.9	71.0	75.3	77.7
1.5	**78.6**	**60.8**	**64.3**	**70.0**	**73.2**
	91.1	61.5	66.1	71.2	74.5
	115.2	62.3	68.0	72.9	75.9
	136.2	64.3	69.3	74.1	76.9
Specific energy, kWh/t					
0.8	**78.6**	**1.65**	**1.6**	**2.34**	**2.31**
	91.1	1.6	1.5	2.3	2.3
	115.2	1.5	1.4	2.2	2.2
	136.2	1.4	1.3	2.2	2.1
1.2	**78.6**	**1.2**	**1.1**	**1.7**	**1.7**
	91.1	1.1	1.1	1.7	1.6
	115.2	1.1	1.0	1.6	1.5
	136.2	1.0	0.9	1.5	1.4
1.5	**78.6**	**0.5**	**0.8**	**0.8**	**1.2**
	91.1	0.5	0.7	0.7	1.1
	115.2	0.4	0.6	0.6	1.0
	136.2	0.3	0.6	0.6	0.9

Conclusions

Modified SFCM was able to chop the proposed two types of residues (rice straw and cotton stalks) with suitable uniformity in cut lengths. Using the modified chopper gives the small-scale animal feed processors the chance to cut the fodder with minimum possible lengths when they operate Modified SFCM at higher feeding rates and higher knife speeds. Both the new knifes can be used to achieve good operational parameters. However, it is important to consider the higher power required during the use of SFCM at higher feeding rates and higher knife speeds. Increasing the knife speeds help to obtain higher values

Fig. 8a Effect of feed rate, knife speed and type on cut length of rice straw and cotton stalks

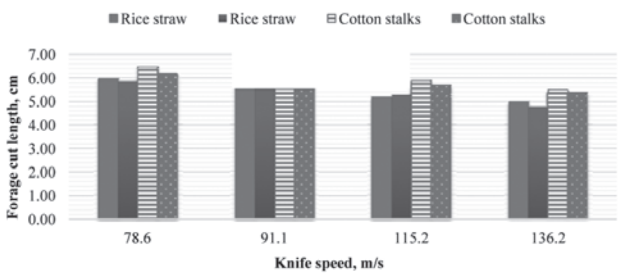


Fig. 8b Effect of feed rate, knife speed and type on cut length of rice straw and cotton stalks

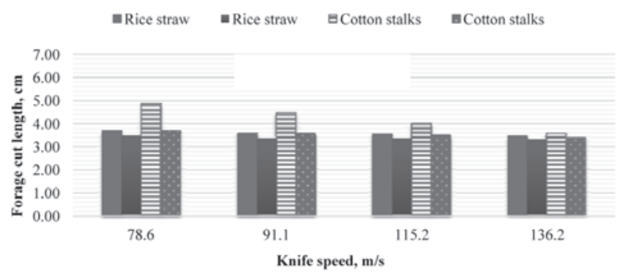


Fig. 8c Effect of feed rate, knife speed and type on cut length of rice straw and cotton stalks

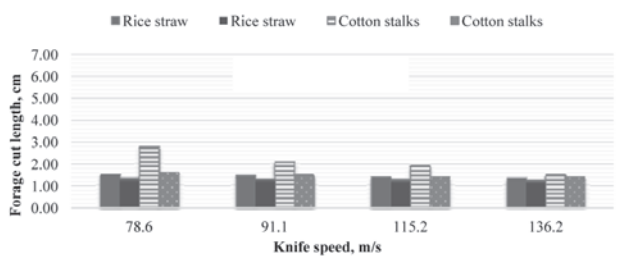
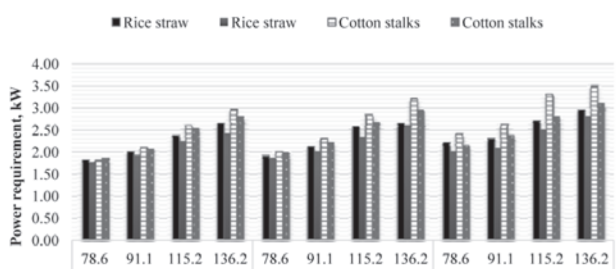


Fig. 9 Effect of feed rate, knife speed and type on power required for cutting rice straw and cotton stalks



of cutting efficiency but increasing the feeding rates will decrease it, so matching between suitable knife speeds and higher feed rates is required. To achieve minimum required specific energy, it is better to consider higher feeding rates and higher knife speeds when power is available and the attention is directed to the production amount.

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Development of an Inclined Plate Seed Metering Mechanism for System of Chickpea Intensification (SCI) - An Innovative Approach to Enhance Chickpea Productivity

by
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Abstract

Familiarity with the System of Rice Intensification (SRI) has opened windows to explore the possibility of yield enhancement in other crops too. This can be accomplished by creating a favorable environment for the exploitation of vigor. Similarly, a set of operations was designed and evaluated by the Department of Agronomy, Indira Gandhi Krishi Vishwavidyalaya, Raipur to increase the productivity of chickpea through crop management technology during the year 2014-15 to 2015-16. This was achieved by seeding 2 seeds per hill in wider spacing (50 × 20 cm), nipping of 3 to 4 top leave of chickpea at 30-35 days after sowing (DAS), mechanical weeding twice at 15-20 DAS and 35-40 DAS, moderate irrigation 5-6 cm twice at the time of sowing and 35 to 40 DAS and one light irrigation 4-5 cm at the time of flowering initiation (55-60 DAS). All these agronomical operations were promotes branching, number of pods per plant and thereby increase in yield of chickpea. The results were highly encouraging and a 40% higher yield increase was realized. These sets of operations were brought under a system termed as System of Chickpea Intensification (SCI). All these operations were performed manually during two crop seasons in the experimental field of the university research farm. For large scale adoption of SCI, the sowing of 2 seeds/hill was mechanized. An inclined plate of the tractor-drawn planter was modified to accommodate two seeds in single-cell of the inclined plate. It was observed that the modified inclined plate metering mechanism performed the dropping of two seed per hill satisfactorily. To achieve 20 cm plant to plant spacing in a 50 cm row spacing the gear ratio of the ground wheel to seed metering unit was optimized. Developed 4-row inclined plate planter (T_1) was compared with manual sowing (T_2) in terms of agronomical parameters and cost of operation for 3 crop seasons of the year 2016-17, 2017-18 and 2018-19.

The average speed of operation, field capacity and field efficiency of developed inclined plate planter were found to be 3.5 km/h, 0.45 ha/h and 63.6% respectively. The average yield obtained by sowing by tractor-drawn inclined plate planter was 2,827 kg/ha. It was similar to manual sowing. The cost of operation and energy requirement of developed inclined plate planter was found to be Rs. 1,228/ha and 590 MJ/ha whereas, it was Rs. 3,512/ha and 188 MJ/ha by manual sowing of 2 seeds/hill for 50 × 20cm planting geometry. The main problem faced in adopting SCI by manual sowing was more time requirement (96 man h/ha) as compared to developed planter (2.25 man h/ha).

