Results of Agricultural Machinery and Post-harvest Engineering Research

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Foreword

At present, Ethiopia is now about to complete the second phase of growth and transformation plan (GTP-II). The core determination of the plan is to perpetuate the growth and development trajectory attained during the previous GTPI, which aimed to attain food security and sovereignty, sustainable supply of raw materials for agro-industries and import substitution, expanding the base for foreign earnings from agricultural exports, and increasing livelihood resilience and environmental sustainability.

The strategic direction envisaged for attaining the above-said overarching objectives is by increasing agricultural production, productivity, quality and market linkages through enhanced adoption and scaling up of agricultural technologies, implementation of cluster-based agriculture, input supply and participation of the private sector. Central to the success of the plan is the contemplation that productivity of different crops would be increased by 40 to 50% from the base year. Accordingly, the Ethiopian Institute of Agricultural Research (EIAR), guided by its vision and mission, is striving to contribute to the fulfillment of these fundamental national objectives by undertaking research and generating appropriate agricultural technologies, information, and knowledge on agricultural mechanization and postharvest handling operations, the pivotal factors for increasing production, minimizing losses and reducing drudgeries.

Quite a number of research results and outputs were generated for the past five years by the agricultural machinery and postharvest research programs organized under the Agricultural Engineering Research Directorate of EIAR. However, before the research results that are derived from completed projects and experiments reach the end users, they need to be reviewed, evaluated, and synthesized for their merits of relevance, innovation, practicality, and most importantly for their potential to bring about positive changes in the lives and livelihoods of the end users.

This volume of publication is, therefore, dedicated to present research results obtained from experiments carried out during the past five years under the agricultural mechanization and postharvest and processing engineering national research programs of the directorate. It is my strong conviction that the materials contained in the proceedings will serve a broad spectrum of users engaged in developing agricultural mechanization and postharvest handling packages, guidelines and manuals as well as those engaged in research and academia who may need to use them as reference materials. Before concluding my remarks though, I would like to thank the authors, editors and the publication staff for their commendable contributions in producing the proceedings.

Diriba Geleti (PhD)
Deputy Director General for Research, EIAR
Welcome Address

Bisrat Getnet

On behalf of the organizing committee and on myself, I welcome you to this important forum, which is an important gathering for the agricultural mechanization and post-harvest professionals. It is also an important forum for other colleagues and partners, who are willing to go with us long enough to see that we make a difference in the agricultural production, post-harvest handling and value addition and wise utilization of the natural resource base without jeopardizing its future service for generations to come. I would like to thank you all for honoring our invitation. This workshop is a forum to deliver the outputs of the programs, which have been going on for the last five years. Today there will be 9 papers, posters and exhibits from the agricultural mechanization and postharvest research programs of EIAR.

This gathering would have not been possible had it not been for the support of the EIAR management. We thank all of you who have found some slot in your busy schedule and have come all the way even from very far places to attend this gathering.

With this brief remark I respectfully invite, if I may, Dr. Diriba Geleti, the Deputy Director of the Ethiopian Institute of Agricultural Research, to open the forum.
Evaluating Two Wheel Tractor Attached Conservation Agriculture Seeders

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Abstract

This paper is based on the recent attempts to evaluate and scale out the best-bet two wheel tractor conservation agriculture technologies to enhance wheat and maize crop production and productivity by project called Farm Mechanization and Conservation Agriculture for Sustainable Intensification (FACASI). The project tried to address the requirement of mechanization by reducing power demand through introducing conservation agriculture techniques such as ripping using two wheel tractor technologies. Previously, Ethiopian Institute of Agricultural Research (EIAR) has already tested the performance of two wheel tractors and recommended the use of two wheel tractors for lighter soils with 15 hp. On-farm field evaluations were carried out using imported conservation agriculture (CA) seeders from Brazil, Bangladesh, China, India and USA. Field capacity, fuel consumption, yield, and biomass were evaluated for maize and wheat crops in 2015 and 2016 seasons in Hawassa Zuria and Tiyo Woredas, respectively. On-station trials were made on the first year at Hawassa and Kulumsa Research Center in 2014. Results showed that tenfold operation time saving advantages were observed using 2WT-seeders over conventional practice. The fuel consumption varied from 9.36lit/ha to 12.56 lit/ha depending on the type of attached seeder and depth of ripping. Furthermore CA seeders increased grain yield by 29% for wheat and 22% for maize (P<0.05) over the conventional practice. VMP and 2BFG seeders for wheat production and John Morrison and VMP seeders for maize production performed best and selected as best-bets technologies. Investigation of how the seeders can be manufactured locally with the available resources is a critical issue for scale-up of the technologies.

Introduction

The need for sustainable intensification in Sub-Saharan Africa (SSA) is widely recognized. Although a lot of emphasis is being placed in current research for development work on increasing the efficiency with which land, water and nutrients are being used, farm power appears to be a “forgotten resource” (Baudron et al., 2015). However, farm power in SSA countries is declining due to the collapse of most tractor hire schemes, the decline in number of draft animals and human labor (e.g. stemming from rural-urban migration and pandemics). A consequence of low farm mechanization is labor drudgery, which affects women disproportionately (e.g. weeding, threshing, shelling and transport by head loading). Undoubtedly, sustainable intensification in SSA will require an improvement of the farm power balance through increased power supply – via improved access to mechanization, and/or reduced power demand via energy saving technologies such as conservation agriculture (Baudron et al., 2015).
In SSA, population is growing faster than food production (population 3% vs. food production 2%) (Tittonell and Giller 2013), thus, demand is not met rising number of undernourished people therefore, there should be a way to reduce dependence on food import, thus, producing more and differently requires more power. African agriculture has lagged behind the rest of the world. At the same time, there has been disinvestment in agricultural research, extension, and production systems from both governments and international donors (DFID, 2009; Eicher, 2009; Haggblade and Hazell, 2009). Yet agriculture in Africa still accounts for 65 per cent of full-time employment, 25–30 per cent of Gross Domestic product (GDP) and over half of total export earnings (IFPRI, 2004; World Bank, 2008). It underpins the livelihoods of over two-thirds of Africa’s poor. Despite the improvements made in African agriculture, continued population growth means that the per capita availability of domestically grown food has not changed at the continent scale for 50 years and has fallen substantially in three regions (Pretty et al. 2011).

The agriculture sector in Africa now provides only 20 percent of the continent’s exports, whereas it provided 50 percent in the 1960s. The New Partnership for Africa’s Development (NEPAD) makes agriculture one of its main priorities “as the engine of NEPAD inspired growth”. It stresses three aspects: improving the livelihoods of people in rural areas; achieving food security; and increasing exports of agricultural products. None of these aims can be achieved without giving serious attention to family farm power in small-scale agriculture in sub-Saharan Africa (SSA). Farm power is a vitally important component of small farm assets. A shortage of farm power seriously constrains increases in agricultural productivity, with a resultant stagnation in farm family income and the danger of a further slide towards poverty and hunger (FAO, 2006).

