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YOSHISUKE KISHIDA

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EDITORIAL

Currently, the global economy is consisted of trades between various countries. For example, countries without oil fuel resources cannot help but import oil fuel from oil producing countries. Likewise, many other resources are not evenly distributed in the world. So, we have developed the global economy by making global trade more free while securing each country's rights. However, USA President, Mr. Trump suddenly set policies which made the country's profit the first priority even though it is the biggest economic country in the world. He set harsh trade policies especially on China. The first and the second largest economic countries are antagonizing each other and fighting a kind of trade war. Their conflict started to severely affect the global economy. The world population is already over 7 billion and is estimated to reach 10 billion in the near future. Farmland for food production that produces food for sustaining human life, is limited and its area per capita is already decreasing. The status of forest is the same. Human beings need to make use of natural resources more efficiently to sustain their lives. To do so, international cooperation and rational discussions are the most important. However, the current American government is destructing such important things. Sustainable Development Goals (SDGs) are becoming widespread slogans, but the current trade war is completely opposite to the purpose of SDGs. We, those who promote agricultural mechanization, have struggled to increase agricultural production with finite natural resources for a long time. Agricultural mechanization is the most essential for us to produce necessary food on the limited farmland. However, the world has suffered due to politicians who think only profits for their own country; instigators of conflicts and wars between religions, countries which force their views on other countries, and various international conflicts. See Iraq and Syria. The wars made farmers' efforts futile and agriculture has not developed, but got destructed and degenerated. We the humans are the part of living system. If we want to survive on the earth for a long time, we have to harmonize with other parts of living system. The harmonization is the highest priority for the human. There are shrines in Japan and various people visit these shrines regardless of their religious sects. It is completely peaceful. Generally all religions prohibit killing and harming people. In spite of that, they kill each other because of differences of religious thoughts. Such a world seems absurd. Even in such countries, population is increasing and we have to increase food production to survive. What is more, we have to do it in sustainable manner. To realize this, developments of innovative technologies and new agricultural mechanization are needed. The work for agricultural mechanization is the most peaceful and most important technology because it produces the most necessary thing for the human survival, the food. We virtually make peace through our work. We should be proud of ourselves and continue to strive for global peace and our survival.

Yoshisuke Kishida
Chief Editor
January, 2019

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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An Assessment of Conventional and Conservation Tillage Systems in Terms of Carbon Dioxide Emissions in Corn Production

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Abstract

The objectives of this study were to investigate the fuel consumption with the adoption of reduced tillage and the effect in crop yield and to evaluate carbon dioxide emissions for the different tillage systems in corn cultivation. Minimum tillage with stubble (MTS), minimum tillage without stubble (MT), conventional tillage with stubble (CTS) and conventional tillage without stubble (CT) were tested for seed bed preparation. The fuel consumption of CTS was 21.5 L higher per hectares than that of CT. The total CO_2 emissions were 69.59 kgCO_2/ha, 64.81 kgCO_2/ha, 140.63 kgCO_2/ha and 82.17 kgCO_2/ha for MTS, MT, CTS and CT, respectively. The total energy consumptions for MTS, MT, CTS and CT were 0.95 GJ/ha, 0.89 GJ/ha, 1.91 GJ/ha and 1.13 GJ/ha, respectively. The values of specific fuel consumption were 3.44 L/t, 2.85 L/t and 6.25 L/t and 3.37 L/t for the for MTS, MT, CTS and CT, respectively. The values of specific CO_2 emissions were 9.66 kgCO_2/t, 8.03 kgCO_2/t, 17.37 kgCO_2/t and 9.59 kgCO_2/t for MTS, MT, CTS and CT, respectively.

Keywords: Corn, Tillage systems, Reduced tillage, CO_2 emissions

Introduction

The agricultural sector is already a large contributor to global energy use and greenhouse gas (GHG) emissions, and the environmental impact of agriculture is likely to increase as our population grows to nine billion and requires more protein and calories (Kastner *et al.*, 2012; Gustavo *et al.*, 2013). Agriculture is responsible for 9% of greenhouse gas emissions for 2014. Greenhouse gas emissions from agriculture come from livestock such as cows, agricultural soils, and rice production (EPA, 2014). While CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution. Agricultural land use and land cover changes, account for about 20 percent of annual global emissions of carbon dioxide (CO_2) covers. A significant portion of CO_2 emissions due to agricultural activity can be reduced by conservation agriculture (IPCC, 2010).

The efficiency and profitability of agriculture depends on energy consumption. Currently a lot of farms are introducing advanced agricultural production technologies and are aiming at higher profitability; however, despite the efforts made, the engine fuel consumption of tractors and other agricultural machinery and exhaust emissions still often exceed the allowable limits (Fathollahzadeh *et al*., 2010; Mileusnić *et al*., 2010). Irrational choice of agricultural machinery and operating regimes of engines, i.e. when permissible motor load is exceeded or is insufficient, has also an adverse effect on the environment. In such cases, noxious exhaust substances, oil products and their fumes are emitted into the atmosphere and all this severely disturbs the natural environmental ecosystems (Mileusnić *et al*., 2010).

Direct and indirect consumption of fossil fuels leads to emissions of greenhouse gases, namely carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Greenhouse gas (GHG) from agriculture and other human activities, atmospheric infrared radiation and absorb heat are warming the Earth's surface. This warming effect has led to an increase in the global temperature during the 20th century. Combustion of fossil fuels cause over 75% of greenhouse gas emissions caused by humans and changes in land use (primarily deforestation) is responsible for the remainder (Snyder *et al.*, 2009). Today's agricultural production relies heavily on the consumption of non-renewable fossil fuels. Fossil energy consumption results in direct negative environmental effects through release of CO_2 and other greenhouse gasses. The sustainable production of agricultural products by reducing the use of fossil energy in agriculture is very important. Effective energy use in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil fuels preservation and air pollution reduction (Pervanchon *et al.*, 2002). To develop production systems that require less fossil energy and at the same time maintain satisfactory performance and reduce greenhouse gas emissions, requires efficient use of fossil energy in agricultural systems (Rathke and Diepenbrock, 2006; Tzilivakis *et al.*, 2005).

The energy required to grow a crop can be calculated by accounting for the energy associated with the inputs required for production. Energy and GHG emissions from agricultural inputs can be divided into primary (e.g., fuel for machinery operations), secondary (e.g., production and transportation of inputs), and tertiary (e.g., raw materials to produce items such as machinery and buildings) sources (Gifford, 1984). Comparisons can be made on a land-area basis (West and Marland, 2002; Adler *et al.*, 2007; Nelson *et al.*, 2009), thus normalizing for the size of a farm, or they can be made on an output basis (e.g., per ton of biomass or per megajoule [MJ] of biofuel; Wang *et al.*, 1999; Farrell *et al.*, 2006; Chianese *et al.*, 2009). It is increasingly common for GHG analyses to be linked with energy analyses of agricultural systems because of global climate change. The methodology for GHG evaluation is similar to energy analysis, in which the inputs are converted to one unit, such as the kilograms (kg) of CO_2e (Lal. 2004; Farrell *et al.*, 2006).

The current situation of worldwide concern over the emission of greenhouse gases and its effect on the climate demands an evaluation, from the perspective of energy efficiency and more specifically of non-renewable energy sources, of tendencies for change in the management of agricultural systems which have arisen in recent years (Guzmán and Alonso, 2008). Knowledge about fossil energy use in agricultural systems is needed, because it can improve the understanding of how to reduce the unsustainable use of limited energy resources and the following greenhouse gas emissions (Dalgaard *et al.*, 2011). Assessment of energy consumption and its environmental impacts in terms of greenhouse gas emissions is a necessity. However, CO_2 is considered to be the major greenhouse gas that contributes to global warming. Reducing energy use, especially fossil fuel consumption, may provide the ultimate answer to CO_2 emission problems because carbon emissions from energy consumption account for a large proportion of the gross carbon emission. Thus, energy consumption is one of the most important sources of carbon emission and causes of climate change. Crop production inputs are then converted to common units of MJ for energy use and kg CO_2 for CO_2 emissions. Farrell *et al.*, (2006) compared six publications and found that the energy use and GHG emissions associated with corn (*Zea mays* L.) production ranged from 5728 to 12,066 MJ per ha per year and from 2441 to 4201 kg CO_2e per ha per year, respectively.

Tillage is a technological operation which requires considerable working time input and ample fuel consumption (Sarauskis *et al.*, 2009). Conventional deep ploughing is the least efficient and most energy-intensive tillage method (Sarauskis *et al.*, 2012). The use of reduced tillage technologies or no-tillage practically does not alter or ever so often even improves soil chemical and physical properties and crop yields are often similar to those obtained using conventional tillage technologies. Calculations of energy balance of the different technologies showed that reduced tillage technologies are often superior not only in terms of lower working time input and fuel consumption but also in terms of being more environmentally-sustainable, i.e. they produce lower greenhouse gas emissions (Castoldi and Bechini, 2010). With reduced energy input intensity one can cut down on crop production costs and contribute to sustainable agricultural development. A well balanced management of energy input intensity is one of the top priorities of contemporary energy policy, since energy is a critical factor of socio-economic development of any country (Sarauskis *et al.*, 2013), which enables safeguarding of energy security, economic competitiveness and environmental protection (Ang *et al.*, 2010). Sarauskis *et al.*, (2013) evaluated energy and environmental aspects of reduced tillage systems applied in maize cultivation. The study of involved 5 tillage treatments: deep ploughing (DP, control), shallow ploughing (SP), deep cultivation (DC), shallow cultivation (SC) and no-tillage (NT). Their experimental evidence suggests that with the application of reduced tillage systems it is feasible to reduce fuel consumption by 13-58% and working time input by 8.4% to nearly 3-fold, to reduce the cost price of maize cultivation technological operations, decrease environmental pollution with CO_2 gas by 30 to 146 kg/ha, compared with the deep ploughing.

Conservation tillage system may contribute to less use of fossil fuels and reduce the need for labor, reduce environmental problems such as soil degradation and loss of biodiversity and contribute to intensive cultivation (Chen *et al*., 2004, Fernande *et al*., 2007). Sustainable agriculture and increased fuel costs in tillage encourage farmers to change farming practices and find replaced economic plowing. Minimum tillage and direct seeding are some ways that farmers are applying recently to reduce soil erosion and fuel costs (Bayhan *et al*., 2006; Yalcin and Cakir, 2006). Bilalis *et al*., (2013) evaluated the differences and similarities in energy flow between conventional and organic tomato and maize crops. Their results indicated that the total energy input in the conventional system was 25.90 and 29.34% higher than that of organic system for tomato and maize, respectively. Gustavo *et al*., (2013) compared energy use and greenhouse gas (GHG) emissions from the cultivation of different crops, highlight the role of sustainable management practices, and discuss the impact of soil nitrous oxide (N_2O) emissions and the uncertainty associated with denitrification estimates in the northeastern United States. They developed the Farm Energy Analysis Tool (FEAT) to facilitate energy and GHG analyses, to extend the inferences of previous research and make this information accessible, and to identify knowledge gaps and areas in which additional research is needed. FEAT is a transparent, open-source model that allows users to choose parameter estimates from an evolving database. Their results show that nitrogen fertilizer and N_2O emissions accounted for the majority of differences between crop energy use and GHG emissions, respectively. Integrating sustainable practices such as no tillage and a legume cover crop reduced energy use and GHG emissions from corn production by 37% and 42%, respectively.

Filipović *et al*., (2004), evaluated five different tillage systems and their influence on fuel consumption, labor requirement and yield of maize and winter wheat production. The compared tillage systems were: 1. Conventional tillage system (CT), 2. Reduced tillage system (RT), 3. Conservation tillage system I (CP), 4. Conservation tillage system II (CM), 5. No-tillage system (NT). The crop rotation was maize (*Zea mays* L.) - winter wheat (*Triticum aestivum* L.) - maize - winter wheat. Comparing the fuel consumption to CT system, RT system consumed 6.8% less, CP system 12.1% less, CM system 27.4% less, while NT system consumed even 82.7% less fuel. The labour requirement showed that RT system saved 7.6%, while CP system required 21.8% less, CM system 38.6% less labour, respectively. NT system saved 81.7% of labour in comparison to CT system. The highest yield of maize in the first experimental year was achieved under CT system and the lowest under RT system. In all others experimental years the highest yield of winter wheat and maize was achieved under CM system, while the lowest under RT system.

Mouldboard plow used high energy as compared to cultivator and zero tillage, for the farmers who cannot afford much inputs energy cost, cultivator can be recommended to grow maize crop successfully on the basis of energy input-output. Further studies are also recommended for the researchers to carry out such similar studies in maize crop. Memon *et al*., (2015), compared mouldboard plow with cultivator and zero tillage in order to seed bed preparation for maize cultivation. The results showed that the highest maize grain yield (4380 kg/ha) was in mouldboard plow as compared to (3972 kg/ha) in cultivator, while the lowest yield was in (3136 kg/ha) zero tillage. The maximum energy input was observed with mouldboard plow (12387 MJ/ha) followed by cultivator (11383 MJ/ha) and the lowest energy input was found in zero tillage (11301 MJ/ha). Shamabadi (2015) evaluated conventional tillage (CT), tow reduced tillage (RT1and RT2) and direct seeding (NT) for sunflower production. The highest energy consumption (12.3 GJ/ha) and carbon emissions (248 kg C-eq/ha and 155 kg C-eq/t) were related to the conventional method. The least energy input (9.12 GJ/ha) and carbon emission (183.3 kg C-eq/ha and 118.6 kg C-eq/t), were related to NT method. In conservation tillage, input energy and fuel consumption per hectare were 30% and 90% lower than conventional method, respectively, but there was no reduction in yield and energy output.

Comprehensive studies have been performed on energy use in different cultivation methods for agricultural products and (Ahmad *et al*., 1991; Bobobee, 1992; Dash and Das, 2000; Elbatawi and Mohri, 1999; Hetz, 1992; 1998; Joshi *et al*., 1992; Mahapatra *et al*., 2003; Mani and Patel, 2012; Sing and Singh, 1992; Sing *et al*., 1997; 2004; Shahan et.al., 2008, Singh *et al*., 2004a; 2004b; Sing, 2010; 2013; Ulger *et al*., 1993). Even though a lot of work is done with concerning the mechanization applications on seed yield and quality characteristics of crops (Dash ve Das, 2005; Dixit *et al*., 2010; Raheman and Roul, 2013; Sharma *et al*., 2006; Tepela *et al*., 2007; Verma, 2010) and effects of tillage systems on soil properties and crop yields (Afolayan *et al*., 2005; Bereket Barut and Akpolat, 2005; Campos and Cadena-Zapata, 2012; Derbela *et al*., 2010; Dhab, 2011; Din and El-Award, 2004; Ebrahen, 2009; Karayel and Ozmerzi, 2003; Koc and Dursun, 2007; Maki and Mohamed, 2008; Mandiringana *et al*., 2006; Nkakini and Akor, 2013), the researches concerning the assessment of conventional and conservation tillage systems in terms of carbon dioxide emissions for are limited. Therefore, in this experimental study, four different tillage systems for seed preparation in second crop corn production: (1) minimum tillage with stubble (MTS), (2) minimum tillage without stubble (MT), (3) conventional tillage with stubble (CTS), and (4) conventional tillage without stubble (CT). The aims of this study were to investigate the fuel consumption with the adoption of reduced tillage and the effect in crop yield and to evaluate carbon dioxide emissions for the different tillage systems in corn cultivation.

Materials and Methods

The Tillage and Cultivation Methods

The study was carried out on production plots of 300 m^2 with 29% sand, 25% silt and 46% clay on an experimental field of Cukurova University in Turkey (Ozturk *et al*., 2006). Corn was sawn as a second crop just after harvest of wheat. Four different methods of seed bed preparation for the second crop corn production tested in the study are given in **Table 1**.

The tillage implements were operated with a standard tractor of 70 kW whereas planting and cultivation operations were performed with a tractor of 50 kW. Tillage equipment consist of three moldboard plows with a depth of 25 cm, rotary tiller with ''L'' knife, depth of 15 cm and working width of 2 m, chisel plow with depth of 35 cm and working width of 2.1 m, disc harrow with 20 discs and working width of 2 m, and field scrubber with 3 m (Ozturk *et al*., 2006).

Experimental field consisted of plots, each with length 50 m × width 6 m, organized randomized complete block design with three replications. Residues left on the field surface after wheat (*Triticum aestivum* L.) harvesting were burned at plots with non-stubble while they were mixed into soil with tillage equipment at stubble plots. The amount of stubble mixed into the soil was 3,380 kg/ha. It is difficult for tillage equipment to prepare effective seedbed and achieve good seed-soil contact when stubble loads are greater than 4,000-5,000 kg/ha (Valzano *et al*., 1997). Wheat residue was left 3,400 kg/ha on plots with stubble (Ozturk *et al*., 2006).

All of the experiment area was irrigated after burning of non-stubble plots. The fertilizer was spread at the rate of 500 kg/ha by a spinning disc distributor and then tillage was applied. Corn was planted in July and harvested in November of the following year. Planting was performed by using single seed drill at 15 kPa vacuum pressures and at 1.3 m/s travel speed, with row distance of 70 cm and spacing in row of 20 cm. The number of corn seed per hectare used for the all treatments was 99,430 seeds. Cultivation practices (fertilization, irrigation, hoeing, and plant protection) were the same for all the treatments according to the needs of the highest yield. After plant emergence, the operations such as cultivation (2 times), fertilization, pesticide application (2 times) and irrigation (5 times) were performed at the same time and same dose on all plots.

Table 1 Tillage methods and equipments used in the experiment

Tillage systems	Tools
Minimum tillage with stubble (MTS)	Rotary tiller + scrubber (two time)
Minimum tillage without stubble (MT)	Rotary tiller + scrubber (two time)
Conventional tillage with stubble (CTS)	Moldboard plow + disk harrow + scrubber (three times)
Conventional tillage without stubble (CT)	Chisel + disk harrow + scrubber (two times)

The effective field capacity of each implement was determined in the operation conditions. The task times for the tillage systems were measured by using a chronometer in order to obtain management data of farm machineries used in seedbed preparation. Fuel energy input for each application was calculated based on the fuel consumption in the operation conditions. At the beginning of each operation, the fuel tank of the tractor was filled fully, and then refilled fully at the end of each operation to determine fuel consumption. The fuel energy input was estimated multiplying the total fuel consumption with diesel fuel energy equivalent. The lubricant consumption of the tractor was calculated depending on its power as follows (Ozturk *et al*., 2006):

$OC = 0.004 \times P_t$ ....(1)

Where; OC is the oil consumption of the tractor in L per hour and Pt is the power of the tractor in kW.

All the data were subject to analysis of variance (ANOVA). The treatment mean divided using least significant difference (LSD) at 0.05 level of probability.

Calculation Methodology Used for CO_2 Emissions

For all mobile sources, one may apply either a fuel-based or distance-based methodology to calculate CO_2 emissions. In the fuel-based approach, fuel consumption is multiplied by the CO_2 emission factor for each fuel type. This emission factor is developed based on the fuel's heat content, the fraction of carbon in the fuel that is oxidized (generally approximately 99% but assumed to be 100% in this tool), and the carbon content coefficient. Since this approach uses previously aggregated fuel consumption data, it is considered "fuel-based." Fuel based approach can be used also when vehicle activity data and fuel economy factors are available that enables calculation of fuel consumption. In the distance-based method, emissions can be calculated by using distance based emission factors to calculate emissions. Because the data on fuel are generally more reliable, the fuel-based method is the preferred approach for this tool. The distance based method should only be used as a last resort as it can introduce considerably higher levels of uncertainty in the CO_2 estimates (GHG Protocol, 2005).

Choice of activity data and emission factors

Fuel consumption data were obtained from direct measurements of diesel fuel used. The lubricant consumption of the tractor was calculated based on equation (1). The CO_2 default emission factors depending on fuel type based on lower heating values are from IPCC, 1996, Volume 2, Section 1.

Fuel-based method calculation for CO_2 emissions

The methods for calculating CO_2 emissions recommended by the GHG Protocol - Mobile Guide (03/21/05) v1.3 (Calculating CO_2 Emissions from Mobile Sources Guidance to calculation worksheets) were used in this study. The following equation outlines the recommended approach to calculating CO_2 emissions based on fuel use (assuming data is first obtained in terms of mass or volume).

CO_2 emissions = Fuel used x Heating value × Emission factor

Diesel-based CO_2 emissions = Diesel used × Heating value × Emission factor

Diesel-based CO_2 emissions = L/ha × 0.0371 GJ/L × 74.01 $kgCO_2$/GJ

Diesel-based CO_2 emissions = $kgCO_2$/ha

Lubricant oil-based CO_2 emissions = Lubricant oil used × Heating value x Emission factor

Lubricant oil-based CO_2 emissions = L/ha × 0.0382 GJ/L × 73.28 $kgCO_2$/GJ

Lubricant oil-based CO_2 emissions = $kgCO_2$/ha

Calculation Methodology Used for The Specific Parameters

The specific fuel consumption

The specific fuel consumption (S_{FC}) and specific seed production (S_{SP}) were defined to analyze the relationship between fuel consumption and corn production. The value of the specific fuel consumption (S_{FC}) indicates the amount of fuel consumed (L) to produce the unit quantity (t) of seed product.

$S_{FC} = FC / GY$ ....(2)

Where; S_{FC} is the specific fuel consumption (L/t), *FC* is fuel consumption (L/ha) and *GY* is grain yield (ton/ha).

The specific seed production

The specific seed production (S_{SP}) is the ratio of fuel consumption to corn yield and indicates fuel consumption (L) per kg of corn seed.

$S_{SP} = SP / FC$ ....(3)

Where; S_{SP} is the specific seed production (kg/L), *SP* is seed production per hectares (kg/ha) and *FC* is fuel consumption per hectares (L/ha).

The specific energy consumption

The specific energy consumption (S_{EC}) is the ratio of energy consumption to corn yield and indicates energy consumption (GJ) per ton of corn seed.

$S_{EC} = EC / FC$ (4)

Where; SSP is the specific energy consumption (GJ/t), *EC* is energy consumption per hectares (GJ/ha) and FC is *GY* is grain yield (ton/ha).

The specific carbon dioxide emission

The specific carbon dioxide emission (S_{CO^2}) was defined to analyze the relationship between CO_2 emissions and corn production. The S_{CO^2} is the ratio of total CO_2 emissions to corn grain yield and indicates CO_2 emissions ($kgCO_2$) per ton of corn seed.

$S_{CO^2} = CO_2 / GY$ ....(5)

Where; SCO_2 is the specific carbon dioxide emission ($kgCO_2$/ton), CO_2 is carbon dioxide emissions ($kgCO_2$/ha) and GY is grain yield (ton/ha).

Table 2 Emission factors and heating values for diesel fuel and lubricant

Fuel type	Lower heating value (GJ/L)	Emission factors (kg CO_2/GJ)
Diesel	0.0371	74.01
Lubricants	0.0382	73.28

Results and Discussion

Fuel Consumption of Tillage Systems

The change of the diesel and lubricant oil consumptions for the tillage systems is given in **Fig. 1** and **Fig. 2**, respectively. The fuel consumptions with the tillage implements for the different methods of soil preparation are given in **Table 3**. Diesel consumption of the tractor with the tillage implements for MTS, MT, CTS and CT were 25.05 L/ha, 23.30 L/ha, 50.90 L/ha and 29.40 L/ha, respectively. Considering diesel consumption with the tillage implements for the second crop corn production, the following results can be drawn:

- While the fuel consumption for MT was 23.30 L/ha, it increased to 25.05 L/ha for MTS. The fuel consumption was 1.75 L/ha due to stubble on soil surface. In other words, the fuel consumption of MTS was about 7% higher than that of MT.
- The fuel consumption of CTS was 21.5 L higher per hectares than that of CT. Since the moldboard plow was pulled at the greatest depth, it was the most fuel consuming implement.
- Compared to MTS the fuel consumption of CTS was 25.85 L higher per hectares.
- The rotary tiller had the lowest

fuel demand but also had the shallowest tillage depth. The chisel plow had lower energy demand than the other tillage implements.

- The total fuel consumption values show that significant energy savings could be obtained with the reduced tillage methods.

CO_2 Emissions of Tillage Systems

The CO_2 emissions of the tillage systems for the second crop corn production and are given in **Table 4**. The total CO_2 emissions were 69.59 kgCO_2/ha, 64.81 kgCO_2/ha, 140.63 kgCO_2/ha and 82.17 kgCO_2/ha for MTS, MT, CTS and CT, respectively (**Fig. 3**). Considering the total CO_2 emissions with the tillage systems for the second crop corn production, the following results can be drawn:

- The highest CO_2 emission was utilizing CTS, with the value of 140.63 kgCO_2/ha, while the lowest CO_2 emission was 64.81 kgCO_2/ha for MT.
- The total CO_2 emission of CTS was 58.46 kgCO_2 higher per hectares than that of CT. Since the moldboard plow was the most fuel consuming implement.
- When compared to CTS, the total CO_2 emissions were 50.5% (71.04 kgCO_2/ha) and 53.9% (75 kgCO_2/ha) less in MTS and MT applications, respectively.
- The total CO_2 emissions values show that significant CO_2 emissions savings could be obtained with the reduced tillage methods.

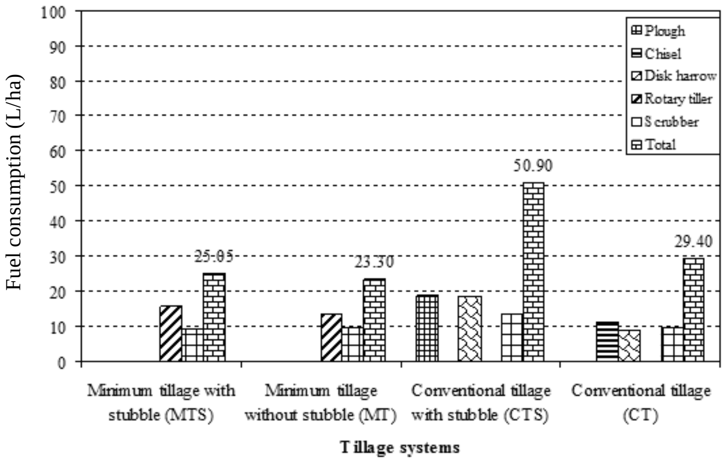

Fig. 1 The change of the diesel consumptions for the tillage systems

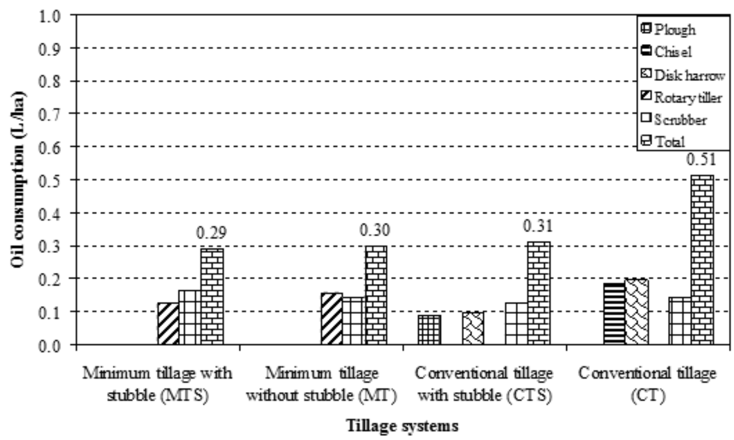

Fig. 2 The change of the lubricant oil consumptions for the tillage systems

Specific Parameters for Corn Seed Bed Preparation With Tillage Systems

The specific parameters for seed bed preparation with tillage systems for the second crop corn production and are given in **Table 5**. According to the results of statistical analyses, tillage systems have statistically ($P<0.01$) affected the seed yield, fuel consumption and CO_2 emissions.

It was found that the total energy consumptions for MTS, MT, CTS and CT were 0.95 GJ/ha, 0.89 GJ/ha, 1.91 GJ/ha and 1.13 GJ/ha, respectively (**Fig. 4**). The total energy consumption was the greatest (1.91 GJ/ha) for CTS compared to other tillage treatments. The lowest ener-

Table 3 Diesel and lubricant oil consumption of tillage systems

Tillage systems	Minimum tillage with stubble (MTS)		Minimum tillage without stubble (MT)		Conventional tillage with stubble (CTS)		Conventional tillage (CT)	
Consumption	Consumption (L/ha)		Consumption (L/ha)		Consumption (L/ha)		Consumption (L/ha)	
Implements	Fuel	Oil	Fuel	Oil	Fuel	Oil	Fuel	Oil
Plough					18.8	0.09		
Chisel							11.2	0.18
Disk harrow					18.4	0.10	8.6	0.19
Rotary tiller	15.85	0.13	13.7	0.16				
Scrubber	9.2	0.16	9.6	0.14	13.7	0.13	9.6	0.14
Total	25.05	0.29	23.30	0.30	50.90	0.31	29.40	0.51

gy consumption was 0.89 GJ/ha for the minimum tillage without stable (MT).

The specific fuel consumption

The values of specific fuel consumption and seed production were calculated for winter rapeseed production and given in **Table 5**. The specific fuel consumption for tillage methods can be calculated based on dividing fuel consumption (L) by its seed yield (tonne = 1,000 kg). The specific fuel consumption (L/t) defined as the ratio of the total amount fuel (L) consumed in the production process to the total amount of harvested product (t). The value of the specific fuel consumption indicates the amount of fuel consumed (L) to produce the unit quantity (t) of seed product. The values of specific fuel consumption were 3.44 L/t, 2.85 L/t and 6.25 L/t and 3.37 L/t for the for MTS, MT, CTS and CT, respectively (**Fig. 5**). The lower value of the specific fuel consumption means the energy efficiency of production is higher. Taking into account the values of specific fuel consumption to prepare seed bed, a 2.85 L fuel (diesel) was consumed to produce 1 tonne corn seed for the minimum tillage without stubble (MT), while 6.25 L fuel was consumed per tonne corn seed production for the conventional tillage with stubble (CTS).

The specific seed production

It was found that the seed yield was 7288 kg/ha, 8179 kg/ha and 8148 kg/ha and 8719 kg/ha for MTS, MT, CTS and CT, respectively (**Table 5**). The seed yield was the greatest (8,719 kg/ha) for CTS compared to other tillage treatments. The lowest seed yield was 7,288 kg/ha for the minimum tillage with stubble (MTS) application. The specific seed production (kg/L), as the inverse of the specific fuel consumption value, was defined as the ratio of the total amount of harvested seed product

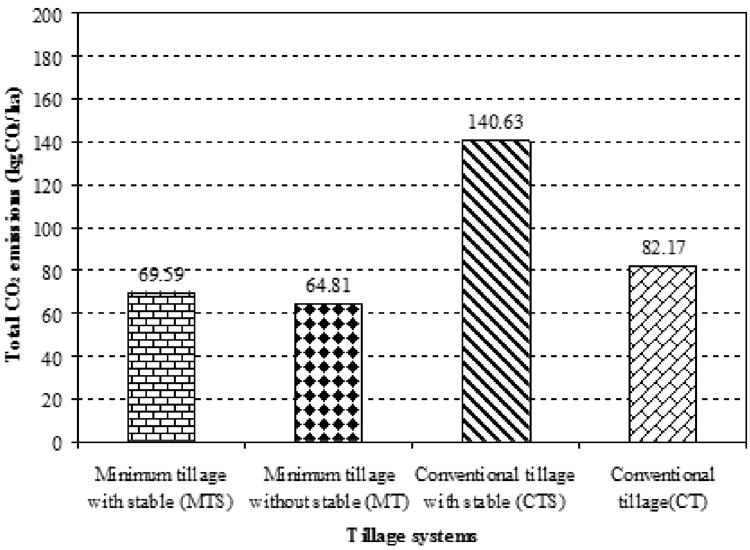

Fig. 3 The change of the total CO_2 emissions for the tillage systems

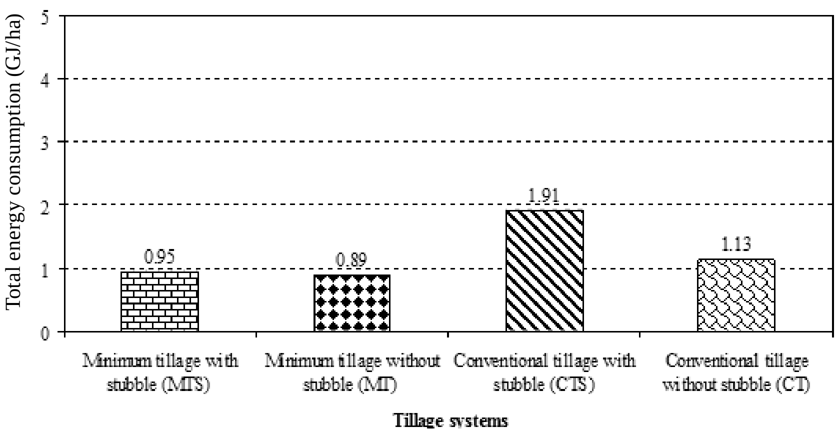

Fig. 4 The change of the total energy consumption for the tillage systems

Table 4 The CO_2 emissions of the tillage systems

Tillage systems	Minimum tillage with stubble (MTS)		Minimum tillage without stubble (MT)		Conventional tillage with stubble (CTS)		Conventional tillage (CT)	
CO_2 emissions	CO_2 emissions ($kgCO_2$/ha)		CO_2 emissions ($kgCO_2$/ha)		CO_2 emissions ($kgCO_2$/ha)		CO_2 emissions ($kgCO_2$/ha)	
Implements	Fuel	Oil	Fuel	Oil	Fuel	Oil	Fuel	Oil
Plough	0.00	0.00	0.00	0.00	51.62	0.25	0.00	0.00
Chisel	0.00	0.00	0.00	0.00	0.00	0.00	30.75	0.51
Disk harrow	0.00	0.00	0.00	0.00	50.52	0.28	23.61	0.54
Rotary tiller	43.52	0.35	37.62	0.44	0.00	0.00	0.00	0.00
Scrubber	25.26	0.46	26.36	0.39	37.62	0.35	26.36	0.39
Subtotal	68.78	0.81	63.98	0.83	139.76	0.87	80.73	1.44
TOTAL	69.59		64.81		140.63		82.17	

(kg) to the total amount of fuel (L) used in the production process. The value of the specific seed production indicates the total amount of harvested product (kg) from the unit production area (ha) corresponds to the unit amount of fuel (L) consumed for seed bed preparation from the unit production area (ha). The specific seed production in winter rapeseed cultivation was 290.94 kg/L, 351.03 kg/L, 160.08 kg/L and 296.56 kg/L for MTS, MT, CTS and CT, respectively, respectively (**Fig. 6**). The higher value of the specific seed production means the energy efficiency of production is higher. Considering the values of specific seed production to prepare seed bed, while 1 L fuel was consumed to produce 160.08 kg corn seed for the conventional tillage with stubble (CTS), 351.03 kg corn seed was obtained per litre (L) of fuel consumption for the minimum tillage without stubble (MT).

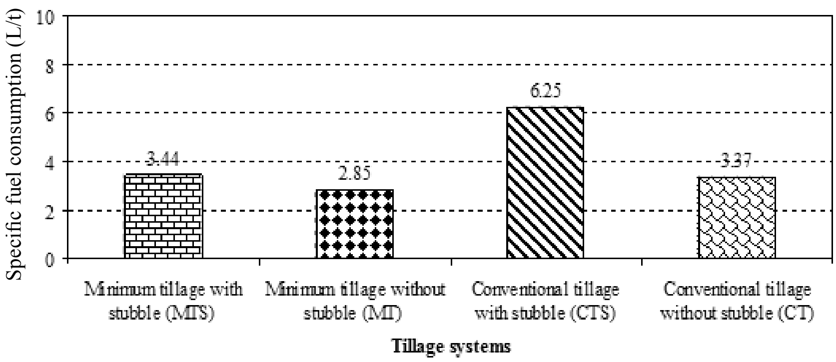

Fig. 5 The change of the specific fuel consumption for the tillage systems

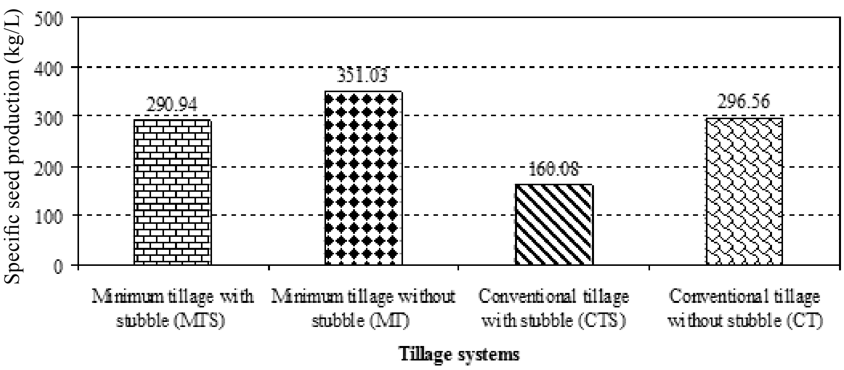

Fig. 6 The change of the specific seed production for the tillage systems

The specific energy consumption

The specific energy consumption (S_{EC}) defined as the ratio of energy consumption (GJ/ha) to the total amount of obtained seed per hectares (t/ha). The value of the specific energy consumption indicates the amount of energy consumed (L) to produce the unit quantity (t) of seed product. The values of specific energy consumption were 13.49 GJ/t, 13.56 GJ /t and 13.50 GJ /t and 13.52 GJ /t for MTS, MT, CTS and CT, respectively (**Fig. 7**). The lower value of the specific fuel consumption means the energy efficiency of production is higher. Taking into account the values of specific energy consumption to prepare seed bed, while 13.49 GJ fuel energy (diesel + lubricant oil) was consumed to produce 1 tonne corn seed for the minimum tillage with stubble (MTS), 13.56 GJ fuel energy was consumed per tonne corn seed production for the minimum tillage without stubble (MT).

The specific carbon dioxide emission

The specific carbon dioxide emission (SCO_2) was defined to analyze the relationship between CO_2 emissions and corn yield. The SCO_2 is the ratio of total CO_2 emissions to corn grain yield and indicates CO_2 emissions ($kgCO_2$) per ton of corn seed. The values of specific CO_2 emissions were 9.66 $kgCO_2$/t, 8.03 $kgCO_2$/t, 17.37 $kgCO_2$/t and 9.59 $kgCO_2$/t for MTS, MT, CTS and CT, respectively (**Fig. 8**). The lower

Table 5 The specific parameters for seed bed preparation with tillage systems

Tillage systems	Yield[a] (kg/ha)	Diesel consumption[b] (L/ha)	Energy (Diesel + oil) consumption (GJ/ha)	CO_2 emissions[c] ($kgCO_2$/ha)	S_{FC} (L/t)	S_{SP} (kg/L)	S_{EC} (GJ/t)	S_{CO2} ($kgCO_2$/t)
Minimum tillage with stubble (MTS)	7,288	25.05	0.95	69.59	3.44	290.94	13.49	9.66
Minimum tillage without stubble (MT)	8,179	23.3	0.89	64.81	2.85	351.03	13.56	8.03
Conventional tillage with stubble (CTS)	8,148	50.9	1.91	140.63	6.25	160.08	13.50	17.37
Conventional tillage without stubble (CT)	8,719	29.4	1.13	82.17	3.37	296.56	13.52	9.59

[a, b, c] Significant at P<0.01

value of the specific CO_2 emissions means the tillage system in terms of CO_2 emissions is efficient. Taking into account the values of specific CO_2 emissions to prepare seed bed, while 17.37 kg CO_2 was released to produce 1 tonne corn seed for the conventional tillage with stubble (CTS), only 8.03 kg CO_2 was released per tonne corn seed production with the minimum tillage without stubble (MT).

Conclusions

In this experimental research, CO_2 emissions were examined for the seed bed preparation with different tillage systems. Taking into account the significant environmental advantages that can be obtained with the adoption of a reduced tillage system; MT appears the best method for the substitution of the moldboard plow. It can be concluded that the second crop corn production is the most remunerative due to its higher energy efficiency.