Keywords: Inclined Plate, Power Transmission, Multiple Index, Missing Index, Effective Field Capacity

Introduction

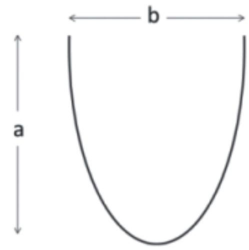
Chhattisgarh state has a good agro-ecological situation for chickpea production in India. In the state chickpea is grown over an area of 356.52 thousand ha with an annual production of 433.15 thousand tones and average productivity of 1140 kg/ha (Anonymous, 2016). The System of Rice Intensification (SRI) has been reported with enhanced productivity of rice through creating a favorable environment for the exploitation of vigor. The research efforts were made to increase the productivity of chickpea through crop management practices during the year 2014-15 to 2015-16 by the Department of Agronomy, Indira Gandhi Krishi Vishwavidyalaya, Raipur. It was found from the experimental results that the System of chickpea intensification (SCI) produced a stable yield of 26-28 q/ha which is about 40% higher compared to a conventional recommended package of practices. SCI technology has five components which were applied in a set viz. wider spacing (50 × 20 cm), sowing of two seeds per hill, nipping at 30-35 days after sowing, aeration and mechanical weeding with small hand tools twice at 20-25 days and 35-40 days after sowing was required to keep the field weed-free and provides aeration in the root zone and controlled irrigation. Sowing of chickpea using the SCI method developed by IGKV Raipur was performed manually (Sonboir, 2018). A metering device draws seed from bulk and delivers them at the desired rates in the seed tubes for sowing in soil, uniformly. Mechanical seed metering devices in planter usually have cells on a moving member to have positive seed metering. Commonly recommended metering systems on planters are horizontal plate, inclined plate, vertical rollers with cells, and cups over the periphery. Since chickpea seeds are medium in size and very susceptible to mechanical damages so, the vertical and horizontal plate metering mechanisms were not considered. This inclined plate is made of plastic. The size of the cell on an inclined plate was decided based on the shape and size of the chickpea seeds.

Bansal et al. (1994) developed a tractor-mounted inclined plate planter for sowing chickpea which could not be sown satisfactorily with standard grain drills. Field experiments were conducted to determine the potential benefits of using the planter compared to the conventional practice of sowing chickpea by hand behind an animal-drawn plough. The planter was found to give 30% economy and produce better grain and straw yields due to a more uniform crop stand. Pandey (2009) reported that the planter provides the desired plant population with uniform plant spacing and depth of operation, which results in uniform crop stand and hence, reduces the cost of cultivation by eliminating thinning operation as well as saves seed and fertilizer. Successful seeding depends on accuracy, precision, and uniformity of seed placement. In SCI manual sowing of 2 seeds/hill was time-consuming, labor intensive and it fails to maintain accurate row to row and plant to plant spacing which directly affects the crop yield and also the cost involved was high. So, to mechanize and attempt the problem faced above, a planter with a suitable metering mechanism was developed.

Material and Methods

The inclined plate seed metering mechanism was designed to optimize the cell size of the metering plate for picking of two seeds per cell. The suitable varieties of chickpea taken for the current study were JG 130, JAK I 9218 and Vaibhav. The physical properties of chickpea such as length, width, thickness, sphericity, geometric mean diameter, aspect ratio, surface area, bulk density, true density, moisture content and porosity were studied. The average length, width and thickness were found to be 8.5 mm, 6.4 mm and 6.0 mm respectively. The average sphericity and geometric mean diameter of chickpeas were found to be 0.81 and 6.90 mm respectively. The average weight of 1000 grain of chickpea seed was 244.8 g. Average aspect ratio, surface area, bulk density, true density, moisture content and porosity of chickpea were observed 75.5%, 157.4 mm^2, 709.5 kg/m^3,875.1 kg/m^3, 19.8%, and 18.6% respectively.

Fig. 1 Volume of cell



Design of cells for metering plate

The volume of some varieties of chickpea (JG 130 and *Vaibhav*) was calculated for design the seed metering plate. The volume of cells was taken as semi-elliptical and calculated by the following formula: Volume of cell = π/2 × a × b × c (**Fig. 1**)

Where,

a = semi-major axis, mm

b = semi-minor axis, mm

c= thickness of cell, mm

Volume of cell = π/2 × 15 × 12 × 4 = 1130.80 mm^3

The volume of cells would be such that it can hold two seeds of chickpea easily. An inclined plate was developed based on the design procedure adopted by Ryu and Kim (1998) and Ahmadi et al (2007). Five design variables shown in **Fig. 2** are defined and used to determine the exact size of the cell.

Dg, depth of the cell should be slightly larger than the length of the seed, therefore 15 mm length of the cells were taken to accommodate 2 seeds/cell. Wg, the opening of the cell periphery of the plate should be 75-80% the length of Dg, so Wg was taken 12 mm for these seeds, such that two seeds were loaded when the cell passes through the seed mass depending upon the orientation of seed. Θg, the opening angle of the groove is defined as an angle between the two straight lines connecting the starting and final points of the cell and the center of the plate respectively. It determines the loading process of the cell, 8° for chickpea seeds were taken under the present study. βrs, the right angle and the left angle of the cell were selected as 60° and 40° respectively such that easy loading of the cell should be done and as well as the seed loaded in the cell should be related upon the release point. Rc, the bottom of the cell was kept around so that the seeds and foreign matter does not cling to the cell. The bottom of the cell had a radius of 2.0 mm. In addition to that, a brush was provided, which was always in contact with the seed plate after the point of release. Two seeds picking from seed box by developed metering mechanism is shown in **Fig. 3**.

Table 1 Specification of inclined plate planter

S. No.	Particulars	Specifications
1	Overall dimensions Length (mm), Width (mm), Height (mm)	2,180, 1,870, 1,150
2	Depth of sowing (mm)	50-60
3	Row to Row spacing (mm)	500, adjustable
4	Working width (mm)	2,000
5	No. of tines	4
6	Types of metering	Inclined plate
7	Ground wheel diameter (mm)	380
8	Types of Furrow opener	Inverted T type
9	Fertilizer metering mechanism	Fluted roller
10	Power transmission	Chain, sprocket and bevel gear

Power Transmission Unit for Seed Metering Unit to Get 20 cm Plant to Plant Spacing

The selection of pulley is given by the following formula (Khurmi, 2002).

$N_1 T_1 = N_2 T_2$

Where,

N_1, T_1 = Number of revolution and number of teeth driving sprocket, respectively.

N_2, T_2 = Number of revolution and number of teeth driven sprocket, respectively.

The chain drive mechanism was used to transmit power from the drive wheel to the fluted roller for the metering of fertilizer and inclined plates for the metering of seeds. An 18 teeth chain sprocket was used at the ground wheel to transmit power to 14 teeth sprocket on the first shaft and this shaft has another end sprocket having 11 teeth. The power from the first shaft was transmitted to fertilizer metering shaft through a 30 teeth sprocket. From the fertilizer metering shaft, the power was distributed to the seed metering shaft having 40 teeth. The view of the power transmission unit is shown in **Fig. 4**.