Another serious concern in SSA is that of soil degradation. The level of degradation varies considerably across the region and is difficult to quantify. However, some figures for soil erosion in Ethiopia were documented in 1988; they ranged from 16 to 300 tons of soil per year being washed away, with an average for the country over 40 tons/year on cultivated land. An FAO/World Bank Ethiopian Highlands Reclamation Study some four years earlier estimated that 1900 million tons of soil a year were being washed away from the cultivated land in the highlands, equivalent to about 100 tons per ha. Even if the erosion rate were halved, there would still be a 2% per year reduction in total grain production in the highlands (FAO, 2006). Erosion and soil degradation in Ethiopia are particularly severe. However, in many other parts of Africa there is abundant anecdotal evidence from smallholders themselves who state that they are obtaining much smaller yields from a particular plot than were being obtained by their fathers and grandfathers (FAO, 2006) thus conservation agriculture is a solution for soil erosion resulted from intensive tillage and lower soil fertility. However, the lack of appropriate implements to seed at the right depth through an organic mulch and with minimum soil disturbance is recognized as one of the major constraints faced by African smallholders on adopting CA (Hobbs et al. 2008; Giller et al. 2009; Johansen et al. 2012; Baudron et al. 2015).

In Ethiopia grain crops are seeded by broadcasting which not only requires additional seed when considered nationally but also considered as one of the factors limiting on-farm productivity. In addition to the soil erosion, which reduces the productivity, the rise in the cost of a feed for draft animal and oxen for meat creates shortage in the available farm power and hence affecting agricultural productivity. In this regard gradual replacement of oxen power with
intermediate technology such as small hp two wheel tractors and engine driven agricultural machineries becomes inevitable for sustainable farming. Therefore, the aim of this study was to conduct evaluation of 2WT-attached CA seeders in order to identify the best-bet technologies which are suitable for maize and wheat crops in Ethiopia.

**Materials and Methods**

**Description of seeders tested**

**Fitarelli Single Row**
The single row CA seed drill (Figure 2a) consists of a cutting coulter followed by a tine opener with a steel drive wheel/press wheel behind. It has a flat horizontal circular seed metering plate, seed box and a fertilizer box. The rubber-tired wheel on the side is for stability and depth control. It has also a toothed seed-covering wheel at the back of the furrow opener. The plastic seed tubes are transparent to show that the seed metering is functioning.

**Fitarelli Two Row**
This CA seed drill (Figure 2b), made in Brazil, and consists of a cutting coulter followed by a tine opener with a steel drive wheel/press wheel behind. It features a horizontal circular flat plate seed box fertilizer box. This planter is same as above but has double rows planting unit. It works perfectly for maize planting, except the modification required on the drawbar arm for placing a counter weight to help balance the front weight caused by the engine of the pulling DF 12/15 walking tractor.

**National Agro Zero till Planter**
National Agro multi-crop Zero till planter, made in India, is made for zero tillage planting (figure 2c). The planter has an inclined plate type seed metering for seeding and fluted roller type metering made from cast iron for fertilizer application. The steel wheel on the side is for driving the metering units from the ground. It has also depth control on the rear steel wheels.

**John Morrison CA seeder**
The seeder, made in the USA, is a single row seeder with a front toothed disc coulters to cut the mulch and has a flat disc to drive the metering units from the ground rotation using a belt drive. It has also plastic roller type metering units for both fertilizer application and seeding (figure 2d).

**Versatile Multi-crop Planter (VMP)**
This VMP planter (Figure 2e) has been developed in Bangladesh for strip until sowing of spring crops. There are four tiller blades mounted to the blade holder that match the four row seed and fertilizer boxes. The row spacing and tillage options are adjustable according to desired crop. In order to ensure deep seed placement an optional set of tine type soil openers can be fixed on a separate toolbar as required in marginal moisture conditions.

**DBFG -100 seeder**
This 2BFG -100 seed and fertilizer machine (Figure 1f) is widely used for sowing of wheat and rice. It is composed of a rotary tiller combined with a seeding and fertilizing unit with stand and road wheels. It can be used for either strip or no till depending on the number of tine fitted and
their design. In a single operation it prepares the soil, controls the weed growth and plants seed as well as applies fertilizers. It is 1160mm wide allowing to plant up to six rows of crops.

![Figure 1](image1.png)

**Figure 1.** (a) Fitarelli single row seeder, (b) Fitarelli double row seeder, (c) National Agro seeder, (d) John Morrison CA Seeder, (e) Versatile Multi-crop Planter (VMP), (f) 2BFG-100 seeder

**Experimental setup**

A one year on station trial followed by a two year on farm exploratory trial were conducted to evaluate walking tractor attached seeders on wheat and maize from 2014 to 2016 cropping seasons. The on station trials were carried out at Hawassa and Kulumsa Research Centers for maize and wheat crops respectively. Likewise, on-farm evaluations were located at Dorebafena and Tula woredas for maize while it was at Dosha and Tiyo woredas for wheat. Two Chinese made and model 12hp and 15hp Dongfeng™ brand 2WTs with different seeder attachments were used for the experiments. Field capacity for tillage, planting, and weeding; fuel consumption and yield were measured according to AIRIC test procedures.

Pre-weed emergence herbicide (Glyphosphate) round up was used 15 days prior to planting/tillage depending on the treatments. *Hidase* wheat variety and *Melkassa II* maize variety were used for the on station trials. Di-ammonium phosphate (18% N₂ and 46% P₂O₅) fertilizer was applied at a rate of 100kg/ha as basal application at planting and top dressed with 50 kg/ha of urea after 35 days of planting or at knee height for all treatments.

The on farm trial involved 11 farmers (6 for wheat and 5 for maize) selected from the two trial sites and managed by the researcher. Farmers were briefed about the experimental setup and trained on how to operate and use the seeder. These trials employed the best bet technologies selected based on the first year on station test results.

**Experimental design and treatments**

The experimental design for on-station trials was a Randomized Complete Block Design (RCBD) with six seeders and control treatments in three replications. The treatments for on station trial were
Conventional tillage with animal drawn moldboard plough (ADMBP) three times followed by row planting with hand and furrow opening and covering was made by the tillage implement;

Reduced tillage with Chinese made Danyang 2BFG-100 2WT attached planter; Single pass by rotary blades in front of the furrow opener with 3-5 cm depth for wheat seeding and 5-6 cm depth for maize seeding;

Zero tillage planting by Brazilian made Fitarelli two wheel tractor attached planter;

Reduced tillage with Bangladeshi made Versatile Multi-crop Planter (VMP) 2WT attached planter; Single pass by rotary blades in front of the furrow opener with 3-5 cm depth for wheat seeding and 5-6 cm depth for maize seeding. Four rotary blades are arranged radially on the line of furrow opening;

Zero tillage planting by Indian made National Agro four row 2WT tractor attached planter;

Zero tillage planting by Brazilian made Fitarelli single row 2WT tractor attached planter; and

Zero tillage planting by USA made John Morisson single row 2WT tractor attached planter

For on-farm trails, four treatments were laid according to the best-bets selected per crop per site

Conventional tillage with animal drawn moldboard plough (ADMBP) three times followed by hand row planting with hand and furrow opening and covering was made by the tillage implement.

Reduced tillage by with Chinese made Danyang 2BFG-100 2WT attached planter; Single pass by rotary blades in front of the furrow opener with 3-5 cm depth for wheat seeding and 5-6 cm depth for maize seeding.

Reduced tillage with by Bangladeshi made Versatile Multi-crop Planter (VMP) 2WT attached planter; Single pass by rotary blades in front of the furrow opener with 3-5 cm depth for wheat seeding and 5-6 cm depth for maize seeding. Four rotary blades are arranged radially on the line of furrow opening.