Tillage systems were affected significantly on grain yield, fuel consumption and CO_2 emissions. It is essential that conservation tillage systems be used to preserve natural life and sustaining soil fertility. In this context, selected tillage systems should be improved and new tillage systems functioning by mixing previous crop residue into soil should be investigated. So, further research is needed to overcome this problem in the tillage systems with residue. The results of this study can be used by policy makers and other relevant agencies for recommendations to farmers in order to use energy more efficiently. Proper management of resources and their application at the right time can improve the efficiency of the farmers in the use of farm inputs.

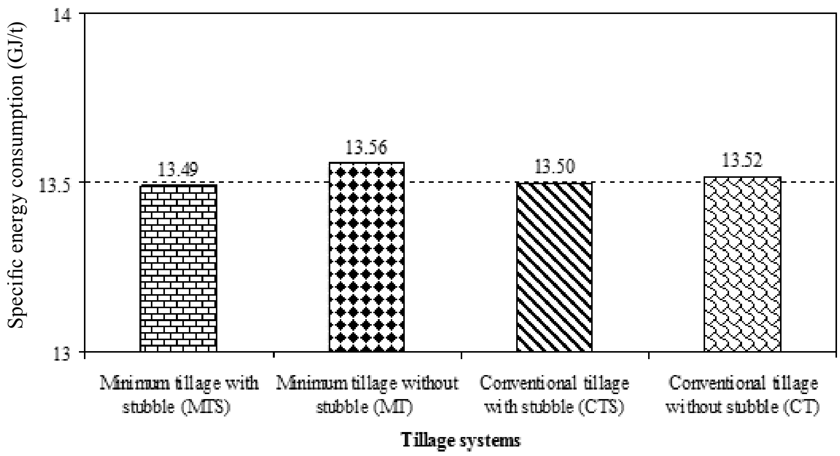

Fig. 7 The change of the specific energy consumption for the tillage systems

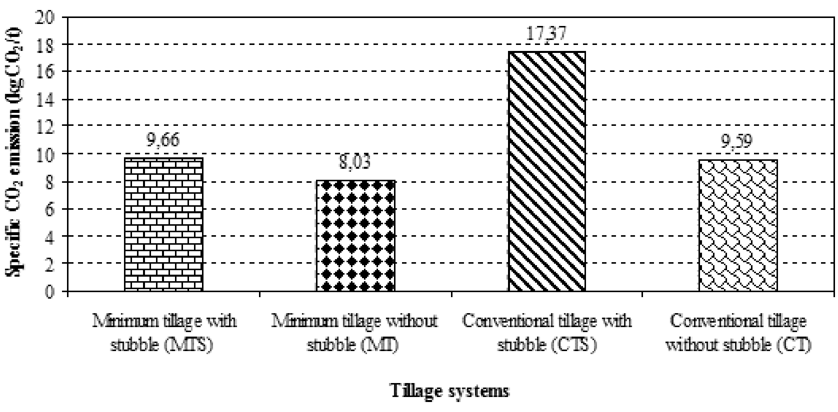

Fig. 8 The change of the specific CO_2 emissions for the tillage systems

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Development of a Slider Crank Squeezing Action Sugarcane Juice Extractor

by

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Abstract

The development of a sugarcane juice extractor was undertaken for macerating and extracting processes to take effect in a farm settlement. The macerating unit was incorporated with sets of pyramidal shaped metal sheet which aids the quick production of fine macerated sugarcane fibre for the extraction of sugarcane juice. The extraction unit of the machine was incorporated with a slider crank device which initiates the juice extraction process. The action of this component removes the stress involved with the use of a press head that is manually operated in a manual sugarcane juice extractor. The performance of the sugarcane juice extractor was evaluated to ascertain its suitability for use in the farm for effective production of cane juice. The machine was tested with five grating (macerating) speeds (602, 765, 791, 1176 and 1520 rpm), three varieties of cane stalks (USR/85/31, ILS-002 and CO-957), three feed rates involving three different operators, three cane size diameters and three loading rates. These factors were selected to investigate the influence of machine variables, crop parameters and their interaction on the machine performance. During performance evaluation of the machine, the highest grating capacity, grating efficiency, extraction capacity, extraction efficiency, machine loss and brix values obtained were 73.7 kg/h, 99.9%, 732.6 kg/h, 84%, 27.3% and 30.0%, respectively.

Keywords: Juice, Squeezing, Macerating Machine, Grating, Extraction, Capacity, Slider Crank.

Introduction

Sugarcane (*Saccharum Spontaneum*) is one of the most important crops from which sugar is produced. According to Adeyemi (2008), sugarcane accounts for 55%-70% of the total world sugar production. Fry (1997) stated that sugarcane accounts for about 62% of the total world's sugar while the remaining 38% is produced from beet which is the second crop from which sugar is conventionally produced. Sugarcane is one of the most important members of the plant kingdom. Almost all the component parts of the plant are useful in different form (Olaoye, 2008). In Nigeria, sugarcane is the major raw material used in the manufacture of sugar. Busari (2005) noted that domestic production of sugar production accounts for only 5% of the sugar consumed in Nigeria with Nigeria importing over 90% of its sugar requirement. Busari (2000) discovered in year 2000 that over sixty potential sugarcane estate sites were identified across the country. Nigeria has the potentials of satisfying domestic sugar requirements and also generating surplus for export (Busari, 2005).

The problems associated with the growth of sugarcane processing in Nigeria include small farm holdings and farm fragmentation resulting from land ownership by inheritance, inefficient transportation system due to poor road network and fleet of vehicles such as trailers that are not suitable for transporting large quantities of sugar cane and other farm products to the factory for immediate processing into high quality sugar; non-availability of appropriate technology for sugarcane processing; and poor storage facilities and practice to preserve harvested canes or extracted juice before being refined into sugar (Adeyemi, 2008). Among the stated problems, transportation system has become a great challenge in the sugar processing industry during transporting of cane stalks from the farm to the factory for refining into sugar. This called for the urgent need to position a sugarcane juice extracting machine in the farm for the purpose of converting harvested cane stalk into sugar in order to reduce the number of trips and bulk load of transporting cane stalks to the factory from the farm site.

For centuries juice has been extracted by crushing and squeezing action of cane stalks. However, several sugarcane juice extractors have been developed in time past when viewing the works carried out by Ilesanmi (2006), Ibadehin (2007), Adeyemi (2008) and Salami (2009). Sugarcane juice extractorshave not been developed to specifically alleviate the transportation system problem confronting the sugar processing industry in Nigeria. However, the evaluation of these developed machines showed that these extractors would not be suitable for on-farm use due to the undesirable results obtained from these machines such as grating/macerating device easily gets blunt immediately after use, production of coarse macerated fibre not found suitable for the extraction of juice and the tiresomeness operation associated with the manual hand press used for extraction of juice. The main objective of this study was to develop a squeezing action sugarcane juice extractor.

Materials and Methods

Description of the Modified Machine

The slider crank squeezing action sugarcane juice extractor consists of grating cylinder made of stainless steel, gravimetric and volumetric capacity of the hopper, automated spring loaded vertical press as pressure vessel, belt and pulley drive, electric motor, speed reduction gear electric motor, idler pulley and slider crank device. The pictorial view of the modified machine is shown in **Fig. 1**.

Modification made on the Existing Machine

The modifications made on the existing sugarcane juice extractor include:

- In order to overcome the production of coarse fibre of macerated sugarcane been produced by the existing sugarcane juice extractor, the inner outer surface of the grating/macerating unit of the modified machine was filled up with sets of pyramid shaped metal sheet for effective production of fine fibre of macerated sugarcane for optimum production of juice during juice extraction.
- In order to overcome the tiresomeness associated with the use of the manually operated press head for juice extraction, this entire component was permanently replaced with a slider crank device powered by a speed reduction gear electric motor through belt and pulley transmission.

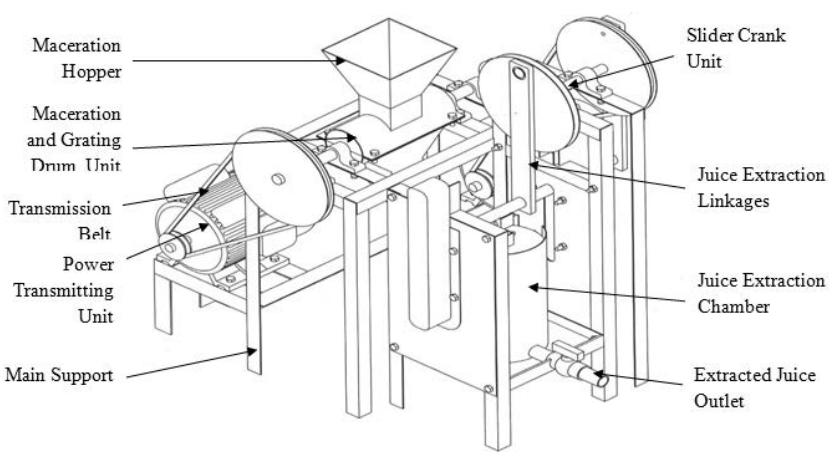


Fig. 1 Pictorial view of the sugarcane juice extractor

Design Calculations

Grating cylinder

The grating speed, power requirement and torque of the grating cylinder were determined using Equations (1), (2) and (3), respectively.

$N = (V \times 60) / \pi D$ ....(1)

where,

N = Grating speed of the grating cylinder (rpm)

D = Diameter of grating drum (m)

V = Peripheral speed of the grating drum (m/s)

The calculated speed of the grating/macerating drum was 294 rpm. The diameter of the grating drum was chosen as 80 mm.

$P = F \times V$ ....(2)

where,

P = Power requirement of grating drum (W)

F = Grating or macerating force (N)

V = Peripheral speed of the grating drum (m/s)

The calculated value of the power required by the grating drum was 1,476 W.

Torque, $T = (P \times 60) / 2\pi N$ ....(3)

where,

T = Torque (Nm)

P = Power required by the grating drum (W)

N = Macerator speed (rpm)

The calculated value of the torque on the grating/macerating drum was 47.94 Nm.

Top width of the hopper

A hopper with trapezoidal shape was considered. The top width of the hopper was obtained using Equation (4).

$T_w = (2X + B)$ ....(4)

where,

T_w = Top width of the hopper (mm)

B = Bottom width of the hopper (mm)

X = Side length of top width of the hopper was obtained using 20° as coefficient of sliding friction of sugarcane (Olaoye, 2011).

The calculated value of the top width of the hopper was 217 mm.

Volumetric capacity of the hopper

The volumetric capacity and volume of the hopper were obtained using the expressions given by Olaoye (2011) as:

$V_v = G_v / \rho_v = B_a \times L$ ....(5)

where,

G_v = Gravimetric capacity (kg)

B_a = Base area in (mm^2)

V_v = Volumetric capacity (mm^3)

ρ_v = Nominal density of the plant material in the crushing chamber (kg/mm^3)

L = Length (mm)

The calculated value of the volumetric capacity of the hopper was 4,019,560 mm^3.

Main shaft design

The combined twisting moment and bending moment was used to determine the shaft diameter using the formula given by Khurmi and Gupta (2006) as expressed in Equation (6).

$T_e = (M^2 + T^2)^{0.5} = (\pi \times S_s \times d^3) / 16$ ....(6)

where,

T_e = Equivalent twisting moment

M = Maximum bending moment

T = Torque transmitted by the shaft

S_s = Allowable shear stress

The calculated diameter of the main shaft was 26.66 mm (but a shaft diameter of 30 mm was used for the design based on availability of material)

Diameter of shaft holding the press head unit

The diameter of the shaft holding the press head unit was obtained using the formula given by Khurm and Gupta (2006). This is provided in Equation (7).

$d^3 = (16 \times M_t) / (\pi \times S_s)$ ....(7)

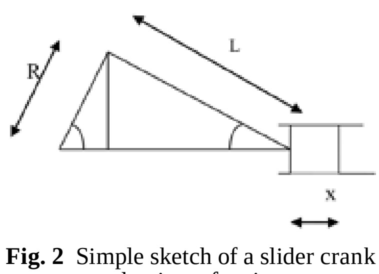


Fig. 2 Simple sketch of a slider crank mechanism of a piston

where,

M_t = Maximum bending moment (Nm)

S_s = Allowable shear stress (MPa)

d = Shaft diameter (m)

The calculated diameter of the shaft holding the press head unit was 27.13 mm (but a shaft diameter of 30 mm was used for the design based on availability of material).

Combined stresses acting on the extraction chamber

The components of the extraction chamber include the press head, cylinder, sieve and shaft holding the press head. The maximum pressure that can be exerted on the macerated cane stalk in the extraction chamber during the juice extraction process was obtained using Equation (8).

$P = 4F / (\pi D^2)$ ....(8)

with F = 1989.58 N, D = 198 mm and, hence P = 64.62 kPa

Due to the action of applied force from the slider crank through the compressing press head, the extraction chamber is subjected to three principal stresses viz. the hoop stress, longitudinal stress and radial stress, collectively known as combined stresses. The hoop stress, longitudinal stress and radial stress were obtained using Equations (9), (10) and (11), respectively, as provided by Olaniyan and Oje (2007) as:

$\sigma_1 = (PR_1) / t$ ....(9)

$\sigma_2 = (PR_1) / 2t$ ....(10)

$\sigma_3 = -P$ ....(11)

with P = 64.62 kPa (from Eqn. 8), R_1 = 99 mm and t = 1.5 mm, , and are calculated from Equations(9), (10) and (11) as 42.65 MPa, 21.325 MPa and - 0.065 MPa, respectively.

Failure occurs in a member subjected to combined stresses when one of the principal stresses reaches the failure value (such as yield stress, which for stainless steel is 215 MPa (Shigley, 2006). Therefore, since $\sigma_1 = \pm\sigma_o$ and $\sigma_1 > \sigma_2$ and σ_3, the extraction chamber when constructed, will not fail under stresses.

Slider crank mechanism

In the design of this machine a distance of 0.24 m was considered for the maximum displacement of the juice press head in order to provide enough pressure needed for juice extraction. Out of this maximum displacement of 0.24 m; 0.14 m length was the distance considered as the gap length between the top of the container of the extraction chamber and bottom of the juice press compressor. While the remaining distance of 0.10 m was considered as the total distance traveled inside the container. The gap length of 0.14 m was to allow for the free entrance of macerated sugarcane stalk (wet bagasse) into the extraction chamber.

After considering a maximum displacement of 0.24 m, other parameters considered were 0.12 m denoted by R serving as the radius of contact and 0.45 m denoted by L serving as the length of the link joining the radius of contact to the rod holding the Juice press compressor.

Adopting the formula used for calculating the displacement of a piston as given by Walsh (2001) and Brown (2005) is presented as:

$X = R - R\cos\theta + L - [L^2 - (R\sin\theta)^2]0.5$ ....(12)

By substituting in the corresponding values of X, R and L into Equ. (12), the calculated value of 0 was 180°.

Fig. 2 shows a simple sketch of a slider crank mechanism of a piston to illustrate the above description. **Fig. 3** presents the orthographic views of the modified machine and **Fig. 4** shows the exploded view of the modified machine assembly.

Operation of the machine

Freshly harvested sugarcane stalks were fed into the machine through its hopper. The electric motor in its switched on position provides the crushing force needed to crush the cane stalk sugarcane placed in the macerating/grating cylinder which carries the central shaft. The sets of pyramid sharp shaped teeth arranged on the central shaft causes the crushing action of the cane stalk. The crushed canes known as wet bagasse are conveyed to the extraction chamber through the connection provided at the bottom of the grating cylinder. At the extraction section of the machine the crushed (macerated) canes are pressed or compressed against a perforated metallic plate by the press head been powered by a slider crank assisted unit. The extracted juice is collected through a tap provided at the bottom of the extraction chamber.

Materials and Methods

Performance Evaluation and Test Materials

The machine was evaluated to assess its performance for its intended purpose. Freshly harvested sugarcane stalks were collected from the Unilorin Sugar Research Institute Farm. These involved three different varieties of sugarcane, namely, USR/85/31, ILS-002 and C0-957. Five working speeds were selected for the purpose of testing the machine. The five selected peripheral speeds of the shaft carrying the macerating drum are 602, 765, 791, 1,176 and 1,520 rpm under no load condition. The speeds were established using a tachometer manufactured by Venture Smiths Industries Instrument Company with model number HT 330 T 42 and Serial number 8103779. Three feed rates were used by using three different operators to feed the machine throughout the period of testing the machine. Operator one was a worker in his mid-thirties, Operator two was a female final year student in her early twenties and operator three was a male final year student in his middle twenties. Three loading rates were used by loading one cane stalk at a time, followed by two cane stalks at a time and lastly three cane stalks at a time. Three sizes of cane stalk based on their diameter size were used and were taken at three different levels. The three different size levels taken were at the cane stalk top level, middle level and bottom level. Variety one (USR/85/31), had average diameter sizes of 12.79 mm, 17.24 mm and 20.58 mm, respectively, for the three different size levels. Variety two (ILS-002), had average diameter sizes of 22.15 mm, 29.63 mm and 35.21 mm, respectively and finally variety three (C0-957), had average diameter sizes of 15.41 mm, 21.82 mm and 26.87 mm, respectively, for the three different size levels. These measurements were all accomplished using a Vernier caliper. This implies that the varieties of cane stalk used for the machine performance evaluation decreased in diameter size irrespective of the size level in the order of variety two (ILS-002), variety three (C0-957) and variety one (USR/85/31).

Performance indices

In carrying out the performance evaluation the following parameters were used:

Grating capacity

Grating capacity can be defined as the amount of cane grated or macerated per unit time. This can be expressed mathematically as:

Grating Capacity (kg/h) $= M_3 / T_1 \times 3.6$ ....(13)

where,

M_3 = Weight of grated cane (g)

T_1 = Time taken to grate (sec)

Grating efficiency

Grating efficiency can be defined as the amount of sugarcane stalk grated per total amount of sugarcane stalk fed into the machine. This is expressed in percentage and can be expressed mathematically as:

Grating Efficiency (%) $= \{(M_2 - M_1) / M2\} \times 100\%$ ....(14)

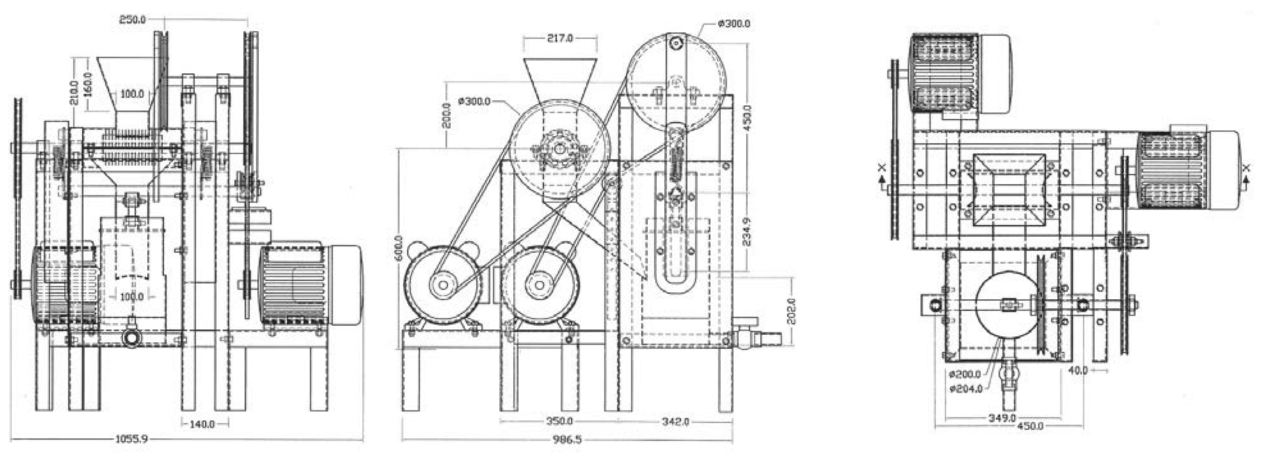
where,

M_2 = Total mass fed into the machine (g)

M_1 = Total mass ungrated (g)

Extraction capacity

Extraction capacity can be defined as the amount of juice extracted per unit time. This can be expressed



Front view Side view Plan view

Fig. 3 Orthographic projection of the modified machine mathematically as:

Extraction Capacity (kg/h) = $(M_4 / T_2) \times 3.6$ ....(15)

where,

M_4 = Weight of juice extracted (g)

T_2 = Time taken to extract (sec)

Extraction efficiency

Extraction efficiency can be defined as the ratio of the percentage of weight of juice extracted to the product of weight of feed and moisture content of the cane. This can be expressed mathematically using the expression given by Tressler and Joslyn (1961) as:

Extraction Efficiency (%) = $J_e / (X.F) \times 100\%$ (16)

where,

J_e = Weight of extracted juice (g)

X = Moisture content of the cane (%)

F = Weight of feed (g)

Moisture content

The moisture or juice content of sugarcane stalk can be defined as the amount of moisture contained in percent in a given weight of stalk. This can be obtained either ways. Either in its dry basis form or it could be in its wet basis form. For the purpose of this experiment the wet basis form is needed. This can be expressed as:

$Mcdb = M_w / M_d \times 100\%$ ....(17)

or $Mcwb = M_w / (M_d + M_w) \times 100\%$ . ...(18)

where,

Mcdb = Moisture content on dry basis

Mcwb = Moisture content on wet basis

M_w = Mass of moisture in the cane (g)

M_d = Mass of bone dried sugar cane (g)

Machine losses

This is the total losses encountered by the machine during grating and extraction operation. This can be expressed mathematically as:

Machine Losses (%) = Grating Loss (%) + Extraction Loss (%)

where,

Grating Loss can be simplified further as:

Grating Loss (%) = $(M_2 - M_5) / M_2 \times 100\%$ (19)

or $M_6 / M_2 \times 100\%$ ....(20)

where,

M_2 = Total mass fed into the machine (g)

M_5 = Weight of collected macerated sugarcane at the extraction chamber before extraction (g)

M_6 = Total mass ungrated cane (g) + Mass of grated cane (g) that did not fall into the extraction chamber during the process of grating (g).

Extraction Loss can be simplified further using the expression given by Tressler and Joslyn (1961) as follows:

Extraction Loss (%) = $100 \{Q_f - (Q_p + Q_r)\} / Q_f$ ....(21)

where,

Q_f = Weight of collected macerated sugarcane at the extraction chamber before extraction (g)

Q_p = Weight of extracted juice (g)

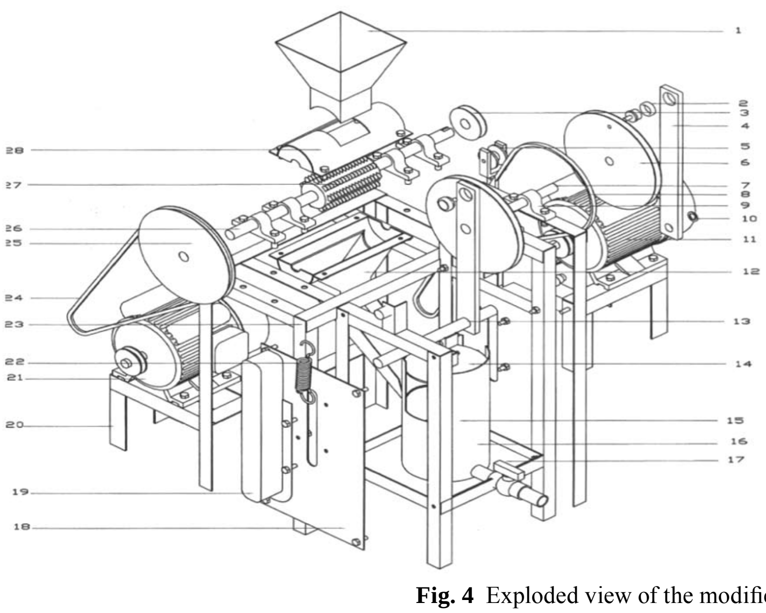
Q_r = Residue left after the juice have been extracted (g)

Brix value

The brix value of the extracted juice was determined directly using a brix refractrometer manufactured by Bellingham Stanles limited, England.

Experimental Design

The experimental design adopted for the machine performance evalu-



S/No	Description of Fig. 4
1	Hopper
2	Ball Bearing
3	Idler Pulley of Main Shaft
4	Connecting Link or Rod
5	Idler Pulley for Slider Crank Mechanism
6	Slider Crank Driven Pulley
7	Mild Steel Shaft
8	V - Belt
9	Pillow Bearing
10	Nut
11	Speed Reduction Gear Electric Motor
12	Discharge Chute
13	Press Rod
14	Press Head
15	Sieve
16	Extraction Chamber
17	Basement Plate
18	Guide Plate
19	Spring Guard
20	Prime Mover Seat
21	Electric Motor
22	Spring
23	Main Frame
24	V – Belt
25	Main Driven Pulley
26	Stainless Steel Shaft

Fig. 4 Exploded view of the modified machine

Table 1 Results of Means for Different Measured Parameters at Different Speeds

Measured parameters	Speed (rpm)				
	602	765	791	1176	1520
Grating Capacity (kg/h)	14.64	15.78	15.71	19.50	27.74
Grating Efficiency (%)	97.30	97.46	97.37	97.27	97.37
Extraction Capacity (kg/h)	300.76	305.99	317.27	353.34	305.30
Extraction Efficiency (%)	40.21	41.01	44.02	46.84	41.04
Machine Losses (%)	12.34	12.22	12.11	12.12	11.98
Brix (%)	22.81	22.43	22.77	23.41	22.89

Table 2 Summary of Analyses of Variance: F-values for Different Factors (Main and Interaction factors) for Different Measured Parameters

Factors (Main and Interaction factors)	Grating capacity (kg/h)	Grating efficiency (%)	Extraction capacity (kg/h)	Extraction efficiency (%)	Machine losses (%)	Brix (%)
Replication	<1	1.851^{ns}	<1	<1	<1	6.58^{ns}
S	50.06*	<1	1.33^{ns}	5.87^{ns}	<1	2.32^{ns}
V	464.86*	1.025^{ns}	404.25*	289.56*	1.93^{ns}	204.11*
S×V	209.62*	2.842^{ns}	51.25*	33.87*	3.47*	60.36*
F	56.93*	<1	8.54*	9.45*	1.56^{ns}	3.09^{ns}
S×F	8.49*	2.34^{ns}	27.53*	21.47*	<1	2.94*
V×F	15.36*	<1	14.51*	10.77*	1.27^{ns}	5.22*
S×V×F	8.37*	1.93^{ns}	17.81*	14.34*	2.89*	12.34*
D	117.69*	<1	126.61*	123.31*	<1	22.53*
S×D	32.24*	2.81*	3.26*	1.27^{ns}	2.19^{ns}	2.21^{ns}
V×D	51.55*	<1	123.83*	102.30*	1.52^{ns}	21.04*
F×D	2.10^{ns}	<1	<1	<1	1.19^{ns}	6.65*
S×V×D	41.77*	<1	23.00*	18.37*	<1	12.49*
S×F×D	1.59^{ns}	1.17^{ns}	<1	<1	1.54^{ns}	3.57*
V×F×D	1.64^{ns}	1.75^{ns}	1.88^{ns}	1.51^{ns}	1.43^{ns}	2.37*
S×V×F×D	1.47^{ns}	1.05^{ns}	1.52^{ns}	1.51^{ns}	1.73^{ns}	3.32*
L	72.87*	<1	6.01*	5.12*	<1	<1
S×L	10.73*	<1	18.66*	20.55*	<1	10.05*
V×L	2.99*	<1	16.37*	21.15*	<1	11.85*
F×L	<1	<1	5.14*	4.28*	<1	1.78^{ns}
D×L	11.92*	<1	8.71*	17.85*	<1	5.45*
S×V×L	8.66*	<1	22.54*	22.31*	<1	3.11*
S×F×L	<1	<1	6.04*	3.92*	<1	1.47^{ns}
S×D×L	10.75*	1.75^{ns}	20.43*	22.58*	2.71*	6.31*
V×F×L	<1	<1	6.64	4.14*	<1	2.38*
V×D×L	6.38*	<1	27.61*	35.72*	1.17^{ns}	3.16*
F×D×L	1.31^{ns}	<1	<1	1.07^{ns}	<1	1.51^{ns}
S×V×F×L	<1	2.82*	6.21*	4.73*	2.07*	3.65*
S×V×D×L	11.25*	<1	13.53*	16.41*	1.05^{ns}	4.39*
S×F×D×L	1.18^{ns}	1.14^{ns}	<1	<1	1.30^{ns}	1.79*
V×F×D×L	1.19^{ns}	<1	<1	<1	1.94*	2.07*
S×V×F×D×L	1.17^{ns}	1.04^{ns}	<1	<1	<1	2.60*

*Significant at 5% level, ^{ns} = not significant, S = Speed, V= Variety, D = Diameter size of cane stalk, F = Feed rate and L = Loading rate.

ation involving five factors at three levels each was the 3x3x3x3x3 factorial experiment in a split-split-split-split-plot design with three replicates (r). Out of the five selected speeds used for the overall testing of the machine, the three speeds considered for the factorial experiment were 602, 791 and 1,520 rpm representing the least, middle and highest speed, respectively. Gomez and Gomez (1984) gave the brief interpretation of what is expected from a split-split-split-split-plot design laid out for this kind of performance evaluation involving three levels each of Speed (S) as Main Plot, Variety (V) as Sub-Plot, Feed rate (F) as Sub-Sub-Plot, Diameter size of cane stalk (D) as Sub-Sub-Sub-Plot and Loading rate (L) as Sub-Sub-Sub-Sub-Plot. The Duncan's multiple Range Test (DMRT) was also used to determine the means differences between significant factors.

Results and Discussion

Results

The summary of the results obtained for the performance evaluation of the machine are presented in **Table 1**. Summary of the Analyses of Variance (ANOVA) obtained for all the measured parameters is represented in **Table 2**. The results obtained using DMRT in testing the means at the various factors level for the different measured parameters is presented in **Table 3.**

Discussion

Grating capacity

The results obtained from the measured samples for grating capacity during machine evaluation showed that the highest grating capacity was 73.7 kg/h. It can be deduced from **Table 2** for grating capacity that S, V, S × V, F, S × F, V × F, S × V × F, D, S × D, V × D, S × V × D, L, S × L, V × L, D × L, S × V × L, S × D × L, V × D × L and S × V × D × L are significant at 5%

Table 3 Results for DMRT showing the Means at various levels of Speed, Variety, Feed Rate, Diameter and Loading Rate for different Measured Parameters

Measured parameters	Factors Levels														
	Speed			Variety			Feed Rate			Diameter			Loading Rate		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Grating Capacity (kg/h)	14.64^{a}	15.71^{b}	27.74^{c}	14.55^{a}	18.18^{b}	25.37^{c}	20.17^{b}	18.28^{a}	19.64^{b}	22.66^{c}	18.73^{b}	16.70^{a}	21.95^{c}	19.30^{b}	16.84^{a}
Grating Efficiency (%)	97.30^{a}	97.37^{a}	97.37^{a}	97.15^{a}	97.52^{a}	97.36^{a}	97.42^{a}	97.24^{a}	97.37^{a}	97.51^{a}	97.31^{a}	97.21^{a}	97.39^{a}	97.29^{a}	97.36^{a}
Extraction Capacity (kg/h)	300.76^{a}	317.27^{b}	305.30^{a}	235.80^{b}	494.22^{c}	193.32^{a}	308.03^{ab}	312.61^{b}	302.70^{a}	302.04^{b}	285.53^{a}	335.77^{c}	300.78^{a}	312.31^{b}	310.25^{b}
Extraction Efficiency (%)	40.21^{a}	44.02^{b}	41.04^{a}	35.14^{b}	63.05^{c}	27.08^{a}	42.14^{b}	42.03^{b}	41.10^{a}	41.32^{a}	38.44^{a}	45.51^{b}	40.85^{a}	42.32^{b}	42.11^{b}
Machine Losses (%)	12.34^{a}	12.11^{a}	11.98^{a}	12.31^{b}	12.38^{b}	11.76^{a}	12.30^{a}	11.86^{a}	12.28^{a}	12.12^{a}	12.25^{a}	12.07^{a}	12.19^{a}	12.20^{a}	12.05^{a}
Brix (%)	22.81^{a}	22.77^{a}	22.89^{a}	21.80^{a}	23.28^{b}	23.40^{b}	22.68^{a}	22.84^{ab}	22.95^{b}	22.32^{a}	23.26^{c}	22.90^{b}	22.84^{a}	22.83^{a}	22.81^{a}

Mean speeds with different letters along the same row are statistically different from each other at p 0.05.

level. Results obtained using DMRT as shown in **Table 3** showed that speed, variety, diameter and loading rate at various levels of operation are statistically different from one another. Grating capacity was seen to be distinct across the three replicates. The trend of mean grating capacity versus speed of operation is presented in **Fig. 5**. It can be deduced from **Fig. 5** that mean grating capacity increases with peripheral speed of operation. The slight difference observed in the graph where grating capacity dropped from speed of 765 rpm to speed of 791 rpm and started increasing thereafter from speed of 791 rpm to speed of 1,520 rpm. This may be attributed to the resistance to grating operation marked by the limiting peripheral speed of 765 rpm.

Grating efficiency

The results obtained from the measured samples for grating efficiency during machine evaluation showed that the highest grating efficiency was 99.9%. It can be deduced from **Table 2** for grating efficiency that S × D and S × V × F × L are significant at 5% level. Results obtained using DMRT as shown in **Table 3** showed that speed, variety, feed rate, diameter and loading rate at various levels of operation are statistically the same. Grating efficiency was found to be the same across the three replicates. The trend of mean grating efficiency versus peripheral speed of operation is presented in **Fig. 6**. It can be deduced from **Fig. 6** that

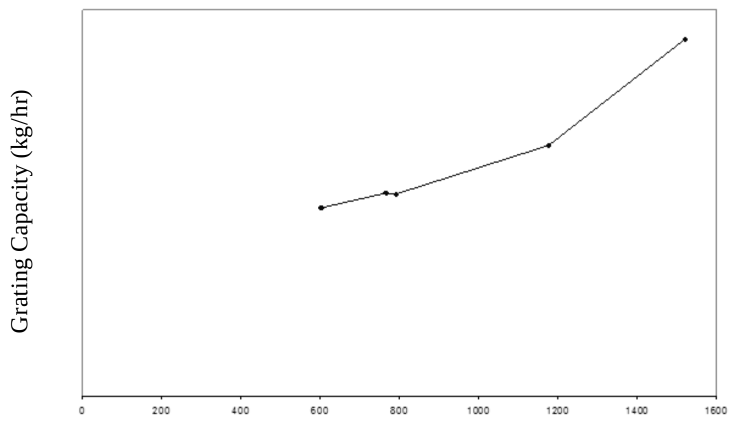


Fig. 5 Graph of mean grating capacity versus speed of operation

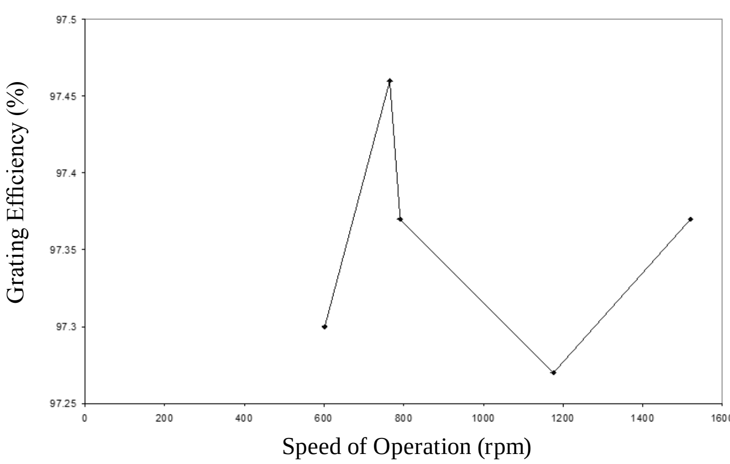


Fig. 6 Graph of mean grating efficiency versus speed of operation

mean grating efficiency increased from speed of 602 rpm to speed of 765 rpm and dropped from speed of 765 rpm to speed of 1,176 rpm and later increased thereafter from speed of 1176 rpm to speed of 1520 rpm. Grating at peripheral speed of 765 rpm gave an indication that the shredded sugarcane stalks were well pulverized for effective sugarcane juice extraction. At higher speed beyond 765 rpm,the grating capacity may improve but adverse fibre quality for juice extraction.

Extraction capacity

The results obtained from the measured samples for extraction capacity during machine evaluation showed that the highest extraction capacity obtained was 732.6 kg/h. It can be deduced from **Table 2** for extraction capacity that V, S × V, F, S × F, V × F, S × V × F, D, S × D, V × D, S × V × D, L, S × L, V × L, F × L, D × L, S × V × L, S × F × L, S × D × L, V × F × L, V × D × L, S × V × F × L and S × V × D × L are significant at 5% level. Results obtained using DMRT showed that variety and diameter at various levels of operation are statistically different from one another. Extraction capacity was seen to be distinct across the three replicates. The trend of mean extraction capacity versus peripheral speed of operation is presented in **Fig. 7**. It can be deduced from **Fig. 7** that mean extraction capacity increased from speed of 602 rpm to speed of 1176 rpm and dropped thereafter from speed of 1176 rpm to speed of 1520 rpm. This increase in the mean of extraction capacity as speed of operation increases may be as a result of more cane stalks are macerated as shown in **Fig. 4**. But in the case of grating speed of 1,520 rpm it must be noted that the grating efficiency is lowered as a result of low shredding quality at higher peripheral speed of the operation of the macerating cylinder.

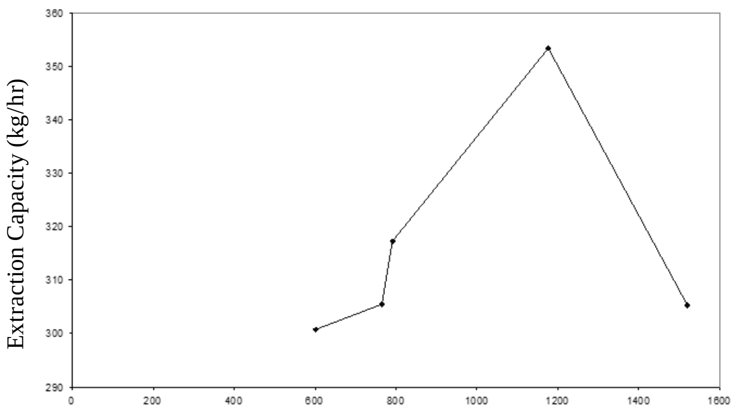


Fig. 7 Graph of mean extraction capacity versus speed of operation

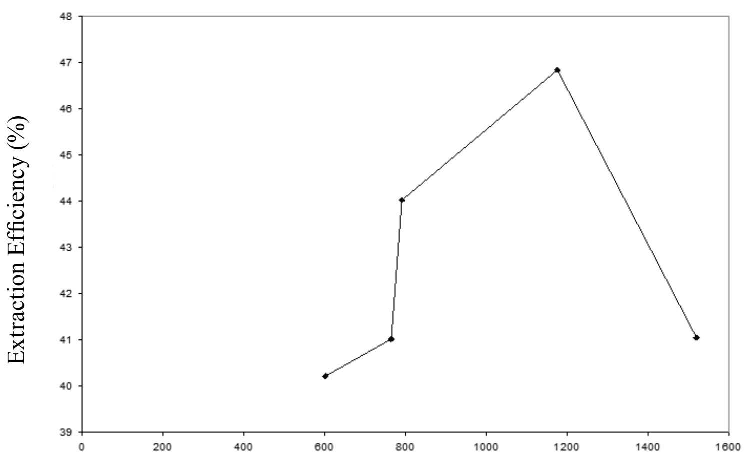


Fig. 8 Graph of mean extraction efficiency versus speed of operation

Extraction efficiency

The results obtained from the measured samples for extraction efficiency during machine evaluation showed that the highest extraction efficiency obtained was 84 %. It can be deduced from **Table 2** for extraction efficiency that V, S × V, F, S × F, V × F, S × V × F, D, V × D, S × V × D, L, S × L, V × L, F × L, D × L, S × V × L, S × F × L, S × D × L, V × F × L, V × D × L, S × V × F × L and S × V × D × L are significant at 5% level. Results obtained using DMRT showed that variety at various levels of operation is statistically different from one another. Extraction efficiency was seen to be distinct across the three replicates. The trend of mean extraction efficiency versus speed of operation is presented in **Fig. 8**. It can be deduced from **Fig. 8** that mean extraction efficiency also followed the same trend with extraction capacity. This is to say that mean extraction efficiency increased from peripheral speed of 602 rpm to speed of 1176 rpm and dropped thereafter from speed of 1176 rpm to speed of 1520 rpm. This increase in the mean of extraction efficiency as speed of operation increases may be as a result of more cane stalks are macerated as shown in **Fig. 4**.