Then power to the inclined plate was transmitted through a set of the bevel (S7) and pinion (S6) gear sprocket having 14 and 10 teeth, respectively, for each plate. Numbers of teeth on each sprocket are given as follow:

Teeth on the sprocket no. 1

$T_1 = 18$

Teeth on the sprocket no. 2

$T_2 = 14$

Teeth on the sprocket no. 3

$T_3 = 11$

Teeth on the sprocket no. 4

$T_4 = 30$

Teeth on the sprocket no. 5

$T_5 = 40$

Teeth on the pinion gear no. 6

$T_6 = 10$

Teeth on the bevel gear no. 7

$T_7 = 14$

$N_1 \times T_1 = N_2 \times T_2$

$1 \times 18 = N_2 \times 14$

$N_2 = 1.28$

$N_2 = N_3$

$N_3 \times T_3 = N_4 \times T_4$

$1.28 \times 11 = N_4 \times 30$

$N_4 = 0.47$

$N_4 \times T_4 = N_5 \times T_5$

$0.47 \times 30 = N_5 \times 40$

$N_5 = 0.35$

$N_5 = N_6$

$N_6 \times T_6 = N_7 \times T_7$

$0.35 \times 10 = N_7 \times 14$

$N_7 = 0.25$

$N_7 = 0.25\ N_1$

Hence, the seed metering plate

Fig. 2 Design variables of the inclined plate - 24 cells to hold 2 seeds/cell

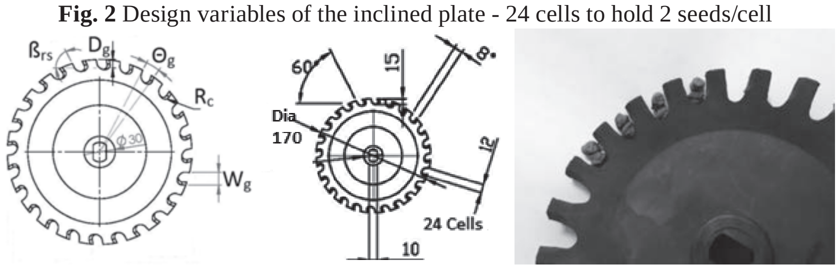


Fig. 3 Two seeds picking from seed box by the developed metering mechanism

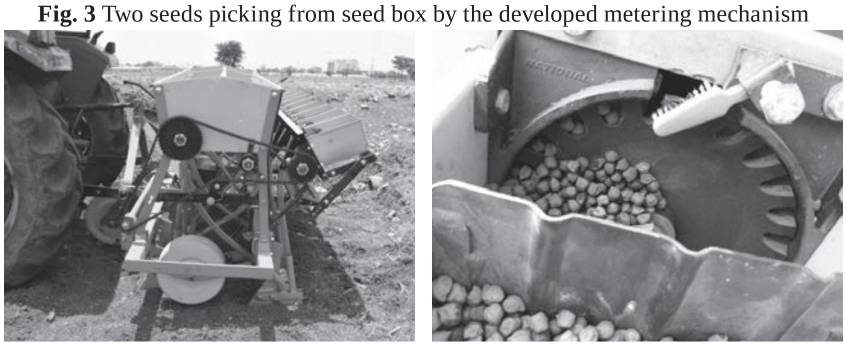


Table 2 Field Performance of manual and machine sowing for SCI

Parameters	Manual Sowing	Machine sowing
The average speed of operation	-	3.2 km/h
Effective field capacity	0.01 ha/h	0.52 ha/h
Field efficiency	52.4%	74.3%
Fuel (l/ha)	-	3.32
Seed rate (kg/ha)	44	42
Average no of seeds/hill	2.2	2.1
Spacing between plant to plant (cm)	19.8	20.3
Seed damage (%)	0	0.23
Germination (%)	92.1	92.4
Multiple index (%)	3.82	3.47
Missing index (%)	2.01	2.81
Quality of feed Index (%)	-	98.45
Cost of operation (Rs./ha)	3,512	1,075
Energy (MJ/ha)	188.2	516

Table 3 Plant height and number of branches of chickpea

Treatment	Plant height, cm			
	30 DAS	60 DAS	90 DAS	At harvest
Manual sowing	19.07	32.56	42.38	51.54
Machine sowing	20.29	35.76	46.00	58.05
	Number of Branches			
Manual sowing	8.31	25.50	26.67	22.84
Machine sowing	8.39	26.77	28.94	24.17

was rotated 0.25 times of the ground wheel. Number of cell in seed metering unit = 24

Hence, one revolution of the ground wheel rotates the following number of cell; = 24 × 0.25 = 6

Peripheral distance covered by one ground revolution of machine = Diameter of ground wheel × π = 380 × 3.14 = 1193 mm

Therefore, seed spacing covered by metering unit having sprocket of 40 teeth = peripheral distance covered by metering unit/number of cell rotate in one revolution of ground wheel;

= 1193/6 = 199 mm = 19.9~20 cm

Description of the Inclined Plate Planter for System of Chickpea Intensification (SCI)

Inclined plate planter consists of frame, seed box, inclined plate, power transmission system, ground wheel and three-point hitching system. Specification of inclined plate planter is given in **Table 1**.

Result and Discussion

Field performance of developed inclined plate planter was evaluated by comparing it with the manual sowing (**Fig. 5**). The field studies were conducted during the Rabi season of the year 2016-17, 2017-18 and 2018-19. The soil depths of the entire experiment field were greater than 1 m. The experimental soil was clay in texture (Sand 18.0%, Silt 32.4%, Clay 49.6%) with a bulk density ranging from 1.38-1.44 Mg /m^3 at 16% moisture content (db). The field preparation was completed with two passes of the cultivator and two passes of rotavator. JG-130 variety of chickpea was selected for the field evaluation. Sowing was completed between 15-25 November. The field performance results are given in **Table 2**.

The performance of the developed machine was found similar to manual seeding. The germination percent, multiple index and missing index of the machine were found better than manual seeding. Energy requirement in sowing operation was found 188.16 MJ/ha for manual sowing whereas it was 590 MJ/ha for tractor-drawn inclined plate planter. The cost of operation and time of operation of sowing of seeds under the SCI method for tractor-drawn inclined plate planter was found 65% and 97% less as compared to manual sowing.