Zero tillage planting by Indian made National Agro four row 2WT tractor attached planter;

Results and Discussions

Uses and features of the CA seeders

Fitarelli two row

Fitarelli two-row seeder is a zero until seeder with two rows for seeds and two rows for fertilizer. The disc cutters are used for cutting the residue and opening the furrow while seeding (Figure 1a). The seeder has a good disc, which can cut the mulch. However, it was observed that this planter was found very difficult in maneuvering (turning) during planting. The manual lifting system of the soil engaging tools requires more effort by the operator, and can be quite tiresome due to the presence of frequent lifting and lowering in small fields. The relatively large turning circle is also a minor disadvantage for this planter in making a turn in small plots, which leads to high turning time. There are also limited options for seed rate changes. Consequently, the operator is forced to make reverse gear operation that again consumes time and fuel. On
the other hand, it has a provision for changes in row spacing. It works perfectly for planting of maize at 70cm row spacing. However, due to lack of flexibility for adjustment it was not suited to handle wheat and other narrowly spaced grain crops.

**Fitarelli single row**
This CA seed drill (Figure 1b) consists of a cutting culture followed by a tine opener with a steel drive wheel/press wheel behind. It features a horizontal flat plate seed and fertilizer boxes. This seeder has the same metering unit as that of the Fitarelli-two row except that it is being a single row. It works perfectly for maize planting, except the modification required on the drawbar arm for placing a counter weight to help balance the front weight caused by the engine of the pulling DF 12/15 walking tractor. Wheat planting can be achieved by decreasing the thickness of the fertilizer-metering plastic rotor with a lathe machine but single row wheat seeding is not recommended for its low field efficiency, high fuel consumption, and high drudgery.

**National Agro (Indian Multi crop Zero till planter)**
National Agro multi-crop Zero till planter, made in India, is made for zero tillage planting (figure 1c). The planter has an inclined plate type seed metering for seeding and fluted roller type metering made from cast iron for fertilizer application. The steel wheel on the side is for driving the metering units from the ground. It has also depth control on the rear steel wheels. It was observed that it was impossible to turn this planter with only one operator due to rigid rear wheels. It needed more than two persons for turning in the field. The operator cannot easily lift the planter and there is difficulty during turning. Furthermore, the metering ground wheel always rotates even at the time of transportation and turning, therefore a considerable modification is necessary. Compared with the rest of the seeders, hitching of the planter to the tractor was also time-consuming. The planter did not have a residue-cutting unit to handle trashes and residues.

For maize planting, the metering discs supplied with planter were good enough to do the planting task while in order to plant the recommended wheat seed rate of 150kg/ha, it was not possible to get this seed rate. It was observed that only 40kg/ha of wheat can be possible with the supplied seed metering gears. Therefore, it needs modification of the metering unit. It was also observed that there was clogging of furrow opening ports, which were used as a means to deliver the desired fertilizer and seed rates. For strip tilling using the rotavator, it was not possible to get the desired contact with the surface unless the rotary blades arrangements and depth adjustment modified.

**John Morrison Seeder**
The seeder, made in the USA, is a single row seeder with a front toothed disc coulters to cut the mulch and has a flat disc to drive the metering units from the ground rotation. It has also plastic roller type metering units for both fertilizer application and seeding (figure 1d). The seeder sometimes would be unable to plant due to the slip caused by the metering ground disc if the soil is dry. However, it is perfect if there is good moisture in the soil during operation of the seeder. The other problem with this planter was clogging of the ports that were placed on the furrow opener with soil during planting. Thus, frequent cleaning of the seed and fertilizer ports is needed. Like the single row Fitarelli, it has low field capacity and high drudgery for wheat seeding. Otherwise, it performs well for maize seeding when used in appropriate soil moisture.
Versatile multi-crop planter (VMP)
The planter (figure 1e), made in Bangladesh, has a capability of seeding row crops that demand seed drilling and planting. It is four-row planter, which can be changed to two rows. Its unique feature is its four-rotavator blades that are arranged radially with a spacing of 20 cm. It has also vertical interchangeable plates to seed row crops like maize and beans in addition to the plastic fluted roller type metering units. It had a problem in engaging and disengaging on the driving sprocket that is located on the fertilizer-metering shaft. One of the two VMP planters under testing worked quite for a short time before the key in the shaft (Figure 2) required replacement. The key was fabricated from low carbon steel leaf spring steel) in order to repair the frequently worn out key at Melkassa Agricultural Research Center. During valuation, it was observed that the planter has a perfect strip making blades, which are radially placed on the rotavator shaft.

![Figure 2. Replaced key made from leaf spring steel (left side) and worn key made from mild steel by the VMP manufacturer (right side).](image)

Danyang 2BFG-100
This planter (figure 1f), made in China, has rotavator smaller blades to perform minimum soil disturbance. The seeder has six rows with a plastic fluted roller type metering units that work perfectly for wheat and maize seeding. The metering units get the drive power by a pair of sprockets from the 2WT axle using chain drive. Width of the furrow openers cannot be fixed at 20 cm in which the basic agronomists recommendation but it was fixed at 18.4 cm spacing within the range of the recommendations for wheat planting which did not have any effect on the yield and other yield parameters.

Agronomic and field performance

Field performance

Field capacity
Figure 3 shows the field performance in land preparation and seeding for different seeder options for conservation agriculture and the corresponding traditional tillage system for maize and wheat cultivation. In conventional tillage system, the field operations include plowing three times with animal drawn plow, manual row planting and fertilizer application. Conservation agriculture treatments on the other hand refer to the combined operations of ripping, planting and applying fertilizer along the ripped line in one pass. Total work rate for CA planters were 7.02 hrs./ha, followed by 9.71 hrs./ha and 9.97 hrs./ha for the six row 2BFG-100, four rows VMP and National Agro planters respectively. In contrast, the work rate for corresponding conventional cultivation practice was over tenfold, 94.13hr/ha. Similar field capacity results were also obtained from on farm trails for best-bet VMP and 2BFG-100 seeders (Figure 4).
Fuel consumption
Fuel consumption under different tillage options is shown in Figure 4a and 4b. It was highest for VMP (15.40 l/ha) followed by Fitarelli two row (14.13 l/ha) in maize cultivation at Hawassa. The reason for the high fuel consumption for VMP was that the average depth of ripping was 7 cm, which is more than the recommended 5-7 cm depth.

Fitarelli two row is very difficult while turning in a small plot which are less than 1 ha. The lowest fuel consumption for maize planting was recorded by Fitarelli single-row, 10.48 l/ha and Morrison single row 11.37 l/ha which was due to single row zero tillage without any ripping power. Fuel consumption was highest 27.96 liter per hectare for Fitarelli two-row seeder as turning time is very high in small plots and hence higher fuel consumed. The lowest fuel is consumed by four row zero till National agro seeder 13.70 l/ha followed by Morrison seeder 14.05 l/ha. 

The mean moisture content of the soil at the time of the field evaluation at Kulumsa
Agricultural Research Center was 40.23%. Therefore, the fuel consumption is a bit higher than normal due to slip associate with higher moisture content of the field.