Machine losses

The results obtained from the measured samples for machine losses during machine evaluation showed that the highest machine loss value was 27.3%. It can be deduced from **Table 2** for Machine Losses that S × V, S × V × F, S × D × L, S × V × F × L and V × F × D × L are significant at 5% level. Results obtained using DMRT showed that speed, feed rate, diameter and loading rate except for variety at various levels of operation are statistically the same. Machine losses were found to be the same across the three replicates of speed, feed rate, diameter and loading rate. The trend of mean machine losses versus speed of operation is presented in **Fig. 9**. It can be deduced from **Fig. 9** that mean machine losses decreases with speed of operation i.e. from 602 rpm to 1,520 rpm. The trend of this graph shows that at lower grating speed of the machine there will be lots of ungrated cane stalks leading to high machine losses during grating operation.

Brix value

The results obtained from the measured samples for brix value during machine evaluation showed that the highest brix value obtained was 30%. In the summary of result of the Analysis of Variance for Brix (%) presented in **Table 2**, it can be deduced that, V, S × V, S × F, V × F, S × V × F, D, S × D, V × D, S × V × D, S × F × D, V × F × D, S × V × F × D, S × L, V × L, D × L, S × V × L, S × D × L, V × F × L, V × D × L, S × V × F × L, S × V × D × L, S × F × D × L, V × F × D × L and S × V × F × D × L are all significant at 5% level. Results obtained using DMRT showed that diameter sizes of the cane stalk at various levels of operation are statistically different from one another. Brix value was found to be distinct across the three replicates. The trend of mean brix value versus speed of operation is presented in **Fig. 10**. It can be deduced from **Fig. 11** that mean brix value decreased from speed of operation of 602 rpm to 765 rpm. Later, the mean brix value then increased from speed of 765 rpm to 1,176 rpm and then dropped from speed of 1,176 rpm to 1,520 rpm. This graph indicates that sugar rupturing was decreased from speed of 602 rpm to 765 rpm and then increased from speed of 765 rpm to 1176 rpm before it finally dropped from speed of 1,176 rpm to speed of 1,520 rpm. This implies that more sugar was ruptured at grating speed of 1,176 rpm.

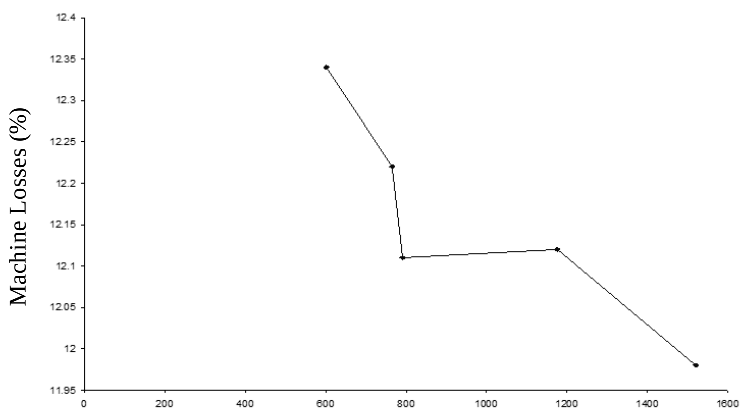


Fig. 9 Graph of mean machine losses versus speed of operation

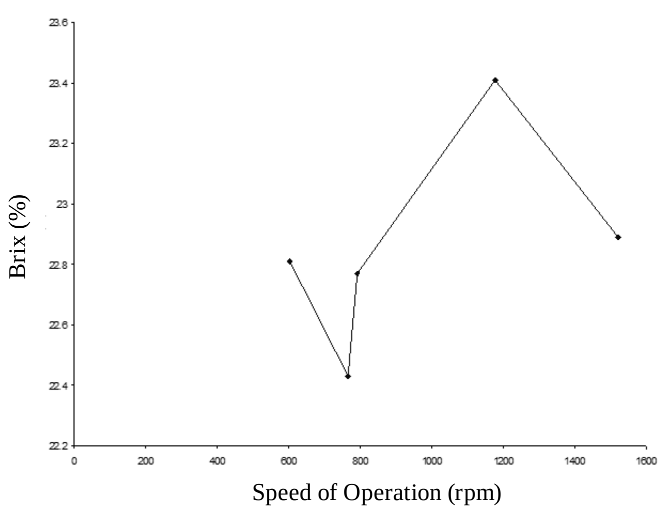


Fig. 10 Graph of mean brix versus speed of operation

Conclusions

A slider crank squeezing action sugarcane juice extractor was developed for crushing and squeezing action of macerated sugarcane stalk for effective production of sugarcane juice. The results of the performance evaluation of the machine indicated that

- The variety and diameter size of cane stalk at various levels of operation affects the extraction capacity of the machine.
- The variety of cane stalk is a major factor affecting the extraction efficiency of the machine.
- The speed, variety of cane stalk, diameter size of cane stalk and loading rate at various levels of operation affects the grating capacity of the machine.
- The diameter size of the cane stalk at various levels of operation affects the brix value of the cane stalk.
- Speed of operation was a major factor that determines the output and efficiency of the machine in the five measured parameters.
- The variety of cane stalk at various levels of operation affects the moisture content of the cane stalk.

- The interactions between (speed and variety), (speed, variety and feed rate), (speed, diameter and loading rate), (speed, variety, feed rate and loading rate) and (variety, feed rate, diameter and loading rate) at various levels of operation affects machine losses.
- Machine losses decreases with increase in speed of grating operation.

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Development and Evaluation of Semi-Automatic Six Row Onion Seedlings Transplanter

by

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Abstract

A six row semi-automatic plug metering type onion seedling transplanter was developed and evaluated for transplanting onion seedlings. The major components of transplanter consist of three-point hitch, plug metering system, funnel, press wheel and power transmission system. One person was required for feeding in each row. Performance evaluation of the transplanter was carried out for transplanting of 60 days old onion seedlings. Manual transplanting operation was also carried out to compare the performance and economics of mechanical transplanting with the developed machine. The field capacity and field efficiency of the developed six row semi-automatic onion seedling transplanter was 0.078 ha/h and 76.53%, respectively. The labour requirement in mechanical transplanting was 115 man-h/ha as compared to 400 man-h/ha in manual transplanting. No significant differences were observed in plant mortality with mechanically and manually transplanted seedlings. The estimated cost of the unit was Rs. 62,500 (US $1,000). The operational cost of mechanical transplanting, with plant geometry of 0.10 × 0.20 m, was Rs 8042 (US $135) /ha as compared to Rs 12,000 (US $200)/ha for manual transplanting.

Key words: India, Onion, transplanter, plug mechanism,

Introduction

Onion (*Allium Cepa*) is an important vegetable crop grown all over the world. It is probably a native of Asia, perhaps moved from Palestine to India. Onion is grown and distributed in all parts of the world. The world production is about 85.94 million tonnes of bulbs from 4.45 million ha (NHB, 2015). China and India are the leading onion producing countries. In India, it is grown especially in South and Central parts. It is cultivated very extensively in Maharashtra and Gujarat as a cash crop due to its high potential for export. More than 20% of the area under its cultivation is found in Maharashtra which accounts for

30% of total onion production. The other states are Himachal Pradesh, Orissa, Karnataka, Uttar Pradesh, Tamil Nadu and Madhya Pradesh. Onion crop is sown by various methods such as direct seed sowing, planting bulbs in field and raising nursery seedlings with subsequent transplanting in field. In India most common method is transplanting because of high yield and better quality produce. However, transplanting of onion seedlings is done manually in all onion growing regions in India because of non-availability of suitable machines. Moreover, there is a sizeable increase in acreage and production of onion in India. In terms of area, there is an increase from 0.87 to 1.22 million ha, while production has increased from 9.38 to 19.30 million tonnes from 2000-01 to 2013-14, respectively (NHRDF, 2014). But, manual transplanting of onion seedling is very tedious and labour intensive than mechanical transplanting as the operation is done in odd posture (bending posture). The labour requirement in manual transplanting of vegetable seedlings is also as high as 253 man-h.ha^{-1} (Satpathy, 2003). Vegetable crops are very sensitive to climatic conditions and require timely operations. However, labour shortage during peak season causes delay in transplanting, leading to drastic reduction in yields (Chaudhari *et al*., 2002).

There are number of semiautomatic transplanters developed for other vegetable crops link tomato, brinjal etc., but as such low cost efficient onion seedling transplanter is not available. In a study by Narang *et al.* (2011), 2-row vegetable transplanter with revolving magazine type metering mechanism was developed for brinjal seedlings. It was reported that plant missing varied from 2.22 to 4.44 per cent, upright plants, depth of planting, plant mortality after 20 days were in the range of 85-90%, 5 to 6 cm and 3.33 to 4%, respectively. The average field capacity of the machine was 0.122 ha.h^{-1} for brinjal crop. Imad (1995) developed a single-row vegetable seedlings transplanter consisting of feeding belt system to facilitate the establishment of bare-rooted transplants. The speed of transplanting ranged from 2 to 7 transplants per min per row. The theoretical capacity of the machine varied between 0.09 and 0.72 ha/h (for a single row). Hayashi *et al.* (2006) developed a planting machine for chrysanthemum cuttings using rotating cups. They developed two models of planting machines suitable for chrysanthemum cuttings: a standard model for cuttings with no lower leaves, and a model that automatically removes the lower leaves. Both models were semi-automatic with rotating cups to facilitate a supply task of an operator with two operators working side by side. In developed countries like USA, Japan, China and Holland onion transplanting operation is done with mechanical transplanters. Considering the smaller land sizes under onion crop, the semi-automatic transplanters may be suitably adopted for Indian conditions. As the demand for mechanization of onion production has increased in India due to shortage of labor, an attempt have been made to develop semiautomatic onion seedling transplanter that is structurally simple, functionally accurate and economically feasible. The objective of this study was to develop a six row semi-automatic onion seedling transplanter suitable to Indian conditions and evaluate its performance.

Materials and Methods

Design Details of Onion Seedling Transplanter

Based on the biometric properties of onion seedlings, optimum operating conditions, and plug type onion seedling transplanter, a prototype was first designed and fabricated accordingly. The part modelling of different components, their assembling and drawings were prepared using CAD software "Pro Engineer Wildfire 4.0". The assembled prototype onion seedling transplanter along with its components is shown in **Fig. 1**. The transplanter consist of main frame with hitching system, ground wheel, furrow openers, press wheels, six row metering system, dropping funnels, operator's seat for six persons. The design details of

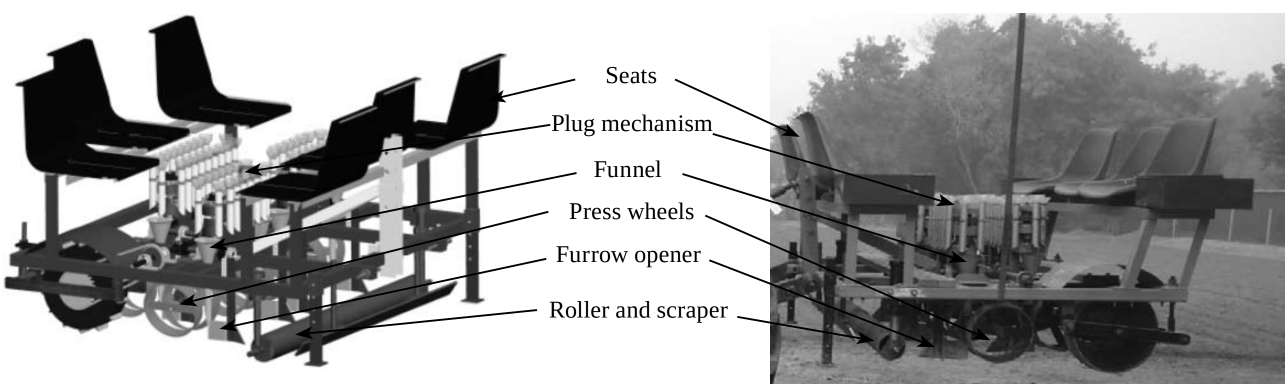


Fig. 1 Prototype onion seedling transplanter

the components are:

Plug metering assembly

The plug metering assembly was fitted on a vertical shaft powered with pair of bevel gears with speed ratio of 1:1. This speed ratio was obtained by using bevel gears set having 15 teeth each. The plug assembly (**Fig. 2**) was made of 1.2 m long chain and two 15 teeth driving and driven sprockets in which driving sprocket powered by vertical plug metering assembly shaft. Twenty plugs (**Fig. 3 a**) were fitted on a periphery of chain at an equal distance of 6 cm each by means of specially designed holding clamps made of GI sheet. The whole plug assembly was mounted on a closed frame such that it could rotate around it. A stationary cam was fitted at the delivery end of the frame just above the dropping funnel to open the lid of plugs.

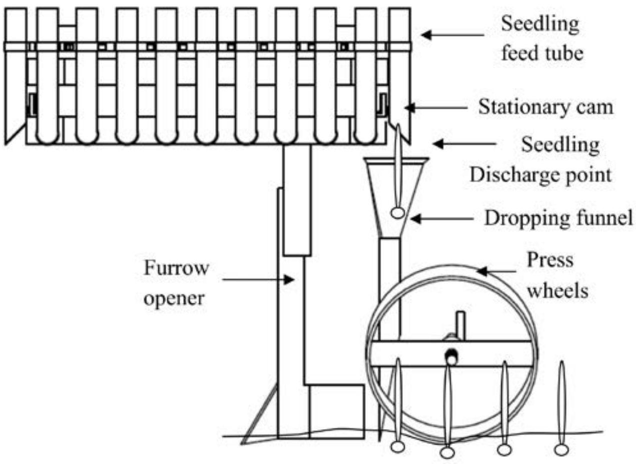
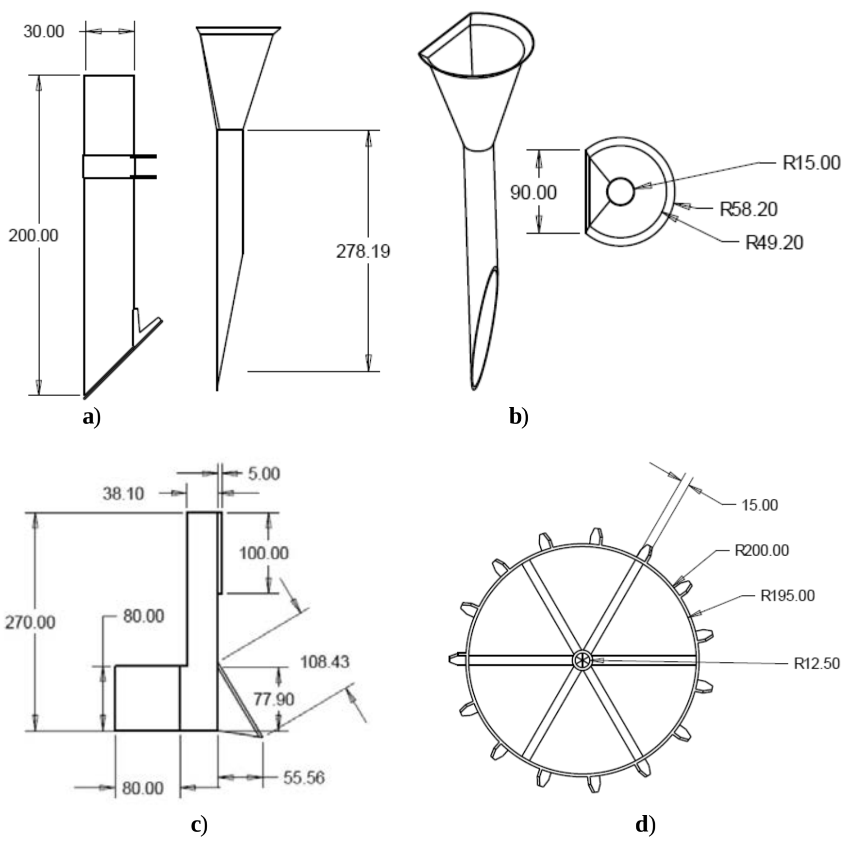


Fig. 2 Plug metering system



Note: All dimensions are in mm

Fig. 3 Design details of different components of onion seedling transplanter **a**) Plug, **b**) Funnel, **c**) Furrow opener, **d**) Ground wheel

Dropping funnel

Seedling dropping from the plug falls in the direction of travel of machine. A drop funnel made of MS sheet was provided to guide the seedlings vertically in the opened furrow (**Fig. 3 b**). The diameter of funnel was 110 mm at top and 30 mm at bottom and height was 100 mm. The MS contour or conduit pipe of 30 mm diameter and 300 mm length was connected at the bottom of funnel as a drop chute. A parabolic cut was made at the bottom of 150 mm of the drop chute pipe.

Furrow opener

The chisel type furrow opener (**Fig. 3 c**) was provided immediately at the back of the dropping funnel to open a thin continuous furrow which requires low draft. The cross-section of the furrow formed by furrow opener should be such that the furrow wall supports the seedlings vertically straight after being dropped from the dropping funnel. The triangular shape soil working tool attached to the standard made up of M.S. flat of 10 mm thickness having 55 mm length and 80 mm height along the standard. The cutting edge was of 110 mm length. The standard was made up of M.S. flat of 40 × 6 mm size with 270 mm length. At the rear, the runners were connected to a standard connecting a drop chute in order to maintain the furrow walls till the seedlings falls in the furrow. At the upper back end of standard the clamping attachment was provided.

Press wheels for furrow closing cum compaction

Each press wheel was made of mild steel flat of 5 mm thick and 76 mm wide. The flat was bent with a diameter of 244 mm to form a wheel. The width of the wheel was 64 mm. M.S. flat of 40 mm width and 6 mm thickness was attached to the wheel from inner side as spokes for support. A hub (inner diameter of 20 mm and outer diameter of 38 mm) was welded at the centre of the wheel on flat. The two press wheels were mounted on a 20 mm single axle bent downward at an angle of 150° at the centre such that the face of wheel makes an angle of 30° with horizontal. The distance between the two wheels at the bottom end was 25 mm and 150 mm at the top end. As the press wheel advances over the root and bulb of seedling, the soil over it would be compacted anchoring the seedling firmly in soil.

Power transmission mechanism

The ground wheels were provided on both sides of the machine. But the power was given to the metering mechanism from drive wheel at the right side of the machine. The other ground wheel functioned as a support wheel when machine was completely lowered down during its operation. Both ground wheels were also adjusted to control the depth of operation. Power transmission system consisted of following components.

Ground wheel

A closed ground wheel with lugs on the periphery was provided at each side of the machine. M.S. flat of 100 × 6 mm was used for the rim. The outer diameter of rim was 360 mm. The flat discs of same size made up of 16 gauge MS sheet were welded to rim along its both edges and the centre hub. The lugs were provided on the outer periphery of rim of drive wheel to minimize the slippage. The lugs were of trapezoidal shape having 100 and 60 mm parallel sides with 25 mm height, welded on outer periphery of the rim (**Fig. 3 d**).

Main shaft

A 25 mm diameter MS shaft was provided along 1.6 m length of main frame in between two ground wheels for transmission of the power from ground wheel to metering systems. This shaft was supported on three self-aligning bearings mounted on the main frame. A sprocket with 21 teeth was mounted on the shaft which was driven by a 25 teeth sprocket on ground wheel axle.

Plug assembly shaft

The step type vertical driving shaft of the plug assembly was driven by 15 teeth bevel gear on a 25 cm long horizontal shaft connected to a main shaft by means of a pair of bevel gears each with 15 teeth. The 10 teeth bevel gear was fitted on the lower end of vertical shaft having 25 mm diameter and upper end of shaft was connected to a 15 teeth driving sprocket. The overall length of the shaft was 250 mm.

Seating arrangement

A seating attachment for operators to fill the plugs with onion seedlings was developed at the front and at the rear end of the machine. Six plastic seats were mounted on the main frame by providing necessary support of frames made of angle iron to accommodate six persons to feed seedlings in metering device. The three operators sat at the rear end and three at the front facing each other (**Fig. 1**).

Seedling trays

Four seedling trays of size 0.35 × 0.20 × 0.12 m made of 18 gauge GI sheet were provided at four corners of machine for keeping seedlings.

Main frame

The complete frame was made up of 50 × 50 × 5 mm and 40 × 40 × 5 mm MS square pipes. Main frame was provided with three point linkage and different components namely metering mechanism, furrow opener, press wheels and power transmission system mounted on it. An auxiliary frame for operator's seats was also mounted on the main frame on both sides. The dimension of main frame was 1.65 × 1.41 × 0.05 m.

Performance Evaluation of Prototype Onion Seedling Transplanter

The prototype onion seedling transplanter was tested (**Fig. 4**) for transplanting recommended 60 days old healthy onion seedlings for two commonly planted verities (variety-N-53, Pusa Riddhi) on a plot of 1000 m^2. The speed of travel was adjusted to match the feeding rate compatible to the operator. The transplanter was operated at 0.18 $m.s^{-1}$ (0.7 $km.h^{-1}$) for recommended plant and row spacing of 100 mm × 200 mm, respectively. The field performance evaluation of prototype onion seedling transplanter was done according to RNAM test code (RNAM, 1983) for paddy transplanter. Manual transplanting operation was also carried out for both the varieties (N-53 and Pusa Riddhi) in two different control plots to compare the results with mechanical transplanting. The following parameters were recorded

Seedling mortality

In order to assess the damage to seedlings during mechanical transplanting, a control plot of 200 m^2 was transplanted manually with

Fig. 4 Field performance evaluation of prototype onion seedling transplanter

seedlings grown on same date and in same batch. Observations for mortality of seedlings occurring after 10, 20 and 30 days after transplanting were recorded for both manually and mechanically transplanted onion seedlings.

Per cent miss transplanting

The seedling feed tubes that were missed to feed by the operator, results in wide spacing between the consecutive transplanted onion seedlings and expressed as the percent miss in transplanting. Percent miss in transplanting was calculated using above formula

$\% \, miss = S_m / (S_f + S_m) \times 100$

Where,

$\% \, miss$ = Percent miss in transplanting

S_m = Number of seedlings missed by operator to feed in seedling feed tubes

S_f = Number of seedlings fed by operator in seedling feed tubes

No of seedlings per hill

The number of seedlings per hill was measured by counting the number of plants per hill in the same line along one meter length. The number of seedlings per hill was measured at five different locations randomly.

Theoretical field capacity, ha/h

The theoretical field capacity (ha/h) of machine was measured in field by considering the width of operations and the travel speed of the tractor.

Theoretical field capacity = (Width of operation (m) × Travel speed (km/h)) / 10

Field efficiency, per cent

Field efficiency (per cent) was calculated as follows from the test data.

E_f = *Effective field capacity* (E_e) / *Theoretical field capacity* (E_T)

$= (W_e \times V_e \times T_P) / (W_t \times V_t \times (T_P + T_N)) \times 100$

Where,

E_f = Field efficiency, per cent

W_e = Effective working width, m

W_t = Theoretical working width, m

V_e = Effective operating speed, m/s

V_t = Theoretical operating speed, m/s

T_P = Productive time, s

T_N = Non-productive time, s

Draft

Draft was measured by two tractors and a dynamometer. The transplanter was mounted on a tractor at the front of which the spring type dynamometer was attached. Another auxiliary tractor was used to pull the machine mounted tractor through the spring dynamometer. The auxiliary tractor pulled the machine mounted tractor with the latter tractor in neutral gear but with the machine in the operating position. The pull was recorded in the dial gauge of dynamometer. In the same field, machine was kept in lifted position on ground and recorded the draft at no load condition. The difference gives the draft of the machine.

$D = P \cos \theta$

Where,

D = Draft, N

P = Pull measured by dynamometer, N

θ = Angle between the line of pull and the horizontal, degrees

Labor requirements, man-h/ha

The total number of labours required per ha during the field evaluation of onion transplanter was recorded. One tractor operator (skilled) labour and six operators (unskilled) to drop the onion seedlings and two helpers (unskilled) were required to assist the onion seedlings droppers to supply the cut onion seedling. As such total nine labours (including unskilled and skilled) were required to operate the developed onion transplanter.

Labour required by manual method, man-h/ha

The total number of labours required per hectare by traditional method was recorded for transplanting onion seedlings.

Table 1 Performance evaluation of 6- row semi-automatic tractor mounted onion seedling transplanter

Variety	N-53		Pusa Riddhi	
Particulars	Traditional	Mechanical	Traditional	Mechanical
Area, m^2	142.8	500	290	500
Row to row spacing, cm	-	20.7	-	19.9
Plant to plant spacing, cm	13.25	12.9	12.33	12.4
Planting depth, cm	1.7	2.9	2.1	3.02
Width of operation, m	-	1.21	-	1.22
Percent miss transplanting, %	0	4.66	0	5.39
No of seedlings per hill	1	1.13	1	1.07
Plant density, No./m^2	35.25	32.6	35.75	32.6
Moisture content of Soil, (db), %	5.09	11.45	5.23	12.03
Bulk density, g/cc	1.49	1.35	1.42	1.34
Travel speed, m/s	-	0.18	-	0.18
Theoretical field capacity, ha/h	0.0098	0.078	0.0075	0.078
Effective field capacity, ha/h	-	0.057	-	0.061
Field efficiency, per cent	-	74.39	-	78.68
Fuel consumption, L/h	-	2.57	-	2.4
Wheel slippage, per cent	-	2.94	-	2.94
Draft, kN	-	3.45	-	3.53

Results and Discussion

Field Performance Results

After the completion of both manual and mechanical transplanting operations in a selected area, different performance parameters were recorded (**Table 1**). The average row spacing at different locations were 20.7 and 19.9 cm for N-53 and Pusa Riddhi respectively against set row spacing of 20 cm. The average plant spacing for developed transplanter were 12.9 and 12.4 cm for N-53 and Pusa Riddhi respectively against recommended plant spacing of 10 cm. Whereas in manual transplanting it was 13.25 and 12.33 cm for N-53 and Pusa Riddhi respectively. The average plant to plant spacing observed in both methods of transplanting were comparable and close to the targeted plant spacing of 10 cm. The variations in spacing in mechanical transplanting can be attributed to the variations in skid values owing to inherent field variations in moisture content, bulk density and small surface undulations. The average planting depth for N-53 and Pusa Riddhi were respectively 2.9 and 3.02 cm with mechanical transplanting and 1.7 and 2.1 cm with manual transplanting. The depth of transplanting was adequate for sustenance and establishment of seedlings in field. The number of seedlings per hill in mechanical transplanting for N-53 and Pusa Riddhi was 1.13 and 1.07 respectively as against precise one seedling per hill in manual transplanting. The percent miss transplanting in mechanical transplanting for N-53 and Pusa Riddhi were 4.66 and 5.39 percent respectively which were closer to recommended acceptable limit of 4 percent. The average plant density in mechanical transplanting was 32.6 seedlings per m^2 against 35.25 and 35.75 seedlings per m^2 in manual transplanting for N-53 and Pusa Riddhi. The reduced plant density in mechanical transplanting was due to increased percent miss transplanting and increased plant spacing as compared to manual transplanting. The forward speeds of 0.18 m/s could be maintained in field while transplanting with machine to achieve maximum field capacity and minimum missing. However, soil bin studies also revealed that the travel speed of 0.18 m/s was optimum to achieve higher successful transplanting rates and field capacity, if seedling feeding rates were not the limiting factor. The theoretical field capacity in manual transplanting ranged from 0.0075 to 0.0098 ha/h against 0.0780 ha/h in mechanical transplanting indicating the satisfactory performance of onion seedling transplanter. The effective field capacity for complete duration of experimentation ranged from 0.057 to 0.061 ha/h. The reduced field efficiency of transplanter (76.53%) was attributed to non-productive time during turning at head lands, loading and unloading of seedlings from seedling tray, adjustments made during the operation of machine and initial adjustments to start the transplanting operation. The loading of pre-cleaned and de-topped seedlings before the start of transplanting operation would reduce the non-productive time to a great extent. The average wheel slippage (per cent) was recorded 2.94 per cent which was within acceptable limit of 5% to affect the plant spacing. The draft required to pull six row onion seedling transplanter in field ranged from 3.45 to 3.53 kN which was observed within drafting capacity of 35 hp tractors. The fuel consumption in operation of six row semi-automatic onion seedling transplanter was found to be 2.4 to 2.57 L/h which shows normal fuel consumption of tractor with transplanter in operation.

Seedling Mortality

The percent seedling mortality for N-53 and Pusa Riddhi increased respectively from 2.93 to 4.17 percent and 3.59 to 5.52 percent in mechanical transplanting and 1.28 to 4.25 percent and 1.4 to 3.27 percent respectively in manual transplanting for 10 to 30 days after transplanting (**Table 2**). The small increment in percent seedling mortality in mechanical transplanting was due to increase in damage to the seedlings in comparison to manual transplanting. The damage was attributed to mechanical damage as well as damage and missing caused by birds.

Table 2 Seedling mortality in manual and mechanical transplanting

Seedling mortality, percent	N-53		Pusa Riddhi	
	Manual	Mechanical	Manual	Mechanical
After 10 days	1.28	2.93	1.40	3.59
After 20 days	2.55	3.38	2.59	3.93
After 30 days	4.25	4.17	3.27	5.52

Cost Economics of Transplanting

In traditional method, the labor requirement at observed average manual transplanting rate of 9 to 11 $seedlings.min^{-1}.person^{-1}$ was 400 man-h/ha. Whereas, due to increase in feeding rate in mechanical transplanting, the average transplanting rate also increased up to 54 $seedlings.min^{-1}.person^{-1}$ which leads to decrease in labor requirement to 115 man-h/ha. The cost of operation for manual transplanting was 90 to 118 Rs./h against 628 Rs./h for mechanical transplanting. But, due to increased field capacity of mechanical transplanting cost was reduced to 8,042 Rs./ha as compared to Rs. 12,000/ha for manual transplanting resulting in net saving of 33% over traditional method. The average payback period was found to be 177.13 h for owning the transplanter by onion grower. The breakeven point (BEP) was found to be 29.23 h which was 11.69% of the annual utility of 250 hours of onion seedling transplanter.

Crop Yield

After harvesting of the crop, the yield of onion for N-53 and Pusa Riddhi variety was 12.20 and 12.65 tonnes/ha in mechanical transplanting as compared to 12.95 and 13.43 tonnes/ha in manual transplanting. The yield was found close to the recommended yield of 15-20 tonnes/ha (Mohanty *et al*., 2001) for kharif season planting. At plant geometry of 0.20 × 0.10 m, the required plant population should be 500,000 plants per hectare. However, in machine transplanting, the plant population obtained was 390,625 (78.13 per cent) of required plant population.

The weight and diameter of ten randomly selected harvested samples from mechanically and manually transplanted plots were determined. The weight and diameter of onion bulbs of N-53 variety ranged from 55.74 to 66.65 g and 62 to 111 mm in mechanical whereas 47.63 to 62.43 g and 52 to 93 mm in manual transplanting respectively for N-53 variety. However, in Pusa Riddhi the weight and diameter of onion bulbs ranged from 49.67 to 66.65 g and 52 to 111 mm in mechanical whereas 50.16 to 58.68 g and 48 to 84 mm in manual transplanting respectively. Weight and diameter of harvested onion bulbs were higher in mechanically transplanted seedlings over manual transplanted seedlings. This may be due to uniform plant spacing and depth of placement of onion seedling in mechanical transplanting. But, the yield of onion bulbs was higher in manually transplanted plot than mechanically transplanted plot. The negligible variation in yield was due to miss transplanting (4.66 and 5.39%) in mechanical method as against zero percent miss transplanting in manual method.

Conclusions

The six row onion seedling transplanter having overall dimensions 1650 (L) × 1410 (W) × 650 (H) mm and weight 315 kg was evaluated for transplanting 60 days old onion seedlings. The field capacity and field efficiency of transplanter was 0.078 ha/h and 76.53% respectively. There was no significant difference in mortality between mechanically and manually transplanted seedlings. A labor requirement in mechanical transplanting was 115 man-h/ha as against 400 man-h/ha in manual transplanting. Average cost for transplanting 1000 onion seedlings with developed onion seedling transplanter was Rs. 33 /- as against Rs. 76/- when done manually. Net saving in mechanical transplanting over traditional method of transplanting was 3,958 Rs./ha. The overall performance parameters of prototype onion seedling transplanter are considered to be satisfactory.

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Status of Rice Transplanters in India

by

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Abstract

Rice is the staple food of millions of people living in the east and south part of Asia. Sowing and planting operations in rice crop follows traditional methods in many parts of this region even though tillage and harvesting operations are mechanized to a great extent. Delicate nature of the seedlings makes development of the machines difficult. However, a lot of effort is put on development of new machines.

Mechanization of rice cultivation practices is important in achieving the best yields and in achieving economy of cultivation. Among various practices, transplanting is one of the most difficult to mechanize. Tranplanters are widely available in advanced countries. These were developed in China, India, Italy, Japan and Korea.

This paper presents the details of rice transplanters and their problems. In addition to recent advances in their development in India, performance of transplanters under actual field conditions is also discussed.

Keywords: Rice Transplanter, Fixed Fork Type Finger, Seedling Mat, Four bar mechanism.

Introduction

Rice is an important crop of India. It contributed 40.93% of total food grain production, 257.13 million tonnes, in the year 2012-13 (Anon, 2014). The gross cropped area under cultivation of rice was 42.75 million hectare with an average cropping intensity of 138.67%. Most of the rice produced in the country is consumed domestically. At world level rice is one of the most extensively cultivated crop (De Datta, 1981). It is the staple food of millions of people. Southern, south eastern and eastern Asia forms the largest rice growing part of the world. At the world level India ranks second in production of paddy, China being the first (Singh, 1983). However, India ranks first in area of production. Rice can be grown under both upland and wet land conditions. It can also be grown in flooded conditions. It is grown in a large variety of soils wherever sufficient water is available.

In the countries of east and south parts of Asia, industrialization is a slow process and has a long way to go to reach the level of developed countries. Rice production activities are still carried out in traditional ways with small hand tools and equipment. However, tillage and harvesting have been mechanized to different levels. It has not been possible to achieve mechanization of sowing and transplanting activities in a large part of this region.

In the cultivation of rice, transplanting is practiced widely (Dev Goswami, 1977). Before the introduction of machines, transplanting was carried out manually. Manual transplanting requires about 250-300 man-h/ha which accounts for 25% of the total labour requirement of the crop (Anon, 1979). A person has to maintain a stooping posture during the manual transplanting operation. It is a labour intensive and a tiresome process (**Fig. 1**).

Transplanting is more expensive than direct seeding because of engagement of farm labour. Mechanical transplanting is an alternative to manual transplanting, in terms of timeliness of operation, reduction of drudgery and low cost of operation.

Fig. 1 Traditional method of transplanting rice

Mechanical transplanting is pursued by a large number of research institutions as the labour availability has become critical during the peak agricultural season. Many methods of direct seeding (Tiwari and Datta, 1983; Srivastava and Panwar, 1991; Singh, 1995; and Devnani, 2002) and a method of tape transplanting (Datt, 1995) are reported from different institutions but have not found wide acceptance.

Demand of Mechanical Transplanters and Seeders for Rice Crop in India

Research efforts aimed at mechanization of rice sowing activities have been made in many countries of the world during the last few decades. Many self-propelled machines were produced commercially. Among rice growing countries of the world, Japan has mechanized transplanting of rice almost fully, about 98% (Anon., 1992). Countries like Thailand, Bangladesh, India, Sri Lanka and Pakistan are still carrying out research for development of mechanical rice transplanter suitable for their countries. Many models of self-propelled rice transplanters and few models of manually operated rice transplanters are available in India. **Table 1** provides a list of these models. When mechanical transplanters were introduced, root washed seedlings were used. It was experienced that separation of seedlings by the transplanting finger from the seedling tray was difficult. Also, distribution of number of seedlings in individual hills was uneven (De Datta, 1981). With the popularity of machines, mat type seedlings were adopted in order to overcome these problems. Gradually mat type seedlings became popular due to its superior performance in terms of less number of missing hills, less number of floating hills, establishment of the required number of seedlings in the hills and reduction of the labour requirement (Dixit *et al*., 2007; De Datta, 1981).

Changes Introduced in the Cultivation Practice of Rice for Mechanization of Seedling-Transplanting Operations

Mechanization of transplanting gave rise to the production of mat type seedlings. This replaced the root- washed seedlings used in the traditional transplanting. A major change in the transplanting process is the increase in row to row spacing. When Annapurna model was introduced in India in 1960s it was designed to keep 10 cm row to row spacing meeting the agronomical requirement. IRRI models adopted about 20 cm row to row spacing. In these models there was a separate compartment in the seedling tray for each row. The amount of seedling that can be loaded into the machine was more if the width was more. Models of power operated machines also adopted wider tray compartments. Yanji Shakti model which was the latest under trial in India has a wide spacing of 23.8 cm. The effect of increasing the spacing on yield is not investigated thoroughly. Duraisamy *et al*. (2010) conducted a field experiment in wet land to optimize the spacing and depth of transplanting in rice cultivation using self-propelled rice transplanter (Yanmar 6 row model). They found that at a spacing of 30 × 22 cm yield of the crop was best. On the face of labour shortage farmers are compelled to adopt the machines with any available spacing.

Preparation of Mat Type Seedlings Man-Hour Requirements

Table 1 List of rice transplanters under trial and adaptation in India

Transplanters tried in laboratory and in limited field trials	Transplanters tried at farmers field level extensively	Transplanters tried for commercial adoption
i) PAU Ludhiana 6-row manually operated transplanter	i) IRRI type manually operated rice transplanter (4-row, 6-row and 8-row models)	i) PAU riding type engine operated rice transplanter
ii) Annapurna manually operated transplanter	ii) CRRI Cuttack 4-row design manually operated rice transplanter	ii) Yanji Shakti self propelled rice transpalnter
iii) APAU Hyderabad manually operated transplanter	iii) CIAE, SARAL-6 manually operated rice transplanter	iii) Riding type Champion RP82, 8 row rice transplanter
iv) TNAU, Coimbaiore animal drawn rice transplanter	-	iv) Walk behind CHAMPION WRP430 rice transplanter
v) IIT, Kharagpur manually operated rice transplanter	-	v) Walk behind Yanmar, model AP4, 4 rows rice transplanter
vi) GBPUAT, Pantnagar animal drawn rice transplanter	-	vi) RHINO, model 8R,8 row rice transplanter
vii) APAU, Hyderabad power tiller mounted transplanter	-	vii) Kubota SPF-28 rice transplanter
viii) IIT, Delhi power operated mechanical rice transplanter	-	viii) V V RTR-01, 4 row rice transplanter
ix) CMERI, Durgapur power operated mechanical rice transplanter	-	ix) Riding type Kubota NSPU-68 CMD rice transplanter
-	-	x) Riding type VP6D rice transplanter

and Cost of Transplanting

Growing of mat type seedlings needs special care. Mat type nursery is raised by many methods. It is generally raised on a plastic sheet or on a leveled concrete surface. Thickness of the mat was 10- 25 mm depending on the soil type (Garg and Sharma, 1989; Anon., 2010). Roots of the seedlings are entangled one another along with soil to form the mat. It offers resistance to the mechanical finger at the time of picking (Garg *et al*., 1982).

Transplanting carried out using manually operated tranplanter that requires 33-66 man-h/ha as reported by various researchers from different locations using different methodologies (Garg *et al*., 1997; Anon., 1983; and Singh and Vatsa, 2006). Considering an average time requirement of 50 man-h/ha, this indicates a saving of 80% of labour requirement in transplanting compared to the manual method. Similarly, power operated self-propelled transplanters require 10-42 man-h/ha with different models of machine (Manjunatha *et al*., 2009; Farooq *et al*. 2001; and Anon., 2004). Accordingly 90% of labour requirement for transplanting is saved. Thus, there would be less dependence on labour which is scarce and uncertain during the peak transplanting season (Dixit *et al*., 2007).