Agronomical Parameters

To study the behavior of developing plants under manual and machine sowed for SCI, five plants were tagged at random in each plot for individual

Fig. 4 Power transmission of seed metering unit to get 20 cm plant to plant spacing

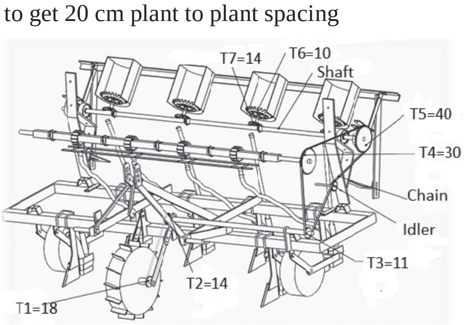


Fig. 5 Sowing of chickpea 2 seeds per hill by manual labor and by developed machine

plant study. To study the agronomical parameters viz. plant population, plant height and branches of chickpea were observed at different stages of growth. The number of pods per plant, stalk yield, grain yield and test weight were also measured. Data on the growth characters and yield attributes were analyzed. **Table 3** shows the plant height at 30 DAS, 60 DAS, 90 DAS and at harvesting for manual and machine sowing in the same crop geometry (**Fig. 6**).

It was noticed that the plant height of machine seeded chickpea was higher than manual sowing. This might be due to more precision by machine sowing to maintain proper row to row and plant to plant distance. The seed emergence percentage was more in the case of machine sown because of Inverted - T type furrow opener could ensure the placement of seeds in the proper soil moisture environment. Inverted - T type furrow opener opened narrow furrow and seed were properly got covered with soil. It was observed that plant population, pods/plant and weight of 1000 grain were found more in comparison to manual sowing this results from better yield in case of sowing by the planter. The finding indicates that for large scale planting under SCI machine planting gives more accurate planting, hence better yield achieved. The pulled data for three reporting years 2016-17, 2017-18 and 2018-19 are presented in **Table 4**.

Table 4 Crop parameters (2 Seeds/hill grown together)

Particular	Manual Sowing	Sowing by Planter
Plant population at harvest (number)	20.20	19.94
Pods per plant (number)	113.40	115.35
Test weight of 1,000 grains (g)	237.42	244.11
Grain yield (kg/ha)	2,737.34	2,826.67
Stalk yield (kg/ha)	3,473.40	3,588.45

Conclusions

1. The row spacing was kept 50 cm and the power transmission system was optimized such that the modified inclined plate of the tractor-drawn planter was able to accommodate two seeds of chickpea in a single cell and drop it in 20 cm distance to get 50 × 20 cm crop geometry. The developed machine can achieve similar precision of manual seeding. The developed machine found suitable for SCI.
2. The seed rate of the developed machine was 42 kg/ha. Multiple Index, missing index and seed damage percent were found 3.4, 3.7 and 0.23% respectively.
3. The average speed of operation, field capacity and field efficiency of developed inclined plate planter were found to be 3.5 km/h, 0.45 ha/h and 63.6% respectively.
4. The average yield obtained by sowing by tractor-drawn inclined plate planter was 2,827 kg/ha. It was similar to manual sowing. Multiple Index, missing index and were found 3.4% and 3.7% respectively. Average seed damage of developed inclined plate planter observed during the operation was 0.23%.
5. The cost of operation and energy requirement of developed inclined plate planter was found to be Rs. 1228/ha and 590 MJ/ha whereas, it was Rs. 3,512/ha and 188 MJ/ha by manual sowing of 2 seeds/hill for 50 × 20cm planting geometry.
6. The cost of operation and time of operation of sowing of seeds under the SCI method for tractor-drawn inclined plate planter was found 65% and 97% less as compared to manual sowing.

Fig. 6 Manual and machine sowed chickpea crop 80DAS during the Rabi Season of 2017-18

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Prototype Design of a Non-Invasive Mechanical Ventilator (NIMV) for Automated Actuation of the Ambu Device, in the Care of COVID-19 Patients in Rural Areas

by

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Abstract

This work deals with the experience of designing a prototype for Non-Invasive Mechanical Ventilation (NIMV) for the care of patients infected with COVID-19, in search of respiratory assistance to people in rural areas that require hospital transfer or emergency respiratory assistance. The system incorporates a connecting rod-crank mechanism to compress and decompress an ambu, for generating positive air pressure through a respiratory interface and thus being able to generate airflow to the lungs of patients with respiratory deficiency. The machine operates three variables: Frequency, Flow and Pressure Level. It has a manual panel to adjust these variables, consisting of three knobs, three buttons and two LED indicators, in addition to a 16 × 2 LCD screen where operational information is presented for device adjustments. That is an endless mechanism for pressure adjustment and, optionally, can be remotely linked to a mobile application via Bluetooth connection, for support of smartphone with Android operating system.

Keywords: Bluetooth, Frequency, Flow, Pressure Level, Rural, Ventilator.

Introduction

The first COVID-19 outbreak detected in Latin America, was reported in February 2020 in Brazil (E. Financiero, 2020). Due to the pathological qualities of the virus and the current globalization, the means of land, sea and air transportation have caused the spread of the virus throughout the continent. Mexico reported its first case of COVID-19 on February 28, 2020 according to the BBC (2020), which has led the country to go through the necessary contingency phases and, as it has happened in other countries, the increasing demand for medical supplies, ventilators, medications, etc. has implied their shortages to face the pandemic. The Autonomous University of Chapingo, through the Center for Interdisciplinary Research and Service in Science, Nature, Society and Culture (CIIS-CINASyC), developed an emerging institutional project to address the national emergency in Mexico, with the aim of designing a low-cost non-invasive mechanical respirator to be implemented in rural clinics. It will provide care for patients with COVID-19 who require transfer to hospital or urgent care. The resulting device adjusts three control variables: frequency, flow and pressure level. The adjustments can be made by means of a manual panel that has an LCD screen to present the information which can be optionally linked via Bluetooth to an application mobile with support for Android. The "app" adjusts the same variables as the manual panel, in this way the operator can comfortably control the respirator from his cell phone and thus, keep a safe distance from infected patients (if desired).

Problem Statement

Until April 24, 2020, the following information had been reported on the official government website worldwide: (**Fig. 1**)

Based on the report of the WHO-China Joint Mission on Coronavirus Disease 2019 and other reports (SDS-MX 2020; COFEPRIS 2020; ETC2 2020; IMSS 2020; WHO-China 2020; VISHAY 2020). The Federal Government foresees three cases:

i) People who require ambulatory treatment from those seeking care with an estimated of 80%, which indicates an amount of 140,367 people corresponding with most of the people infected that can receive ambulatory treatment.

ii) People who require hospitalization WITHOUT intensive care are estimated to be 14%, they are 24,564 persons who are not critically ill patients.

iii) People who require hospitalization with intensive care. For them, a percentage of 6% is estimated, which gives a figure close to 10,528 people, and they are those patients who will be in critical condition.

For this reason, the present proposal seeks the creation of a hybrid ventilator that serves to care for transfer patients from rural areas to sectors with medical care. Those are patients with blood oxygenation below 87% and need to be hospitalized, due to infection by COVID-19. They are patients in an early stage, where symptoms are moderate, and which can be treated with ambulatory medication, either at home or in rural clinics. On the other hand, the IMSS (2020), IMSS-BIENESTAR reports:

"It operates in 19 entities of the Republic, providing medical services to 12.3 million people who live in marginal rural or urban areas.