![Fuel Consumption Graph](image1)

**Figure 5.** a) Fuel consumption for maize planting at Hawassa, 2014 b) Wheat seeding at Kulumsa

**Depth of planting/seeding**

The depth of seeding for all the seeders were not statistically significant from the agronomists recommendation for wheat which was at the range of 3 to 5 cm, whereas the conventional method of seeding is very high and 1 cm below the recommended seeding which intern might have a reduced yield due to deeper seeding (Figures 6a & 6b & Figure 7).

![Depth of Seeding Graph](image2)

**Figure 6 a) Seeding depth for wheat seeding Kulumsa Research Center, 2014 b) Seeding depth for wheat seeding at Kulumsa Agricultural Research Center, 2015**
Agronomic performance

Weeding

The agronomic performances of the CA seeders were compared and the results are shown below. As seen from the table below, the conventional method had the lowest weeding time than reduced and zero until treatments. Zero till seeders such as National agro registered the highest weeding time (p<0.05) when compared with the rest of the treatments whereas reduced tillage such as VMP, 2BFG-100 were recorded higher weeding time when compared with the conventional tillage as the main purpose of land preparation especially soil inversion is to control weeds (Tables 1 and 2). Practicing CA needs better control for weeds. Considering, the multiple task execution of the seeders to apply seeds and fertilizers in addition to opening furrows, the labor saving advantage is very pronounced when compared with the time spent for weeding if hand weeding is preferred to chemical application.

Table 1. Mean weeding time for wheat cultivation

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Replication (N)</th>
<th>Mean Weeding time (On station (2014)</th>
<th>Mean Weeding time (On farm (2015))</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Agro</td>
<td>3</td>
<td>450.67 ±58.69a</td>
<td>52.67±5.02a</td>
</tr>
<tr>
<td>VMP</td>
<td>3</td>
<td>197.33 ±14.41b</td>
<td>84.05±13.20a</td>
</tr>
<tr>
<td>John Morrison</td>
<td>3</td>
<td>172.44 ±39.11bc</td>
<td>-</td>
</tr>
<tr>
<td>Fitarelli 1R</td>
<td>3</td>
<td>160.44±44.51bc</td>
<td>-</td>
</tr>
<tr>
<td>2BFG-100</td>
<td>3</td>
<td>121.78±33.92bc</td>
<td>61.70±13.64a</td>
</tr>
<tr>
<td>Fitarelli 2R</td>
<td>3</td>
<td>84.00 ±29.97c</td>
<td>-</td>
</tr>
<tr>
<td>Conventional</td>
<td>3</td>
<td>75.11 ±18.92c</td>
<td>8.12±4.06b</td>
</tr>
</tbody>
</table>

1 Time for twice weeding
2 John Morrison seeder was not selected for wheat seeding for on-farm evaluation
3 Fitarelli single and double rows were also not selected for wheat seeding for on-farm evaluation
Grain yield
Grain yield of wheat under different tillage option is shown in Figure 6. On station trials at Kulumsa Research center indicated that grain yield increment was registered in 2016. Conventional tillage practice gave better yield than the rest of the best-bet technologies selected in 2015. Conversely grain yield showed, significantly higher in all CA seeded plots at on station in 2016. Average yield was highest for 2BFG-100 seeder (2991.44 kg/ha) followed by VMP (2705.56 kg/ha), National Agro (2536.67 kg/ha) and the lowest from conventional practice. (2065.33 kg/ha) plot. Over season, the yield obtained in 2015 was lower than the other cropping seasons. This is attributed to the effect of El Niño phenomenon that occurred throughout the country during that season where the problem was severe in Kulumsa area thus the lower yield attributes due to the occurrence.

On-farm evaluations indicated that conventional yield was better than the best-bet CA options applied in 2015 (Figure 7). In a different way the yield obtained from the CA seeded plots in 2015 was higher than the conventional treatment. In 2016, the effect of the previous year’s El Niño occurrence may possibly had been severe in Tiyo area for the lower yield attributes.

Figure 7. On station trial wheat grain yield at Kulumsa Research Center, 2015 and 2016 (up) and on farm trial grain yield for wheat seeding at Tiyo district, Assela, Ethiopia 2015 and 2016(down)

On-farm evaluations indicated that John Morisson and VMP seeders were superior in both years when compared with the conventional yield of maize at Hawassa Zuria and they were regarded as best-bet CA seeders (Figure.8). In a different way the rest of the seeders were
yielding lower than the conventional seeded plots in both years. This was due to the shallow depth seeding and lower soil until as compared to the other two CA seeders.

**Figure 8.** On-farm trial maize grain yield in 2015 and 2016 at DoreBafena district, Hawaassa, Ethiopia

### Conclusion

The on-station trials indicated a 10 fold field operation time saving using 2WT-based CA seeders compared to the conventional tillage practice. Grain yield results also showed 29 % and 22 % increment in wheat and maize trials respectively. Among tested seeders VMP seeder performed best and selected as best-bets for both wheat and maize crops while 2BFG and John Morrison seeders performed best for only wheat seeding and maize seeding respectively. Fuel consumption of the seeders vary from 9.36 lit.ha⁻¹ to 12.56 lit.ha⁻¹ depending on the type of attached seeder and depth of ripping (zero till or ripping). Weeding is one of the major concerns in adopting CA. Pre-emergence herbicides may not be options to control weeds effectively and hence, the research need to focus on the need for mechanical weeding until complete CA technology package takes place as the soil cover resolves the issue of weeding. The cost of tillage is much higher than the cost of manual hand weeding in most places in Ethiopia. Although the manual weeding is very laborious involving drudgery, it can still be used as means to promote these technologies. The CA seeders are promising for future scale up and research should focus on developing the seeders and make available locally by training manufacturers capable of large-scale production with precision.

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Abstract

This study was conducted to design, develop, and test tef row seeder for smallholder tef farmers. Tef row seeders were designed and developed to improve planting efficiency and reduce drudgery involved in manual planting method. The seeders were made of durable and cheap material affordable for the smallholder tef farmers. Unskilled farmers also made the operating, adjusting, and maintaining principles simple for effective handling. The newly developed seeders were found as highly labor saving as they reduced labor hours more than 10 times than manual row planting by hand and achieved the recommended 5 Kg/ha seed rate. The actual field capacity were found to be 0.136 ha/hr, 0.095 ha/hr and 0.09 ha/hr for Melkassa site and 1.04 ha/hr, 0.092 ha/hr and 0.078 ha/hr for Debrezeit for Melkassa I, Melkassa II and Melkassa III tef seeders respectively. The field efficiency of the seeders were found to be 80.3 %, 63.4% and 68.3 % for Melkassa while for Debrezeit 61.1 %, 61.54 % and 59.3% for Melkassa I, Melkassa II and Melkassa III tef seeders respectively.

Introduction

Despite its importance, the productivity and production of tef is very low mainly attributed to the traditional farming practices. Improving the production and productivity of the crop is one of the important targets. The main inputs to improve tef productivity are required type and amount of fertilizers, reduced seed rate, and row planting. In this regard, wise utilization of seed through appropriate seeding rate is crucial.