Labour cost involved in transplanting should be divided into two—(i) Cost involved in nursery preparation; and (ii) Cost involved in planting operation. Labour costs reported by various researchers are given in **Table 2**.

Size of Land Holdings in Indian Farms

Size of land holdings is an important parameter for the introduction of any agricultural machine. In India, it appears that 85% of the holdings are in the size group of 2 ha or less. This accounts for 44.6% of the cultivable area. Further 14.2% holdings are in the range of 2-10 ha and this accounts for 44.8% of the area. Finally, the last 0.7% of the holdings are in the size group of 10 ha and more and this accounts for 10.6% of the area. Thus, it is observed that 85% of the operational holdings are in the size group of (less than 2 ha) and this covers only 10% of the area (Anon., 2014). Fragmentation of land into smaller plots further limits free movement of the machines.

Table 2 Labour cost for transplanting by manual and mechanical methods

	Nursery preparation, man-hour/ha	Planting operation, man-hour/ha
Manual transplanting in random spacing	32 (Kumar and Kumar, 2012)	250-300 (Anon, 1979 ; Singh *et al*., 1985)
	35 (Dixit, 2010)	328 (Dixit, 2010)
		292 (Sahay *et al*., 2002)
		32 (Kumar and Kumar, 2012)
Manual transplanting in rows	As above	300 (Baruah *et al*., 2001)
		300-350 (Swain, 2002)
Mechanical transplanting with manually operated transplanter	44 (Datt, 1995)	55 (Datt, 1995)
	30-35 (Anon., 1980)	44.4 (Garg *et al*., 1997)
	7.5-12.5 (Garg *et al*., 1997)	30-35 (Anon., 1980)
	50 (Kumar and Kumar, 2012)	80 (Kumar and Kumar, 2012)
		73 (Dixit, 2010)
Mechanical transplanting with self-propelled transplanter	20 (Garg and Sharma, 1989)	15 (Farooq *et al*., 2001)
	12 (Farooq *et al*., 2001)	31.2 (Sahay *et al*., 2002)
	50 (Kumar *et al*., 2008)	24 (Manjunatha *et al*., 2009)
	40 (Baruah *et al*., 2001)	34 (Kumar *et al*., 2008)

Popularity of Rice Transplanters

According to the sources of power used mechanical rice transplanters are

(a) Manually operated transplanter
(b) Animal operated transplanter
(c) Power tiller operated transplanter
(d) Tractor operated transplanter and
(e) Self-propelled transplanter

Manually Operated Rice Transplanters

First designs of manual rice transplanters were operated with a handle making forward and backward strokes with hand. Out of them, one popular model similar to the IRRI, Philippines design, has two handles. One handle is used to pull the machine in forward direction whereas the other handle is used to actuate the finger in forward and backward stroke for transplanting. The operator pushes the handle so that the finger- tip would pass through the slot made in the seedling gate. The picked up seedlings were put in a hill in the puddled soil. During return motion the finger moves slightly away from the slot so that the finger- tip would not hit the tray.

Out of a number of models, IRRI type manual rice transplanter has been tried extensively in many countries and many modifications of this model were also introduced.

Another model being introduced in India and elsewhere has a crank operated by one hand while the other hand pushes a handle making the machine travel.

IRRI type manual rice transplanter

Anon (1980) reported that International Rice Research Institute, Philippines has designed three models of manually operated rice transplanters. Planting unit of these machines is similar in design. One model of IRRI type transplanter available in India has the features given in **Table 3**.

Power Operated Self-Propelled Rice Transplanters

Performance evaluation of various types of rice transplanters were carried out by various researchers at different parts of India (Behra and Varshney, 2003; Biswas, 2004; Choudhary and Varshney, 2003; Garg and Sharma, 1987 and Pandey, 2004). Out of a number of power operated rice transplanters, Yanji Shakti model self-propelled rice transplanter is the most commonly used. Planting systems of other power operated transplanters have similar construction and design.

Yanji Shakti self-propelled rice transplanter

Anon. (1999) reported details of 'Yanji Shakti' make 8-row self-propelled rice transplanter marketed by M/s V.S.T. Tillers Tractors Ltd., Bengaluru . Salient features of the machine are given in **Table 4**.

The self-propelled rice transplanter has (a) planting unit, (b) seedling tray and tray movement unit, (c) power transmission unit, (d) float, (e) traction and transport wheels, (f) steering unit, (g) engine, and (h) chassis.

Planting unit is made of a planar quadric cycle chain having a coupler extension. Crank is the smallest link driven by the power supply from the engine through a series of power transmission elements. The coupler is extended to form a coupler extension. Planting finger is mounted on the coupler extension. It is moved by the four bar linkage and traces a suitable locus. The finger passes through a slot provided on the tray and moves to the soil where the seedlings are planted. About 3-8 numbers of seedlings are planted in a hill. Soon after placing the seedlings in the hill they are pushed into the soil by a cam actuated seedling pusher unit. The seedling pusher returns gradually due to a disc cam mounted on the shaft of the crank. Number of seedlings picked up from the tray can be controlled by an adjustment provided on the finger. Depth of planting can be adjusted by operating a lifting arm up or down which moves the planting unit up or down using a threaded vertical shaft.

Table 3 Features of an IRRI type manual rice transplanter

Type of machine	: Manually operated rice transplanter
Power	: Manual, 1 person
Row spacing	: 20 cm
No. of rows	: 4
Planting depth	: 2- 6 cm, adjustable
Average no. of seedlings per hill	: 3-6
Tray displacement per stroke, adjustable	: 9-13 cm
Size of seedling mat	: 20 cm × 40 cm
Standing water depth in the field	: 1-3 cm
Type of seedling used	: Mat type

Table 4 Specification of Self-Propelled Rice Transplanter (Anon., 1999)

Model	: 2ZT-238-8
Engine	: 165 F, air cooled diesel engine (2.4 kW, 2600 rev./min)
Working mechanism	: Crank connecting rod transplanting mechanism
Number of rows	: 8
Row spacing, mm	: 238
Distance between hills, mm	: 100, 120 (adjustable)
Depth adjustment	: Infinitesimal adjustment with screw rod
Forward speed, km/h	: 1.57, 1.94
Field capacity, ha/h	: 0.15-0.20
Length of crank, mm	: 35
Length of connecting rod, mm	: 90
Length of rocker arm, mm	: 90
Distance from crank center to tip of fork, mm	: 190
Width of separating fork, mm	: 12.5
Width of seedling gate, mm	: 16
Paddy field driving wheel	: 15 lugs, inclination angle 220, outside diameter = 700 mm
Rubber tyre wheel for transport	: Diameter 705 mm

Power Operated Tractor Mounted and Power Tiller Drawn Rice Transplanters

A tractor mounted transplanter was designed by Punjab Agricultural University, Ludhiana about 3 to 4 decades back and a power tiller operated model was designed by Andhra Pradesh Agricultural University. Both designs were demonstrated but were not manufactured commercially.

Field Trials and Demonstrations in India

Under All India Coordinated Research Project on Farm Implements and Machineries, different types of manual and self-propelled rice transplanters are being tested and demonstrated among the farmers almost in all states of India. There are 25 centres spread across the country which together carry out research and development activities, prototype manufacturing, prototype feasibility testing, front line demonstration and custom hiring of machines. State governments are also popularizing different models through their Farm Mechanization Programmes. Various Governments have also extended subsidies to the farmers for the purchase of transplanters. It was reported that large scale frontline demonstration of an 8 row self-propelled rice transplanter was carried out at farmers field covering a total area of 96 ha during 2004-2013 in different villages of Khurda, Puri, Balasore, Cuttack, Bhadrak and Sonepur districts of Odisha State (Pradhan, 2016). Walk behind and riding type self-propelled rice transplanters were demonstrated in an area of 66 ha in Mandalagera, Halapur, Hirekotnikal and Chintamandoddi villages of Raichur district (Anantachar, 2016). Recently, ten models of various transplanters were evaluated at Tavanur by Kerala Agricultural University, Thrisur (Anon, 2016).

Development of Mechanical Transplanters and Their Planting Mechanisms

Manually Operated Transplanters and Their Planting Mechanisms

Anon. (1979) reports that manually operated transplanters were developed in China, India, Japan, Philippines and the United Kingdom.

Mahapatra (1973) reports the development of manually operated root washed Annapurna transplanter in Bhubaneswar, India. Anon. (1986) reports the development of a manually pulled ground wheel driven transplanter at ANGRAU, Hyderabad, India.

In IIT Kharagpur India, several investigations were carried out to develop a manually operated transplanter using either root-washed seedlings or mat type seedlings. These include the works of (Gupta, 1973; Parida, 1975; Mukherjee, 1976; Ghate, 1976; Choudhury, 1983; Naghavi, 1987; Saha, 1988 and Dewangan, 1994). All these machines are claimed to have performed well during the experimental stage but no attempt has been made to commercialize these.

In other parts of India also similar efforts are continued (Biswas, 2004; Datt, 1995; Singh and Hussain, 1983; Kurup and Datt, 1981 and Manian *et al*., 1987).

Different models of manual transplanters have been tested at different places by different researchers and found satisfactory performance (Biswas, 2004; Datt, 1995; Garg and Sharma, 1984; Manian *et al*., 1987; Singh *et al*., 1981; Singh *et al*., 1985 and Verma *et al*., 1989).

Animal Operated Transplanters and Planting Mechanism

Available information suggests that only China and India have worked on animal operated transplanters.

Gupta (1983) reports the development of a bullock drawn transplanter at GBPUAT, Pantnagar. The animal drawn transplanters were not accepted by the farmers. It may be due to nonuniform speed as well as the non-familiarity to operate these machines by the animals. Biswas (2004) reports the development of an animal drawn unit at TNAU, Coimbatore.

Power Tiller Operated Transplanters and Planting Mechanism

Anon (1986) reports the development of a power tiller mounted transplanter at APAU, Hyderabad. Two similar models-one with 7 rows and the other with 8 rows are made. They could be attached to two different makes of power tillers.

Tractor Drawn and Self-Propelled Transplanters and Planting Mechanism

Power operated rice transplanter may be tractor operated, power tiller operated or self-propelled type. In India, work on the power operated transplanters was carried out at different organizations. These include Acharya NG Ranga Agricultural University (ANGRAU), Hyderabad; Central Mechanical Engineering Research Institute (CMERI), Durgapur; Indian Institute of Technology (IIT) Delhi; Indian Institute of Technology (IIT) Kharagpur and Punjab Agricultural University (PAU), Ludhiana.

Singh *et al*. (1980) report the development of a tractor mounted transplanter at PAU Ludhiana, India in 1975. It was a 10-row unit and used pairs of moving fingers. The machine was designed to use mat type seedlings. Kinematically, a four bar linkage mechanism was used to effect the movement of the transplanting finger to the planting tray, to the soil and back.

Agrawal *et al*. (1986) report the development of a six-bar compound linkage mechanism at IIT, Delhi. This was proposed to be used in a self-propelled transplanter. Basu *et al*. (1987) describe the details of the transplanting mechanism developed at CMERI, Durgapur. They have used computer aided design for the development of four-bar mechanism. Similarly, different types of self-propelled transplanters as well as its transplanting mechanism have been developed by various researchers (Anon, 1979; Khan and Gunkel, 1988; Kohli and Agrawal, 1993; Kohli and Agrawal, 1994; Kurup and Datt, 1981; Parida, 1975, Thomas, 2002 and Kumar and Thomas, 2015).

Preparation of Mat Type Seedlings for Use in Mechanical Transplanters

In traditional method of transplanting rice seedlings are uprooted one by one manually. The roots are washed off the soil and bundled in bundles of about 8 cm diameter for transport. In the main field, they are planted in puddled soils. These seedlings are called root washed seedlings. (Anon, 1979 and Kurup and Datt, 1981). Soil bearing seedlings popularly known as mat type seedlings have gained popularity with the introduction of mechanical transplanters.

Automation in Transplanting Machines

Yun, *et al.* (2007) developed solutions for mechanism dynamics. They could eliminate the interference due to reverse driving of the mechanism elements and proposed a dynamic sequence solution. Yun, *et al.* (2011) made use of eccentric gear system in the transplanting mechanism of a high speed transplanter. Jianneng *et al.* (2003) carried out dynamic analysis of high speed transplanters using elliptical gears.

Kaizu and Imou (2008) developed a method to detect rows of rice seedlings in the field. This can be used for automatic navigation of rice transplanters. Weise *et al.* (2000) investigated the relationship between steering angle and turning radius of an autonomous transplanter in field conditions. Nagasaka *et al.* (2004) developed an automatic guidance system for rice transplanter. They found that the maximum value of deviation from a straight line travel was 12 cm with a root-mean-square value of 5.5 cm when travelling at a forward speed of 0.6 m/sec. In their opinion this accuracy is sufficient for transplanting operations. Nagasaka, *et al.* (2007) developed a low-cost guidance system for use with a low cost global positioning system. This was implemented in a rice transplanter model. They also modified the transplanter to carry long mat-type hydroponic rice seedlings. Luo and Zhang (2007) developed a navigation control system. It could determine the position and orientation the machine located in a field. Nagasaka *et al.* (2002) employed real time kinematic global positioning system (RTK GPS) in order to estimate position of transplanter in the field. They used fiber optic gyrosensors to calculate the direction and the inclination of the machine in the field.

Chiu and Fon (2000) developed a system for rolling the seedling mats. Using this system the capacity of the trays increased three fold. Chiu *et al.* (2006) developed an automatic pallet loading system for rice seedling trays.

Performance of Rice Transplanters

Anon. (1983) recommends a procedure for testing of mechanical rice transplanter. Parameters considered important for the evaluation of the performance of a transplanter are given below:

(i) Speed of operation;
(ii) Level of water in the field;
(iii) Puddling Index;
(iv) Distance between hills;
(v) Distance between rows;
(vi) Depth of planting;
(vii) Standing angle of planted seedling;
(viii) Number of seedling per hill; and
(ix) Transplanting faults, namely,
  a. Missed hills, per cent;
  b. Floating seedling hills, per cent;
  c. Buried seedling hills, per cent;
  d. Damaged seedling hills, per cent; and
  e. Successive misplanting.

Many researchers including Swain and Maity (1981), Singh *et al.* (1981), Singh *et al.* (1985), Anon. (1986), Manian *et al.* (1987), Khan and Gunkel (1988) and Verma *et al.* (1989) have used most of the above parameters for evaluating the performance of the transplanter. The UN sponsored Regional Network for Agricultural Machinery has conducted tests on various rice transplanters in different countries. They have also used most of the above parameters for evaluating the performance.

Seedling and Machine Parameters Related to Transplanting

Many factors involved in raising mat type seedlings influence performance of mechanical rice transplanters. Most of the unsuccessful planting operations are caused by the use of inferior and unsuitable seedlings (Anon., 1979). Transplanting accuracy of the transplanter depends on mat characteristics like
(i) Seedling height,
(ii) Plant density, and
(iii) Moisture content of mat.

Other factors affecting transplanting accuracy are machine related parameters.

(i) Seedling height

Garg *et al.* (1982) stated that the mat condition affects performance to a great extent. Seedlings above 25 cm height posed problems in the working of the machine and also sustained damage at the time of transplanting. Seedling height of 25 cm which could be achieved in 20-30 days was found to be most suitable.

With poorly prepared field conditions and inundation of the land, survival of seedlings becomes poor. This can be overcome partly if large size seedlings of higher age are used. This needs modifications in the techniques of raising seedling mat.

(ii) Plant density or number of seedlings/cm²

Dixit *et al.* (2007) suggest that plant population of 2 seedlings/cm² in the mat is good for operation of the transplanter. Behera *et al.* (2007) studied on seedling density. Seedling density of 1.76 No./cm² (corresponding to 70 g seeds/mat), 2.17 No./cm² (90 g/mat) and 2.65 No./cm² (110 g/mat) were tried. Density of mat significantly affected the number of seedlings planted per hill. They found that 110 g/ mat seed rate giving seedling density of 2.65 No./ cm² should be used to obtain 2-3 seedlings per hill in the transplanter they used. Choudhury (1983) stated that the number of seedlings/ hill should be in the range of 3-6.

(iii) Moisture content of mat

Garg *et al.* (1982) reported that mat condition affects performance of transplanters to a great extent. Moisture content was a very critical factor affecting the performance of a transplanter. Higher moisture of seedling mats caused higher mat consumption and greater number of plants per hill. A dry mat, on the other hand, poses considerable resistance while being cut by the fingers causing mechanical failures. Similar observations were also reported by Behera *et al.* (2007).

(iv) Machine parameters

Choudhary and Varshney (2003) studied the influence of machine parameters on performance of 8-row self-propelled rice transplanter in laboratory condition. The experiment was carried out at two operating speeds (1.40 and 1.80 km/h) and three finger lengths (7, 12, 17 mm). They reported that for achieving 2-3 number of seedlings per hill, the density of seedlings in the mat should be between 2.0-3.0, 1.25-2.00 and less than 1.25 seedlings/cm^2 for 7, 12 and 17 mm finger length, respectively. Similar observations were reported by Behera *et al.* (2007).

Problems and Prospects of Development and Adoption of Mechanical Rice Transplanters in India

Main functional part of the transplanter is the picking-cum-planting unit (Choudhury, 1983). Planting finger is the most critical part in the planting unit. It meters the number of seedlings planted per hill. Different types of transplanting fingers are used in the transplanters. Fixed fork type finger is the simplest and most popular. During operation, seedlings are picked up from the tray and held in the fork. When the fork enters the puddled soil, the seedlings are pushed into the soil and the fork is withdrawn. The included area between the forks is calculated on the basis of size of the seedling at its base (Naghavi, 1987). Most transplanters used planar four bar linkage mechanisms with the planting finger forming a coupler point (Singh *et al.*, 1981; Agrawal *et al.*, 1986; Basu *et al.*, 1987; Kohli and Agrawal, 1993; and Thomas, 2002). In the Chinese self-propelled rice transplanter named 'Yanji Shakti' the planting finger executes motion in a loop while travelling through picking and planting points.

Popularity of mechanical rice tranplanter is very low. Various reasons attributed to low popularity are given below:

(i) Raising of mat type seedling is the main constraint for low popularity of rice transplanter. Raising of seedling and transplanting with transplanter requires lot of skill (Singh *et al.*, 1981). Management of the raised nursery is also a difficult task.

(ii) Adoption of mechanical transplanting technique leaving the traditional method requires high initial investment cost in the transplanter, precision leveling of the land and expenditures on plastic sheets and mat frame. Training of operator is also required.

(iii) In India, about 85% farmers are small and marginal having less than 2 ha land (Anon., 2014). Fragmentation of land into smaller plots further limits free movement of the machines.

(iv) Sale and service centre of the mechanical transplanters are in cities at distant places from the farmers field. In case of machine breakdown or problems faced in the field the farm work suffers.

(v) Manual rice transplanters have not been accepted by the Indian farmers for a variety of reasons like complex mechanism, involving complex operation and engagement of both hands, intermittent operation, walking rearwards during operation, difficulty in maintaining hill to hill distance, strenuous operation under adverse environmental condition and unsatisfactory performance.

(vi) In waterlogged area, the existing transplanters are not able to perform satisfactorily.

Mechanical transplanter suitable for India may have to satisfy the following requirements:

(i) The cost of the transplanters are very high for farmers having small area of land. Efforts should be made to develop the machine and make them available at lower cost.

(ii) As farmers shift from the traditional practice of transplanting to mechanical transplanting, the machine should be easy to handle and its performance should not be affected much by the poor puddling conditions and by the undulations of the land.

(iii) Breakdown of the transplanter is very common. The machine used in the field should be robust so that during operation only few problems would occur. Most of the area in India is under rainfed condition. So one should ensure operation of the machine at the time rain is available irrespective of variations in the age of seedlings.

(iv) In the waterlogged area, there may be a suitable provision in the transplanter so that it can operate satisfactorily in that condition also.

(v) The machine should be made such that farmers would be able to operate it with minimum skill.

(vi) Most of the transplanting operation is carried out by women labourers. So, the machine should be easily operated by women as well.

(vii) The transplanter should be easily repaired or fabricated by the local artisan so that in case of breakdown of the machine or some part of it, work may not be hampered.

In mechanical transplanter, the planting fault may be attributed to the following causes:

(i) Missing hills: Missing hill is the major planting fault in a transplanter. About 0-14% missing hills have been observed in a self propelled rice transplanter depending on seedling density on the mat and age of seedlings (Choudhary and Varshney, 2003;

Garg *et al*., 1997; and Manjunatha *et al*., 2009). The number of missing hills may be primary due to non-uniformity of seedling stand in the mat. The non-uniformity of seedlings in a mat was greater at lower seedling density leading to higher number of missing hills. Missing hills may also be due to clogging of seedling gate, improper functioning of tray indexing mechanism and improper adjustment of the transplanting finger.

(ii) Uneven transplanting: Uneven transplanting may be due to uneven seedling indexing mechanism and faulty planting fingers. It has been observed that the transplanting finger cut an area of mat during operation of the machine irrespective of presence or absence of seedlings in the mat. In a different case, a mechanical transplanter showed variation in number of seedling per hill mostly due to entanglement of roots and failure of pawl and ratchet mechanism of the tray indexing unit (Swain and Maity, 1981; and Garg *et al*., 1982).

(iii) Uneven transplanting depth: Uneven transplanting depth is due to undulating field condition, improper adjustment of planting finger with respect to float and improper adjustment of float.

(iv) Too many seedlings picked up per stroke: Too many seedling picked up per stroke may be due to high density of nursery seedlings and due to improper handling of mat during transportation.

(v) Floating of seedlings: Floating of seedlings may be due to hard puddled soil bed, planting finger working too shallow and improper working of the planting finger.

(vi) Bent or lodged seedlings in hills: Bent or lodged seedlings in hills may be due to a planting finger which penetrates too deep into the seedling tray, too much seedlings grown in the mat and due to improper handling of mat during transportation.

(vii) Damaged hills: Damaged hills may be due to improper working of planting finger.

As mentioned above, the planting faults can be reduced to a large extend by improving the transplanting mechanism.

(i) Design of the finger: Shape of opening and area of opening influence the total number of seedlings picked up at a time and the force at which the seedlings are being held in the finger. Included angle between the forks affect the force at which the seedlings are being held. The area between the forks will be the area separated from the seedling mat. Hence, seedling density in the seedling mat and area between the forks of the finger should match. Besides the above two design factors, angle of entry of the fork into the seedling mat and the angle of sharpening of the tip of fork will affect the seedling separation from the mat. Angle of orientation of the finger at the time of planting and the angle of orientation of the finger at the point of picking affect inclination of the seedling with respect to the ground.

(ii) Planting mechanism that drives the finger through required points: In many transplanters, the transplanting finger is driven by a kinematic chain in which the finger is located at a point of extension of the coupler link. Angle of orientation of the finger at the time of picking and at the time of planting are related because of this reason. Hence, these two orientation angles are optimized together in the finger driving mechanism. Design of the mechanism also dictates velocity and acceleration of the finger at these two points. The seedlings are carried by the finger from the point of picking to the point of planting. During this travel, if the finger moves slowly and the force at which the seedlings are held is not strong enough the seedlings may get detached from the finger and fall freely to the ground. This will result in floating seedlings.

(iii) Design of seedling tray indexing mechanism: Seedling tray indexing mechanisms in different transplanters are different. Due to improper matching of tray indexing mechanism with the movement of the transplanting mechanism, there can be transplanting faults. The velocity of the seedling tray indexing motion was required to match with the velocity of the transplanting mechanism in order to reduce the missing hills and uneven planting. Fresh seedlings should be available during each stroke of the planting mechanism. This requires that feed, the distance travelled by tray during a cycle of planting, should be optimum.

Basic factors like width, length, angle and speed of movement are considered in designing a seedling tray indexing mechanism. Movement of the tray per planting cycle is decided by the area of mat taken away by the planting finger. The area taken by the finger depends on the size of the finger.

(iv) Design of seedling pusher: In some transplanters due to improper design of the seedling pusher, the seedlings are not completely removed from the finger and at the same time it does not stand properly in the puddled soil. Design of the pusher body, its mode of operation and the timing of operation would affect the success of the planting operation. By proper synchronization of the movements of the seedling pusher and the finger, the seedlings are pushed at proper time and the planted seedlings placed at its proper posture.

(v) Design of depth adjustment unit: For proper stand of the hills as well as for reducing the number of floating hills, there is a need of maintaining proper planting depth. Uniform planting depth can be obtained by adjusting the planting unit and by adjusting the height of float with respect to the ground.

(vi) Design of driving wheel: The driving wheel of the transplanter should be designed in proper way so that the slippage of the wheel in the puddled field is uniform. Non-uniform slippage will affect the uniformity of the spacing of planted hills. Proper design of diameter of driving wheel, number of lugs, shape of lug, orientation and inclination of lugs on the wheel and width, thickness and height of the lugs play an important role in reduction of the slip in puddled soil.

(vii) Design of power transmission system: Power transmission system also affect the transplanting faults in a rice transplanter. The power transmission for moving the planting arm, movement of the seedling tray indexing unit and the forward speed of the planter should be optimized so that the ratios of velocity of the planting unit, speed of tray movement and the forward speed of the planter for each stroke are constant.

Quality of transplanting can be improved by improvements in the following machine parameters in a rice transplanter:

(i) Area of opening of fork of transplanting finger should match with seedling density of the mat. If seedling density differs for different mats there should be provision for adjustment of area of the fork or provision to replace the entire fork.

(ii) Finger of the transplanting mechanism are designed so that the fork may easily hold required number of seedlings during picking whereas the seedlings should be easily removed during planting of the seedlings.

(iii) Removal of the seedlings from the finger by the pusher should be at proper time. The pusher should separate the seedling when the finger just goes inside the soil. Before entering into the soil or after leaving the soil, if the seedlings were separated, there may be a chance of floating of hills.

(iv) For uniform planting of the seedlings, the ground wheel should be designed properly so that the slippage is almost constant for a particular soil condition. For getting uniform slippage of the machine, the field should also be thoroughly tilled and puddled evenly. By knowing the slippage on the particular soil condition, the plant spacing of the transplanting mechanism can be set.

(v) For proper and even planting of the seedlings, the ratio of forward speed of the transplanter to the velocity of the transplanting unit should be constant. Movement of the seedling tray by the indexing mechanism for each stroke also should be constant.

(vi) For getting uniform depth of transplanting, the planting unit is mounted on the float. By maintaining uniform depth of planting, occurrence of floating hills and improper posture of seedlings can be reduced.

Limitations of Transplanting Mechanisms

(i) Mechanisms of transplanters are either four-bar mechanisms or compound chain mechanisms with six links. They cannot be designed directly and a procedure of combined analysis and synthesis is followed. Thus, it becomes almost impossible to achieve a unique solution.

(ii) Many mechanisms developed by the research workers were analyzed for the path of motion of finger. Some workers have also analyzed for velocities. However, acceleration analysis is reported rarely. In fact high magnitudes of acceleration can lead to vibration in a transplanter and make it inoperable. It is known that the APAU model power tiller mounted transplanter suffered from vibration due to acceleration effects during field trials.

(iii) In mechanical transplanters, the finger follows a return path different from the path of planting in order to ensure that the fingers do not disturb the seedlings packed in tray by pushing them upwards. Even though this can be achieved by suitable mechanisms, this requirement demands adopting linkages giving specific paths leading to high variations in velocity and high accelerations.

(iv) Also the seedlings that are planted in a hill should be anchored properly. Otherwise they can be left floating after the planting operation. This also may require envisaging some design requirements. Many researchers have analyzed the path of finger near the planting region. A seedling pusher mechanism was added to the planting mechanism developed at CMERI, Durgapur.

(v) Controlling the number of seedlings is achieved mainly by maintaining the size of finger opening. There is no provision to adjust the size of opening in order to maintain same number of seedlings irrespective of variations in size of individual seedlings. Seedling size can vary with various factors as age of seedling, growing conditions and crop variety.

(vi) All mechanisms used so far work well if availability of seedlings is ensured at the time of picking. This also seems to be one of the main reasons for adopting mat type seedlings. If proper mechanisms are available which can pick the desired number of seedlings irrespective of variations in seedling stand density in the tray, the performance would have been better. Alternatively, a seedling feed system may be augmented in the machine in order to assist the picking operations.

(vii) No mechanism has been successful for continuous planting of conventional root-washed seedlings. Had this been achieved, it would have been easier to introduce these machines in India without too much change in their mind set of farmers.

Conclusions

A transplanter suitable for the cropping practices prevalent in India needs to be developed in order to overcome bottlenecks in the mechanization of rice cultivation. This is a very tedious work requiring suitable research inputs. Alternatively, changing the cultivation practice so as to accommodate operations with currently available machines is also being tried out as done in Japan and some other industrialized countries.

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Development and Evaluation of Low Pressure Multi Briquetting Machine

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Abstract

A hand operated low pressure biomass multi briquetting machine was developed and evaluated which works on screw press mechanism for rural development. The developed system mainly consists of multi square moulds, multi circular moulds, single circular mould pressing plates, base plate, supporting stand and steering wheel. Rice husk, tamarind kernels, groundnut shells, and sawdust were used as raw materials along with cow dung and tamarind powder as binding material for preparation of briquettes. The developed machine was tested with various combinations of agricultural residues and developed various combinations and proportions of raw material briquettes and studied the thermal and physical properties of developed briquettes. The developed machine is low cost and simple in operation and able to produce sixty briquettes per hour.

Keywords: Screw Mechanism, Briquettes, Bio- waste, Rural development

Introduction

The need for alternative sources of energy has been a sensitive issue for the past years. In India, the harnessing and utilization of renewable energy has been a significant part of the government's strategy to supply the energy needs of the country. To minimize the dependence on imported fuel and to solve problems on energy shortage, considerable efforts have been made to utilize the country's available resources. The use of the several forms of renewable energy such as the geothermal, wind, and solar are studied and researched upon to maximize the benefits that can be harnessed for the country. Briquetting of biomass is a booming alternative energy source found in rural areas. Biomass fulfills 90% of the rural energy and 40% of urban energy needs. In India Agricultural & Horticultural activity generates annually about 500-600 million tons of agricultural waste. The major residues are rice husk, coffee husk, coir pith, jute sticks, Bagasse, tree leaves, groundnut shells, saw dust, mustard stalks and cotton stalks etc.

As discussed by Cheremisinoff *et al*. (1980), biomass is essentially a plant material, ranging from algae to wood, in form. However, agricultural residues such as manures, straws, cornstalks, and other by-farming products, are considered to be one of the chief sources of biomass for energy production. The energy content of biomass is relatively uniform, on the order of 9000 Btu/lb (20,890.188 kJ/kg), which is roughly half to two-thirds of coal's heating value. Moreover, there are major advantages of biomass as fuel which are as follows: biomass contains negligible sulfur, generates little ash, and most importantly, is continually renewable. These advantages make it more appropriate to use biomasses as fuel.

Akubuo O. F. and Okonkwo C. O. (2013), stated that, the briquetting machine is of great importance to poor and developing countries as it addresses the issues surrounding the efficient utilization of abundant quantities of agricultural wastes and residues which provide an enormous untapped fuel resource. Amanor and Nartey I. (2014) suggested that, the manual biomass briquetting machine suitable for the production of biomass briquettes on a small scale with a production capacity of 488 kg/h was designed and constructed and used in the production of biomass briquette using carbonized jatropha husk. Grover *et al*., (1996), categorized the briquetting technologies on the basis of compaction into high pressure compaction, medium pressure compaction with a heating device and low pressure compaction with a binder. Ivan P. Ivanov *et al*., (2003), suggested that the content of biological binder in the charge should be about 10% in order to obtain the briquettes of satisfactory quality.

As the number of industries is growing day by day, the energy required is also increasing proportionately and the present power supply is unable to meet the energy demand. To combat this energy shortages developed as well as developing countries are keeping more efforts on R&D to tap alternative energy sources. As discussed by Maglaya andBiona (2010), briquetting increases the homogeneity of the mixture, allowing a more uniform and controlled combustion performance.

Biomass densification represents a set of technologies for the conversion of biomass into a fuel. The technology is also known as briquetting and it improves the handling characteristics of the materials for transportation, storage etc. This technology can help in expanding the use of biomass in energy production, since densification improves the volumetric calorific value of a fuel, reduces the cost of transport and can help in improving the fuel situation in rural areas.

Keeping in view, the advantages of the briquetted fuels in developing countries like India, where in many poor households, there is an acute shortage of fuel for domestic purposes and at the same time there is big demand for the conventional energy sources such as LPG for domestic consumption, many alternate sources of energy production are being explored. Briquetting technologies have always been on large scale with high capacity machinery producing briquettes at high temperature and pressure. Though they are eco-friendly in nature, they could not cater to the needs of poor rural households and also could not generate employment opportunities for the rural poor.

There is need for low pressure manually operated technologies in briquetting that can help the rural households to meet their domestic energy needs without harming the environment. There is also need for generating employment opportunities for the rural people using these types of renewable energy technologies. The existing technologies have many technical and managerial problems. A low cost, small capacity, low pressure, manually operated briquetting machine is needed to sustain lives of the rural poor.

Variation of the parameters such as temperature and pressure, affects the performance of the briquettes produced. Along with that, the amount of the binding agent used in the production can also be a factor that affects the performance of the briquettes (Kaliyan& Morey, 2009). Most of the developed hand operated briquetting machines are able to produce a single briquette in pass; it may cause more drudgery of the operator and need more time. After going through many developments that took place in this direction and from the review of literature and research on the biomass briquetting, an attempt was made to develop a hand operated low pressure biomass briquetting machine

Materials and Methods

A hand operated low pressure biomass briquetting machine was developed and evaluated at College of Agricultural Engineering, Madakasira, which is based on screw press mechanism. The developed system mainly consists of multi square moulds, multi circular moulds, single circular mould pressing plates, base plate, supporting stand and steering wheel. A screw is a mechanism that converts rotational motion to linear motion, and a torque (rotational force) to a linear force. The screw passes through a hole in another object or medium, with threads on the inside of the hole that mesh with the screw's threads. When the shaft of the screw is rotated relative to the stationary threads; the screw moves along its axis relative to the medium surrounding it. The screw shaft can be driven by a handle or a wheel. It works by using a coarse screw to convert the rotation of the handle or drive-wheel into a small downward movement of greater force. The screw rod carries a steering wheel at the upper end whereas the lower end holds thick rectangular metal plate. The top of rectangular thick plate consists of a bearing in which the journal is fixed to the lower end of the screw shaft by nut and bolt and fixed body of the bearing was welded to the metal plate so that the rotary motion of steering wheel could be converted to linear motion of the thick plate. The bottom of rectangular thick plate consists of six number of iron rods welded to the plate at varies places by matching the alignment of individual briquette mould to act as pistons. In this study two thick rectangular plates with iron rods were used. At the end of iron rods, various thick plates of uniform matching sizes to the specific mould of square and circular metal pieces were welded to press the biomass slurry inside the selected briquette mould as shown in **Fig. 1a** and the CAD view of the developed system is shown in **Fig. 1b**. When the screw is rotated with the steering wheel, the linear motion of the rectangular thick metal plate with iron rods compresses the biomass in the mould into briquettes against a base plate and briquettes can be ejected by means of a simple rotation of steering wheel, hence the rectangular plate with pistons by push the briquettes out. For briquettes ejections, the base plate must be pulled to one side.

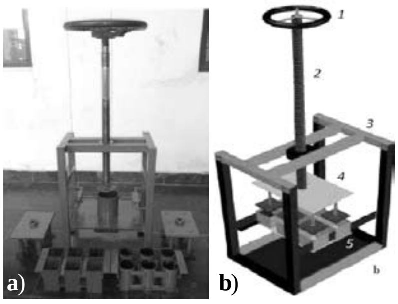


Fig. 1 a) A view of developed hand operated briquetting machine, **b)** CAD view of briquetting machine: 1. Steering wheel, 2. Screw rod, 3. Frame, 4. Pressing plates and 5. Moulds

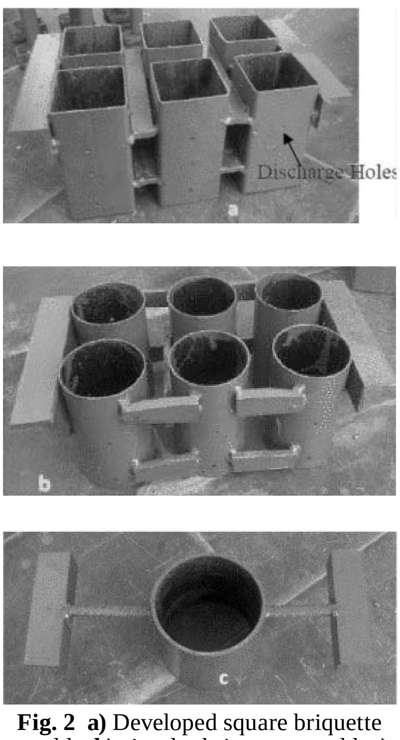


Fig. 2 a) Developed square briquette moulds, **b)** circular briquette mould, **c)** Single briquette mould

Briquette Moulds

These are required to hold the biomass slurry and to act as cylinder during biomass pressing. The iron rods (pistons) which are welded to the rectangular iron thick metal plate at lower end of the screw shaft enters inside the cylinder and press the biomass against the base plate. In this study three types of moulds namely square (70 × 70 × 120 mm), circular cross sections (70 mm Ø with depth of 120) and single circular cross section (105 mm inner diameter, 110 mm outer diameter with 120 mm depth) mould were developed to produce six briquettes during each operation as shown in **Fig. 2 a**, **b** & **c** respectively.

Development of Pressing Plate with Pistons

These are made up of mild steel with six square plates welded to the rectangular thick metal plate pistons which were fitted to the lower end of screw shaft. The dimensions of the single square plate are 280 mm length, 180 mm width and 10 mm thickness which could be fitted to the extreme end of the piston for square mould. Each of the square plate is having dimensions of 65 × 65 × 10 mm as shown in **Fig. 3a** and the dimensions of the circular single plate having the diameter of 5 cm with 10 mm thickness which could welded to the extreme end of piston for circular mould is shown in **Fig. 3 b**.

Biomass Briquettes Development

Raw materials used

The following raw materials were used in different proportions to develop the briquettes. The raw materials were mixed in different proportions and tested as three trials as follows:

a) Rice husk:

Rice husk is the hard and protective shell covering over the rice kernel (*Oryza Sativa*) shown in **Fig. 4a**. For every tone of polished rice, 280 to 300 kg of rice husk is produced.

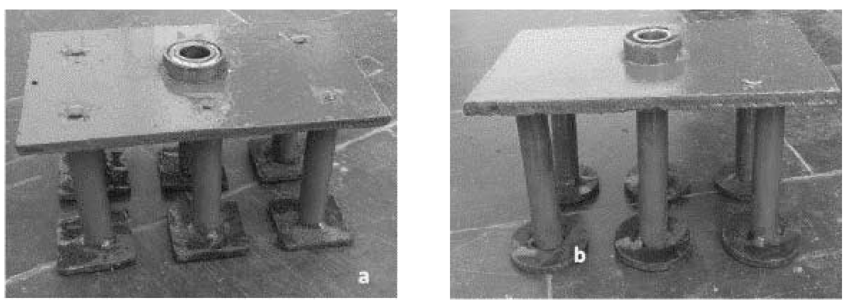


Fig. 3 a) Developed square mould pressing plates, **b)** Developed circular mould pressing plate

It has medium calorific value and high ash content. The calorific value of the rice husk as a raw material is about 3,000 Kcal/kg.

b) Saw dust:

Saw dust is composed of fine particles of wood as shown in **Fig. 4b**. This material is produced from cutting with a saw, hence its name. The particle size ranges from 0.3-0. 6 mm. The calorific value of the saw dust as a raw material is about 3,600 Kcal/kg.

c) Tamarind kernel:

Tamarind kernel is the upper layer of the tamarind seed which is the by-product of tamarind seed (*Tamrindus indica* L.) shown in **Fig. 4c**. These are obtained at tamarind mills

d) Ground Nut shell:

Groundnut (*Arachis hypogaea*) shell shown in **Fig. 4d** is residue left after the removal of the kernel from the pod. It is commonly used as boiler fuel mostly in oil extraction mills. The bulk density is around 100 kg/m^3. On an average one tonne of pods yield about 330 kg of shell. Its ash content is low.

Proportions of raw materials used

The following raw material proportions were used to find the best combination of briquettes.