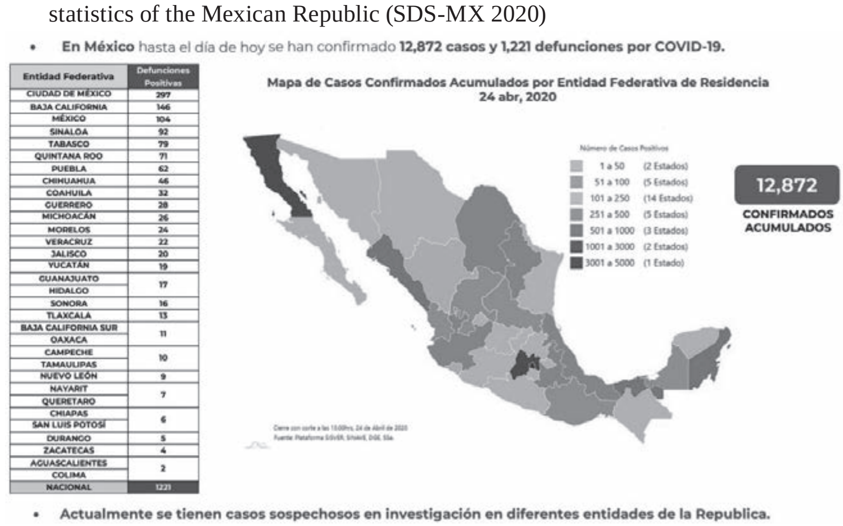
The Program provides first and second level care services in its medical units. The latter through 80 hospital units that serve the specialties of General Surgery, Gynecology and Obstetrics, Internal Medicine, Pediatrics, Anesthesiology, Family Medicine and Epidemiology (WHO-China, 2020). This is just one of the programs offered for care in rural areas (INEGI 2015, 2019). If the contagion curve breaks towards marginalized areas, the clinics that operate in these zones could present a congestion of attention and also not have the equipment to treat, care and transfer people infected with COVID-19.

Proposed Solution

Methodology

The Logical Framework Matrix (MML) methodology was implemented. This tool allows visualizing the scope of the Project. It is based on indicators and means of verification, each result is a particular objective, which, as a whole, allow achieving the general objective and that, in turn, leads to the object of study (**Table 1**).

Fig. 1 Screenshot of the Daily Technical Communiqué COVID-19 MEXICO, statistics of the Mexican Republic (SDS-MX 2020)



Mechanical Design

The purpose of the apparatus is to carry out the activation of controlled cyclical pressure, transmitting the rotary force to a respiratory emergency device, better known as ambu with the objective of transmitting the force in an oscillatory way (**Fig. 2**). In this way, the force exerted is transduced into the air pressure outlet, thereby replacing an emergency respirator that is activated manually, by an automatic system of assisted and controlled activation, based on studies previously carried out (Junco and Betancourt, 2011; Rodríguez, del Pozo and Navarro, 2013).

Fig. 2 Device for manual assistance of respiratory emergency (Ambu)

The machine works through the oscillator-connecting rod-crank mechanism and receives the movement of the electronic circuit that is fed of the alternating current, through the reducer motor, model 2RK6GN-AUL of 127 V AC, reducing the rotation frequency from 1,500 rpm to 30 rpm, allowing oscillation at 37,699 rad. The dimensions of the connecting rod are 3 times the measurement of the crank, guaranteeing its stable balance and its safe operation. The crank is modeled as a double supported beam. The weight force generates a bending moment on it, the normal stress that is generated is much less than the normal allowable stresses for the steel, which guarantees resistance with a safety coefficient of 10.

The most troubling situation during machine operation is the generation of mechanical vibrations due to the torque transmitted by the motor. For this, the model of the vibratory system was proposed as forced vibrations with damping. The vibration amplitude is determined according to Equation 1 (Singeresu).

$$x = \frac{F_o}{\sqrt{(k + m\omega^2)^2 + (c\omega^2)^2}} \qquad (1)$$

Where,

F_o: excitation force of the vibration; N;

Table 1 Logical Framework Matrix of the Non-Invasive Respirator Prototype

Description	Indicators	Means of Verification
END Non-invasive ventilator, for transfer and primary treatment in rural clinics for patients infected with COVID-19, who present non-critical symptoms or require transfer to hospital for care	Stage 1 (Short-term goal)	Action plan
Final purpose To design a mechanical ventilator to operate the ambu device and to provide non-invasive ventilation care to COVID-19 patients. This system will have pressure, frequency and flow controls, checked by a manual panel and a remote interface from the smartphone	Emerging project to address the national emergency	Schedule of activities
Results		
1. Mechanical and electronic simulation of the respirator, validation of the programming algorithms	1. Execution of simulations in specialized engineering software	1. Qualitative and quantitative results refined by simulation in specialized engineering software
2. Control of pressure, flow and frequency variables	2. Prototyping for actual testing of hardware and software for sensor instrumentation and processing for information display	2. Check List for evaluation control of effectiveness tests
3. Testing, adjusting, calibrating and measuring the optimum operating point of the ventilator control variables	3. Tests of electronic instrumentation	3. Quantification of measurement and comparative values
4. Assembling of parts in lathe, CNC Router and 3D printing	4. Design parts in low-cost materials without sacrificing quality with acceptable mechanical tolerances for operating practice in manufacturing the appliance	4. Review of mechanical tolerances and resistance of parts
5. Manufacturing and assembly process in machine and tool workshop	5. Ventilator assembly in the total	5. Check List control of project assembly stages
6. Design of mobile application for Android for remote control of the device through Bluetooth connection	6. APP design for remote control of the non-invasive ventilator system	6. Compiler debugging tests

K: equivalent stiffness of the system; N · m;

m: equivalent mass of the system; kg;

c: power sink N · s/m;

ω: angular velocity that causes forced vibration; rad/s.

Considering the magnitudes of each parameter, it is obtained:

Vibration amplitude X

$X = 2 \times 10^{-18}$ m (2)

It is much less than the permissible vibration amplitude, which guarantees the stable work of the machine without the transmission of noise.

For the transmission of force, a connecting rod-crank mechanism was used, which has a displacement of 15°, from its maximum point to its minimum point, thus obtaining an oscillatory mechanism that, depending on the angular speed of the motor, performs the pressure (**Fig. 3**) and the relaxation of the ambu (**Fig. 4**). In this way, the ambu acts as a spring that lets air out through its exhaust valve, which will arrive through its ventilator circuit to the non-invasive connection interface of the patient, thus helping to bring an assisted mode of automatic breathing.

The previous mechanism only controls the frequency with which the ambu is constantly pressed to release air through the respiratory circuit. For pressure control, a pressure mechanism for change of area was added. For this, a device called “pressure shell” was implemented which is a trapezoidal spherical device, whose function is to transmit the pushing force of the connecting rod-crank mechanism:

The trapezoidal design aims to make the trajectory to increase the area of contact with the ambu or vice versa, decrease the contact area, this is reflected in the output pressure of the respiratory circuit. To make the trajectory of the pressure shell, an endless mechanism was placed, which performs the 7 cm trajectory and places the pressure shell at 3 levels. To position it at these levels, 3 optical sensors were integrated to detect its advance on the trajectory and position the pressure shell on the exact point (**Fig. 6**).