Planting is one of the most important cultural practices associated with tef production. Tef is traditionally planted by broadcasting about 15-55 kg ha⁻¹ of seeds manually under different conditions in different regions of the country (Ketema, 1997). This traditional way of broadcasting seeds does not ensure desired plant population and cannot achieve uniform row-to-row distance between plants, which makes intercultural practices such as weeding very difficult. Broadcasting requires additional seed per hectare compared to row sowing method thus increases cost of production. The 25-50kg/ha of tef seed rate used by farmers is too dense (Bekalu and Tenaw, 2015) and thus increases competition among plants for nutrients, water, sunlight and CO₂ (Fufa et al., 2011) which ultimately resulting in sub optimal yield (Berhe, 2008; Melaku, 2008). Moreover broadcasting at higher seed rate make the mature plant to lodge or fall over (Berhe, 2009; Chanyalew and Kebede, 2013). Therefore, tef plants have no chance to express their production potentials. In line with this, row planting can play an imperative role in suitable crop establishment leading to a significant improvement in production and productivity.

Planting in rows on the other hand is a potential technique to ease up subsequent operations like weeding and harvesting. Amount of seeds planted along the rows and distance uniformity between seeds are important factors in crop production, which can affect uniform crop growth and yield. Tef row planting which requires 3-5 kg/ha of seed rate and placing the seeds at a depth of 2-3 cm in the soil without soil compaction showed positive response to improve tef yields. These improved practices initiate the tef roots to better anchor the soil, get efficient nutrient uptake and develop well through silted soil.

Developing and Testing Tef Row Seeder

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Exploratory trials conducted to test row planting of tef in different parts of the country confirmed that it is most meritorious in increasing production (Agricultural Transformation Agency, 2013; Berhe, Gebretsadik, Edwards, & Araya, 2011). As a result, row planting had been demonstrated and massive rural people mobilization were conducted all over the country during 2012 to 2014. The technique employed a farmer and two additional family members (mostly women and child) using empty plastic bottles or similar small containers for pouring/drilling the seed and fertilizer manually by hand. Planting furrows are opened by animal drawn traditional plough just before planting. However, manual row planting by hand result in uneven inter and intra row distribution of seeds (bunching and gaps in the field); the seeds are drilled at a higher seed rate than recommended, mainly due to the very small size of the seed. Manual row planting by hand is also associated with unavoidable drudgery and requires great labor hours (70 to 100 hrs/ha) making it costly and unlikely for adoption in larger plots. For farmers to adopt tef row planting, there has to be a technology that ease the drudgery and saves operation time. This requires efficient row seeder suitable to the crop and the farming community. Thus, the agricultural mechanization research directorate has been involved in developing manual and/or animal pulled/pushed tef seed drilling planters. In light of the foregoing discussion and facts, the need of undertaking this study was to design, develop, and test tef row seeder.

Methodology

Design and development
The tef seeder is designed to replace manual row planting mainly for smallholder farmers considering size of land holdings and their economic status. Beside the engineering property and the crop agronomic requirement, the following design consideration were taken: ease of fabrication, affordability, operation easiness and farmers' land holding size.

The initial prototype seeder (Melkassa I) (Figure 1) was designed calibrated and field-tested at MARC. The prototype was then demonstrated to farmers and agricultural experts. Based on stakeholders’ feedback, two other tef seeder options (Melkassa II and Melkassa III) (Figure 2 and Figure 3 respectively) were designed and developed at the Agricultural Engineering Research workshop at Melkassa in years between 2014 and 2015. Melkassa I seeder is designed to be pushed by human power without fertilizer option. Melkassa II is meant for drilling both tef seed and fertilizer in row and pulled by pair of oxen, single ox, or a donkey with different harness and also with option to be pushed by humans. Melkassa III is meant for drilling seed only (without fertilizer option) and the power source is the same with Melkassa II. The metering system is the same for the three seeders.

Field Testing
Preliminary test, with the aim that the functional parts are working as expected, was carried out on Agricultural Engineering Research test plot at Melkassa. Once it was found that the functional parts were working properly, field performance were carried out at Debrezeit research center representing hard soil using the first version (Melkassa I). The seeder was compared with manual row planting by hand, traditional broadcasting, and Canadian broadcaster. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The plot size was 10 m by 10 m (100 m²).
**Measurements**

Turning time at the end of the field was added with actual operating time for effective field capacity determination. Theoretical and effective field capacity of the seeder was determined by the following two equations:

\[
\text{Theoretical field capacity, ha/hr} = \frac{w \times s}{10}
\]

Where, \( S = \) Forward speed, km/hr and \( w = \) Width of coverage, m

\[
\text{Effective field capacity, ha/hr} = \frac{A}{T}
\]

Where, \( A = \) Field coverage, ha and \( T = \) Actual time of operation, hrs.

\[
\text{Field efficiency in \% = } \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}}
\]

**Components of tef seed drills**

Main components of the tef seeder were seed hopper, seed metering device, seed tube, seed covering, runner wheel, seed discharge tube, and frame including handle. For the design of the seed hopper and metering device, the physical properties of the crop (Table 1) were considered.

**The frame**

The frame is like the chassis for the seeder, it forms the platform on which other components are fixed. The material of the main frame was selected based on achieving a reasonable weight and required strength and reliability and readily available material.

**Seed hopper**

The seed hopper is a container in which the seeds to be planted are kept before their gradual release into the hose. The hopper for Melkassa I has trapezoidal shape and a slope of 30° to ensure free flow of seeds. The Hoper for Melkassa II has the same shape as the previous but has two compartments for drilling fertilizer and seeds simultaneously. Melkassa III has the same shape but only one compartment. The seed hoppers also have a cover.

![Table 1: Physical properties of tef seed](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of repose/degree</td>
<td>23.4</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>1.01</td>
</tr>
<tr>
<td>Width (mm)</td>
<td>0.59</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>0.71</td>
</tr>
<tr>
<td>Bulk density(kgm⁻³)</td>
<td>840</td>
</tr>
</tbody>
</table>

Source: (Zewdu & Solomon, 2007)

**Seed metering device**

Metering device picks required number of seeds and delivers them into the soil through the tube at required depths created by furrow openers. In the design of seed metering device the size of the seed, the intra row spacing between seeds and desired plant populations were considered. The metering mechanism is 120 mm long radial arms made of 6mm diameter mild steel. Seed scoping cups are tangentially fitted at the outer tip of the rotating arms for picking a hill of seeds from the hopper and drop them in the seed funnel.
When the arms rotate, the radial arms rotate seed picking cups scoop the seeds from hopper and drop them in seed funnel. The size and number of cups is determined to drill the recommended 5-10 kg/ha seed rate. A ground wheel is provided to drive the metering unit, which is vertically attached, on a horizontal shaft through a chain and sprocket transmission.

### Results and Discussions

#### Functioning of the seeders
Three tef seed drill prototypes have been developed and field tested. The result indicated that the metering unit of the seeders achieved the recommended agronomic seed rate of 5 Kg/ha at 20 cm row to row spacing. Thus, seed metering and delivery systems meet the functional and operational requirements of tef row planting. Field tests conducted under the sandy loam soil at MARC showed good performance in terms of ease of operation. However, mobility (propelling and turning) problem, tiresomeness, and fatigue in short operating time (about 0.5 hrs.) and difficulties during transporting were observed to restrict the smooth functioning of the seed drills on clay soil types under wet soil moisture condition. This is more pronounced with the use of animal drawn Melkassa II and III planters.