Trail-1:

C-1: rice husks (100 gm) + saw dust (1 kg) + tamarind kernel powder (200 gm) + dung (1 kg) + water (1/2 lit)

C-2: tamarind kernel (1 kg) + dung (300 gm) + saw dust (300 gm) + water (2 lit)

C-3: Groundnut shell (250 gm) + dung (1 kg) + tamarind kernel powder (250 gm) + Water (1 lit)

Trail-2:

C-1: rice husk (200 gm) + tamarind kernel powder (500 gm) + dung (1.5 kg) + saw dust(1 kg)

C-2: tamarind kernel (1 and 1/2 kg) + cow dung (500 gm) + saw dust (300 gm) + water(1 and 1/2 lit)

C-3: groundnut shell (400 gm) + tamarind kernel powder (500 gm) + dung (1 kg) + water (2 lit)

Trail-3:

C-1: rice husk (200 gm) + tamarind kernel powder (500 gm) + dung (2 kg) + saw dust (1 kg)

C-2: tamarind kernel (1 and 1/2 kg) + cow dung (750 gm) + saw dust (300 gm) + water (1 and 1/2 lit)

C-3: groundnut shell (400 gm) + tamarind kernel powder (500 gm) + dung (1 and 1/2 kg) + water (2 lit)

Preparation of Raw Material for Briquettes

Before development of briquettes, the raw materials were soaked in water for 12 h for easy binding and mixed the recommended proportions of biomass slurry. After mixing the raw material with different proportions the slurry was filled into the respective selected moulds as shown in **Fig. 5**.

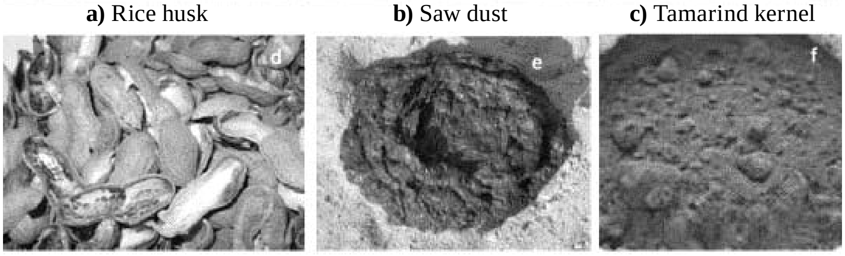
Briquettes Development

After feeding the slurry into the selected moulds, the filled device were placed on the base plate of the machine and the loaded material was compacted with the help of pistons by rotating the steering wheel of screw shaft. Pistons are attached metal plates as discussed above. Plate is connected to screw shaft by nut and bolt arrangement. Pistons got linear motion by rotating the screw with the steering wheel. When steering wheel rotates clockwise direction pistons press the respective briquettes as it got linear motion. The air and water inside the biomass slurry comes out from the holes made on the respective briquette holder. The briquettes under production are shown in **Fig. 6**.

Ejection stage of formed briquettes

After pressing, remove the base plate by rotating the steering wheel

a) Rice husk **b)** Saw dust **c)** Tamarind kernel



d) Groundnut shell **e)** Cow dung **f)** Tamarind kernel powder

Fig. 4 Various raw materials used for the development of briquettes

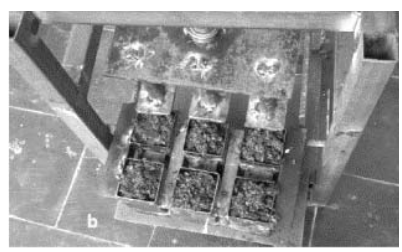


Fig. 5 Loading of slurry in to the developed moulds: **a)** Slurry in circular mould, **b)** Slurry in square mould

in anticlockwise direction and pulling out by a handle. Keep the collection tray just below the base plate position and again rotate the steering wheel in clockwise direction, so that the formed briquettes comes out from the individual briquette mould and dropped on collection tray as shown in **Fig. 7 a** & **b**. The ejection stage of square briquettes from square mould and the circular mould and also the circular single briquettes are shown in **Fig. 7 c** & **d**. After collecting the formed briquettes from the machine, the briquettes were dried either by sun or oven drying to keep the more storage life and kill the fungus inside the biomass slurry.

Analysis of Physical and Thermal Properties of Briquettes

Determination of bulk density

For determining the bulk density of raw materials, a box of 70 × 70 × 120 mm dimensions was used. The density was determined by filling the box with raw material and measured the weight. The bulk density of the briquettes was determined by dividing the mass of the briquettes to their volume.

Bulk density (kg/m³) = Mass of briquette / volume of briquette

Determination of resistance to water penetration:

For measurement of the percentage of water absorbed by a briquette when immersed in water was determined to identify the storage life. Each briquette was immersed in 500 ml of water at room temperature for 35 seconds. The percent gain of water was then calculated and recorded.

Water gained by briquette (%) = $(W_1 - W_2) / W_1 \times 100$

Resistance to water penetration (%) = 100 - water gain

Where, W_1 = Initial weight of briquette, W_2 = final weight of briquette.

Determination of moisture content:

The moisture content of the briquettes with different raw materials was determined by oven dry method. About two samples were selected from each composition of the raw material and measured the initial weight (W_1).Then the selected briquettes were kept in hot air oven for 24 h with temperature of 105 ±1°. After 24 hrs the briquettes are allowed to cool down for 5 min. The final weights were measured and noted. The moisture content (MC) on dry basis (d.b.) was calculated by using the following equation.

MC% (d.b.) = $[\{(W_1) - (W_2)\} / (W_2)] \times 100$

Where, W_1 = weight of briquette before oven-drying, g, W_2 = weight of briquette after oven-drying, g

Determination of shatter resistance:

After drying of the briquettes during transportation, the weight of briquettes may reduce, hence the shattering resistances of developed briquettes were measured. Each briquette was subjected to ten repeated drops from a half meter distance on a concrete surface. Initial weight of selected briquettes were measured and noted as W_1. After dropping from a specific distance, the final weight of briquette was measured, and then the percent loss was then calculated by using the following formula.

Percent weight loss (%) = $\{(W_1 - W_2) / W_1\} \times 100$

Shatter resistance (%) = 100 - % weight loss

Where, W_1 = weight of briquette before shattering, g, W_2 = weight of briquette after shattering, g

Determination of compression ratio:

Compression ratio of briquettes of different combinations of raw material was determined as the ratio of density of briquette to the density of the raw material.

Compression ratio = density of briquette / density of raw material

Combustion studies of developed briquettes:

The combustion studies were carried out under room temperature to know the quality of briquette. For combustion studies a chulha is constructed by arranging the bricks on

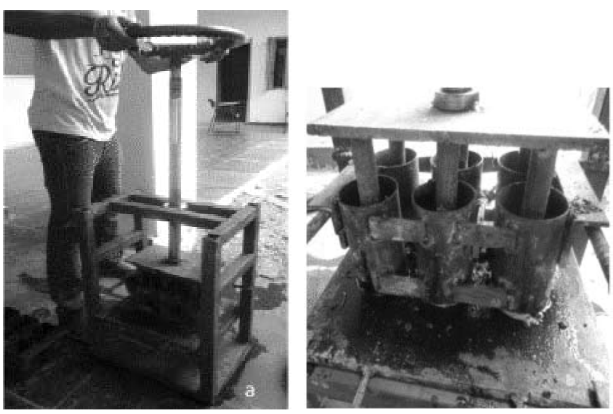


Fig.6 Production of briquettes with developed machine along with square mould: **a)** Pressing of briquettes, **b)** A view of pistons inside the respective circular mould

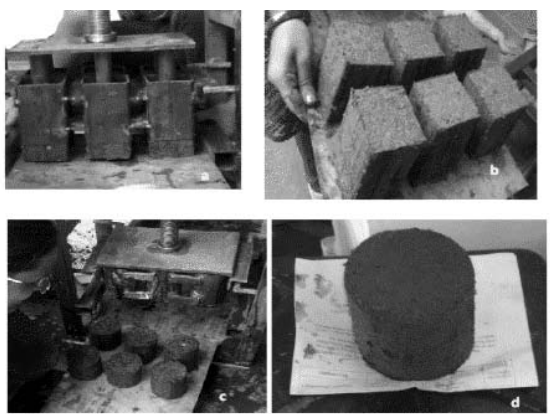


Fig. 7 a) Ejection stage of formed square briquettes, **b)** After ejection stage of formed briquettes, **c)** Ejection stage of circular briquettes, **d)** Single briquette after ejection three sides and fourth side as open to keep the fuel. A bowl having water up to 500 ml was taken and placed on the constructed chulha. Initially the temperature of water was measured by using infrared thermometer as shown in **Fig. 8 a** & **b**. For testing the burning capacity of developed briquettes, three briquettes were considered from each of the combination and placed inside the chulha. For initial burning agent, an amount of 10 ml petrol was chosen and poured on the placed briquettes. For every five minutes, the raised temperature of briquettes (fire) and water was measured and noted down by infrared thermometer as shown in **Fig. 8 a** & **b**. Also the Time taken reach the boiling point temperature is measured by using infra-red thermometer, Measure the time taken to burn the fuel completely and finally the water evaporated after complete burning of the fuel was determined by deducting the water retained after complete combustion of fuel from the initial amount of water taken.

Results and Discussion

The developed machine was tested with different raw materials (rice husk, groundnut shell, tamarind kernel and saw dust) and binding materials with different combinations. It was observed that, the tamarind proved to be the best raw material and its powder also good binding materials. Rice husk due to its roughness and abrasive nature, found difficulty in binding with other materials. The production capacity of the developed machine was determined and found to be 48 briquettes per hour. It requires two persons to operate the machine. The detailed performance results of briquettes are given bellow.

Bulk Densities of Briquettes in Various Combinations of Raw Material

After production of briquettes with different combinations of the raw materials, the bulk density was measured. The bulk density values of circular briquettes in first combination is 382.7 kg/m^3, 401.5 kg/m^3 and 391.7 kg/m^3 in all the trails respectively, whereas for square briquettes, the bulk density values are 398.7 kg/m^3 410.5 kg/m^3 and 401.7 kg/m^3 in all the trails respectively. The bulk density values of circular briquettes in second combination is 483.04 kg/m^3, 492.7 kg/m^3 and 474 kg/m^3 in all the trails respectively, whereas for square briquettes, the bulk density values are 475.5 kg/m^3 487.4 kg/m^3 and 465.9 kg/m^3 in all the trails respectively. The bulk density values of circular briquettes in third combination is 391.8 kg/m^3, 397.8 kg/m^3 and 407.4 kg/m^3 in all the trails respectively, whereas for square briquettes, the bulk density values are 397.4 kg/m^3 402.5 kg/m^3 and 419.7 kg/m^3 in all the trails respectively.

Fig. 8 Boiling of water by burning developed briquettes **a)** Burning of briquettes, **b)** Measuring temperature using infra-red thermometer

The bulk density value for second combination (tamarind kernel (1 kg) + dung (300 gm) + saw dust (300 gm) + water lit) are found to compared to other combination. The comparison of bulk densities in all the combination in all the trails were presented in **Fig. 9 a** & **b**.

It was also observed that, the bulk density values are high in case of square briquettes as compared to circular briquettes in all the combination in all the trails due to more weight and volume ccopancy as compared to circular briquettes. It also indicates that substantial space could be saved in storage of briquettes and transport with this combination with square briquettes.

Moisture Content

The moisture content of developed briquettes after immediate development was measured as discussed above to know the burning capacity by initial and final weight (dried briquette weight). The moisture content of second combination in all the trails was found to be less. The moisture content values of circular briquettes in first combination is 35.7 (%), 38.25 (%) and 37 (%) in all the trails respectively, whereas for square briquettes, the moisture content values are 60.4 (%), 53.2 (%) and 68.8 (%) in all the trails respectively. The moisture content values of circular briquettes in second combination is 30.5 (%), 32 (%) and 28 (%) in all the trails respectively, whereas for square briquettes, the moisture content values are 56.7 (%), 50.2 (%) and 63 (%) in all the trails respectively. The moisture content values of circular briquettes in third combination is 37.25 (%), 45.67 (%) and 43.23 (%) in all the trails respectively, whereas for square briquettes, the moisture content values are 59.7 (%), 56 (%) and 65.2 (%) in all the trails respectively. It also observed that, for circular briquettes as compared to square briquettes shows that less moisture content and also absorb less moisture from the atmosphere during storage and transportation.

Shatter Resistance (%)

Tests were conducted for determining the hardness of the developed briquettes as discussed above. Randomly selected briquette of known weight and length was dropped from the height about half meter on concrete floor for ten times. The weight of disintegrated briquette and its size was noted. The percent loss of material was calculated.

The shatter resistance values of circular briquettes in first combination is 66.3 (%), 67.38 (%) and 68.2 (%) in all the trails respectively, whereas for square briquettes, the shatter resistance values are 40.4 (%), 42.4 (%) and 41.7 (%) in all the trails respectively. The shatter resistance values of circular briquettes in second combination is 83.1 (%), 84.4 (%) and 87.1 (%) in all the trails respectively, where as for square briquettes, the shatter resistance values are 40.5 (%), 45.2 (%) and 46.1 (%) in all the trails respectively. The shatter resistance values of circular briquettes in third combination is 58.6 (%), 59.5 (%) and 56.4 (%) in all the trails respectively, whereas for square briquettes, the shatter resistance values are 41 (%), 42 (%) and 48.1 (%) in all the trails respectively.

The shatter resistance values for second combination (tamarind kernel (1 kg) + dung (300 gm + saw dust (300 gm) + water (1 lit)) was found to be high. It indicates that the tamarind has more hardness due to high shattering resistance enables the briquettes to stay in original shape even when handled roughly without care. The comparison of shatter resistance in all the combination in all the trails were presented in **Fig. 10 a** & **b**.

Resistance to Water Penetration (%)

It is measure of percentage water absorbed by a briquette when immersed in water to estimate the resistance water absorbance from the atmosphere as discussed above. The water penetration values of circular briquettes in first combination is 62.13 (%), 69.25 (%) and 65.22 (%) for circular briquettes in all the trails respectively, whereas for square briquettes, the water penetration values are 58.2 (%), 60.4 (%) and 58.4 (%) in all the trails respectively. The water penetration values of circular briquettes in second combination is 75.15 (%), 78.1 (%) and 76.9 (%) for circular briquettes in all the trails respectively, whereas for square briquettes, the water penetration values are 71.15 (%), 75.12 (%) and 72.7 (%) in all the trails respectively. The water penetration values of circular briquettes in third combination is 58.9 (%), 56.4 (%) and 51.3 (%) for circular briquettes in all the trails respectively, whereas for square briquettes, the water penetration values are 56 (%), 51.7 (%) and 52.3 (%) in all the trails respectively.

It was observed that combination-2(C-2) have high resistance to water penetration. The high resistance to water penetration makes the briquettes less prone to water absorption when stored in open places that

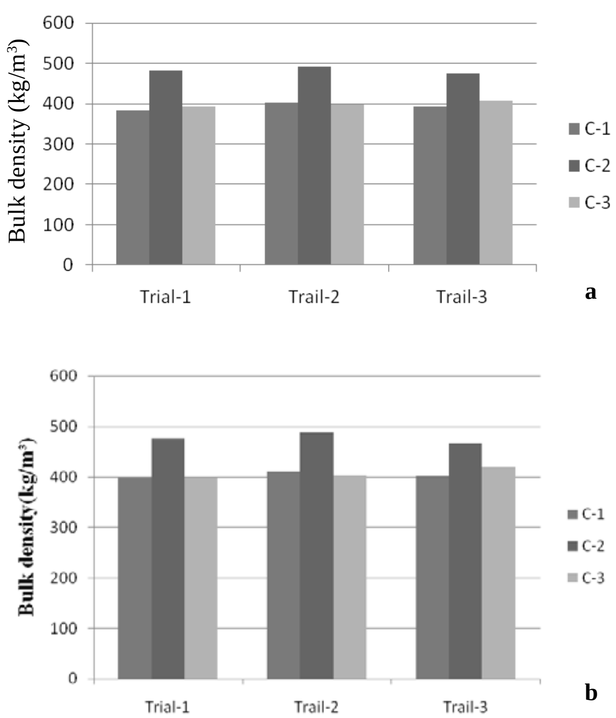


Fig. 9 Comparision of bulk densitity in three combinations of raw material in three trails:
a) Circular briruettes, **b)** Square briqeuttes

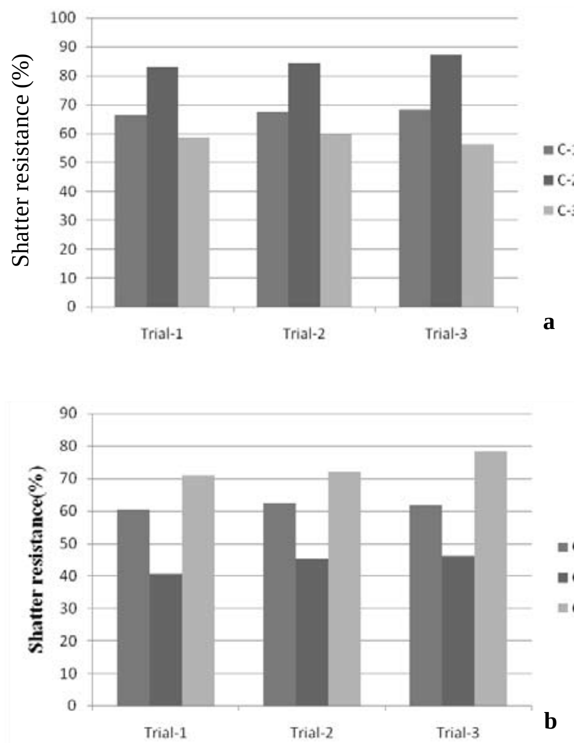


Fig. 10 Comparision of Shatter Resistance in three combinations of raw material in three trails:
a) Circular briquettes, **b)** Square briquettes

retains the calorific values for long time. The comparison of moisture penetration in all the combination in all the trails were presented in **Fig. 11 a** & **b**.

Compression Ratio (%)

Compression ratio was determined as the ratio of density of briquette to the density of the raw material to identify the compression and binding of the raw material. The compression ratio values of circular briquettes in first combination is 77.3 (%), 72.5 (%) and 76.5 (%) for circular briquettes in all the trails respectively, whereas for square briquettes, the compression ratio values are 72.5 (%), 69 (%) and 73.5 (%) in all the trails respectively. The compression ratio values of circular briquettes in second combination is 97.5 (%), 92.7 (%) and 93.5 (%) for circular briquettes in all the trails respectively, whereas for square briquettes, the compression ratio values are 93.5 (%), 89.5 (%) and 91.7 (%) in all the trails respectively. The compression ratio values of circular briquettes in third combination is 50.6 (%), 54.9 (%) and 58.4 (%) for circular briquettes in all the trails respectively, whereas for square briquettes, the compression ratio values are 64.5 (%), 68.7 (%) and 69.4 (%) in all the trails respectively. The comparison of compression ratio in all the combination in all the trails were presented in **Fig. 12 a** & **b**. It was observed that the compression ratio values for combination-2 are high. It also observed that, for circular briquettes as compared to square briquettes more or less equal.

Combustion Studies

The combustion studies were carried out under room temperature to know the burning qualities of developed briquettes in all the combinations in all the trails. It was observed that, the temperature of fire as well as water has been increasing from starting to the test to the ending of the test. It also observed that, the temperature of fire and water from starting to ending with the first combination circular briquettes was varied from initial to 157°C and 34°C -82.5°C whereas for square briquettes initial to 152°C and 34°C -84°C. The comparison of burning characteristics of first combination are presented in **Fig. 13 a** & **b**.

The temperature of fire and water from starting to end with the second combination circular briquettes was varied from initial to 158°C and 34°C -94.5°C whereas for square briquettes initial to 152°C and 34°C -94°C whereas the temperature of fire and water from starting to ending with the third combination circular briquettes was varied from initial to 150°C and 34°C -89.5°C whereas for square briquettes initial to 152°C and 34°C-90°C. Compared to the above all combinations the second combination (tamarind kernel (1 kg) + dung (300 gm)) will gives the better burning efficiency with effectively but initially catching of fire is slow compared to all combinations.

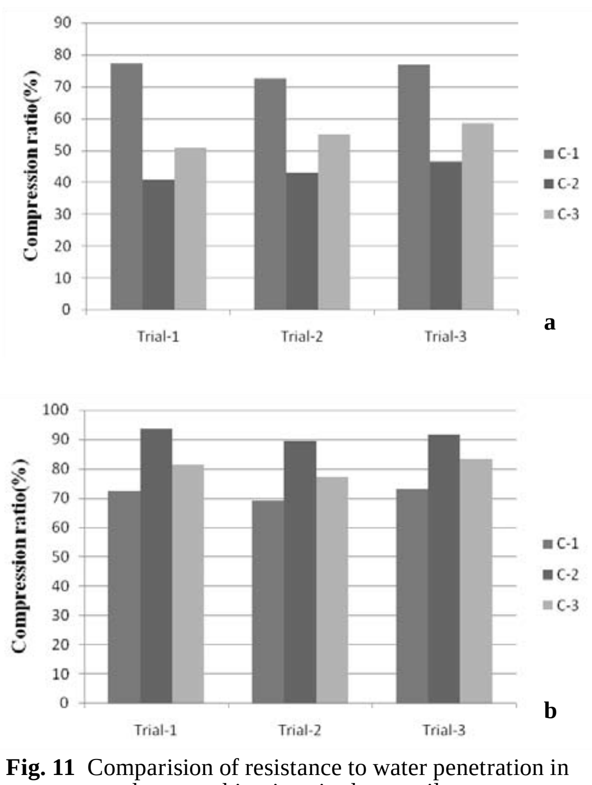


Fig. 11 Comparision of resistance to water penetration in three combinations in three trails
a) Circular briquettes, **b)** Square briquettes

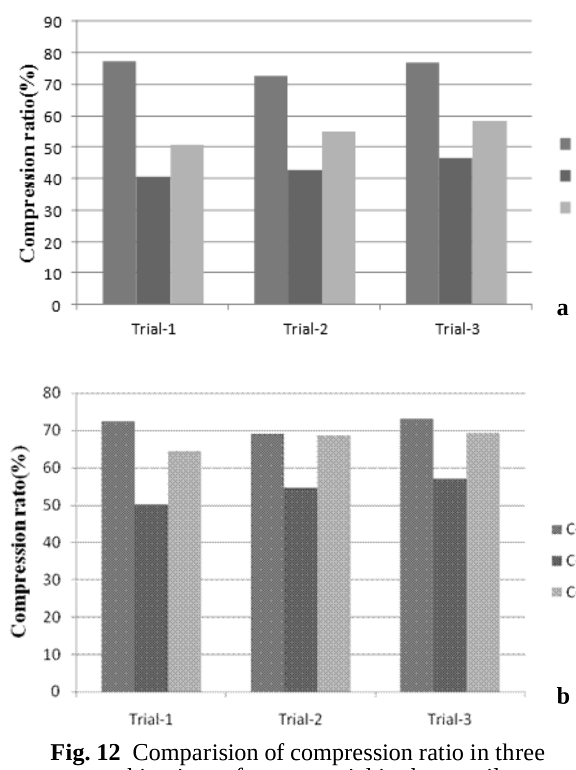


Fig. 12 Comparision of compression ratio in three combinations of raw material in three trails
a) Circular briquettes, **b)** Square briquettes

Conclusions

From the above obtained results, the following conclusions were drawn.

1. A low pressure biomass briquetting machine which can produce multi briquettes at a time using locally available raw material was developed.
2. Briquette with higher durability was produced using the constructed briquetting machine.
3. The developed machine was tested with various combinations of agricultural residues with different proportions of raw material and binder levels.
4. It is hoped that this produced manually operated briquetting machine will be useful to small and medium scale briquette manufacturers.
5. The machine had a capacity of 60 briquettes per hour and it required two persons to operate the machine.
6. The briquettes had higher calorific value than the raw biomass.
7. Use of the briquettes in local domestic stove with grate was found to be satisfactory.

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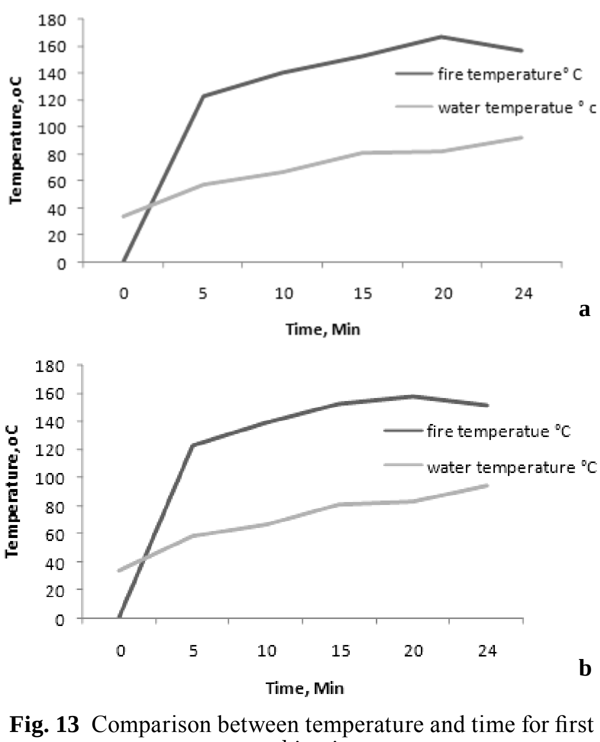

Fig. 13 Comparison between temperature and time for first combination
a) Circular shape briquettes, **b)** Square shape briquettesa

A Laboratory Study of the Pneumatic Sowing Device for Dotted and Combined Crops

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Abstract

Discussed issues combined sowing of two crops. The amendments confirmed patents, existing pneumatic sowing machines, it became possible to create a new sample device, which is able to sow seeds in different sowing method, both combined and dotted. This article describes the work of the pneumatic sowing unit and the results of the laboratory tests.

Key words: apparatus, seeding, disc, seeder, seeds.

Introduction

At joint cultivation of cereals and leguminous plants for green mass turns out more rich in protein, while significantly reducing costs are placed to receive it compared with separate farming of cereals and legumes and their subsequent mixing. In addition, at joint cultivation, legumes have a positive effect on the yield of cereals, while cereals serve as a support for beans, the stems are withered. Such joint crops, even in wet weather, almost no creep and a good cleaning [1, 2].

In our country widely used combines are for such crops as vetch + oats, soy + corn, peas + oats, peas + corn, broad beans + corn, etc. Important condition of their joint cultivation includes proper selection of mixture components in terms of ripening or harvest ripeness. It is also important the ratio of cereal and legume components in the AGRsi: the best is equal to their ratio. A mixture of annual plants would well choke the weeds. These compounds do not require additional care, their clean for green forage at the end of flowering, and on the silage after the formation of beans.

To conduct combined crops using pneumatic drills, but they are not able to fully perform the tasks, namely the seeding method combined in one row by placing them at different depths [3].

Materials and Methods

Known planter with pneumatic sowing devices, which has a number of disadvantages: [4]

a) sowing machines do not provide for intercropping with observance of the step of seeding in the required sequence;
b) does not ensure the placement of seeds of two crops at different planting depth.

Fig. 1 presents sections of the seeders created us for combined sowing of two crops.

Our task was to create a planter with pneumatic sowing devices allowing you to sown as dotted and combined way,—the two cultures at the same time in one row with respect of the schemes of sowing, while not complicating, and simplifying construction (**Fig. 2**)

We have developed pneumatic sowing device for dotted and combined crops includes seed hopper 1, is divided by a partition 2, on axis 3, is mounted a seed disc 4 is divided into two parts along the axis of the conical cell 5, the air nozzle 6, the drive part 4 is connected externally to each other, and the gap between the inner sides of the open half-cells 5 and side walls 7 of the apparatus, not exceeding 3 mm, one part of the disc 4 rigidly mounted on the dowel, and the second in the form of a rim attached to its upper half by screws 8, with the possibility of displacement around the horizontal axis [5].

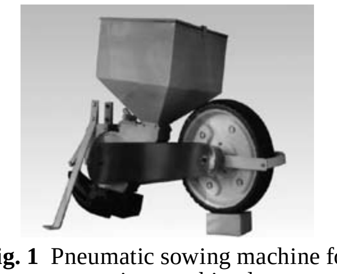
Fig. 1 Pneumatic sowing machine for sowing combined

While sowing the seeds of two cultures, of two parts of the seed hopper is divided by a partition, by gravity fall into the conical through-cell seed disc is divided into two parts along the axis of the conical cells. Rotating sowing disc brings the conical cell, filled with seeds, to the air nozzle which is the output, is divided into two branch pipes; their air flow is directed to the seeds that fell in the conical cells of the relevant parts of a seed disc. The air flow pushes one seed to the bottom of the end-to-end conical cell, and the other blows out.

The sowing disk, revolving on an axis, stuck in a cell with seed meets seed ejector, located on the inner surface of each of the disc under a tapered cells. The ejector stuck seeds then seeds are removed from the cell and sent to the bottom of the furrow opened by the Coulter.

It was established experimentally that the implementation of the circumference of the cells forms an ellipse with the increase in its size and in this location a large circle perpendicular to the direction of rotation a seed disc, leads to a reliable filling of the cells of the seeds, without reducing the number of cells on the disk that is needed when dividing the disk into two parts. The choice of the value of the gap between the disc parts and the side walls not more than 3 mm due to the fact that in the case of increasing this value, small seeds can pass through the holes, which is unacceptable [6].

When switching on the dotted sowing is sufficient to connect the two separated parts, turning them into one seed disc. This sowing machine allows to move from the dotted sowing combined on and Vice versa—simply and without additional disks (**Fig. 3**).

Were conducted laboratory studies of the device, during which special attention was paid to longitudinal uniformity of seed distribution in row on the fast modes corresponding to the translational speed of the drill to 10 km/h. the quality of seed used corn and soy. It was necessary to identify the patterns of change of the distance between the sown seeds of both cultures and to compare the nature of their variation. This should set the size of the sample, the average value of which with a given accuracy would characterize the survey population.

The variability of longitudinal uniformity of seed distribution in the row, was evaluated by the coefficient of variation V (15%). Given the experience of error P = 4% and a high probability of the result (d = 0.99), set the required number of measurements n, wherein the confidence level corresponds to the confidence score K = 2.58 and concluded that the distribution of intervals between seeds is considered sufficiently reliable. The number of measured intervals between seeds was taken to be 100. The coefficients of variation V, average error m, error of experience P, average interval $\bar{X}$, standard deviation and the actual value of the interval distribution X^2F by the criterion of least squares was determined by the known formulas [7].

The number of degrees of freedom when partitioning the sample into 8 classes amounted to μ = 8 - 2 - 1 = 5. When P = 0.99 and μ = 5 was found, the distribution of corn

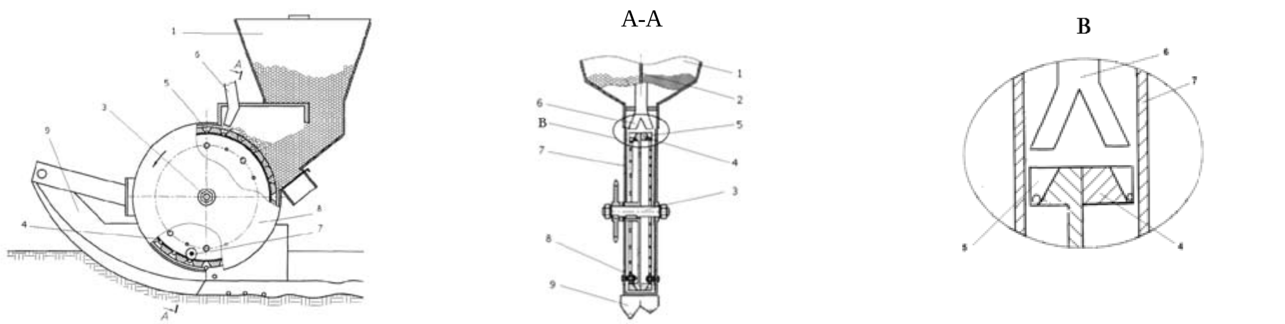

Fig. 2 Sowing unit for a combined dotted and crops

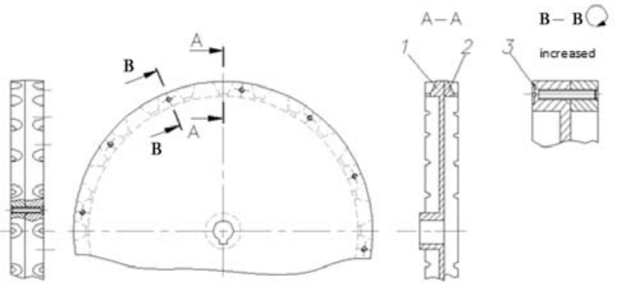

Fig. 3 Sowing disc for combined sowing

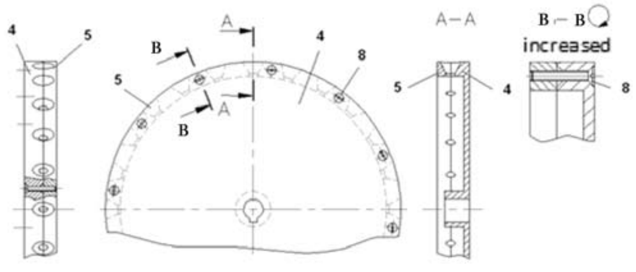

Fig. 4 Sowing disc for dotted sowing

seeds X^2F =4.43 and soybeans X^2F = 3.24, much lower than the table value.

Results and Discussion

The obtained results (**Table 1**) allow accepting the hypothesis of normal distribution of the seed sowing apparatus.

With a probability of 0.99 it can be argued that the apparatus for combined crops provides an average spacing between seeds within 218-234 mm at sowing seeds of corn and 49-54 mm for sowing soybean seeds that meets the requirements of the machinery combined seeding.

Conclusions

Designed pneumatic sowing machine for sowing combined different versatility through the use of dual seed disc and increased operational reliability due to more simple design. Ensure compliance with agrotechnical requirements concerning the uniformity of seed distribution in row, the growth performance and yield of two crops from one area of crop 10-15%.

The application of the proposed sowing machine and combined for dotted crops allows to simplify the design, makes it convenient to operate and financially advantageous. Such metering apparatus is possible without additional costs to move from seeding on combined dotted and Vice versa, which is very important.

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■■

Table 1 The statistical characteristics of the distribution of intervals between seeds

Culture	$\bar{X}$, mm	σ, mm	V, %	m, mm	P, %	The actual value X^2F
Corn	225.6	23	14.5	2.3	1.1	4.43
Soy	53.8	5.4	12.3	0.65	1.2	3.24

Performance Evaluation of an Axial-flow Pearl Millet Thresher

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Abstract

An axial-flow pearl millet thresher was evaluated to determine its threshing efficiency, cleaning efficiency, scatter loss, mechanical grains damage and throughput capacity. The Analysis of Variance (ANOVA) was used to determine the effects of the 3 factors considered for use in the study. Test results showed that the thresher's optimum threshing efficiency of 94.4% was obtained using the millet crop of 7.8% moisture content. Under this same test condition, the cleaning efficiency, grain damage and throughput capacity obtained were 94.8%, 2.52% and 38 kgh^{-1} respectively. Test results also showed that throughput capacity increases as feed rate increases. But the peripheral speed of the cylinder-drum had no effect on the throughput capacity of the thresher. The cleaning efficiency was found not to change with increase in the peripheral speed of the cylinder-drum. The feed rate of 150 kgh^{-1} resulted in having threshing efficiency, cleaning efficiency, scatter loss percentage and throughput capacity mean values of 93%, 93.02%, 23.6% and 51.06 kgh^{-1} respectively.

Keywords: Threshing efficiency, cleaning efficiency, mechanical grains damage, scatter loss, throughput capacity.

Introduction

Millet is one of the commonest cereals cultivated across Africa and Asia. Millet is the general name for most of the smallest cereal grains (Kajuna, 2001). It is often planted in tropical regions of the world where there are little amount of annual rainfall because it has more drought-tolerance than any other known annual crop. Thus, millet does well in regions with low amount of annual rainfall ranging from 200 to 800 mm per annum (Bidinger, 1981). Millet serves as food for most of the populace in the regions where the crop is cultivated (Kothari *et al.*, 2005). Millet is taken as good substitute for rice in places where it is planted and eaten almost as much as rice is consumed in other area. Millet is said to have high nutritional value and has been compared with rice (Kajuna, 2001). Millet can be processed into local meals such as tuwo, pap etc and can be taken as dessert or appetizer in the form of kunu, fura etc. These local desserts during occasions are served as refreshment for entertainment. The stock of millet is being used for the making of thatch for roofing of local huts and for making of mats, hand fans etc. Also the crop residual is fed to farm animals and poultries (Robert, 2013). However, before the kernels can be processed into food, the harvested ear head must be threshed. But the traditional way of threshing millet is very laborious and time-consuming (Irtwange, 2009). The conventional methods of threshing millet are either by flailing or beating harvested ear head in sacks or on special floors by male. The female gender, most often than not, thresh the crop by pounding in mortal with pestle. Both flailing and pounding have been described by Ali (1989) as heavy agricultural task because of the amount of energy expended by humans in carrying out the tasks. Not only does manual threshing expend a lot of energy but also it is very time consuming as the average output per person per day is 10 kg (FAO, 2013). Since most of the millet farmers are peasant farmers, they cannot afford to own a combine for the harvesting, threshing, cleaning and bagging of their crops. Thus, millet is still harvested manually in places where it is planted with the use of handheld sickle or scythe. After harvesting, the crop is left on the farm to dry to a moisture content between 10% and 12% before being threshed (Kajuna, 2001). Because of the drudgery and low per person output involved in the threshing and cleaning of the crop, a number of researchers (Wagami, 1979; Ndirika, 1994; Kamble *et al.*, 2003; Simonyan and Imokheme, 2008; Irtwange, 2009; Olaoye, 2011; Gbado *et al.*, 2013) have attempted to develop motorized threshers for threshing and cleaning of millet and other crops. Other multi-crop threshers have also been developed for threshing different crops such as sorghum, soya beans, cowpea, wheat etc (Joshi, 1981; Akubuo, 2002). These multi-crop threshers may and may not be adoptable for the threshing of diverse varieties of millet (Singhal and Theirstein, 1987). All of these engine-powered threshers have been evaluated to determine their suitability for use in carrying out their intended function of threshing and perhaps cleaning of the threshed crops. But finding a good thresher for millet that is capable of threshing and cleaning a sizeable amount of the crop, say 100 kgh^{-1}, is an arduous task at the moment (Robert, 2013). Moreso, many of the known threshers have high scatter losses with unacceptable range of damaged grains coupled with poor threshing and cleaning efficiencies (Joshi, 1981). In the study carried out by Kamble *et al.* (2003) on the performance of a millet thresher, the throughput capacity and cleaning efficiency of the machine evaluated were not stated. Gbado *et al.* (2013) in evaluating another millet thresher left out the mechanical damage done to the threshed millet by the machine. Moreso, the feed rate of the millet thresher was not one of the factors varied, thus its throughput capacity was not reported. Hence, the objective of this work is to assess the performance of an axial-flow pearl millet thresher developed at the Department of Agricultural Engineering, Ahmadu Bello University, Zaria, Nigeria. This study also tends to determine the best operating condition of the pearl millet thresher by considering factors such as moisture content of the crop, feed rate and threshing speed.

Materials and Methods

The instruments and materials used for the performance evaluation of the millet thresher are quartz stopwatch, digital tachometer (*DT 2235B*) of sensitivity of one revolution per second and an electronic weighing mettle with a sensitivity of 0.01 kg. The balance was used to measure the varying masses of un-threshed pearl millet at three selected moisture contents. The stopwatch was used to measure time taken by the thresher to thresh and clean the weighed mass of the crop, while the tachometer was used to measure the speed of the threshing drum during machine evaluation. The indices used for the thresher's evaluation include threshing efficiency, cleaning efficiency of the threshed crop, scatter loss and grain damage that can be owed to the thresher as well as the throughput capacity of the thresher. In evaluating the thresher, randomized complete block design (RCBD) was used to assess its performance at 3 levels of moisture content of the crop (7.8%, 9.7% and 10.3%), 4 levels of feed rate (60 kgh^{-1}, 90 kgh^{-1}, 120 kgh^{-1} and 180 kgh^{-1}) and 4 levels of threshing speed (5.5 ms^{-1}, 7.3 ms^{-1}, 9.2 ms^{-1} and 11.0 ms^{-1}). **Fig. 1** shows the pearl millet thresher during its evaluation exercise. The Analysis of Variance (ANOVA) was used to study the effect of each of the three factors and their interactions on the performance of the axial-flow pearl millet thresher. The SAS Proprietary Software Version 9.0 was used for data computation.