In the previous image, the 3 optical positioning sensors of the endless mechanism is observed.

Electronic Design

The electronic design is divided into 7 sections:

Main Control System

It is in charge of processing the information of the analog and digital inputs, sensors, outputs for the control of electromechanical actuators, display of information and management of wireless connection via Bluetooth (**Fig. 7**).

To reduce costs and due to its high existence in the market, an Atmego328p was implemented, assembling the minimum starting system.

Motor 1 Control

The motor to control the connecting rod-crank mechanism is an OM

Fig. 3 Movement of connecting rod-crank mechanism, upper maximum position

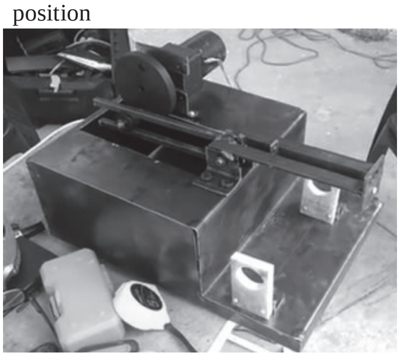


Fig. 4 Movement of connecting rod-crank mechanism, lower maximum position

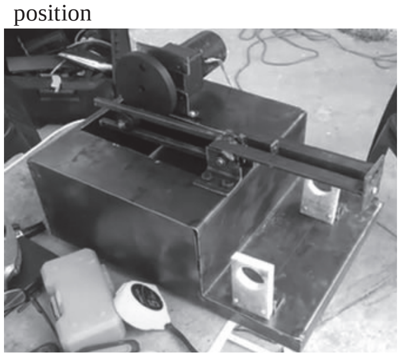


Fig. 5 Force transmission device “pressure shell”

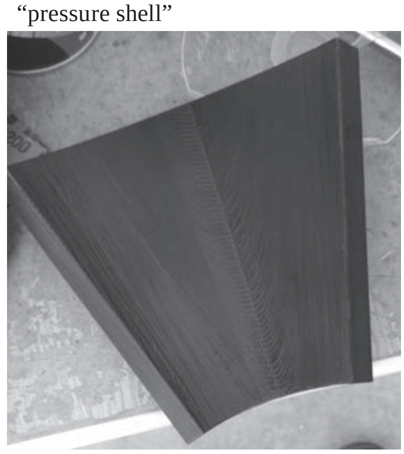


Fig. 7 Diagram of the central control system

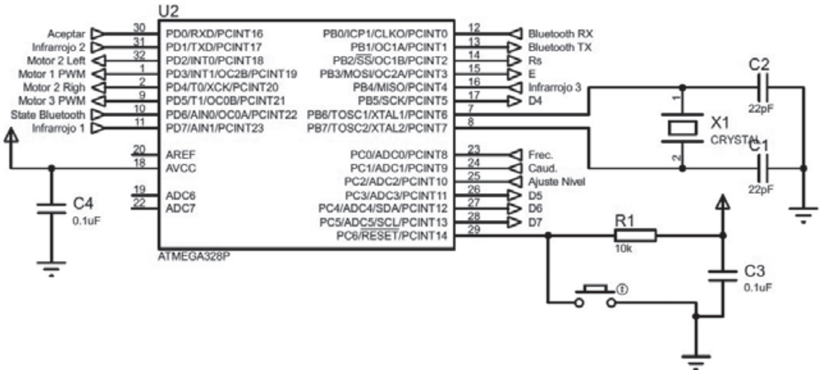
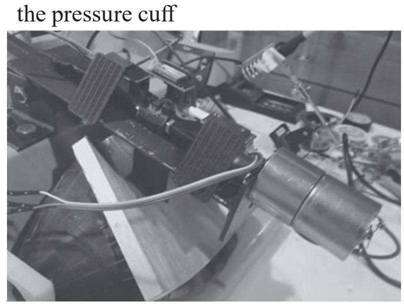


Fig. 6 Endless mechanism for positioning the pressure cuff



(Oriental Motor) 2RK6GN-AUL 115 V AC at 60 Hz, with 0.19 A, 1500 r / min, implemented the OM 2GN50K O. Motor (2020). For that, a solid-state relay controlled it, although a DIMMER module for PWM control was installed and thus adjust the motor speed (**Fig. 8**).

Motor 2 Control

For the control of the endless mechanism, a 12-gear motor was placed at 30 min^{-1} with 12 N · m of torque, with a DC unipolar motor. The assisted H-bridge configuration with relays was implemented, since the motor consumes 2 at 3 A of current (**Fig. 9**).

In order to control the pressure area of the shell installed in the endless mechanism, 3 infrared sensors were installed in the electronic connection. The mechanism has shutters that block the passage of light to send the corresponding binary signal. The machine operates in three pressure levels, each position sensor is approximately 2.5 cm apart. The resulting electronic diagram is shown in **Fig. 10**.

Motor 3 Control

The ambu has a knob for flow control, if this is not included, the accessory for flow control can be placed through a butterfly valve, in this valve a servo motor with a flange adjusted in 3D printing is placed, which allows controlling the air flow from 0 to 100%. The connection is simple (**Fig. 11**). A MG 995 servo motor of 15 kg / cm fed at 5 V was implemented.

Wireless Communication and Information Display

For the display of user information, a 20 × 4 blue background LCD screen was used COFEPRIS (2020), where the welcome screen and settings menu are displayed. For the Bluetooth connection, an HC-05 module was used, this with the intention of using the “State” pin to detect the Bluetooth connection (**Fig. 12**).

Control Panel

The manual control panel has 3 potentiometers that allow adjusting the options of “Frequency”, “Level” and “Flow”. It has an “Accept” button that loads the parameters adjusted by the machine and also a

“Reset” to restore the parameters to default mode. Finally, there are 2 LEDs, one that allows the user to observe whether the machine is on or not, and another one to notify the status of the Bluetooth connection (**Fig. 13**).