#### Field capacity
The field capacity and field efficiency was calculated and the results are presented in Figure 1. The theoretical field capacity was determined as 0.17 ha/hr., 0.15 ha/hr. and 0.125 ha/hr. for Melkassa I, Melkassa II and Melkassa III respectively. The actual field capacity of the seeders were found to be 0.136 ha/hr., 0.095 ha/hr. and 0.09 ha/hr. for Melkassa site and 1.04 ha/hr., 0.092 ha/hr. and 0.078 ha/hr. for Debrezeit in the same order as previous. From the actual and theoretical field capacity, the field efficiency of the seeders were found to be 80.3 %, 63.4% and 68.3 % for Melkassa while for Debrezeit 61.1 %, 61.54 % and 59.3% for Melkassa I, Melkassa II and Melkassa III respectively. The newly developed seeders were found as highly labor saving equipment as they reduced labor hours 10 times than with manual row planting by hand. The result also showed that highly significant difference between the newly developed seeder and manual row planting. Lack of labor during peak planting periods may cause delay in the operations. In such situations, these row seeders are effective means for timely sowing of tef.

![Field capacity at Melkassa and Debrezeit testing site](image)

**Figure 1: Field capacity at Melkassa and Debrezeit testing site**
Agronomic field evaluation
Agronomic field evaluation was done for Melkassa I seeder only owing to the fact that Melkassa I seeder performed better at laboratory testing. The seeder was compared with manual row planting by hand, traditional broadcasting, and Canadian broadcaster and the results are presented below (Table 2). No significant variations were observed in emergence count. Numerically maximum emergence count (306/0.25m²) was observed in tef plot planted with Melkassa I seeder while the minimum emergence (170/0.25m²) was observed in tef plot planted manually by hand. The maximum emergence count for Melkassa I seeder may be because the seeder provided favorable environment i.e., optimum seed placement and lower seed rate.

Grain yield is the important component of plant performance under a set of growing conditions. Any physiological or agronomic parameter at a given stage of growth would be of further use only when its effect is reflected on yield either way. Planting tef in a row with the new seeder resulted in slightly higher grain yield than the other methods of planting but with no significant difference at 5 % level. Here it should be noted that the seeders were designed and developed to provide at least the same yield level but to have higher field capacity and to avoid drudgery associated with manual row planting by hand. There is no any significance difference between the treatments in the other parameters also (Table 2).

Table 2: Statistical summary of agronomic data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Melkassa I seeder</th>
<th>Hand drilling</th>
<th>Canada broadcaster</th>
<th>Conventional broadcasting</th>
<th>LSD value at 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergence count/0.25m²</td>
<td>306.68</td>
<td>170.45</td>
<td>292.55</td>
<td>263.23</td>
<td>NS</td>
</tr>
<tr>
<td>Plant height(cm)</td>
<td>110.47</td>
<td>112.40</td>
<td>113.40</td>
<td>112.09</td>
<td>NS</td>
</tr>
<tr>
<td>Panicle length(cm)</td>
<td>45.00</td>
<td>46.27</td>
<td>47.40</td>
<td>46.22</td>
<td>NS</td>
</tr>
<tr>
<td>Total tiller</td>
<td>7.33</td>
<td>8.00</td>
<td>5.00</td>
<td>6.78</td>
<td>NS</td>
</tr>
<tr>
<td>Shoot biomass(q/ha)</td>
<td>74.06</td>
<td>69.06</td>
<td>75.50</td>
<td>72.87</td>
<td>NS</td>
</tr>
<tr>
<td>Straw(q/ha)</td>
<td>59.85</td>
<td>56.89</td>
<td>61.54</td>
<td>59.43</td>
<td>NS</td>
</tr>
<tr>
<td>Grain yield(q/ha)</td>
<td>14.21</td>
<td>12.17</td>
<td>14.00</td>
<td>13.46</td>
<td>NS</td>
</tr>
<tr>
<td>Grain straw ratio</td>
<td>0.24</td>
<td>0.21</td>
<td>0.23</td>
<td>0.23</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS- not significant

Conclusion

The seeders are intended to minimize the drudgery and time wastage for drilling seeds by hand in continuous bending down position and the fatigue that generally characterize traditional seed planting by most farmers. The seeders serve as an intermediate technology to replace row planting mainly for smallholder farmers. From engineering and manufacturing perspective Melkassa I seeder was found easy to clean, easy to transport and also easy to operate by average adult male and female operators as compared to Melkassa II and Melkassa III seeders. The seeder is also very compact. The field test results showed that the newly developed seeders were found as highly labor saving as they reduced labor hours more than 10 times than manual row planting by hand and achieved the recommended 5 Kg/ha seed rate. The actual field capacity were found to be 0.136 ha/hrs 0.095 ha/hrs and 0.09 ha/hrs for Melkassa site and 1.04 ha/hrs, 0.092 ha/hrs and 0.078 ha/hrs for Debrezeit for Melkassa I, Melkassa II and Melkassa III tef seeders respectively. The field efficiency of the seeders were found to be 80.3 %, 63.4% and 68.3 % for Melkassa while for Debrezeit 61.1 %, 61.54 % and 59.3% for...
Melkassa I, Melkassa II and Melkassa III seeders respectively. In general, the planters were found to work effectively on sandy loam soil types at moderate moisture condition. However, further improvement of existing planters to minimize the drudgery while turning and development of a new row planter design capable of working in a wet clay soil condition will be required to solve mobility problems.

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CSA. 2015. Agricultural Sample Survey Time Series Data for National and Regional Level


Developing and Evaluating Animal-drawn Multi-crop Planter

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Abstract
Availability of efficient, affordable and less drudgery row seeding equipment is limited in Ethiopia. The available row seeding equipment are characterized by their low field capacity, poor performances and higher energy requirement (in the case of animated planters) and high machinery purchase and operation costs (in the case of tractor operated ones). Moreover, the available planters are developed to be crop specific, which limits their application area to a certain crop. To alleviate the existing problem, a new, animal drawn multicrop type planter (AMCP) was developed and evaluated on bean, wheat, maize, and sorghum against conventional method of planting using hand row planting technique (CMP) that farmers now days are using. The trials were conducted at Melkassa Agricultural Research Center (MARC) on well-prepared plots having 10x40m² areas and following RCBD experimental design with three replications. The parameters for the evaluations were seeding pattern, field capacities, plant population densities, and draft requirement. The seed spacing achieved by AMCP on bean (12.77±2.79cm) and maize (19.64±5.34cm) crops, and its seeding rates on wheat (127.23±5.69 kg/ha) and sorghum (13.46±1.06 kg/ha) were found to be statistically non-significant compared to the spacing and the seed rates achieved by employing CMP. The field capacities and efficiencies of the planter on bean (0.161±0.02 ha/hrs, 67.22%), maize (0.173±0.01 ha/hrs, 71.39%), wheat (0.143±0.02 ha/hrs, 65.53%) and sorghum (0.169±0.01 ha/hrs, 72.13%) were found to be statistically significant compared to those of CMP. On plant population densities, no significant variation was observed between ACMP and CMP on each of the crops. Its actual draft requirement was measured to be 637.50±18.22N, which is below the average draft output of a pair of oxen.