Determination of Moisture Content

The moisture content of the millet samples used was determined using the standard oven-dried method in accordance with ASAE (1998). The initial and final weights of the grains before and after oven drying were measured using the electronic balance. The threshed millet grains were oven dried at 105°C for 18 to 24 hours (until the crop attains a constant mass) to determine its moisture content. The equation used for the determination of moisture content of the crop was given by Mohsenin (1980) as:

$M = (W_1 - W_2) / W_2 \times 100\%$ ....(1)

where,

M = grain moisture content of the grain (%),

W_1 = weight of grains before oven-drying (g)

W_2 = weight of grains after oven-drying (g)

Threshing Efficiency (T_E)

Threshing efficiency (T_E) is defined as the percentage ratio of threshed grains to the total quantity of sample grain after a threshing process. It was given by Ndirika (1994) as:

$T_E = 100 - Q_U / Q_T \times 100$ ....(2)

where,

T_E = threshing efficiency (%)

Q_U = unthreshed quantity of grains in a sample (kg)

Q_T = the total quantity of grains in the given threshed sample (kg)

Cleaning Efficiency (C_E)

Cleaning efficiency (C_E) is the ratio by weight of clean grains collected at the grain outlet to the total weight of the chaff and clean grains collected at the same outlet expressed in percentage. The equation

Fig. 1 The thresher during performance evaluation exercise

used for determining cleaning efficiency was given by Ndirika (1994) as:

$C_E = (W_t - W_c) / W_t \times 100$ ....(3)

where,

C_E = cleaning efficiency (%)

W_t = total weight at the outlet (kg)

W_c = chaff weight at the outlet (kg)

Mechanical Grain Damage (M_D)

Mechanical grain damage (M_D) was used to determine the quantity of visible damage or breakage done to grains that can be owed to the thresher. The mechanical grain damage as given by Nkirika (1994) is expressed as:

$M_D = Q_b / Q_t \times 100$ ....(4)

where,

M_D = mechanical grain damage (%)

Q_b = the quantity of damage grains (kg)

Q_t = sample size (kg)

Scatter Loss (S_L)

During threshing operation, some grains were lost as scatter loss from the pearl millet thresher and were not collected with others at the grains outlet. This was evaluated using the equation given by Ndirika (1994) as:

$S_L = Q_l / Q_t \times 100$ ....(5)

where,

S_L = Scatter loss (%)

Q_l = the quantity of grains scattered (kg)

Q_t =total quantity of sample grains (kg)

Throughput Capacity (T_C)

The throughput capacity is the amount of the actual cleaned grain that the develop thresher was able to process per time. It was given by Ndirika (1994) as:

$T_C = Q_s / T$ ....(6)

where,

T_C = Throughput capacity (kg s^{-1})

Q_s = quantity of grains collected at the grain outlet (kg)

T = time taken to thresh (s)

The throughput capacity was however converted to kgh^{-1} in order to determine the quantity of grain that the thresher was able to process per hour.

Results and Discussion

Performance Evaluation

Table 1 shows the result of the performance evaluation of the axial-flow millet thresher for the different feed rates and crop moisture contents. The threshing efficiencies obtained ranged from 89.5% to 95.6% which was observed to increase as moisture content of the crop decreased. The feed-rate of 120 kgh^{-1} gave the highest threshing efficiency at each moisture content level while 90 kgh^{-1} feed-rate gave the least threshing efficiency at each moisture content level. Ndirika (1994) had threshing efficiency values ranging from 94.4% to 96.8%, while Kamble *et al.* (2003) had threshing efficiency values ranging from 78.1% to 96.6%. Thus, the threshing efficiency obtained during performance evaluation of the axial-flow pearl millet thresher is within the values obtained in other research works (Ndirika, 1994; Kamble *et al.*, 2003). The cleaning efficiency of the thresher also increased with decrease in moisture content of threshed crop, but the cleaning efficiency fluctuated with increase in feed rate at any particular crop moisture content. The cleaning efficiency of the thresher ranged from 88.4% to 97%. The highest value of cleaning efficiency was obtained at the lowest crop moisture content evaluated. Ndirika (1994) obtained cleaning efficiency range of 85% to 90% which was numerically lower than the range gotten in this evaluation. Gbado *et al.* (2013) got 56.3% to 62.7% cleaning efficiency while Abolaji (1980) had 88.5% to 92.3% cleaning efficiency. The mechanical grain damage was found to be almost uniform in all the crop moisture contents involved which ranged from 2.38% to 2.82%. At each of the feed rate investigated, the highest value of grain damage was at 9.7% crop moisture content. Ndikira (1994) reported grain damage range of 1.3% to 2.1% while Abarchi (2011) got 0.9 to 2.60% grain damage from a different millet thresher. Kamble *et al.* (2003) reported grain damage of 2.75% to 8.25%. Thus, the grain damage of the evaluated thresher is within those of other researchers (Ndirika, 1994; Kamble *et al.*, 2003; Abarchi, 2011). The scatter loss was within 18.9% to 37.3% and decreased with increase in feed rate. The lowest scatter loss at any given feed rate of the thresher occurred at 9.7% crop moisture content; the highest scatter loss occurred at 10.3% crop moisture. Ndirika (1994) reported a scatter loss of 3.5 to 4.5%. Gbado *et al.*

Table 1 Performance evaluation results of the thresher at diverse feed rate

Crop Moisture content (%)	Feed Rate (kgh^{-1})	Threshing Efficiency (%)	Cleaning Efficiency (%)	Grain damage (%)	Scatter Loss (%)	Throughput capacity (kgh^{-1})
10.3	60	90.79	89.87	2.38	37.29	16.75
	90	90.30	88.72	2.48	33.38	20.80
	120	91.51	89.31	2.60	29.62	31.06
	150	90.95	88.42	2.64	28.77	38.78
9.7	60	91.22	90.00	2.69	24.16	25.12
	90	89.45	87.43	2.64	24.27	32.10
	120	94.66	93.86	2.80	25.55	48.70
	150	92.41	93.55	2.82	18.92	60.30
7.8	60	94.69	93.63	2.69	30.11	22.68
	90	93.37	91.85	2.63	29.66	30.54
	120	95.56	95.16	2.71	26.29	44.79
	150	95.56	96.99	2.76	23.21	55.33

(2013) and Abolaji (1980) got scatter losses of 11.4% to 27.4% and 36.8% to 51.7%, respectively. This implies that Ndikira (1994) and Gbado *et al.* (2003) got lower and higher scatter losses respectively when compared with the result of this study. The throughput capacity of the thresher evaluated ranged from 16.75 kgh^{-1} to 60.3 kgh^{-1}. The throughput capacity increased with feed rate. The highest throughput capacity value of 60.3 kg h^{-1} was obtained at 150 kgh^{-1} feed rate and 9.7% crop moisture content. It was observed that the highest value of material throughput (60.3 kgh^{-1}) was obtained where the least scatter loss (18.9%) occurred. Similarly, the lowest throughput capacity (16.8 kgh^{-1}) occurred at the highest scatter loss (37.3%). Abolaji (1980) and Ndirika (1994) got the highest material throughput capacity values of 23.4 kgh^{-1} and 47.5 kgh^{-1}, respectively.

Analysis of Variance (ANOVA) of the Experiment

Table 2 presents the F-values obtained during Analysis of Variance (ANOVA) for the parameters investigated. The interaction of the three factors considered in this study showed no significant effect on all the test parameters. Likewise the interaction of either of any two out of the three factors considered in this study were not significant. The results of the interaction between two or three independent factors been not significant indicate that the main effects were not being influenced by the interactions (Walpole *et al.*, 2007). This lends credence to the ANOVA results of the main effects for all the test parameters investigated.

The ANOVA result for threshing efficiency shows that speed and moisture content are significant at 1% level. This implies that the threshing efficiency obtained depends on the moisture content of the crop and the speed at which the threshing drum was operated. But the threshing efficiency was not affected by the feed rate of the thresher. For cleaning efficiency, crop moisture content was the only factor that was significant at 1% level. Feed rate and threshing speed did not affect the cleaning efficiency of the thresher. Crop moisture content, threshing speed and feed rate at 1% level of significance had effect on grain damage. Crop moisture content and threshing speed at 1% level of significance had effect on scatter loss. Feed rate at 5% level of significance had effect on scatter loss. The throughput capacity was not affected by the threshing speed. But the throughput capacity of the axial-flow pearl millet thresher was affected by the crop moisture content and feed rate at 1% level of significance. Kamble *et al.* (2003) reported the outcome of the performance evaluation of another type of pearl millet thresher and observed that crop moisture, thresher feed rate and peripheral speed at 1% level of significance had effect on threshing efficiency, mechanical breakage of grains and scatter loss.

Duncan Multiple Range Test for Main Effects

The Duncan Multiple Range Test was used to rank the mean values of threshing efficiency, cleaning efficiency, grain damage, scatter loss and throughput capacity obtained at different levels of operation of moisture content, feed rate and threshing speed. Likewise it was used to check the mean differences of the effected factors. The results obtained from Duncan Multiple Range Test are presented in **Tables 3** to **5** for moisture content, feed rate and threshing speed, respectively. From **Table 3**, the highest threshing and cleaning efficiencies were obtained at 7.8% crop moisture content. These efficiencies decreased with increase in crop moisture content. The least scatter loss and grain damage were also obtained at the lowest crop moisture of 7.8%. The throughput capacity of 38 kgh^{-1} was obtained at the lowest crop moisture content of 7.8%. It was found that this throughput capacity was statis-

Table 2 ANOVA result of the performance evaluation of thresher

		Observed F values					F tabulated	
Source of Variation	Degree of Freedom	Threshing Efficiency	Cleaning efficiency	Grain Damage	Scatter Loss	Throughput Capacity	5%	1%
Replication	2	17.3	10.32	4.97	3.71	2.42	3.09	4.82
Crop Moisture content, M	2	9.04**	8.16**	27.90**	9.80**	35.67**	3.09	4.82
Feed rate, F	3	2.42^{ns}	2.46^{ns}	11.11**	3.19*	80.59**	2.71	3.98
Speed, S	3	4.95**	1.43^{ns}	79.66**	6.16**	1.35^{ns}	2.71	3.98
M × F	6	0.47^{ns}	0.85^{ns}	1.33^{ns}	0.45^{ns}	1.45^{ns}	2.19	2.99
M × S	6	1.24^{ns}	0.81^{ns}	0.53^{ns}	0.58^{ns}	0.73^{ns}	2.19	2.99
F × S	9	0.58^{ns}	1.42^{ns}	0.51^{ns}	1.52^{ns}	1.37^{ns}	1.97	2.59
M × F × S	18	0.33^{ns}	0.44^{ns}	0.64^{ns}	0.69^{ns}	0.54^{ns}	1.72	2.13
Errors	94							
Total	143							

^{ns} = not significant, * = significant at 5% level and ** = significant at 1% level tically the same with that obtained at 9.7% crop moisture content with the value of 41.56 kgh^{-1}. Generally, the thresher performance was best when the crop moisture content was set at its driest point. Conversely, at the highest evaluated crop moisture content of 10.3%, the thresher had the least desired results for all the test parameters. From Table 4, threshing and cleaning efficiencies followed a similar pattern of ranking except for the efficiencies obtained at 150 kgh^{-1} feed rate. The feed-rate of 90 kgh^{-1} recorded the least value in each case of threshing and cleaning efficiencies. Threshing efficiencies obtained at 60 and 150 kgh^{-1} feed rates were statistically the same. But the threshing efficiencies at 90 and 120 kgh^{-1} feed rates are statistically different. For cleaning efficiency, the mean values at 120 and 150 kgh^{-1} feed rates were statistically the same. Also from Table 4, the grain damage was ranked into two classes; the lower feed rates of 60 and 90 kgh^{-1} gave the lower class grain damage values of 2.58 and 2.59% and the higher feed rates of 120 and 150 kgh^{-1} gave the upper class grain damage values of 2.7 and 2.73%. As for the scatter loss, the highest feed-rate value of 150 kgh^{-1} has the lowest scatter loss value of 23.63%. This scatter loss value of 23.63% is not statistically different from the 27.15% scatter loss value obtained at 120 kgh^{-1} feed rate. The Table indicates that scatter loss values at 60 and 90 kgh^{-1} feed rates are statistically the same. The throughput capacities at all levels of feed rate were statistically different one from another. However, the throughput capacity increased as feed rate increased. The mean throughput capacity of 51 kgh^{-1} was obtained at a feed rate of 150 kgh^{-1}, while the lowest mean throughput capacity of 21.52 kgh^{-1} was obtained at a feed rate of 60 kgh^{-1}.

Table 3 Duncan multiple ranking of performance indices at moisture contents

Independent variable	Levels (%)	Threshing Efficiency	Cleaning Efficiency	Grains Damage	Scatter Loss	Throughput Capacity
Moisture	10.3	90.89^{b}	89.08^{b}	2.72^{a}	32.27^{a}	26.85^{b}
	9.7	91.93^{b}	91.21^{b}	2.73^{a}	27.32^{b}	41.56^{a}
	7.8	94.82^{a}	94.43^{a}	2.52^{b}	23.22^{c}	38.03^{a}

In any column, means followed by a common letter are not significantly different at 5% level

Table 4 Duncan multiple ranking of performance indices at feed rates

Independent variable	Levels (kg hr^{-1})	Threshing Efficiency	Cleaning Efficiency	Grains Damage	Scatter Loss	Throughput Capacity
Feed Rate	60	92.24^{ab}	91.16^{ab}	2.59^{b}	30.52^{a}	21.52^{d}
	90	91.04^{b}	89.33^{b}	2.58^{b}	29.10^{a}	27.82^{c}
	120	93.91^{a}	92.78^{a}	2.70^{a}	27.15^{ab}	41.52^{b}
	150	93.00^{ab}	93.02^{a}	2.73^{a}	23.63^{b}	51.06^{a}

In any column, means followed by a common letter are not significantly different at 5% level

Table 5 Duncan multiple ranking of performance indices at Cylinder Speed

Independent variable	Levels (ms^{-1})	Threshing Efficiency	Cleaning Efficiency	Grains Damage	Scatter Loss	Throughput Capacity
Cylinder Speed	5.5	90.54^{b}	90.25^{a}	2.40^{d}	23.05^{b}	37.79^{a}
	7.3	92.67^{b}	90.71^{a}	2.57^{c}	25.13^{b}	35.72^{a}
	9.2	94.08^{a}	92.95^{a}	2.72^{b}	31.09^{a}	34.59^{a}
	11.0	93.92^{a}	92.39^{a}	2.93^{a}	31.14^{a}	33.81^{a}

In any column, means followed by a common letter are not significantly different at 5 % level

Table 5 shows the result of Duncan ranking of threshing speed at the four different cylinder-speed levels of operation. The Table shows that the highest threshing efficiency of 94.08% was obtained at 9.2 ms^{-1} threshing speed. The threshing efficiency of 93.92% obtained at 11.0 ms^{-1} threshing speed is statistically the same with the threshing efficiency of 94.08% obtained at 9.2 ms^{-1} threshing speed. Also the threshing efficiency of 90.5 and 92.7% obtained at 5.5 and 7.3 ms^{-1} threshing speed, respectively, are statistically the same. Thus, the two uppermost threshing speeds gave a better threshing efficiency than those with lower threshing speeds. The cleaning efficiencies at all levels of threshing speed were statistically the same. This implies that the cleaning efficiency obtained was the same regardless of the speed at which the pearl millet thresher was operated. However, the grain damage obtained at different levels of threshing speed was statistically different from one another. The grain damage of the thresher ranged from 2.4 to 2.93%. The grain damage from the pearl millet thresher showed an increasing pattern as the threshing speed was increased. The scatter loss percent followed a similar ranking pattern with that of threshing efficiency at the different threshing speeds. The lower class of scatter loss of 23.05 and 25.13% obtained at 5.5 and 7.3 ms^{-1} threshing speed, respectively, are statistically the same. The higher class of scatter loss of 31.09 and 31.14% obtained at threshing speeds of 9.2 and 11.0 ms^{-1} cylinder-speed, respectively, were also statistically the same. The results of throughput capacity obtained at the different levels of threshing speed ranged from 33.81 to 37.8 kgh^{-1} and were found to be statistically the same. This implies that the throughput capacity of the thresher was not affected by the threshing speed.

Conclusions

An axial-flow pearl millet thresher was evaluated to ascertain its suitability for use in threshing pearl millet. It was found that the threshing and cleaning efficiencies ranged from 89 to 96% and from 87 to 97%, respectively, while that of grain damage from the thresher ranged from 2.38% at 60 kgh^{-1} feed rate and 10.3% crop moisture content to 2.82% at 150 kgh^{-1} feed rate and 9.7% crop moisture content. The scatter loss of the thresher needs to be improved upon as the percentage scatter loss from it ranged from 19 to 37% which is uneconomically high. The throughput capacity of 60.3 kgh^{-1} was obtained at 150 kgh^{-1} feed rate and 9.7% crop moisture content.

The moisture content of the crop affected the performance of the thresher for all the test parameters. The feed rate has effect on grain damage and throughput capacity of the thresher at 1% level of significance and on scatter loss at 5% level of significance. The threshing efficiency, grain damage and scatter loss are affected by the threshing speed at 1% level of significance.

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Design and Development of Combined Conservation Tillage Machine with Chiselers and Clod Pulverizing Roller

by

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Abstract

A 'Combined Conservation Tillage Machine' was designed and developed with two main units, viz. deep soil loosening unit and clod pulverizing unit. Deep soil loosening unit consisted of five winged chisel tines mounted on three beams rectangular frame with sliding type depth control device for tilling soil up to 250 mm depth while maintaining the crop residues at the field surface. The clod pulverizing unit comprised of a 1.6 m wide spiked roller clod crusher with two floating arms mounted at the rear of chisel tines for soil pulverization and consolidation of tilled soil. Four sets of mounting arrangements of chisel tines on the frame were evaluated. The positioning of one chisel tine at the centre of front beam, two tines each on middle and rear beams at 45° imaginary line with respect to direction of travel gave significantly minimum draft (9.04 kN), maximum area of soil disturbance (0.228 m^2) and minimum specific draft (41.81 kN/m^2). Among other three arrangements evaluated; the draft, area of soil disturbance and specific draft varied in the range of 9.9-14.81 kN, 0.131-0.179 m^2 and 62.42-101.79 kN/m^2, respectively. Evaluation of the machine with best arrangement of tines under tilled and consolidated clean field conditions gave field capacity of 0.28 ha/h at 76.65% field efficiency and consumed 3.87 l/h of diesel. The developed machine was recommended for controlled field traffic method of soil cultivation in laser levelled fields under surface managed standing crop residues for promotion of conservation agriculture.

Introduction

Mechanization in agriculture holds the key for sustainable agricultural development through efficient input resource management and reduced production cost. In many countries mechanization is viewed with concern because of soil compaction as a result of heavy traffic passes on the soil. Repeated use of tillage implements over the years creates impermeable soil layers or hardpans which influence the bulk density, porosity and penetration resistance of soil, affecting thereby the growth and yield of crops. Hardpan due to subsoil compaction of agricultural soil is a global concern due to adverse effects on crop yield and environment. Compaction is associated with tillage while ignoring high axle loads of common harvest and transport equipment (Voorhees *et al*., 1986; Petelkau and Dannowski, 1990). In India, with the advent of green revolution, mechanization has increased manifolds in an effort to increase crop production. The movement of heavy machineries such as grain combine harvesters (6-7 t), sugarcane harvesters (9-14 t), high h.p. tractors with mounted equipment (5 t), field sprayers, tractor trailers, loaded trucks for carrying agricultural produce after harvesting etc. as well as by natural compaction processes have caused subsoil compaction at many locations in the country (Thakur and Kumar, 1999 and Kumar, 2003). Reduced availability and uptake of water and plant nutrients due to restricted root growth, decreased water infiltration and permeability, increased density and strength of soil mass, and reduced soil aeration are the results of soil compaction. Subsoil compaction whether natural or induced deteriorates soil physical properties and may result in reduction of crop yield and quality.

Generally, the primary tillage operations are performed with mould board and disc ploughs. Large size clods are exposed during ploughing which require many secondary tillage operations to prepare a fine seedbed conducive for seed germination and plant growth. These ploughs normally work to a depth of 200 mm and invert the soil by throwing action. The negative effects of these equipment are uneven field surface, disturbance of soil biota, rapid evaporation of soil moisture, more number of passes of secondary tillage implements for soil pulverization, compaction and formation of plough pan by slipping tractor tyres at tilling depth and no retention of residue at the field surface. A variety of tillage implements have been developed at Pantnagar for subsoil cultivation upto 550 mm depth (Mandal and Thakur, 2010 a and b; Singh, 2010; Kumar, 2010 and Kumar and Thakur, 2013). The use of subsoiling equipment, however, is recommended after 2 to 4 years intervals depending upon soil types and conditions. Apparently, there is no equipment in use in India for soil management which can till soil without inversion at depth greater than 150 mm (heavy duty cultivator) but less than the depth (250 mm) beyond which the subsoiling is recommended. Therefore, a need was felt to develop a machine which can till soil in the depth range of 150 - 250 mm without soil inversion, reduce the soil compaction, maintain the level of field, preserve the micro-organism, retain crop residues at the surface, conserve soil moisture and perform soil cultivation in laser levelled fields. This paper, therefore, describes the development and field performance of a 'combined conservation tillage machine' (Murmu, 2011) with chiselers and a clod pulverizing roller for seedbed preparation without altering the level of fields.

Materials and Methods

The combined conservation tillage machine consisted of two main units, i.e. a chiseling unit and a clod pulverizing unit. The chiseling unit consisted of mainly a rectangular frame with three beams, five winged chisel tines, depth control device and hitching system. The clod crushing unit consisted of a roller with spikes mounted on its periphery, two floating arms and a set of angle iron brackets (**Fig. 1**). The description of the developed machine is given below:

Chiseling Unit

Frame

The square beams of 75 × 75 × 10 mm size having 1,800 mm length were positioned parallel to each other at centre to centre distance of 400 mm in each pair and welded together with m.s. flats of 800 × 75 × 15 mm size from the sides to form a rectangular frame with overall dimensions of 1,800 mm (length) × 875 mm (width). Five winged inclined tines could be mounted on the frame with clamps and had provision to adjust in horizontal as well as vertical planes. A category-II hitching system was selected for mounting this equipment with the power unit.

Winged chisel tines

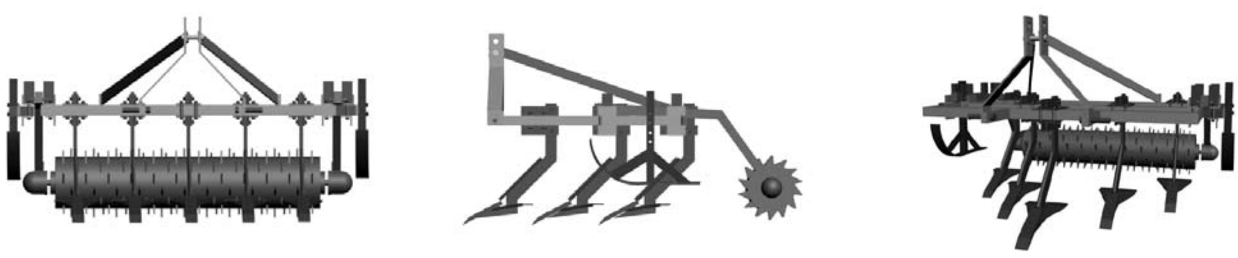
Different components of winged tines for deep soil loosening are leg, shin, share, wings, gusset plates and side plates. The design of winged tines is based on the general soil mechanics equations by Hettiaratchi *et al*. (1966) and McKyes and Ali (1977) for narrow tines and the concept developed by Spoor and Godwin (1978) for deep soil loosening equipment. The various components of tines are described below:

a) Leg and foot

The leg of chiseler was made in three parts i.e. upper part of 350 × 75 × 15 mm size, middle part of 370 × 75 × 15 mm size and lower part of 120 × 75 × 15 mm size of mild steel flats. The middle part was inclined at an angle of 45° with respect to upper part for reduced draft. The lower end of leg was sandwiched between two side plates of 75 × 15 mm size called 'foot' and tapered at 22° for mounting a share. The lateral portion of side plates provides space for attachment of gusset plates for mounting the wings of chiseler.

b) Shin

The chiseler generally operates at 200-250 mm depth, resulting in wear and tear of front side of the leg.



a) Elevation **b**) Side view **c**) Isometric

Fig. 1 Different views of developed machine

To overcome the wear of leg, a high carbon steel shin of 25 × 25 mm cross-section was provided at its front side. It was tapered in the front at 90° cone angle and is replaceable after wear.

c) Share

It is the main component of chiseler which actually opens the soil. It has highest wear rate at its tip because of maximum stress concentration. Therefore, for differential rate of wear, share is made of mild steel with chamfered cutting tip onto which a replaceable tool steel (EN-45) tip was welded. Tip of the share was provided with a rake angle of 22° for easy penetration and minimum draft. The share was hard surfaced by depositing wear resistant material in the form of a grid to enhance its life. Share was mounted on the base plate with countersunk bolts.

d) Gusset plates

Gusset plates were fabricated from m.s. flat of 230 × 50 × 10 mm size to support wings on the foot. Gusset plates of each tine had 22° lift angle from front side in horizontal plane and 10° in lateral plane for proper upheaval of soil. These plates were cut on front side at 45° to obtain an included angle of 90° while the rear sides were left as such to match the covering plates provided at the rear of tines.

e) Wings

Wings were made from high carbon steel, as these wings also wear out fast due to shearing of soil. For easy penetration and minimum draft while cutting soil with wings, the edges were tapered at 45° from the front side and supported on the gusset plates as described above. They were mounted on the gusset plates with countersunk nuts and bolts.

f) Covering plate

The covering plate was made of m.s. flat of 600 × 75 × 10 mm size. It was positioned separately along the side plates for easy movement of soil towards the rear of tines. The covering plate is replaceable after wear.

Depth control device

Depth control device was fabricated from a square hollow beam of 45 × 45 × 5 mm size and 600 mm long. Four holes were drilled at a spacing of 50 mm vertically upward for depth control. The first hole was drilled at 150 mm above the ground level. The lower end of this hollow beam is attached with a m.s. flat of 600 × 75 × 7 mm size and curved at its front and rear ends in a shoe shape for sliding on the soil surface.

Clod Crushing Unit

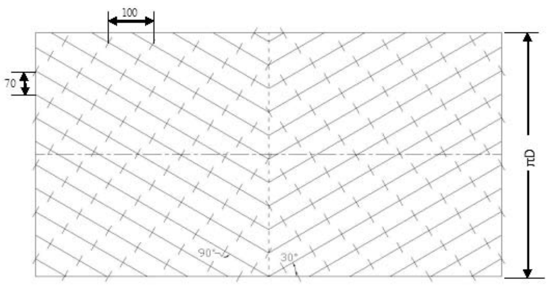
The problem of clod formation is more prominent in arid and semi-arid agro-climatic zones. Large size clods are exposed during primary tillage operation which requires many secondary tillage operations to prepare a fine seedbed conducive for seed germination and plant growth. The chiseling equipment often result in poor quality seedbed with large size soil aggregates exposed at the surface which must be shattered and consolidated for moisture conservation. Thus, a hollow roller type clod crusher unit with spikes at its surface was developed for obtaining desired results under different soil types and field conditions. The development of main components of this unit is described below:

Clod crushing roller

The spikes were welded onto a hollow mild steel cylinder of 1,600 × 350 (Ø) × 5 mm dimensions to develop a spiked clod crusher. The roller was kept hollow so that it could be filled with soil, sand or gravels to increase its weight, if needed, for proper clod crushing by dismounting the side flanges. The roller was mounted at the rear of frame with floating arms and positioned exactly behind the soil loosening winged chisel tines for proper pulverization and consolidation of tilled soil.

Spikes

The spikes were fabricated from 60 × 50 × 8 mm m.s. flat and had tip angle of 40° which was selected for least resistance to cutting of clods (Kostritsyn, 1956). The full width of roller was divided in two halves and helix angles of 30° with respect to longitudinal axis of rotation of the roller were drawn from its centre to outer ends of roller at a spacing of 70 mm. The helix angle of 30° was selected which produces minimum axial thrust (Pandya and Shah, 1978). Also, the helix angle of 30° to both ends of the roller from its centre displaces the tilled soil towards the ends, thus it provides a smooth levelled field surface. Marks were made with a chalk at a spacing of 100 mm in rows. The marks in alternate rows were made at the centre of a pair of spikes of preceding row for effective pulverization



a) Designed clod crusher (All dimensions in mm)


b) Fabricated spiked clod crusher

Fig. 2 Developed spiked clod crusher of clods (**Fig. 2**). A total of 185 spikes were welded on the marked position at a mounting angle of 33° rearwards for minimum resistance and self-sharpening of tips according to Thakur and Varshney (1993).

Floating arms and brackets

Two floating arms were used for mounting of roller with the frame. Each floating arm was fabricated from a square hollow beam of 50 × 50 × 6 mm size and 650 mm length. Similar, size square beam having 550 mm length was welded with the first beam at an included angle of 145°. Angle irons of 50 × 50 × 6 mm size having 300 mm length were welded on the frame at its both sides. The brackets were used for mounting of clod crusher roller with the frame. The floating arms were mounted between the brackets with locking pins.

Field Performance Evaluation

The developed machine was evaluated in the field on the basis of machine and soil parameters by adopting standard protocols. Three investigations carried out were as follows:

(i) The effect of positioning of chisel tines on the frame at 30° and 45° imaginary V- lines on performance of machine under field surface residues conditions (**Fig. 3**).

(ii) The effect of chisel tines performance in terms of soil disturbance and draft while mounting at four different positions on the frame for same width of equipment (**Fig. 4**). Four arrangements of five tines on the frame were:

(a) Set-I: One tine at the centre of front beam + 2 tines on the middle beam + 2 tines on the rear beam mounted at 45° angle imaginary V-lines with central longitudinal axis of frame

(b) Set-II: Two tines on the middle beam + 3 tines on the rear beam equally spaced within selected constant width of cut

(c) Set-III: Three tines on the middle beam + 2 tines on the rear beam equally spaced within the selected constant width of cut

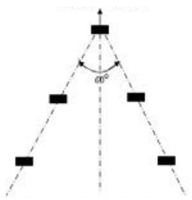
(d) Set-IV: Two tines on the front beam + 1 tine at the centre of middle beam + 2 tines on the rear beam equally spaced within the selected constant width of cut.

(iii) Performance evaluation of developed machine at its best parameters established through two investigations.

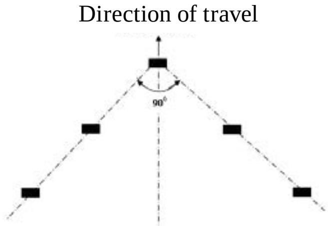
Results and Discussion

Effect of Positioning of Chisel Tines

At imaginary V-line on the frame all the 5 tines were positioned on the frame at two imaginary V-line, i.e. (i) at 30° with direction of travel or 60° included angle and (ii) at 45° with direction of travel or 90° included angle. The machine was operated in combine harvested wheat field having anchored stubbles of about 300 mm height after removal of loose straw from the field. It was observed that at 30° V-line, the machine failed to work satisfactorily as the loose stubbles were raked by the tines causing frequent clogging. However, at 45° imaginary V-line, the machine worked satisfactorily

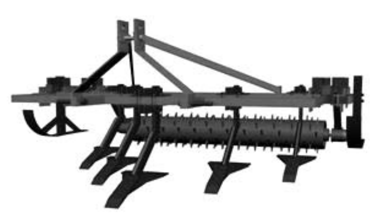


a) Chisel tines mounting on the frame at 30° angle imaginary V-lines with central longitudinal axis (Direction of travel)

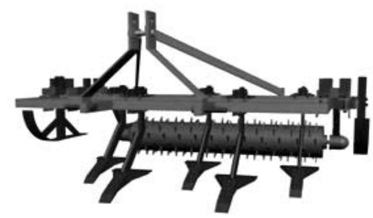


b) Chisel tines mounting on the frame at 45° angle imaginary V-lines with central longitudinal axis (Direction of travel)

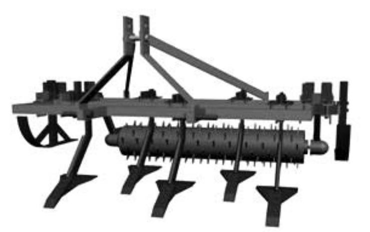
Fig. 3 Conceptual views of different mounting angles of tines at imaginary V-lines with direction of travel in Investigation No. 1



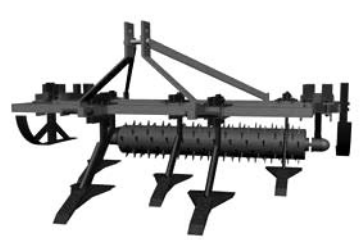
a) One tine on the front beam, two tines on the middle beam and two tines on the rear beam (Set-I)



b) Two tines on the middle beam and three tines on the rea beam in staggered pattern (Set-II)



c) Three tines on the middle beam and two tines on the rear beam in staggered pattern (Set-III)



d) Two tines on the front beam, one tine on the middle beam and two tines on the rear beam (Set-IV)

Fig. 4 Conceptual views of different arrangements of tines on developed machine for field evaluation in Investigation No.2

Fig. 5 Combined conservation tillage machine in cross-tilling operation during second pass

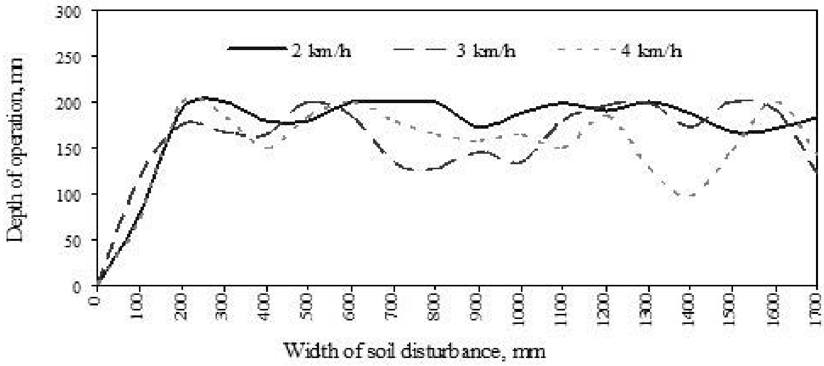


Fig. 6 Area of soil disturbance for 200 mm depth of operation

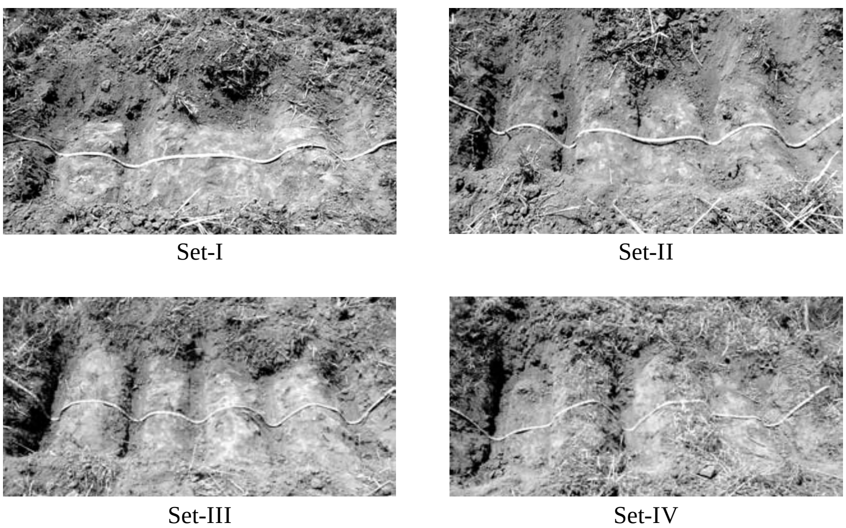


Fig. 7 Area of soil disturbance for different sets of winged chisel tines

Table 1 Performance of developed machine with different arrangements of chisel tines on its frame

Arrangements of tines	Draft of machine, kN	Area of soil disturbance, m^2	Specific draft, kN/m^2
Set-I	9.04	0.228	41.81
Set-II	14.81	0.147	101.79
Set-III	10.45	0.178	62.42
Set-IV	9.90	0.131	79.09
S. Em.±	0.2224	0.0098	2.958
C. D. at 5%	0.7686	0.0340	10.223

without clogging. The cross-tilling (second pass) operation allowed the loose wheat stubbles ahead of chisel tines and caused clogging of the machine as evident from **Fig. 5**. The average depth of penetration of tines i.e. the average of 5 furrows + 4 ridges formed in a cross-sectional width of 1.7 m, reduced with the increase in forward speed of travel. It was obtained as 186, 169 and 167 mm at a depth setting of approximately 200 mm at 2, 3 and 4 km/h speeds of travel, respectively. Accordingly, the area of soil disturbance varied as 0.296, 0.284 and 0.282 m^2 for forward speeds of 2, 3 and 4 km/h, respectively as shown in **Fig. 6**.

Effect of Mounting of Chisel Tines on Specific Draft

The effect of tine configuration on the frame at a constant depth of cut (150 mm), constant width of cut (1.7 m) and constant forward speed (2 km/h) under combine harvested and chopped surface managed wheat stubbles condition is illustrated in **Fig. 7** and the results are presented in **Table 1**.

The mounting configuration of tines on the frame significantly affected the depth of penetration of machine. The average depth of furrow varied as 163, 126, 140 and 153 mm, average depth of ridge from ground level varied as 118, 71, 72 and 49 mm while the average overall depth of tillage varied as 143, 101, 110 and 106 mm, in respect of Set-I, Set-II, Set-III and Set-IV, respectively. As a tine moves forward, the soil to its sides fails at an angle of (45-Ø/2) degree with the vertical and forms a trough which has been demonstrated by Hettiaratchi and Reece (1974). The tines in Set-I were positioned at 45° imaginary V-line in such a manner that the trough formed by a leading tine is overlapped by the preceding tines, thereby requiring less force to fail the soil. In other arrangements (Set-II to Set-IV), each tine works independently and there is no interaction effect as evident from **Fig. 7**. The area of soil disturbance was maximum with Set-I. However, the Set-II had no significant difference between the area of soil disturbance as compared to Set-III and Set-IV. But there was a significant difference ($p \leq 0.05$) between area of soil disturbance in Set-III and Set-IV.

The following scientific inference could be drawn from the results presented in **Table 1**:

i) The relative positioning of chisel tines on the frame had significant effect on its draft. The lowest draft of 9.04 kN was found with Set-I and followed in an increasing order by Set-IV (9.90 kN), Set-III (10.45 kN) and Set-II (14.81 kN).

ii) The average area of soil disturbance was found significantly maximum as 0.228 m^2 with Set-I followed by Set-III (0.178 m^2), Set-II (0.147 m^2) and Set-IV (0.131 m^2).

iii) The average specific draft of machine was significantly ($p \leq 0.05$) low as 41.81 kN/m^2 with Set-I, followed in an increasing order by Set-III (62.42 kN/m^2), Set-IV (79.02 kN/m^2) and Set-II (101.79 kN/m^2). For efficient tillage, both the draft and area of soil disturbance must be considered with the aim of minimizing the specific resistance, i.e. draft per unit area of soil disturbance and accordingly, force prediction models for interacting tines have been developed (Godwin *et al*., 1984). They reported that the total draft is significantly reduced as the tine spacing are reduced, and the area of soil disturbance peaks and the specific resistance reaches to its minimum value at a spacing of approximately 1.4±0.25 times the working depth. The tine arrangement in Set-I has produced minimum draft, maximum area of soil disturbance and minimum specific draft and was, therefore, finally selected on the developed machine. However, the spacing between tines mounted on second and third beams of the frame could be laterally reduced as per need such that the clogging of combine harvested crop residues is altogether avoided by smooth flow of materials behind the machine.