Feeding System

An ATX model: LPD2-300W was

Fig. 8 Diagram for control of motor AC OM 2RK6GN-AUL of connecting rod-crank mechanism

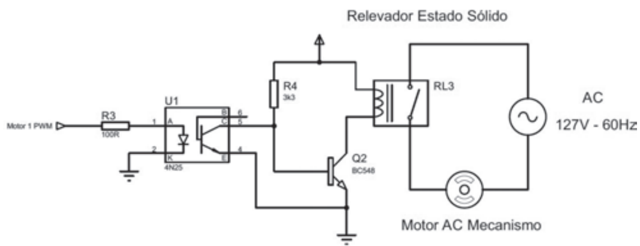


Fig. 9 Diagram for control of 12 V DC gear motor for worm gear

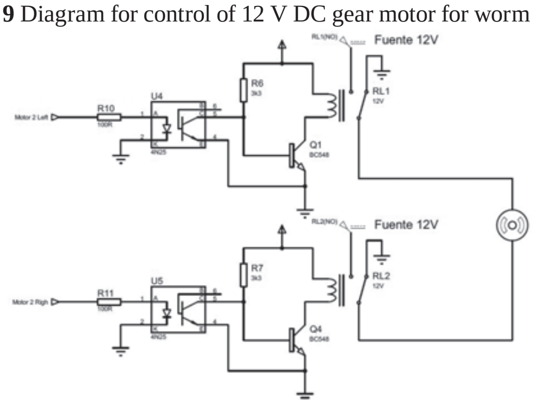


Fig. 11 Diagram of servomotor for air outlet flow control

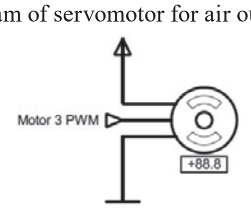
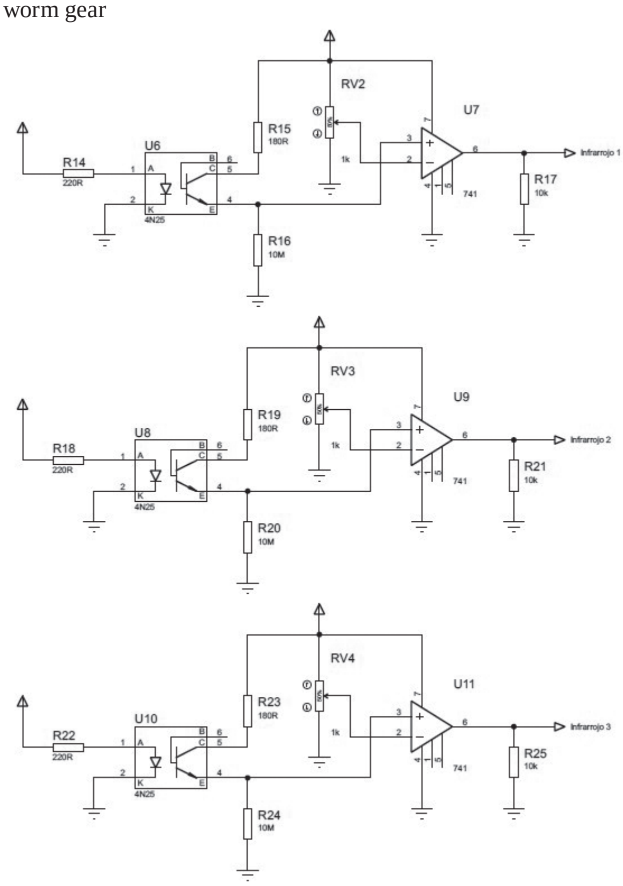


Fig. 10 Diagram of level position sensors for stroke control of the worm gear



used to supply power, from which the earth terminals, 5 V and 12 V, were taken to supply all the electronic devices in the system. In order to make an adequate distribution of the supply voltage, a PCB compensated by a bank of 10, 20 and 100 µF capacitors of the electrolytic and ceramic type was designed. These capacitors are of utmost importance because the connection of all devices generates a demand from the source, which causes the systems to constantly turn off, and the solution is to implement such a capacitive bank for the 12 V and 5 V supplies (**Fig. 14**).

Subsequently, the Gerber coordinates and the NC Drill coordinates were generated. With the help of the FlatCAM software, the CNC work files with the extension ".ncc" were configured to be manufactured on a 3-axis CNC router (**Fig. 15**).

Bluetooth and App Connection

The system has a remote control from the use of an application for mobile devices with Android operating system support, which allows controlling, frequency, flow and pressure level. It is shown in the following graphical user interface (GUI) (**Fig. 16**).

The GUI has two sliders that send an integer number made up of three digits, that is, between 000 and 100. On the other hand, it has three buttons that control the level of the respirator. Finally, a send button, which concatenates the Frequency, Level and Flow and encapsulates them in a package called Data. The Data package is made up of the following data frame:

Data = $f_1\, f_2\, f_3\, N\, c_1\, c_2\, c_3$

Where,

1. $f_{1\text{-}3}$: is the number of the frequency with three digits between 000 and 100.
2. N: is the level the preset values. They can be {1,2,3}
3. $c_{1\text{-}3}$: is the number of % of flow between 000 and 100.

Example, the string "0201050" represents 20% of frequency, level 1 and 50% of flow.

The exchange of messages between the embedded Hardware and the app are as follows, Data and Ack. Where Data contains a buffer of encoded data so that the HE understands that the first three digits are frequency, it is followed by level and finally the last three digits are the flow value. On the other hand, the Ack message sends an acknowledgment indicating that the message arrived properly.

The estimated time for sending

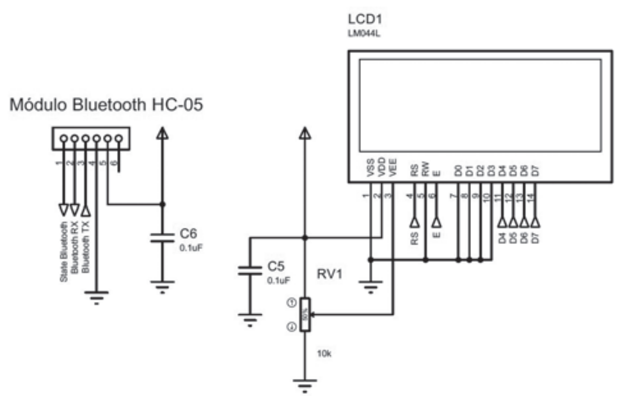


Fig. 12 Bluetooth HC-05 connection module and 16 × 4 display

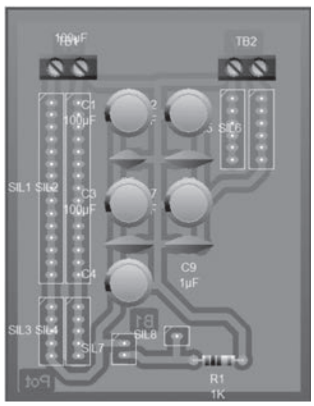


Fig. 14 Real Word view printed circuit board

Fig. 16 Graphical User Interface in app format for Android operating system

Fig. 13 Diagram of manual control board

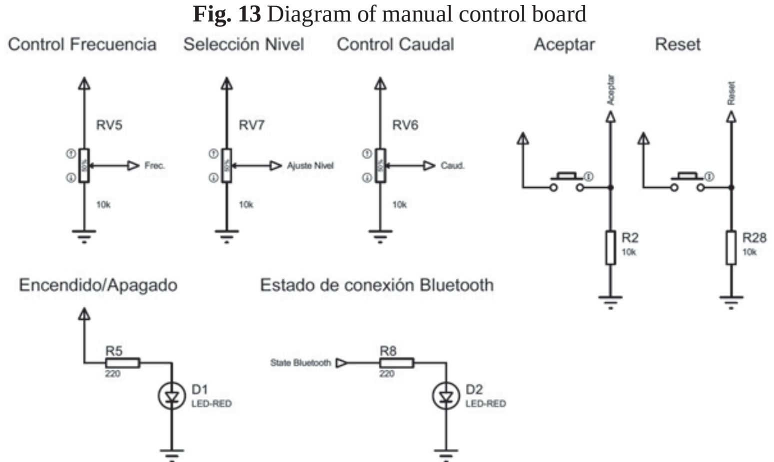
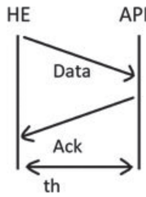


Fig. 15 Manufacture of PCB in 3-axis CNC Router

Fig. 17 Information sending diagram



information is based on the following formula.

$$T_{envio} = th \cdot 2 \quad (3)$$

Where, th is the end-to-end time between the app and the HE, estimated as [a] is 5 ms.