Introduction

Ethiopia is endowed with huge potential for growing different types of crops. However, despite the potential, the nation's agriculture is characterized by its low productivity and subsistence nature, which is mainly related with the traditional method of crop establishing technique, especially the seed sowing, which farmers have been employing for centuries. Farmers usually use broadcasting technique, which leads to non-uniform application, higher seed and fertilizer rates, high competitions among seedlings for nutrients and sunlight and also greater drudgery/difficulty for successive management practices.

However, recently, most farmers of the country have realized the advantage of row planting and started to adopt the method. In addition different stakeholders encouraging farmers by introducing animated and tractor operated seeders. For instance, JICA introduced a single row manually operated maize planter with field capacity and seed spacing performance of 0.027 ha/hrs and 13.21±2.14 cm respectively. CIMMYT introduced a manually operated jab planter that would be used in zero tillage farming. Rotary jab planter that work manually and using draft animals were introduced to light soil areas of the country. Fitsum (2017) developed ripper attached maize planter, which could be used for strip tillage practices. Meseret (2017) developed animal drawn two row maize planter with a field capacity of 0.21 ha/hr⁻¹. Tamirat (2017) developed a pair of oxen drawn two row sorghum seed drill which had field capacity of 0.39 ha/hr⁻¹ and seeding rate of 15.08 kg/ha. AIRIC (1992) developed a non-wheeled type tillage-
cum-planter which could work on any soil type and condition. However, the acceptance of the technology was poor as the planter had limitations in guiding and controlling the pulling oxen as the operation involves both hands for holding handle of the plow with one hand while oscillating planter arm with the other.

Generally, adoption rate of most of the existing planters by farmers is limited. The manually operated planters need a well-prepared seedbed to perform to their best which farmers could not deliver using traditional tillage tools. Besides, the field capacities of such planters are poor and do not insure on time completion of sowing seeds. Their energy requirement on poorly prepared seedbed is also tremendous which cause drudgery to operators. The adoption rate of most of the animal drawn planters was also low as they do not meet the agronomic requirements of the crops and they are difficult to manage during operation especially at headlands. Moreover, the available animate type planters in general are developed to be crop specific (mono-crop type) which enforces the resource poor farmers to purchase other planters for addressing crops other than the planter designed for.

Walk behind tractor-operated planters have also been introduced to farmers by different stakeholders. Most of these planters developed to be multi-crop type and they meet the agronomic requirements of the crops they designed for. However, the cost of operation, owning the equipment and the power source is too expensive for farmers. Besides, as most of these planters have low field capacities (owing to their large weight), their use in areas exhibiting low precipitation amount and erratic distribution is limited. Thus, efficient, affordable, and multi-crop type seeder/planter needs to be developed and introduced to farmers so that row-planting technique shall be adopted.

**Methodology**

**Development of the planter**
The implement developed was animal-drawn, seed-cum-fertilizer multicrop planter, which addresses maize, bean, sorghum, and wheat crops. It is equipped with two ground-engaging wheels with diameter of 48cm where one of them produces the necessary force to drive the seed and fertilizer metering units through chain-sprocket drive. The sprocket gear ratio \(g_r\) was three and the total weight of the planter at full loads of seed and fertilizer hoppers is 68kg. The overall length, width, and height of the planter are 135cm, 100cm and 100cm respectively.

For the objective of reducing refilling time loss, the planter is equipped with two layers of trapezoidal hoppers which each has distinct seed (with 37.5L capacity) and fertilizer granules (18.75L capacity) compartments. The upper hopper serves as storage structure for replenishing the lower one at constant rates with the reduction amount and, it is made to be detachable whenever necessary. The lower hopper contains seeds and fertilizers granules that are ready to be metered and delivered to the ground by the metering unit placed inside the hopper. On the rear wall of this hopper, there are openings/windows through which seeds and fertilizer are thrown out of the system to reach to the ground. These two hoppers are connected with flexible hoses, and flow of seed and fertilizer in the hoses is due to gravitational force.
The metering system of the planter is a scoop type where by seeds and fertilizer granules are scooped from the bottom of the lower hopper and delivered to the ground via flexible hoses (which are connected with furrow openers) passing through the openings of the hopper. These scooping type-metering units are eight in number (four for the seeds and four for the fertilizer) and are mounted on the carrying shaft, which is placed inside the lower hopper. Each metering unit is made from metallic cups which have nearly equal diameter bolts inside them and they are connected to hubs (inserted in the main shaft carrying all the metering units) using threads. The outer peripheries of these hubs were drilled to have quadrantal and pentagonal arrangements of the scooping cups whenever necessary. The presence of nearly equal sized bolts in the cups is for regulating the seeding rate as well as the number of seeds dropped per spot to the desired amount through adjusting the volume of the scooping cups using screw driver. Whereas, the hubs at the peripheries are drilled so that the desired seed spacing between plants can be achieved. Thus, for small seeded crops like wheat, barley, and sorghum which need just drilling, adjusting seeding rate to the desired level is achieved through changing the volume of the cup using screw driver. But for large seeded crops (maize and bean) which need plant to plant spacing on the ground, removing out some of these cups on the hub and rearranging the remaining ones at equal angles will provide the desired seed spacing. The number of seeds dropped per spot for such large seeded crops will also be adjusted by changing the volume of the scoop cups with screwdriver keeping the required number and the arrangement of the cups on the carrying hub. The scooping cups are designed to throw seeds and fertilizer at the slowest average speed of the power source on a well-prepared seedbed.

The planter is also equipped with adjustable runner type furrow openers with integrated soil covering mechanism. The depth adjustment is done by loosening the bolts which anchors the furrow openers with frame and raising/lowering the openers to the desired depth. Row width adjustment is done by removing/adding and sliding the furrow openers to the recommended row spacing of the crop to be addressed. Thus, for wheat and barley, the planter will become four-row type with row spacing of 20cm. For bean, it will be a three-row planter having 40cm row spacing. For maize and sorghum, it will be a two-row planter having 75cm row spacing.
The diameter of imaginary circle \( (d_m) \) a single metering unit created as it revolves and number of the scooping cups \( (n_c) \) on it are determined based on the relation between the revolving units of the planter, gear ratio and seed to seed spacing in a row (Richard et.al, 2011).

\[
d_m = \frac{W_d}{\pi g_r} \quad \text{(Eq. 1)}
\]

\[
n_c = \frac{x W_d}{\pi g_r} \quad \text{(Eq. 2)}
\]

where \( d_m \) = diameter of imaginary circle created by revolving metering unit, m

\( n_c \) = number of scooping cups, no; \( x \) = spacing b/n plants within a row, m;

\( W_d \) = diameter of ground wheel, m; \( g_r \) = gear ratio

The speed of the seeds \( (V_s) \) at throwing point of the scooping cups is determined based on the following relationships.

\[
V_s = \pi n_m d_m \quad \text{(Eq. 3)}
\]

where \( V_s \) = peripheral velocity of the metering unit (seed speed at throwing point), m.s\(^{-1}\)

\( n_m \) = revolution of the metering unit, rpm

\( d_m \) = diameter of imaginary circle created by revolving metering unit, m

The shaft diameter of the planter is determined based on the maximum shear stress theory (Richard et.al, 2011).

\[
\tau_{\text{max}} = \frac{16}{\pi d^3} \sqrt{[C_m M_{\text{max}}]^2 + [C_t T]^2} \quad \text{(Eq. 4)}
\]

where \( \tau_{\text{max}} \) = maximum shear stress, N/m\(^2\); \( d \) = diameter of the shaft, m; \( M_{\text{max}} \) = maximum bending moment on the shaft, Nm; \( T \) = net torque on the shaft, Nm; \( d \) = diameter of the shaft, cm; \( C_m \) = numerical combined shock and fatigue factor for bending moment, No.; \( C_t \) = numerical combined shock and fatigue factor for torque, No.