Table 2 Soil and machine parameters during field evaluation of machine

i. Soil parameters	
Soil type	Silty clay loam
Initial soil moisture content (d.b.), %	13.27
Initial soil bulk density (dry), Mg/m^3	1.4
Clod MWD after operation of machine (first pass), mm	13-15
ii. Machine parameters	
Width of operation, mm	1,700
Average depth of operation, mm	160
Average forward speed of tractor, km/h	2.14
Tractor wheel slippage, %	15-17
Field capacity of machine, ha/h	0.28
Field efficiency, %	76.65
Fuel consumption, l/h	3.87

Field Performance of Machine at Best Setting

The results of field performance evaluation in terms of field capacity, fuel consumption etc. of the developed machine with best parameters obtained from Investigations No. 1 and No. 2 are presented in **Table 2**. All the measurements were taken by adopting the standard protocols for field experiments. The field capacity of machine with best arrangement of chisel tines (Set-I) having 1.7 m width of coverage, 160 mm depth of cut and 2.14 km/h speed of operation in a clean, tilled and consolidated silty clay loam soil was found to be 0.28 ha/h with 76.65% field efficiency while using a 41 kW tractor. The fuel consumption of the machine was obtained as 3.87 l/h.

Conclusions

On the basis of results obtained from field performance evaluation of ‘Combined Conservation Tillage Machine’ the best positioning of chisel tines on the frame should be at 45° imaginary V-lines with the central longitudinal axis of the frame. This positioning of tines has resulted in minimum draft (9.04 kN), maximum area of soil disturbance (0.228 m^2) and minimum specific draft/resistance (41.81 kN/m^2). Further, by reducing the spacing between the tines such that they could operate within the tractor rear tyres, the developed machine could be used as a ‘Controlled Field Traffic’ machine for better traction and overcoming recompaction of tilled soil.

Acknowledgements

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Optimum Design of a Chisel Plow for Grain Production in the Republic of Buryatia, Russian Federation

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Abstract

A severe climate conditions, specifics of the landscape, and soil diversity are some of the causes of unsustainable grain production in the Republic of Buryatia. The importance of developing technological solutions with regard to energy saving and soil protection criteria are now crucial. The finite element method, used in design of various agricultural machinery for tillage and soil-resistance simulation experiments, was used for analysis and design of a new universal chisel plow for subsoil tillage. The optimal parameters of the designed chisel plow model were obtained using related software that allows rational use of energy and material resources for agriculture use. The chisel plow design was optimized by decreasing its mass and increasing its service life.

Keywords: Chisel plow, Finite element method, Shape optimization, Grain production, Republic of Buryatia

Introduction

Grain production is one of the main sectors of agriculture in the Republic of Buryatia. The severe climate conditions, specifics of the landscape, and soil diversity are among the causes of unsustainable grain production in the republic (Bolonev, 2001). The total sown area is 152,600 ha, with grain and leguminous crops occupying about 56% of this area. Wheat represents the largest share of grain crops, accounting for over 52.7%, followed by oats and barley (Buryat State

Statistic Service, 2016).

The main types of soils on arable land of Buryatia are chestnut soil (43.2%), gray forest soil (22.5%), and black earth (12.3%) (Batudaev *et al*., 2010). During the Soviet period the traditional moldboard cultivation technology which involves multiple passes of tractors and machines in the field has been used in the Republic of Buryatia. Theoretical and technological basis of farming were the recommendations developed in the central regions of the USSR. As a result serious problems of soil compaction and fertility preservation of arable land have arisen and become more acute every year.

There are two significant issues in the basic process of soil tillage: energy and environmental problems. While energy costs increase rapidly due to the operation of a large range of machines, the environmental problem arises from the mechanical impact on the soil, resulting in wind and water erosion. Consequently the importance of developing technological solutions with regard to energy saving and soil protection criteria become crucial (Beluchenko, 1996).

The most promising soil protective, resource-saving technology currently in the Republic of Buryatia is minimum tillage. The minimum tillage method presupposes use of subsoil and deep soil tillage devices, such as the chisel plow. In farming, chisel plows are designed for subsoil tillage of compacted soil layers that prevent natural air and water exchange. Shanks with a chisel knife form the slits, through which there is exchange of oxygen and moisture to the underlying layer of soil. This process improves the condition of the surface layer. Determining the optimal design of a chisel plow allows for efficient use of energy and material resources (Davletshin & Tihonov, 2012; Tsvetkov, M., *et al*., 2012). However, there is insufficient knowledge of optimal parameters for chisel plows.

The purpose of this study was to develop an advanced, resource-saving chisel plow for grain production in the Siberian region, which includes the Republic of Buryatia. The chisel plow design was optimized by decreasing its mass and increasing its service life, using the finite element method (FEM). The proposed design reduced resistance of soil to the working parts and increased operational reliability of the device, as well as quality of the tillage. However, there is insufficient knowledge of optimal parameters for chisel plows.

FEM has become the leading way to reach numerical solutions in evaluating the most significant physical and mechanical features of details, units, and machines, which often arise in the process of machine building. FEM allows elimination of the disadvantages of the original plow model and optimizes its shape. Among the weaknesses of the original model were high energy consumption during soil tillage, low operational reliability, and poor quality of soil crumbling (Alyamovskiy, 2007; Feng & Moses, 1986).

Table 1 Material properties

Property	16 Mn	65 Mn
Density (kg/m^3)	7850	7820
Young's modulus (Pa)	2.12×10^{11}	2.11×10^{11}
Poisson ratio	0.31	0.29
Yield strength (Pa)	3.45×10^{8}	7.85×10^{8}
Tangent modulus (Pa)	7.94×10^{10}	7.94×10^{10}
Tensile yield stress (MPa)	470	735
Ultimate strength (MPa)	660	981

Materials and Methods

Materials

The original chisel plow model had a shank of six holes for attachment to the frame and fixing the 'shank-chisel knife' with two bolts in the longitudinal vertical plane. The material properties are given in **Table 1**. (Zhang, Q., *et al*., 2012).

Methods

FEM

The essence of FEM is to substitute basic isometric construction with complicated geometric forms by sue of a discrete mathematical model that keeps the physical essence and features of the basic detail. The most important part of this model is construction of elementary volume complexes of pre-assigned form united in a finite element composed mesh (Arora, 1989; Inshakov & Natalenko, 2005).

In the present study, use of special software allowed the applying of FEM to static analysis (Araya & Gao, 1995; Basov, 2014; Kaplun A.B., *et al*., 2015). The method has three main parts: the determination of properties of the mechanical structural materials, using static analysis; a shape optimization analysis that requires determining the subsoil chisel structure; and mathematical data processing of the chisel model with the response to surface method and the global optimization method. The model with preset parameters was run and the optimization results determined. The modeling methods include different parameters and main steps for desired shape construction (Abo Al-kheer, A., 2011; Bate & Wilson, 2012; Trushin, 2008). FEM is a numerical solution for structural analysis that demonstrates its applications with ANSYS (Yong & Hanna, 1977).

The meshing is the conversion of a whole model into a number of small elements. Different kinds of meshing are used in the pre-processing and, in the present study, tetrahedral mesh was used for high accuracy. The number of elements represents the solution accuracy of the model (Kharmanda *et al*., 2009).

Shape optimization

Nine parameters for shank shape optimization were used: shank length, handle thickness, bolt hole depth, bolt hole diameter, bolt hole position, abscissa A in central ditch, ordinate A in central ditch, abscissa B in central ditch, ordinate B in central ditch, central ditch depth, and central ditch width.

Mathematical methods

Mathematical data processing during development of the chisel shank model was used with the response to surface method. The global optimization method was maintained for determination of the parameter values of the best model. Finally, the model characteristics before and after the improvement were compared.

General elements of the chisel plow optimization analysis using appropriate software are shown in **Fig. 1**.

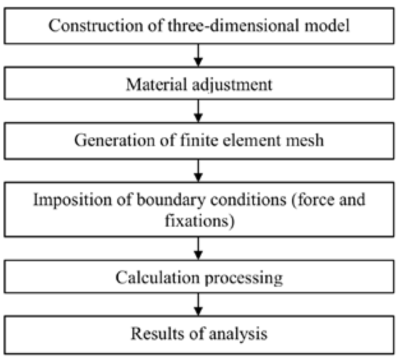


Fig. 1 Phases of finite element analysis of construction

Results and Discussion

Results of the Static Analysis of the Original Chisel Plow Model

The mesh view of original shank, knife, and chisel plow after assembly is given in **Fig. 2**. The static analysis was used to quantitatively assess the structure deformation and stress state. A description of the original chisel plow model is given in **Table 2**.

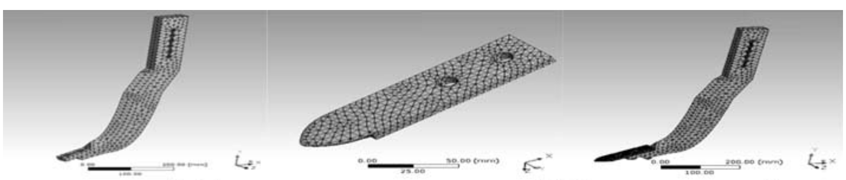
The shank material of the original model was 16 Mn steel (Young's modulus 2.12×10^{11} Pa and Poisson's ratio 0.31). Shank model mass was 12.68 kg. The total number of the finite element model was 5224 and the total number of nodes 8927 (**Fig. 2a**). For control distribution under the mesh, the shank and knife were divided into finite elements 15 and 5 mm, respectively (**Fig. 2**).

The chisel knife of the original model had a simple structure (**Fig. 2b**), with 65 Mn steel as the material, because it possesses good mechanical properties. It weighed 0.43 kg. The total number of the model finite elements was 4582 and the total number of nodes 7888.

Force and fixation conditions were used as boundary conditions. The surface of the chisel knife was connected with a shank and fixed by six bolts. To determine elastic deformation to the toe of the chisel knife, forces of + 3500 N in the X direction and -2500 N in the Z direction were applied (**Fig. 3**). According to the previous studies the static force matches the dynamic force required for chiseling at a depth: 300; 350;400 mm; and at a speed: 4; 4.5; 5 km/h. Based on this knowledge we use 4301.2N of +3500 N in X axis and -2500 N in Z axis (Zhang, Q., *et al*., 2012).

The software reports the results of the analysis as a three-dimensional model, giving different zones various colors that correspond with the range of the appropriate physical feature. Four types of analysis were applied to the original chisel plow model.

For the original chisel plow model, after assembly and under action of the force, the maximum equivalent stress was 112.62 MPa, the maximum equivalent elastic strain was 5.34×10^{-4}, and total deformation was 1.48 mm (**Fig. 4**). Results of the static analysis of the original chisel plow model are given in **Table 3**.



a) shank **b**) knife **c**) assembled

Fig. 2 Meshed model

Table 2 The original chisel plow model description

	Material, steel	Mass (kg)	Mesh (mm)	Number of elements	Number of nodes	Force (N)
Shank	16 Mn	12.68	15	5224	8927	X +3500 Y −2500
Knife	65 Mn	0.43	5	4582	7888	X +3500 Z +2500
Assembled	16 Mn; 65 Mn	13.22	15; 5	11142	19846	X +3500 Y −2500

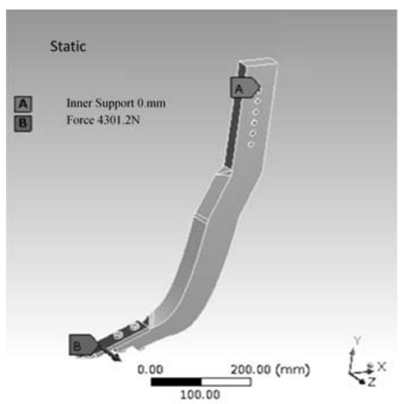
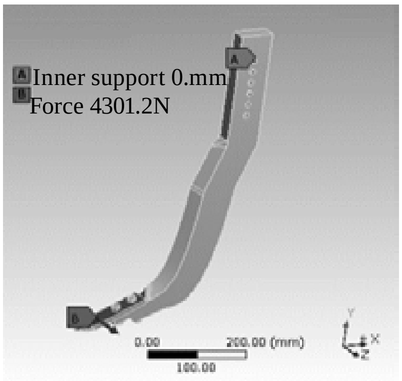
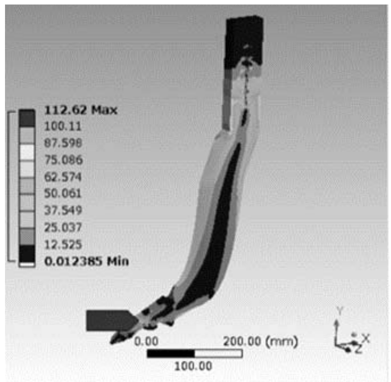


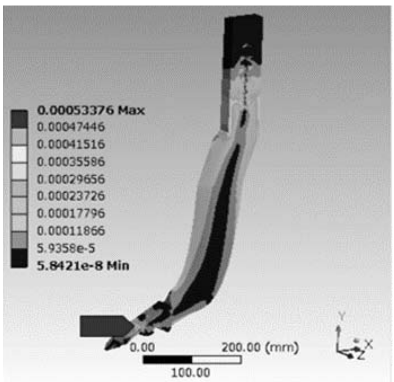
Fig. 3 Boundary conditions



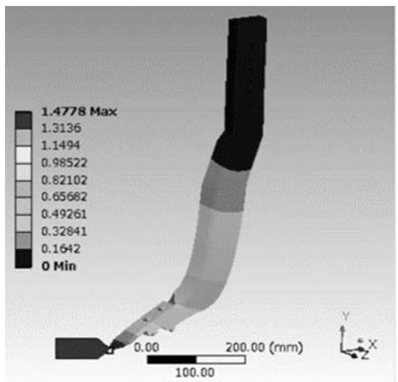
a) Boundary conditions



b) Equivalent stress (MPa)



c) Equivalent elastic strain (mm/mm)



d) Total deformation (mm)

Fig. 4 Results of static analysis for the original model

Table 3 Results of the static analysis of original chisel plow model

	Mass (kg)	Equivalent stress (MPa)	Equivalent elastic strain (mm/mm)	Total deformation (mm)
Shank	12.68	105.24	4.96×10^{-4}	0.99
Knife	0.43	170.15	8.06×10^{-4}	0.28
Assembled	13.22	112.62	5.34×10^{-4}	1.48

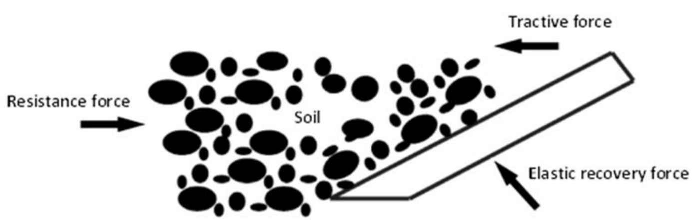


Fig. 6 Mechanical analysis of knife of the chisel plow

a)

b)

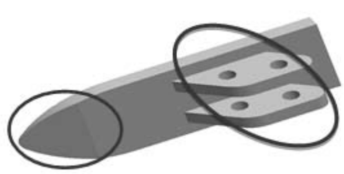


Fig. 7 Chisel shank (**a**) and knife (**b**) after optimization of the three-dimensional model

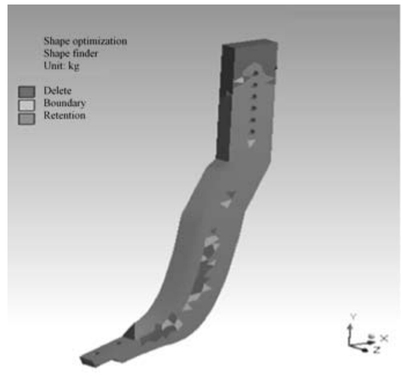


Fig. 5 Results of shape optimization for the shank

Shape Optimization

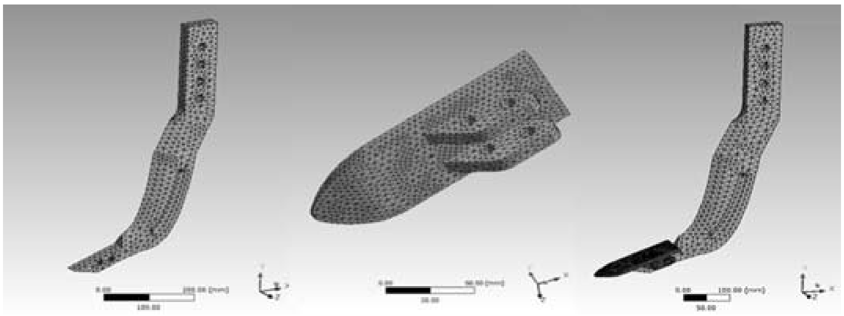
Shape optimization results for the shank of chisel plow are given in **Fig. 5**. In real conditions, the program calculations are difficult to implement. By considering the initial parameters and results of the static analysis, it was decided to reduce the mass of the part by 8% instead of the 20% offered by the program.

The chisel plow works under three balanced forces (**Fig. 6**). The static analysis demonstrated that the original model had equivalent stress of 170.15 MPa and tensile ultimate strength of 981 MPa. Thus, deformation change to the chisel plow was minor, and this was confirmed by the static analysis results. Therefore, we decided to change the shank and knife fixation.

The chisel shank and chisel knife after optimization of the three-dimensional model effect are shown in **Fig. 7**. The mesh view of the optimized shank, knife, and assembled chisel plow is given in **Fig. 8**. The description of the optimized chisel plow model is given in **Table 4**.

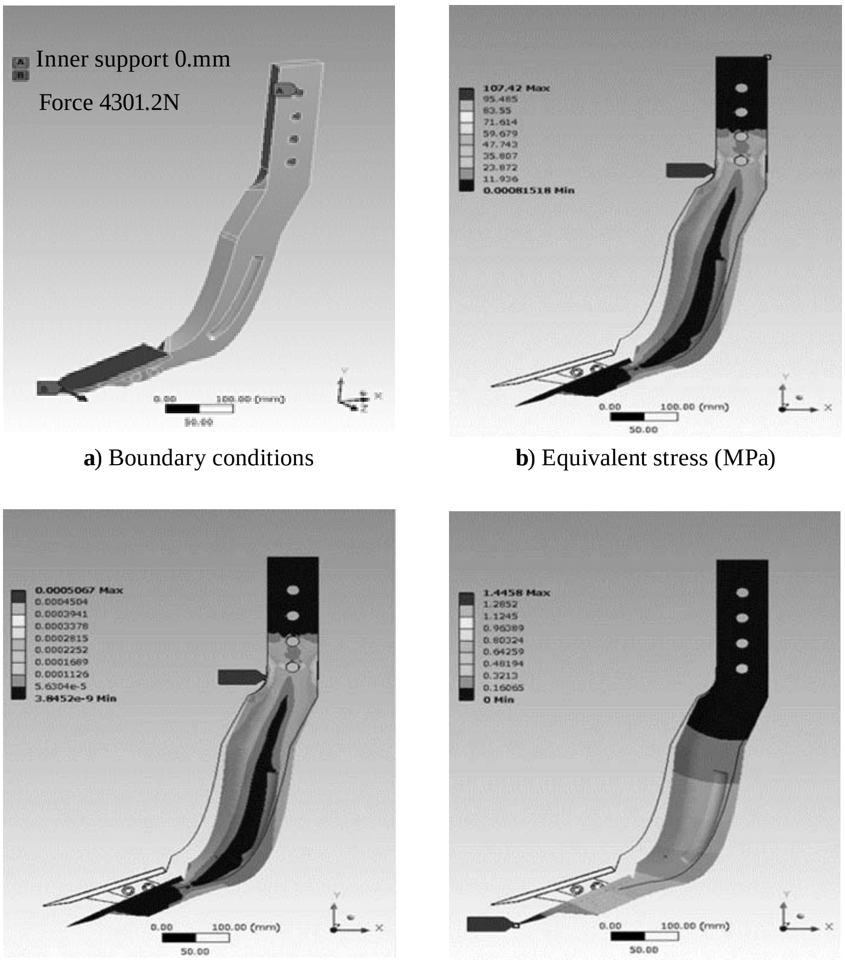
Results of Static Analysis of the Optimized Chisel Plow Model

The optimized model of the chisel plow, after assembly and under action of the force, had maximum stress of 107.42 MPa, maximum elastic strain of 5.07×10^{-4} mm/mm, and total deformation of 1.45 mm (**Fig. 9**). Results of the static analy-



a) shank **b**) knife **c**) assembled

Fig. 8 Meshed optimized model



a) Boundary conditions **b**) Equivalent stress (MPa)

c) Equivalent elastic strain (mm/mm) **d**) Total deformation (mm)

Fig. 9 Results of static analysis for the optimized model

Table 4 The optimized chisel plow model description

	Material, steel	Mesh (mm)	Number of elements	Number of nodes	Force (N)
Shank	16 Mn	15	5420	9432	X +3500 Y −2500
Knife	65 Mn	5	12688	20853	X +3500 Z +2500
Assembled	16 Mn; 65 Mn	15; 5	11142	19846	X +3500 Y −2500

sis of the original model are given in **Table 5**. The results indicated that for the same action of force, the maximum equivalent stress of the optimized model decreased by 4.6%, the maximum equivalent elastic strain of the optimized model decreased by 2.1%, and total deformation of the optimized model decreased by 5%; additionally, mass of optimized construction decreased by 8%. Total deformation for knife is 0.027 mm. The knife deformation is one tenth of the original since the modification occurred in the chisel shank structure, specifically in the edge shape where knife is attached, total deformation for knife decreased from 0.28 to 0.027.

Parametric Results

The parametric results concerning equivalent stress, equivalent elastic strain, total deformation, and mass showed that the optimized model of chisel plow was more practicable than the original. Construction of the optimized model of the chisel plow was also more practicable for farm use. The proposed model reduced resistance of soil to the working parts and increased operational reliability of the device, as well as the quality of tillage.

Conclusions

An optimum design of chisel plow for grain production in the Republic of Buryatia was developed to solve the problem concerning energy saving and soil protection criteria. The proposed model reduced resistance of soil to the working parts and increased operational reliability of the device, as well as the quality of tillage.

Data of the equivalent stress, equivalent elastic strain, total deformation, and mass were obtained using the FEM to determine the optimum design of the chisel plow; these values for the optimized construction have decreased by 4.6, 2.1,

Table 5 Results of the static analysis of optimized model

	Mass (kg)	Equivalent stress (MPa)	Equivalent elastic strain (mm/mm)	Total deformation (mm)
Shank	10.75	88.56	4.18×10^{-4}	0.98
Knife	1.29	27.79	1.32×10^{-4}	0.027
Assembled	12.16	107.42	5.07×10^{-4}	1.45

5, and 8% compared with the original design, respectively. Optimization of the chisel plow design was achieved by decreasing its mass and increasing its service life.

The results of the analysis depend on the physical and mechanical properties of the soil. Further experiments in real farm conditions are necessary to verify the analysis and determine the degree of discrepancy.

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Simulation of Monkey and Human Climbing Up the Palm Tree


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Abstract

Climbing the palm tree for treatments is a tedious and dangerous task which has to be done between 5 to 7 times in each growing season. Youngsters are reluctant to do the work and elders do not have enough energy. Some kind of powered machine is needed to climb the tree while carrying a worker with it.

Two robots have been designed and partly fabricated by Behroozi Lar which simulates the exact steps of a Monkey or human climbing the palm. The exception is that this robot is six legged rather than a four legged Monkey or three metal ropes around the tree rather than one rope that the workers use. The machine is composed of three major parts: 1) control parts; 2) hydraulic and 3) mechanical components. The machine works with a 5 kW engine and can be operated electronically by remote control, automatically by pushing a key or by the worker. A hydraulic block makes the ropes step up or down. Through control valves, it operates valves to open or close hands or loosen and tighten each ropes round the tree trunk to climb up or down the tree. The mechanical parts include the chassis which carries the 5 kW gasoline engine, the operator stand and holds the hands or ropes operational.

The machine; the size of an average human can be carried by hand from one tree to another no matter what the spacing between the palms. It can climb a 15 m tall palm in less than 3.5 minutes that is faster than the speed of a worker. The cost of operation is much less than human work also. The machine is much cheaper than any tractor operated machine named palm harvester. The hydraulic block has been fabricated and tested successfully.

Such a machine is very much in demand for the Middle East palm growing region including Saudi Arabia, Kuwait, Iraq, Iran, UAE, Jordan, Oman and elsewhere.

Keywords: climber, Palm, robot, Middle East, powered

Introduction

Climbing the palm tree for treatments is a tedious and dangerous task which has to be done between 5 to 7 times in each growing season. Youngsters are reluctant to do the work and elders do not have enough energy. Some kind of powered machine is needed to climb the tree while carrying a worker with it. Such a machine is most needed especially for the main growing date fruit countries such as the Middle East states. Dates in the Middle East are eaten as a staple food rather than the California Madjool dates which is served as desert [18].

Many equipment are available for reaching up the trees in the markets [4 and 6] but they are for sports and or hunting [19 and 20]. See for example **Fig. 1**. These are neither implements nor a climber. None serves for the purpose of treating the palm trees such as trimming, sawing dead leaves, pollination, spraying, sacking (**Fig. 2**) the fruit, harvesting and so forth [7].

Several models and methods however designed and developed for dates harvesting [2, 9, 11, 12, 14 and 15]. Literatures are also available for dates mechanization [5, 13], and services [17]. Most of these devices or models may be good for smooth tree trunks such as coconut [8] not for logy palm trunk. The idea of finding a model backs to 1965 [1].

Light weight ladders are used in California for trees not even half as tall as the ones in the Middle East. But ladders have many fatality and injuries. It is reported [3] that thousands are injured and hundreds are killed every year. The same report indicates that the ladder related injuries have increased by 50% during the past 10 years.

A mechanical foot operated climbing device exist which is good for soft trunk trees only and does not carry a power source with it either. A power operated saddle is shown in **Fig. 3** which may work only in mechanized farms with enough row spacing and level ground like in **Fig. 4** but not in irregularly spaced trees in the Middle East (**Fig. 5**) and lumpy surface. Such a powered elevator was made in Iran (**Fig. 6**). Ten pieces were purchased by the ministry of agriculture and distributed among dates grown provinces for harvesting. None worked for even one day.

Materials and Methods

The Robot's Description

Two models were developed: 1) which imitates the way a monkey climbs the tree (**Figs. 7** and **8**) and is shown in **Figs. 9** and **10** and **2**) which simulates the usual human rope climbing (**Figs. 11** and **12**). The main parts of both models are the hydraulic block and a 5 kW 2-stroke gasoline engine. The difference between the two models is in their mechanical parts only. The second model which is an improvement of the first, fits better and safer for climbing the palm tree because it is more adjustable to the trunk diameter and has a better grip. Both models climb up or down the tree in paces of 4.8 m/min but it can easily be changed to much more speed by only changing the spine hydraulic cylinder length. The size of the machine as it is now is about the size of a human which can easily be transported from one tree to another no matter how irregular the tree row spacing or the ground surface. The basic human like climber model is shown in **Fig. 13**. Both models can be carried on a three wheeled carrier as shown in **Fig. 14**.

Operation

Climbing up or down a tree involves the six following steps (**Fig. 15**). Descriptions are given in **Ta-**


Fig. 1 Stand for hunting


Fig. 2 Sacking the fruit


Fig. 3 Fork lift for harvesting


Fig. 4 Mechanized culture


Fig. 5 Irregular cultivation in Middle East


Fig. 6 A telescopic cylinder for harvesting


Fig. 7 Spine contracted


Fig. 8 Spine stretched

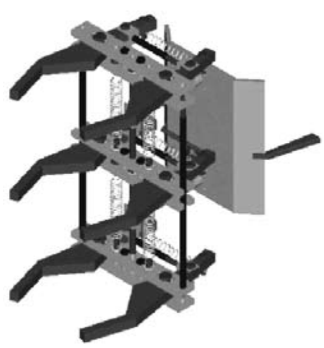


Fig. 9 A robotic Monkey

Fig. 10 Climbing up the tree

bles 1 and **2**.

Hydraulic Circuitry

Hydraulic circuitry of both models is shown **Fig. 16**. Description of the components by number are shown beside the figure.

Calculations for the Human Simulation Model

The following were assumed or calculated:

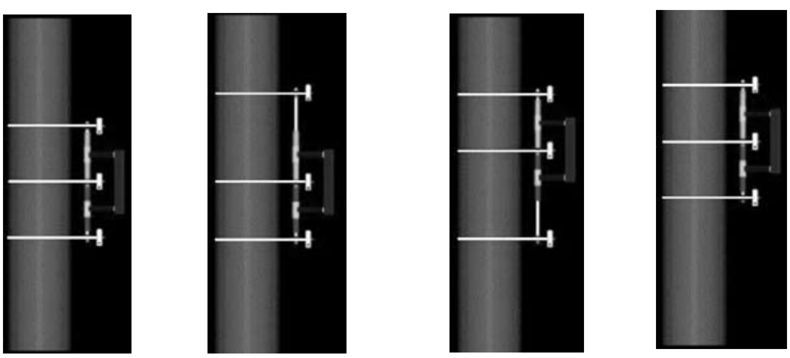
1. a 20 bar working pressure

Fig. 11 Human climbing by rope in Oman

Fig. 12 The robot do the same as Fig. 11 and safer.

Fig. 13 The human simulation robot

Fig. 14 The robot is carried to the tree



Step 0 Step 1 and 2 Step 3 and 4 Step 5 and 6

Fig. 15 Six steps to climb one pace/

2. Climber speed 80 mm/s.
3. Friction coefficient between tree trunk and metal = 0.25.
4. Weight of operator = 600 N.
5. Total weight of machine including the operator = 800 + 1200 = 2,000 N.
6. Hydraulic cylinder wall thickness = 2.5 mm.
7. Steel specific mass = 7,800 kg/m^3

The hydraulic power was calculated from equation (1)

$P_{hyd} = (Q \times \Delta p) / (600 \times e_p)$ ....(1)

Where: P = pump power, kW

Q = fluid flow, l/min

Δp = pressure drop, bar

e_p = pimp efficiency = 0.8

and the engine power from equation (2)

$P_{eng} = (P_{hyd} / e_{eng}) \times 2.5$ ....(2)

Where: P_{eng} = engine power, kW

e_{eng} = engine mechanical efficiency = 0.7

2.5 = the design factor

The selected engine was a 5 kW, 2 stroke gasoline type.

The required flow for the mentioned climbing speed was calculated to be 24 l/min. Therefore an external gear pump with 20 bar pressure and 24 l/min output pump was selected

The spine piston rod diameter to carry the assume 2,000 N load was calculated to be 50 mm and its piston rod of 400 mm long.

The ram's cylinders extension of 100 mm beyond the tree trunk diameter is adequate to open hand and legs or slacken the spring wire rope.

The buckling of the piston rod was calculated from equation (3) bellow:

$F = 9.81\ \pi^2 E J / L^2 S$ ....(3)

Where: F = allowable buckling load, N

E = module of elasticity = 20.6 × 10^6 (for steel), N/cm^2

J = second moment of area of the piston rod = π d^4 / 64, cm^4

L = free (equivalent) buckling length, = 2l cm

l = total length of piston rod when fully extended.

S = safety factor = 3.5

Which turned out the permissible load is much less the total weight of machine and operator.

The spine piston rod diameter was calculated from equation 4 bellow,

$A = F / \Delta p$ ....(4)

Where: A = piston rod area, m^2

F = weight on the rod, kN

Since A = $(\pi \times D^2) / 4$ then the rod diameter, D in m, will equal,

$D = \sqrt{4F / (\pi \times \Delta p)}$ ....(5)

Table 1 Steps for climbing up and coming down one pace for a Monkey (**Figs 7** and **8**)

Climbing up		Coming down	
step	action	step	action
0	Hands and legs closed on tree trunk	0	Hands and legs closed on tree trunk
1	Hands open	1	Legs open
2	Spine stretched up	2	Spine stretched down
3	Hands closed on trunk	3	Legs closed on trunk
4	Legs open	4	Hands open
5	Spine detract up	5	Spine detract down
6	Legs closed on trunk	6	Hands closed of trunk

Table 2 Steps for climbing up and coming down one pace for a worker by rope (**Fig. 11**)

Climbing up		Coming down	
step	action	step	action
0	Legs pressing on the trunk and spine pushing backward to tighten the rope on the trunk.	0	Legs pressing on the trunk and spine pushing backward to tighten the rope on the trunk.
1	Hand on the rope, spine bent forward to slacken the rope.	1	Hand on the rope, legs free down.
2	Rope rolled up by hand and spine stretched up.	2	Legs push tight against trunk.
3	Spine backward to tighten the rope.	3	Spine forward to slacken rope.
4	Legs free up.	4	Rope rolled down by hand.
5	Spine detract up.	5	Spine retract down
6	Legs push on the trunk.	6	Spine backward to tighten the rope on the trunk.

Conclusions

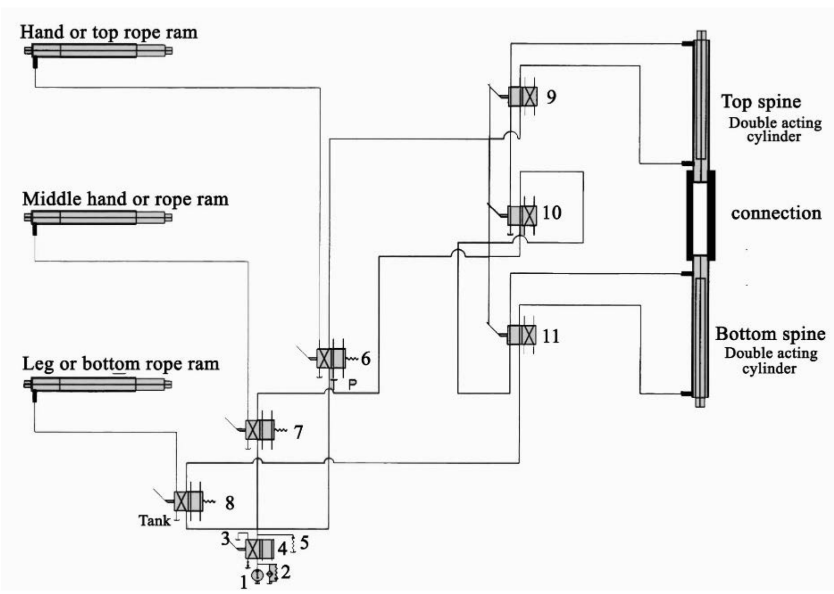
The designed machine for human simulation climbing with rope works better and safer than the monkey model one. The ropes stand on the tree trunk at an arbitrary angle of 15 degree with respect to horizon guarantees the absolute safety even if the hydraulic block fails completely.

The machine work capacity per day is at least 5 times faster than a customary manual climbing.

The engine power after reaching the top of the tree may be used for power devises such as saw, pollinator, sprayer and other tasks taking off the burden of the laborer.

The climber works just like an elevator except for its discrete movement and valves manipulation by the driver.

The described machine is a basic design but can easily be redesigned for improvements. The present design can be operated by anyone old or young while enjoying the work. No fear of future labor shortcom-



No.	Description of **Fig. 16**
1	Hydraulic Pump
2	Filter
3	tank
4	Main 2 × 4 (2 position 4 ports) valve
5	Safety valve
6	Hand or top rope 2 × 4 valve for climbing up
7	Middle hand or middle rope 2 × 4 valve for climbing up
8	Leg or bottom rope 2 × 4 valve for climbing up
9	Hand or top rope 2 × 4 valve for coming down
10	Middle hand or middle rope 2 × 4 valve for coming down
11	Leg or bottom rope 2 × 4 valve for coming down

Fig. 16 Hydraulic circuitry and components for the robots

ings that highly affect the dates production and exports from the Middle East states.

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Indian Agriculture Counting on Farm Mechanization

by

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Abstract

The mechanization of Indian farms is imperative to enhance input use efficiency, reduce human drudgery, increase production and productivity of food-grains, reduce cost of production and to address issues of labour scarcity and timeliness of farm operations. The status of farm mechanization for different crops, farm power availability, farm machinery manufacturing and sale, standardization and testing, and Government initiatives to ensure mechanization of Indian agriculture are assessed in this study. The total farm power availability in Indian agriculture was 2.24 kW/ha in 2016-17. It had a share of 1.324, 0.018, 0.021, 0.460, 0.193, 0.091 and 0.130 kW/ha from tractors, power tillers, combine harvesters, diesel engines, electric motors, humans and draught animals, respectively. The overall mechanization levels for rice, wheat, maize, sorghum, pulses, oilseeds, cotton and sugarcane crops were 45, 63, 40, 26, 34, 34, 26 and 24%, respectively. The increasing trend in establishment of custom hiring centres and hi-tech hubs along with farm machinery banks at village level has ensured availability of modern agricultural machinery for different field operations to small and marginal farmers. The quality of farm equipment is ensured by testing involving laboratory and field performance evaluation and followed by certification at designated testing centres. There is a need to innovate custom service or a rental model by institutionalization for high cost farm machinery to reduce the cost of operation.

Key words: Agricultural machinery, Custom hiring, Farm power availability, Mechanization level, Test code

Introduction

Indian agriculture employs about 52% of total work force with a GDP (at constant price 2011-12) contribution of 15% (2016-17). It contributes to 25, 22, 13 and 25% of the global production of pulses, rice, wheat and cotton, respectively. Indian economy is also influenced by agriculture and allied sectors besides its volatile nature of production. In recent past, India has witnessed a major shift in economy from agriculture to service sector with a GDP contribution of 54% (2016-17). Over the years, Indian farming system has not given an expected remuneration to farmers besides its remarkable growth in food-grain production and processing sectors. However, agriculture remains as principal means of livelihood for over 58% of the rural households.

It is the prodigy of soil of India that it provides food to 1.3 billion population with just an average farm size of less than 1.08 ha. Small and marginal land holdings (< 2.0 ha) contribute to 86% of total operational land holdings and cover 47% of total operated area (Anonymous, 2018). The varied soil, climatic condition, topography, flora and fauna throughout country increase the challenges of timeliness in farm operations, uniformity in technology adoption and availability of location specific farm implements and machinery (Mehta *et al.*, 2014a). Hence, agricultural mechanization plays a complementary role to address the above situations and to contribute in increasing production, productivity and profitability in agriculture by achieving timeliness in farm operations, enhancing input use efficiency, reducing unit cost of production with increasing competitiveness. In addition to timeliness in farm operations, it also reduces labour requirement and human drudgery. This subsequently balances the labour requirement between agriculture and agro-based industries.

The agricultural mechanization is at an early stage in India and growing at 7.5% per annum inspite of challenges of small land holdings, cropping pattern, market prices of crops, minimum support price (MSP) and government policies and legislations. The ignorance of these challenges will exaggerate the redundant labour force, low return against inputs for yield and ultimately decrease the enthusiasm in agriculture. Further, in the near future Indian agriculture may require energy intensive agriculture with higher input use efficiency, better soil health management practices and value addition to produce in production catchments. This may be due to low probability of increase in net cultivated area and scarcity of agriculture labour. Therefore, an attempt has been made in this paper to study the present scenario of farm power availability, farm mechanization levels for major crops, and Government initiatives to assure the availability of farm machinery at village level and to ensure quality manufacturing along with promotion of the farm mechanization on a large scale.

Farm Power Availability

The production and productivity of food-grains are considered as factors of available mobile farm power sources like tractors, draught animals, power tillers, combine harvesters, agricultural workers and stationary power sources like diesel engines and electric pump sets/motors. The time-series data on farm power sources and agricultural production of India were compiled and used in the study. The secondary data related to food-grain productivity, net sown area, and other relevant agriculture statistics were collected and compiled from various sources such as Agricultural Statistics and Agriculture Census published by the Directorate of Agriculture, and Basic Agricultural Statistics and Livestock Census published by Government of India. The data on population of agricultural workers (men and women) and draught animals (exotic cattle/cross breeds, indigenous cattle and buffaloes) were collected and compiled from the Population Census 2011 and Livestock Census 2012 (Anonymous, 2014a), respectively published by the Government of India. The data on population of tractors and power tillers were collected and compiled from Tractor Manufacturers Association (TMA) and Power Tiller Manufacturers Association (PMA), respectively. The data on population of diesel engines and electric pump sets/motors were collected from Report of study on "Pilot project to ascertain the use of diesel for irrigation" and Agricultural Research Data Book 2017, respectively (Ranganathan et al., 2016; Anonymous, 2017a).