In general terms, the system architecture is illustrated in **Fig. 18**.

Basically, the system's user interface collects the frequency, level and flow data and sends them via Bluetooth protocol, for the respirator to receive and activate the programming layers of the corresponding actuators and sensors.

Programming

The programming algorithm was designed in C ++ language and has a total of 526 lines of code, the extensive coding can be consulted in the following link:

https://www.mediafire.com/file/ai7lfkda7fkcdge/Programaci%F3n_Respirador_UACh_Final.txt/file

Results

The work realized was carried out in an operational technical way in 4 work teams: electronic, mechanical, programming and wireless connection. With the individual systems simulated and under rapid prototyping tests, all parts of the system were joined.

In the mechanical part, parts had to be designed in lathe and welding workshops, the result can be seen in **Fig. 19**.

Some parts were designed in solidworks and manufactured in 3D printing as shown in **Fig. 20**.

Subsequently, the electronic section was assembled, the programming software was loaded into the microcontroller and performance tests were carried out (**Fig. 21**).

Once all the sections were presented, the feeding, sensing and control circuits were interconnected (**Fig. 22**).

The final result was the design of a prototype mechanical ventilator that allows the activation of an ambu device and can provide non-invasive mechanical ventilation care to COVID-19 patients, for hospital transfer and urgent medical attention in rural areas. This system has a manual panel that adjusts the variables of pressure, frequency and flow by means of three knobs, and it also provides the option of making the remote pairing by Bluetooth connection to a Smartphone with Android operating system, which allows wireless control of the system through its App.

A more detailed explanation can be found at the following links:

1. https://www.facebook.com/MediosChapingo/videos/1180563885621304/UzpfSTUzMzk4NTQyOTk1ODI0NjozMDc5MDI0MjQyMTIxMDA2/
2. https://www.youtube.com/watch?v=SOoslq03teg

Conclusions

The current crisis that the world is going through due to the pandemic

Fig. 18 System wireless communication architecture diagram

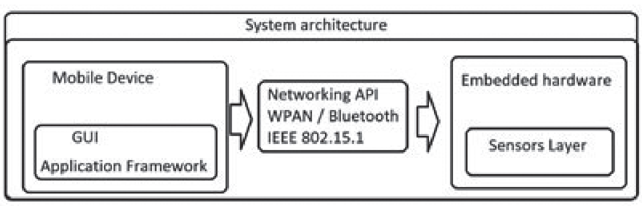


Fig. 19 Mechanical manufacturing

Fig. 20 3D printing on BCN3d Sigmax R19 printer

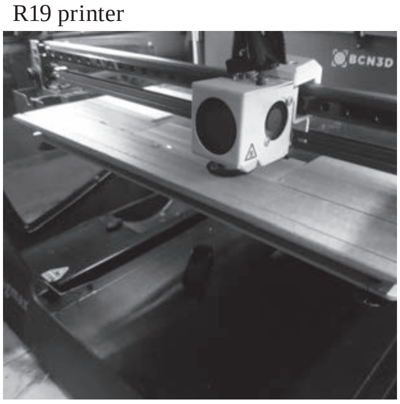


Fig. 21 Electronic assembly

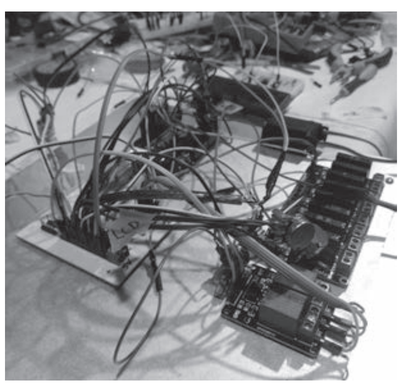


Fig. 22 3D printing on BCN3d Sigmax R19 printer

of the new coronavirus “sars cov 2” or better known as COVID-19, has led humanity to carry out acts of global solidarity and teach us the lesson of being prepared as a nation with the scientific tools necessary to face the crisis caused by a pandemic. The lack of ventilators, medicines, devices, buildings and supplies in hospitals has led to an increase in the death statistics for people infected by COVID-19. Mexico must learn the lesson, history is taught to avoid repeating, and with that, the experience of this crisis, should serve as an exercise of reflection about investment funds in the field of research, to develop the proper technology and to be prepared for any possible new pandemic in the future. Thereby, reconsidering its powers as a third world country, and how deep-rooted it is with the industrial production funds of other governing countries, Mexico must envision obtaining its own resources so that international blockades do not affect the forms of production of medical devices, supplies, medicines, etc. That without a doubt are major issues on the federal government’s agenda. This work develops the initiative of a biomedical product that seeks to be an alternative for ventilator shortages, not only at a national level but also at a global level. It is planned to continue with the design, to develop the pertinent improvements and to obtain evaluations and approvals of the standards necessary for its manufacture and use.

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Fig. 23 3D printing on BCN3d Sigmax R19 printer

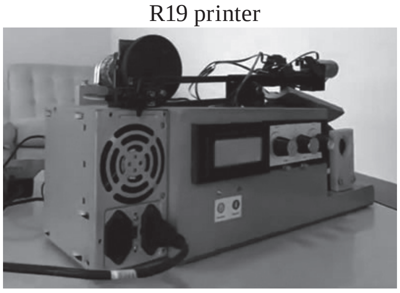
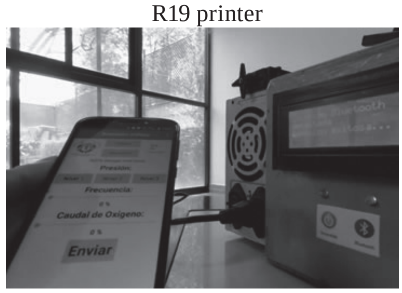


Fig. 24 3D printing on BCN3d Sigmax R19 printer



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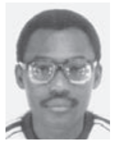
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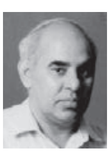
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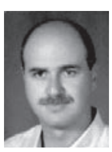
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