The power availability from different farm power sources was calculated by taking an average power of 0.05, 0.38, 5.60, 3.70 and 5.60 kW for an agricultural worker, draught animal, power tiller, electric motor and diesel engine, respectively (Anonymous, 2014b). However, power availability from tractor was estimated by taking an average power of 13.4, 18.7, 26.1, 33.6 and 41.0 kW for the power range of <14.9, 15.7-22.4, 23.1-29.8, 30.6-37.3 and >38.0 kW, respectively. The life of tractor, power tiller, combine harvester, electric motor and diesel engine was considered as 15, 10, 6, 15 and 15 years, respectively. Total power availability on Indian farm was calculated by dividing sum of total power by total cultivated land of 140 million ha (Goering, 1992; Bector *et al.*, 2008; Mehta *et al.*, 2014b).

It was observed that the percentage of agricultural workers to total workers decreased from 59.1 in 1991 to 54.6% in 2011 and projected to be 40.6% in 2020 of which 45% will be women workers. This is undoubtedly due to much lower wages in agriculture as compared to industry and the disguised unemployment leading to extensive labour migration. The farm power availability from human was 0.091 kW/ha in 2016-17. The population of draught animals in the country reduced from 78.42 in 1971-72 to 47.46 million in 2016-17. The power availability from this source has come down from 0.221 kW/ha in 1971-72 to 0.130 kW/ha in 2016-17. During the year 2016-17, the population of tractors, power tillers, combine harvesters, diesel engines and electric motors was 6.35, 0.46, 0.04, 11.48 and 7.50 million, respectively. The corresponding farm power availability from tractors, power tillers, combine harvesters, diesel engines and electric motors was calculated as 1.324, 0.018, 0.021, 0.460 and 0.193 kW/ha, respectively. The total farm power availability was 2.24 kW/ha during 2016-17. During the same period, the farm power availability from mobile (human, draught animal, tractor, power tiller and combine harvester) and stationary (diesel engine and electric motor) sources was 1.585 and 0.650 kW/ha, respectively. In the mobile power sources category, power availability from tractor was the highest (1.324 kW/ha) whereas in the stationary power availability, diesel engine had the highest share of 0.460 kW/ha. This indicated growing trend towards use of mechanically operated farm equipment over traditional human and animal powered equipment implying adoption of mechanization on Indian farms.

Farm Mechanization Levels

The farm mechanization has an inbuilt advantage to make farmer's daily life more comfortable by reducing labour requirement and drudgery associated especially of women workers. Hence, mechanized farming will be an indicator of high standard and good management systems during agricultural operations along with upgrading the standard of living of farmers and agricultural workers. The mechanization levels in different farm operations such as seedbed preparation, sowing/planting/transplanting, weeding/interculture, plant protection, and harvesting and threshing for major crops (rice, wheat, maize, sorghum, millets, pulses, oilseed, cotton and sugarcane) production systems were assessed. The crop wise and overall mechanization levels were calculated by taking an average of operation wise and weighted mechanization levels.

The farm mechanization levels assessed for major cereals, pulses, oil-seeds, millets and cash crops are given in **Table 1**. It indicates that the seedbed preparation operation is highly mechanized (more than 50%) for major crops whereas harvesting and threshing operation is the least mechanized (lower than 30%) for major crops except for rice and wheat crops. In seedbed preparation, mechanization level is higher in rice and wheat crops as compared to other crops. However, mechanization level for sowing operation is the highest for wheat crop (60%). The mechanization levels in planting/transplanting operation for sugarcane and rice crops are only 10 and 20%, respectively. In case of harvesting and threshing, the mechanization levels in rice and wheat crops are more than 60% and there is no mechanization in cotton crop. The overall farm mechanization levels for rice, wheat, maize, sorghum and millets, pulses, oil-seeds, cotton and sugarcane crops are 45, 63, 40, 26, 34, 34, 26 and 24%, respectively. The overall farm mechanization level of the country is 40% which is lower than other developing countries such as China - 59.5% (Fang, 2017) and Brazil - 75%.

Table 1 Mechanization levels for major crops in India

	Mechanization levels for field operations, %			
Major crops	Seed bed preparation	Sowing/ planting/ transplanting	Weeding and interculture and plant protection	Harvesting and threshing
Rice	70	20	30	60
Wheat	70	60	50	70
Maize	60	40	30	30
Sorghum and millets	50	30	15	10
Pulses	50	40	20	25
Oilseed	50	40	20	25
Cotton	50	30	25	0
Sugarcane	55	10	20	10

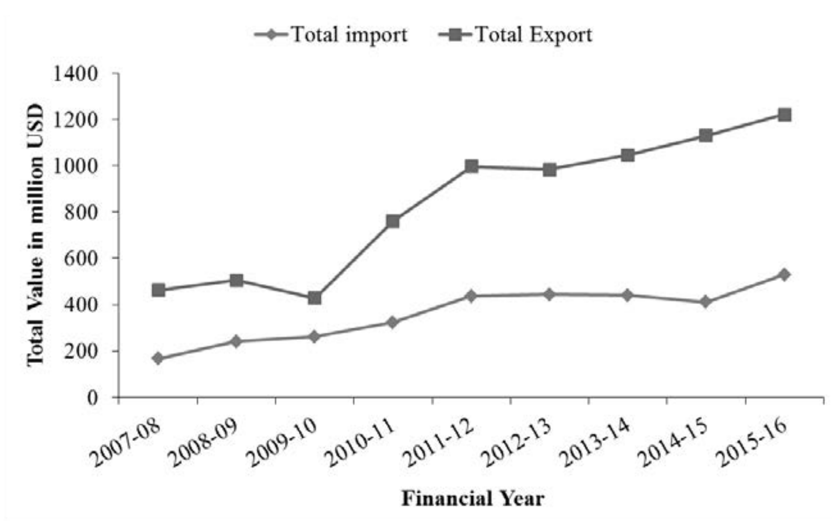

Fig. 1 Total export import of selected agricultural machinery and equipment

Farm Machinery Manufacturing and Sale

The Government of India is emphasising on increasing mechanization levels for different crops to enhance crop productivity with reduced energy consumption. Now, in India there are 250 medium to large scale manufacturing units, 2,500 small scale industries, 15,000 tiny industries and about 100,000 village level artisans manufacturing farm machinery and equipment. The farm machinery industry has grown at Compound Annual Growth Rate (CAGR) of 7.5% and reached capital value of USD 7.30 billion. In monetary terms, tractor and major agricultural machinery industry has generated an amount of US$ 4.4 billion during 2015-16 (Anonymous, 2014b). The values of total import and export of farm machinery during the year 2015-16 were US$ 530 and 1221 million, respectively (**Fig. 1**). Sugarcane harvesters, cotton pickers and rice transplanters are the major agricultural machinery being imported by India. Numbers of Indian farm machinery manufacturers are also exporting farm machinery to south Asian countries and developing countries.

Tractors play an important role in mechanization of Indian agriculture. The Indian tractor industry is the largest by volume in the world and accounts for one third of global production. In India, 29 tractor manufacturing units are established so far by 21 tractor manufacturing companies. The tractor segment is dominating Indian market and is expected to reach revenue of $6500 million by 2019. Mahindra & Mahindra Ltd., Mumbai is market leader with 42.7% share in sale of tractors in India and closely followed by TAFE, Chennai. The sale of tractors increased at a CAGR of 9.75% during last 56 years and reached a level of 711,478 units in 2017-18. The current trend in sale of tractors indicated the highest share of 49% for 31-37 kW category tractors and followed by 35% share for 23-30 kW tractors. The requirement of high power category tractors in India increased for using high capacity farm machines on custom hiring basis. The population of tractors in India reached to 6.90 million in 2017-18 as compared to 3877 units in 1961-62. The trend of increasing sale of tractors over the years indicates a rising acceptance of tractor operated agricultural machinery and equipment by farmers. It was also observed that rainfall pattern, land holding size and government policies affected the sale of tractors in India.

The current market for power tillers in India is estimated at 50,000 numbers during 2016-17. The market for power tillers in India is mainly concentrated in the eastern and southern parts of the country owing to small land holdings per farmer in these regions and cultivation of rice crops. The power tillers market in India is dominated by two players from south India viz. VST Tillers Tractors Ltd., Bengaluru (Karnataka) and Kerala Agro Machinery Corporation Ltd. (KAMCO), Athani (Kerala). These two companies collectively cater to more than 68% of the market. The remaining market is catered by power tillers mainly imported from China. Imports from China now accounts for about 30 per cent of the total industry sale as compared to 10% market share enjoyed by imported tillers a few years back. The demand for power tillers imported from China is growing on account of it being about 10-20 percent cheaper than its Indian counterpart. The power tiller industry is expected to grow in future owing to the Government subsidy, good monsoon, availability of easy financing and non-availability of labour in the agriculture sector.

The market for combine harvesters in India is estimated at 4,500-5,000 units per annum and catered by more than 50 manufacturers. The tractor mounted and self-propelled combine harvesters occupy around 60 and 40%, respectively of the total combine harvesters market in India. The tractor mounted combine harvesters are mainly used on custom hiring in southern states viz. Tamil Nadu, Kerala, Andhra Pradesh and Karnataka of the country. Farm machinery manufacturers from Punjab state such as CLAAS India Ltd., Preet Agro Industries Pvt. Ltd, Balkar Combines, Vishal Combines, Standard Combines, Kartar Agro Industries Pvt. Ltd, Hira Agro Industries, etc have a strong presence in the combine harvester market in India.

In India, the sale of transplanters, power weeders, combine harvesters, rotavators and threshers is growing at a CAGR of 50, 50, 28, 20 and 10%, respectively (Mehta *et al*., 2014a). Farmers prefer power weeders for interculture operation, tractor drawn as well as knapsack sprayers for plant protection and combine harvesters for grain harvesting. Farmers are using high capacity and energy efficient machinery such as laser guided land levellers, rotavators, planters, zero till drills, self-propelled rice transplanters, threshers (multi-crop and paddy) and combine harvesters on custom hiring. These technologies will help in protecting and managing soil and water resources with reduced power and labour requirement and investment on tractor and equipment. However, the practice of farm mechanization with conservation agriculture is still to be popularized to increase its adoptability and to stop burning of crop residue in combine harvested fields. This will not only reduce energy requirement for crop production but also provide solution for controlled traffic farming and bed planting.

Now, most of tractor manufacturers have also started manufacturing and sale of farm equipment and machinery in country. They are providing complete farm mechanisation solution for wheat and paddy crops. Number of world leading farm machinery manufacturers such as John Deere India Pvt. Ltd., BCS India Pvt. Ltd., Lemken India Agro Equipment Pvt. Ltd., Maschio Gaspardo India Pvt. Ltd., Yanmar India Pvt. Ltd., Kubota Agricultural Machinery India Pvt. Ltd., etc. have also established their farm machinery manufacturing units in India to cater to the needs of Indian market (Mehta *et al*., 2014a).

Standardization and Testing of Farm Machinery

The adoption of agricultural machinery is greatly influenced by testing/standardization, quality control and after sale services available to the farmers. Standardization and quality of farm implement and machinery manufacturing in India is ensured mainly by FAD 11 committee of BIS and over 500 standards on agricultural machinery are prescribed. The BIS test codes are available for most of the tillage machinery. However, there is a need to develop test code for laser guided leveller, vegetable transplanter, mulch laying machine, raise bed planter, specifications of rotavator blade, manure spreader, spiral seed grader, turbo happy seeder, straw mulcher, pneumatic planter, groundnut digger, automatic nursery raising machine, pre-geminated paddy seeder, fruits and vegetable graders, paddy thresher cum winnower, straw baler, hay rake, post hole digger, onion digger, rice straw chopper, etc. In the present scenario, minimum performance standard for all the agricultural machinery need to be developed to ensure the quality of farm machinery manufacturing.

The testing of farm machinery/equipment is of utmost importance to ensure quality of newly developed machinery and to facilitate for export. The testing involves laboratory and field performance evaluation of farm machinery and followed by certification at a designated testing centre. Testing is conducted with well-defined standard parameters defined by Bureau of Indian Standards (BIS), ASABE, ISO and OECD standards. The Government of India established four farm machinery testing stations in Central (CFMTTI, Budhni), Northern (NRFMTTI, Hisar), Southern (SRFMTTI, Anantpur) and North-Eastern (NEFMTTI, Biswanath-Chariali) regions of the country. The establishment of six new centres of Farm Machinery Training & Testing Institutes (FMTTIs) is proposed in the states of Uttar Pradesh, Maharashtra, Gujarat, Bihar, Odisha and Chhattisgarh. The testing network is further strengthened by establishment of 32 specialized farm machinery testing centres in country. These centres include 22 centres at State Agricultural Universities, 4 centres at ICAR institutes, 4 centres at state government institutes, one each at Central Agricultural University and at Indian Institute of Technology Kharagpur.

Government Initiatives on Farm Mechanization

The Government of India has also taken initiatives and programmes like Rashtriya Krishi Vikas Yojana (RKVY), National Food Security Mission (NFSM), National Horticulture Mission (NHM), Gramin Bhandaran Yojana (GBY), Sub-mission on Agricultural Mechanization (SMAM), scheme on Promotion of Agricultural Mechanization and Machinery for In-situ Management of Crop Residue in the States of Punjab, Haryana, Uttar Pradesh and NCT of Delhi, etc.

The major objectives of SMAM are to demonstrate the agricultural machinery on the farmers' fields to increase farm mechanization and productivity, test and evaluate machines through identified testing centres to ensure quality and performance, support the custom hiring centres of agricultural machinery and hi-tech hubs to ensure the availability of agricultural machinery, increase trained and skilled personnel, etc. In consequence, the concept of 'Custom Hiring' assures the distribution of mechanical power beyond large holding to small/marginal land holdings. It also facilitates availability of farm machinery/equipment on hire and assists in enhancing mechanization status.

The estimated budget proposed for the scheme for three years (2017-20) is USD 1.05 billion. This includes a share of 60 and 40% by Central Government and State Governments, respectively. However, a share of 90 and 10% will be borne by Central Government and State Governments, respectively for North Eastern and Himalayan states. During the period from 2014-15 to 2016-17, 38074 persons have been trained in different parts of country by testing centres under SMAM. During last three years, 4335 farm machinery were tested at recognized testing centres and 376,852 were distributed through subsidy under SMAM. The number of custom hiring centres, Hi-tech hubs, farm machinery banks at village level and custom hiring centres in NE states established during the period were 4108, 41, 1710 and 2173, respectively (Anonymous, 2017b). The target under SMAM is to establish 19883, 613 and 22338 numbers of custom hiring centres, Hi-tech hubs for management of high value crops and farm machinery banks at village level, respectively by 2019-20. This is expected to increase farm power availability and average level of mechanization for different farm operations to 2.45 kW/ha and 50%, respectively by 2020.

The objectives of the new scheme on Promotion of Agricultural Mechanization and Machinery for In-situ Management of Crop Residue in the states of Punjab, Haryana, Uttar Pradesh and NCT of Delhi are to provide financial assistance to establish Farm Machinery Banks or Custom Hiring Centres of in-situ crop residue management machinery, to procure agriculture machinery and equipment for in-situ crop residue management and to execute Information, Education and Communication strategies to create awareness on in-situ crop residue management among farmers, users and stakeholders. Under Central Sector component of the scheme, 100% cost of USD 168 million will be met by the Central Government. The scheme is being implemented during two years (2018-19 and 2019-20) to check burning of crop residue in field and thus address the issues/problem of air pollution in Punjab, Haryana, Uttar Pradesh and NCT of Delhi.

Conclusions

India has achieved considerable progress in farm mechanization during last one and half decades. The use of mechanically operated farm equipment increased on Indian farms over traditional human and animal power equipment. The farm power sources such as tractors, power tillers, combine harvesters, diesel engines and electric motors contributed to 1.324, 0.018, 0.021, 0.460 and 0.193 kW/ha, respectively in total farm power availability of 2.24 kW/ha during 2016-17. The overall farm mechanization levels for rice, wheat, maize, sorghum and millets, pulses, oil-seeds, cotton and sugarcane crops are 45, 63, 40, 26, 34, 34, 26 and 24%, respectively.

The farm machinery industry has grown at Compound Annual Growth Rate (CAGR) of 7.5% and reached a capital value of USD 7.30 billion. The sale of tractors increased at a CAGR of 9.75% during last 56 years and reached a level of 711,478 units in 2017-18. The present trend is towards the use of high capacity and energy efficiency farm machinery on custom hiring basis. The testing network of farm machinery was strengthened by establishment of 32 specialized farm machinery testing centres in SAUs, ICAR institutes, state Govt. institutes etc. in addition to four farm machinery testing stations under Government of India to enhance quality of farm machinery manufacturing in country.

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■■

Prospective Technologies, Types and Calculation of the Technical Means for the Production of Forages in Arid Regions of the Country

by

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Abstract

In arid regions of the country with their adverse water and temperature regimes the rational use of pastures significantly contributes to the preservation of the productivity of vegetation cover.

It was shown that within a few years of intensive use of hayfields and pastures, legumes begin to degenerate. Their presence in the herbage should be maintained in various ways.

It was noted that simple sowing of legumes in the existing herbage is impractical due to the fact that young sprouts of legumes will be suppressed by cereal native vegetation.

On the pastures it is advisable to improve the surface quality of the crop, the cost of which is 2-3 times lower than that of the radical improvement.

It was found that the most effective method of surface improvement is a strip tillage and sowing legumes with local application of the fertilizers.

There has been developed methodologies and identified the types of combined machines for processing of the degenerating plots of the grassland with sowing of the grass seeds and local application of mineral fertilizers.

It is shown that the developed methods and the combined unit for strip processing of fodder grounds lead to an increase in the yield of 1.8-2.5 times and allow to reduce the consumption of fuel by 40-50 percent.

The volume of work on restoration of the productivity of degraded grassland has been defined.

The quantity of needed grassland machinery and the relevant technical-economic indicators of the scheduled lane-processing of the degraded grassland of the area of 0.5 million hectares within 5 years has been calculated and presented.

The data on the technology of improving natural forage lands (hayfields and pastures) in the semi-desert and desert zones, on saline soils of steppe regions and semi-deserts are brought in.

For this purpose, are offered combined units APS-2.8, APP-4.2 and ALS-2.5, MPTD-3.0, MPTD-6.0, MPTD-12, developed by VIM, performing per one passage milling processing of the upper humus layer of soil to a depth of 8-10 cm, subsoil loosening of the saline horizon to a depth of 30-40 cm, sowing of salt-resistant seeds of wild-growing grasses and grass mixtures, rolling crops.

In the modern conditions of industrial animal husbandry simple production of voluminous leafy feed is not yet enough, thus it is important to provide animals with high-nutritive feed.

The usage of the combined units APS-2.8, APP-4.2 and ALS-2.5, MPTD-3.0, MPTD -6.0, MPTD -12 allows to sustain high quality of the grass stand, to combine single-phase agro-technologies of production of the agricultural products and to reduce material and labor costs.

Key words: arid soils, degraded soils, hayfields, pastures, strip sowing, availability of the technical equipment, combined units, innovative machines and technologies.

Goal of the Research

Development of the technologies

and calculations of the required quantity of grassland equipment for performing processing on the area of development of 0.5 million hectares within 5 years with the aim to preserve the productivity of vegetation in the zones with arid climate.

Materials and Methods

The planned area of development of such pastures is relatively small—some 0.5 million hectares.

Conducted calculations and given data are referred to the technology of improving natural forage lands (hayfields and pastures) on the saline soils of steppe areas and semi-deserts with the use of a combined unit ALS-2.5 performing for one passage milling of the upper humus layer of the soil to a depth of 8-10 cm, subsurface loosening of the saline horizon to a depth of 30-40 cm, sowing salt-resistant seeds of wild-growing grasses and herbs, rolling crops.

Calculation of the needs for the technical means for the performance of technological operations for the production of coarse feed from leafy crops in the agrotechnical terms has been made on the basis of the normative needs for the equipment with the usage of adequate conditional coefficients for transferring the number of the equipment into the number of standard units developed by VIM.

To determine the need for grassland equipment for Russia as a whole (or for the Federal districts, agro-zones, regions), it is necessary to make calculations in the following sequence: to determine the amount of the treated area in thousand hectares and to set the standard for the need for the aggregates per 1,000 hectares of area in standard units (st. un.).

The overall need - N for the combined units for the total size of the processed area can be defined as follows.

$N = (\eta \times L) / 1000$

where η-standard needs (in st. un.) per 1000 hectares of arable land or crops of a particular culture; L - the area of arable land (crops), ha.

Taking into account that the performance of the combined unit is 1.5 ha/h and normative annual loading Assembly ALC-2.5 114 h is determined by annual output BA, ha:

$B_A = \Pi_A \times \Gamma_3$

$B_A = 1.5 \times 114 = 171$ *ha*

where Π_A productivity of the unit, ha/h; Γ_3 - annual loading, h.

Having calculated the annual output of the unit, the required number of units ALS-2.5 per 1000 hectares can be determined

$\eta = 1000 / B_A$

$\eta = 1000 / 171 = 5.85$ (st. un.)

Next, the required number of units ALS-2.5 for an area of 500 thousand hectares for 5 years can be determined:

$N = \eta \times L / 1000 \times T$

$N = 5.85 \times 500000 / 1000 \times 5 = 585$ *(et.ed.)*

The estimated number of aggregates of ALS-2.5 by 0.5 million hectares is 585 st. un.

The farmers can easily determine the quantity and quality choice of the available equipment on the basis of the accounting data.

Then, this machinery is transferred by using of the corresponding coefficients into standard (conditional) units.

Further on, the standard needs for the machinery can be calculated as per the area of the arable land and sown areas of agricultural crops, with the help of those normative tables.

Finally, the existing fleet of machines in conventional units is compared with the normative.

If the lack of vehicles has been detected, the total amount of the necessary technological equipment that has to be bought by the farmer as per the overall volume of technological work within the agronomic terms can be determined through the transition of the conditional coefficients into physical units.

Such procedures are used to define the needs for other agricultural machinery in the scales of the country, the Federal districts and agricultural zones

Results and Discussions

At the present stage of development, the land use strategy should be changed in the context of the serious food crisis of the last decade.

Statistic data showed that there is a significant responsibility for the correct use of all the agricultural lands in order to provide consumers with the agricultural production; all the skills and knowledge should be used to encourage the increase in the productivity and improvement of the performance.

Presently machinery and mechanisms play an important role in agricultural production; therefore, it is necessary to develop highly effective agricultural machines and harvesting equipment.

These can be implemented by the wider use of automation, information technologies and new materials to achieve high accuracy and extended operating time, as well as the possibility of using technologies in mountainous, arid climate zones and other areas with adverse climate, which is an urgent issue.

The total area of lands in Russia subject to desertification or potentially dangerous in this respect exceeds 100 million hectares.

Vast plots of natural grasslands are characterized by highly degraded grass stands (50-60% of the total area) and low yields (0.5 to 5 tons/ha of green mass).

Rather thinned grasslands and loose sands, where the dense-growing vegetation is absent, become the centers of active wind erosion and dust storms.

Despite the sharp decrease in the number of livestock at the agricultural enterprises, due to an increase in the number of livestock in the private sector, the load on pastures is 2.5-3 times higher than that of the permissible norms (for the feeding forage stock).

Surface improvement in quality of a grass stand is carried out on hayfields and pastures having in the structure not less than 30-40% of herbs of valuable types if those plots are not subject to erosion and have a rather high general projective covering (not lower than 40%) and a relatively good humidification.

Surface improvement comprise: the set of techniques to optimize the water-air regime of the soil (harrowing, disking and chipping), application of the fertilizers, sowing herbs and the use of herbicides.

Sub-arid pastures and hayfields provide more than 25% of all feed produced at the natural forage lands of the country. The productivity of natural pastures is low and subject to considerable fluctuations in years and seasons. In winter pastures often receive only 15-20% of feed units in comparison to the period of active vegetation of plants.

Due to overloading and unsystematic use of pastures, vegetation cover and soil degradation is on the rise.

The need to take urgent measures to improve these areas is also determined by the fact that in the future there should be an increase in the production of livestock products.

When perennial grasses begin to degenerate, it is advisable to carry out surface improvement, the cost of which is 2-3 times lower than that of the fundamental improvement.

The most effective technique is a strip treatment of the sod with additional seeding of legumes, and the fertilizers applied.

At the severely depleted pastures on the sandy soils, where the change of vegetation is slowed down by the invasion of shrubs, pre-sowing plowing may be undesirable.

Under these conditions, there is a need for sowing directly into the existing grass. This method is a compromise option between a very slow natural change of vegetation cover and a complete and relatively fast plowing of the field.

As shown by the results of domestic and foreign research, this method increases the productivity of degenerate lands in 1.5-2 times, increases the duration of their use in 1.5 times and reduces labor, material and energy costs in 2 times or more.

Long-term researches of the technology of improvement of arid and sub-arid pastures in the Volga region, in the North Caucasus, in West Siberia, Kazakhstan and on Altai confirm high efficiency of strip sowing of wild-growing salt-resistant grasses on pastures of semi-desert and in arid regions of Russia with application of the combined units APS-2.8 (**Fig. 1**), APP-4.2 (**Fig. 2**) and ALS-2.5, MPTD-3.0, MPTD-6.0 (**Fig. 3**), MPTD-12 (**Fig. 4**).

Figs. 1-6 show combined aggregates for surface improvement of arid soils and the results of strip sowing of salt-resistant seeds of wild grasses and grass mixtures.

Surface improvement technologies used for the fodder grounds are as follows. During the preparation work is used SLM-20 machine aggregated with the tractor of 1.4 class with an annual download of 114 h and an annual output of 2,280 ha (as processing 0.5 million ha requires 44 cars).

Loosening of the saline layer, fertilizing, surface milling above the sodic horizon, pre-sowing seedbed soil compaction, planting seeds,

Fig. 1 Aggregate APS-2.8

Fig. 2 Aggregate APP-4.2

Fig. 3 MPTD-6

Fig. 4 MPTD-12

Fig. 5 Results of the strip under -sowing

Fig. 6 View of the meadow lane after the field processing unit MPTD-6

herbs and post-sowing rolling is shown by the example machine ASL-2.5 aggregated with tractors CL. 5 with annual download of 114 h, the annual output of 171 ha (as processing of 0.5 million ha within 5 years will require 585 machines).

Conclusions

The use of machines for strip sowing of grasses in the sod of hayfields and pastures has a number of advantages:

- improvement in the species composition of the grassland of cultural, natural and degraded forage lands;
- increase in the content of legumes by 16-25%,
- increase in the yield of grasses by 1.8-2.5 times,
- reduction in fuel consumption by 40-50%,
- costs reduction by 30%,
- labor costs reduction - by 3-3.5 times.

Application of the combined units APS-2.8, APP-4.2 and ALS-2.5, MPTD-3.0, MPTD-6.0, MPTD-12 provides combination of single-phase agro - technologies of production of agricultural products, reduction in the material and labor costs that promotes, in its turn, solution of problems of food safety.

At the fourth year after the surface improvement operation the herbage of sown legumes begins to fall out, and the yield of the improved land is gradually reducing.

If the operation of soil improvement is resumed every 3 years, then, according to our calculations, sowing legumes will lead to an average increase in the production at the improved 3-5 fields, at least by 20% for 6 consecutive years.

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ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

1624

Design and Development of Sapota Cleaner: **M. N. Dabhi**, All India Coordinated Research Project on Post Harvest Technology, Dept. of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University. Junagadh-362001, Gujarat, INDIA, mndabhi@jau.in; **P. R. Davara**, same

Freshly harvested Sapota fruits have latex and scurf over surface. The sapota cleaner was designed and developed to remove this latex and scurf. Cleaner was run at different speed i.e. 60, 65 and 70 rpm. The capacity in a batch was varied 15, 20, 30, and 45 kg. The cleaner was run for 90 seconds. The cleaning efficiency and damage percentage were calculated. The best combination of cleaner speed, capacity, cleaning efficiency and damage percentage was found with 70 rpm, 20 kg/batch, 99.95% and 2.04% respectively.

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1629

Effects of Ethephon and Methyl Jasmonate on Efficiency of Trunk Shakers in lemon Harvesting: **Mohammad Mehranzadeh**, Assistant Professor, Dept. of Agricultural Machinery, Dezful Branch, Islamic Azad University, Dezful, IRAN, mmehranzadeh@gmail.com; **Mohammad Chenari**, Agricultural Mechanization Engineer, same

This type of research was conducted to study mechanical harvesting of lemons together with application of abscission materials as harvest facilitators, and to determine suitable concentrations of these materials. Experimental treatments included harvesting lemons with a shaker and without using an abscission material and harvesting lemons with a shaker together with abscission material (ethephon at 400, 800, and 1,000 ppm, and methyl jasmonate at 1,000, 2,000, and 3,000 ppm). The measured variables in this test included harvest percentage, harvest efficiency, and fruit detachment force. Results of statistical analysis showed that fruit harvest percentage, harvest efficiency, and fruit detachment force varied significantly between the various treatments at the 1% level. Harvesting with a shaker together with ethephon and methyl jasmonate at 1,000 and 3,000 ppm, respectively, had the maximum harvest percentages, the highest harvest efficiency, and the minimum fruit detachment force.

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1659

Design of Water Hyacinth (Eihhornia crassipes) Harvester: **O, E. Omofunmi,** Dept. of Agricultural and Bioresources Engineering, Federal University Oye-Ekiti, NIGERIA, omofunmieric@yahoo.com**; S.A. Ebifemi**, Dept. of Mechanical Engineering, Yaba College of Technology, Yaba, Lagos, NIGERIA; **A. B. Eweina**, same

Water hyacinth (*Eichhornia crassipes*) is a free floating aquatic plant that grows in still or slows moving fresh water bodies and has become one of the world's worst aquatic weeds due to its ability to form dense floating mats on the water's surface. These mats have significant impacts on rivers, wetlands, dams, lake, and irrigation systems. However, water hyacinth, which evades waterways and reduces recreation and aesthetics value of water bodies, needs to be controlled. This purpose of this study was to design a harvester for control of water hyacinth. The anatomy and physiology of the water hyacinth were used to design the machine using basic engineering procedures. The main feature of the water hyacinth harvester included an electric motor (2.0 hp), mower disc (100 × 70 × 7.36 mm), shaft (26 mm diameter) with 4 blades made of stainless steel. The machine operates with capacity of 10,646 tons /hr. at the speed of 3.04 m/s. The capacities of the loading and delivery conveyors are 846.60 tons /hr. and 538.75 tons /hr. respectively. Fabrication of the designed water hyacinth harvester, using local materials will promote and enhance indigenous technologies that will improve physical control of the plant.

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1662

Dynamic Model of Solar Photovoltaic Systems: **Buzunova Marina U**, Ph.D. in Physical and Mathematical Sciences, Assistant Professor, Dept. of Electric Systems and Physics, Irkutsk State University of Agriculture, RUSSIA, enerqo@irsha.ru; **Kuznetsov Boris F**, Sc.D. in Technical Sciences, Professor, same; **Alexeenko Artem A**, Postgraduate, same; **Enkhbayar. G**, Ph.D, in Technical Science, professor, department of Mechanical Engineering, Mongolian University of Life Sciences, MONGOLIA; **Rakhmet. Kh**, Ph.D, Electrical Engineer, same

The paper deals with the simulation of the solar photovoltaic system in the Simulink program. The main purpose of the model is to analyze the dynamic operating modes. Much attention is paid to the simulation models of the battery and controller whose function is the distribution of energy flows. The paper describes consistency criteria of energy flows. The energy excess and energy deficit parameters are used as the evaluation criteria of coherence of energy flows. Graphical illustrations of simulation results are presented in the paper.

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1663

Waste Vegetable Oil Substitutes for Diesel Fuel and Its Effect on Engine Performance and Environment: **A. E. Ahmed**, Professor Dr. in Agricultural and Biosystem Engineering, Faculty of Agriculture, Alexandria University, EGYPT; **M. A. Sabbah,** same; **A. I. Moussa**, Head researcher, Agr. Eng. Res. Institute, ARC, Ministry of Agriculture, same; **S. S. El-Shazly**, Assistant researcher, same

Energy is the prerequisite for modern civilization. Fossil fuel is still the main source of energy. But the endless consumption of fossil fuel has brought its reserve about to an end. As a result, researchers are seeking for alternative and cost effective fuels to meet the human demands. Biodiesel is a renewable fossil fuel derived from vegetable oils. It is non-toxic, biodegradable and non-flammable having a very high flash point making it one of the safest of all alternative fuels. Besides, it runs in most normal diesel engines with little modifications to the fuel system. Boidiesel must be treated before utilization as an alternative fuel. Low content of catalyst is one of the important point needed for passing the EN 14214 and ASTM D6751 international biodiesel standards. Using water is the traditional method for purifying biodiesel.

When using water washing to purify biodiesel, data cleared that most of impurities were vanished during the first wash. The impurities were decrease after every washing till the third or fourth washing. For the stirring time 9 minutes, the suitable pH was found with stirring speeds 1,200 and 1,550 rpm in the third wash. Water washing needs drying operation after washing to get rid of excess water which can harm the engine. Water content in biodiesel when using saw dust with silica gel, saw dust, wood chips with silica gel and wood chips in the purification were 0.04, 0.045, 0.04 and 0.05% respectively. Glycerol values in biodiesel when using saw dust with silica gel, saw dust, wood chips with silica gel and wood chips were respectively 0.23, 0.24, 0.24 and 0.24 %. The Methanol values in biodiesel when using saw dust with silica gel, saw dust, wood chips with silica gel and wood chips were respectively 0.01, 0.02, 0.01 and 0.02 %. Besides, results showed that the power produced with biodiesel at 20% (B20) was reduced by about 4% compared with diesel fuel. The Maximum torque value of biodiesel (B20) and diesel fuel were 258 and 295 N,m. respectively, and the maximum power of biodiesel (B20) and diesel fuel were 17.3 and 18 kW respectively. However, the CO produced using biodiesel blend at 20% with 75% load reduced by about 12% compared to diesel, CO_2 reduced about 14%, O_2 increased about 4%, NOx increased about 1.2% and exhaust temperature increased by about 0.9%. The total production cost for one liter of biodiesel when using water and dry washing are 4.969 and 4.604 L.E respectively.

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1669

Design and Development of Tractor Operated Multi-Purpose Tool Frame with Attachments for Sugarcane Cultivation: **Sukhbir Singh**, Sr. Scientist (FMP), Division of Agricultural Engineering, Indian Institute of Sugarcane Research, Lucknow-226 002, UttarPradesh, INDIA, srsukhbir@rediffmail.com; **Ashok Tripathi**, Professor & Head, Dept. of Farm Machinery & Power Engineering, VSAET, Sam Higginbottom Institute of Agriculture, Technology and Sciences, (Deemed-to-be University), Allahabad-211 007, Uttar Pradesh, INDIA; **A. K. Singh**, Principal Scientist & Head, Division of Agricultural Engineering, Indian Institute of Sugarcane Research, Lucknow-226 002, Uttar Pradesh, INDIA; **R. D. Singh**, Principal Scientist, same

A prototype of tractor operated multi-purpose tool frame with attachments for sugarcane cultivation was designed and developed at ICAR-Indian Institute of Sugarcane Research, Lucknow. The equipment consisted of a rectangular mild steel square pipe frame with provision to attach different attachments viz. furrower for furrow opening at 750 and 900 mm row spacing for sugarcane planting; interculturing, herbicide spraying, fertilizer application attachments in sugarcane. The attachments can be attached either individually or in combination as per the need. There is a provision for height adjustment of interculturing tine in the range of 500 to 650 mm as per the field condition. The field performance evaluation of the prototype was carried out in sandy loam soil. A trapezoidal 250 mm deep furrow having top and bottom width of 320 mm and 180 mm was formed with the furrower with effective field capacity of 0.28 ha/h and field ef-

ficiency of 86%. During combined interculturing, spraying and fertilizer application operation, effective field capacity was 0.57 ha/h with field efficiency of 86.3%. The weeding efficiency was 83.2%, depth of interculturing 100 mm and herbicide application rate 265 l/ha. With the use of the developed equipment, the cost of combined operation of inter-row interculturing, intra-row weeding through herbicide spraying and fertilizer application was reduced from Rs. 4328 to 1841/ha (57.4%) as compared to conventional practice of using tractor operated cultivator for inter-row and manual hoeing for intra-row weeding with manual broadcasting of fertilizer. The corresponding labour saving was 129.2 man-h/ha (97%).

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EVENT CALENDAR

2019

◆ **53rd Annual Convention of ISAE and International Symposium on "Engineering Technologies for Precision and Climate Smart Agriculture"**
January 28-30, Varanasi, INDIA
https://www.isae.in/conventionile/8935064.pdf

◆ **Agricultural Equipment Technology Conference (AETC)**
February 11-13, Kentucky, USA
https://www.asabe.org/AETC2019

◆ **Agro & Poultry East Asia—International Trade Show—**
February 22-24, Nairobi, KENYA
http://africanfairs.com/agronwke/form.php

◆ **3rd Rendez-Vous Techniques AXEMA**
February 23, Paris, FRANCE
https://cloud.agoraevent.fr/Site/144103/4647/Event

◆ **SIMA**
February 24-28, Paris, FRANCE
https://en.simaonline.com/

◆ **World Agri-tech Innovation Summit**
March 19-20, San Francisco, USA
https://worldagritechusa.com/

◆ **HortEx Vietnam 2019**
March 13-15, Ho Chi Minh City, VIETNAM
https://www.hortex-vietnam.com/

◆ **22nd FOODAGRO AFRICA 2019 in Ethiopia**
March 21-23, Addis Ababa, ETHIOPIA
http://africabizevents.com/fc/

◆ **3rd International VDI Conference—Smart Farming 2019**
May 14-15, Düsseldorf, GERMANY
https://www.vdi-wissensforum.de/en/event/smart-farming/

◆ **XXXVII CIOSTA & CIGR Section V International Conference**
June 24-26, Rhodes, GREECE
http://ciosta2019.com/

◆ **VDI conference on "Automation and Robotics in Agriculture"**
June 24-26, Rhodes, GREECE
http://ciosta2019.com/

◆ **2019 EFITA International Conference**
June 26-27, Berlin, GERMANY
https://www.vdi-wissensforum.de/en/event/automation-and-robotics-in-agriculture/

◆ **ASABE 2019 Annual International Meeting**
July 7-10, Massachusetts, USA
https://www.asabe.org/Event-Detail/2019-annual-international-meeting

◆ **IDF World Dairy Summit**
September 23-26, Istanbul, TURKEY
http://www.idfwds2019.com/

◆ **22nd FOODAGRO AFRICA 2019 in Kenya**
October 3-5, Nairobi, KENYA
http://africabizevents.com/fc/

◆ **22nd FOODAGRO AFRICA 2019 in Tanzania**
October 17-19, Dar-es-Salaam, TANZANIA
http://africabizevents.com/fc/

◆ **ASIA AGRI-TECH EXPO & FORUM**
October 31-November 2, Taipei, TAIWAN
https://www.agritechtaiwan.com/en-us/

◆ **Agritechnica**
November 10-16, Hanover, GERMANY
https://www.agritechnica.com/en/

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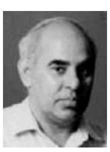
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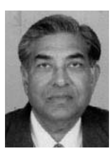
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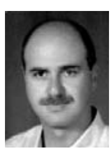
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(Vol.48, No.2, Spring, 2017-)

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Vol.49, No.3, Summer 2018

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Vol.49, No.4, Autumn 2018

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e. have a 50 to 100-word abstract, preferably preceding the main body of the article;
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e. Papers are printed in black and white. Tables and figures must be made so as to be clearly understood in black and white.
f. **The data for the graph must also be included. (e.g. EXCEL for Windows)**
g. Tables and figures must be preceded by texts or discussions. Inclusion of such tables and figures not otherwise referred to in the text/discussion must be avoided.
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i. Express measurements in the metric system and crop yields in metric tons per hectare (t/ha) and smaller units in kilogram or gram (kg/plot or g/row).
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k. Convert national currencies **in US dollars** and use the later consistently.
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