The draft requirement of the planter was estimated based on weight of the planter and its rolling resistance, soil resistance and condition, width and depth of furrow made and field gradient (Sharma and Mukesh, 2010).

\[
D_S = C_r (C_r \cos \theta \pm \sin \theta) + k.n.a.b \quad \text{(Eq. 5)}
\]

\[
C_r = \sqrt{\frac{Z}{W_d}} \quad \text{........................................ (Eq. 6)}
\]

Where \( D_S \) = seed drill draft requirement, N; \( C_r \) = coefficient of rolling resistance, No.; \( k \) = soil resistance, N/m\(^2\); \( G \) = weight of the implement including seed, N; \( a \) = depth of furrow, cm; \( b \) = width of furrow, cm; \( \theta \) = ground gradient, degree; \( Z \) = maximum tolerable wheel sinkage depth, cm; \( W_d \) = ground wheel diameter, cm

The appropriate wheel width of the planter \( (L) \) was estimated based on the relationship of a cylinder and a plane surface contact (Richard et.al, 2011).

\[
b = \sqrt{\frac{(2F)}{\pi E} \left( \frac{(1-v_1^2)E_2}{E_1} + \frac{(1-v_2^2)E_1}{E_2} \right) \left( \frac{1}{d_1} + \frac{1}{d_2} \right)} \quad \text{(Eq. 7)}
\]

\[
p_{\text{max}} = \frac{2F}{\pi bL} \quad \text{........................................ (Eq. 8)}
\]
Where $b$ = longitudinal half contact length between the wheel and the plane/soil, cm; $\rho_{\text{max}}$ = the maximum pressure developed at the longitudinal contact zone, Pa; $\nu_1$ = Poisson ratio of the plane or soil, No.; $\nu_2$ = Poisson ratio of wheel, No.; $E_1$ = Young’s modulus of elasticity of the plane or soil, GPa; $E_2$ = Young’s modulus of elasticity of wheel, GPa; $d_1$ = diameter of the plane, $\infty$; $d_2$ = diameter of the wheel, cm; $F$ = weight of the planter, N; $L$ = width of the wheel, m

Performance Evaluation

Study site
The field evaluation of the planter was conducted on maize, sorghum, wheat and bean crops at Melkassa Agricultural Research Center/MARC/. Melkassa is located 115 km from Addis Ababa in the Central Valley of Ethiopia. The place is situated at an altitude of 1466 m above sea level and lies on the geographical coordinates of $8^\circ\ 24'\ 0"\ N, 39^\circ\ 20'\ 0"\ E$ Latitude and Longitude respectively. It receives 763 mm mean annual rainfall, of which 70% falls during the major cropping season: June to September. The dominant soil type in the area is sandy loam.

Adjustment of the planter
For bean planting, the planter was adjusted to have three equally spaced (40cm) furrow openers and to place the seed at 4-6cm depths. The volume of each of the scooping cups of the three seed metering units was adjusted to pick two seeds per revolution of the metering units in order to have higher chance of seed emergence. However, the volumes of the scooping cups on the rest seed-metering unit were kept at zero level/depth so that it cannot scoop seed from the hopper. The scooping cups on each of the three seed metering units were also adjusted to have pentagonal arrangement so that 10cm plant-to-plant spacing within a row can be achieved. The same adjustment was also made on the fertilizer metering units except that they were adjusted to provide 100kg/ha DAP fertilizer. In case of wheat planting, four furrow openers were equally spaced at 20cm interval and adjusted to place seed at 2-4cm depths. The scooping cups were adjusted to drop 120-140 kg.ha$^{-1}$. The scooping cups on each of the four seed metering units were also adjusted to have pentagonal arrangement. The fertilizer metering units were adjusted to provide 100kg/ha DAP fertilizer.

Maize and sorghum were planted by adjusting the planter to have two furrow openers spaced at 75cm. Like bean and wheat, five scooping cups with pentagonal arrangement on each metering unit were used for sorghum. However, two scooping cups arranged at 180$^\circ$ were used in case of maize. The scooping cups were adjusted to provide the recommended 12-14 kg/ha seed rate for sorghum and, to drop two seeds per spot for maize at 25cm plant-to-plant spacing. The fertilizer metering units for both cases were adjusted to provide 100kg/ha DAP fertilizer.

Treatments and cultural practices
Comparative evaluations of two treatments animal drawn multi-crop planter (AMCP); and the conventional manual row planting (CMP) were conducted on station for maize, sorghum, wheat and bean crops. The plot size for each treatment was 10 x 40m$^2$ arranged in Randomized Complete Block Design /RCBD/ with three replication. CMP practice is characterized by placing the seeds in the furrow and covering of them manually. In AMCP plots the machine did both seed placing and covering. All treatment plots were plowed three times with traditional ox drawn plow ‘Maresha’ thus evaluations were made on a finely prepared seedbed. The cone-penetration index of the fields were 0.234±0.08KN and 0.31±0.01KN KN at 0-10cm and 10-
20 cm soil depths respectively. The seeds used for the test had 89.3%, 94%, 97.4% and 97.8% germination rates for sorghum (Melkam), maize (Melkassa 2), bean (Nasir) and wheat (Sofumer) crop varieties respectively.

The trail fields were weeded twice by hand each time weeds reached more than 10 cm in height. In the conventional method, sowing of maize and bean seeds were done by placing two seeds per spot keeping the recommended seed spacing and seed depth of the crops. Whereas, wheat and sorghum seeds were drilled in furrows keeping the recommended seeding rate. The number of labor force involved in seeding and fertilizer application of maize and sorghum crops were six, whereas for bean and wheat crops three and seven persons were used respectively. The parameters for comparison of the treatments were seeding pattern, field capacity, and plant population density. Actual draft requirement of the planter was also determined.

Seeding pattern
For bean and maize trials, the seed spacing and the number of seeds per hill were measured from 1.5 m sample lengths of the four middle rows of a plot during seed sowing. The rows were purposely left opened for a while until measurements were taken and then covered manually. The sample locations had consecutive staggered arrangement to account field variation caused by either field preparation or gradient. Data regarding depth of seed placement achieved was also measured from the same locations using steel tapes and steel scale.

During seed spacing measurement, miss/skip/was assumed/considered whenever the spacing between two hills was greater than 1.5 times the theoretical spacing, i.e. 10 cm (Katchman and Smith, 1995). The same data were taken for wheat and sorghum except that instead of measuring the seed spacing and seeds per hill, the seeding and fertilizer application rates of the planter were measured by comparing the weights of seeds and fertilizer first filled in the hopper with the remaining amounts at the end of the trial for each plot.

Field capacity
Effective field capacities (EFC) for each trial were calculated by dividing the total area worked by the period spent from the beginning of the first furrow pass to the end of the last one. The field efficiency (FE) was calculated as the ratio of the actual field capacity to the theoretical one (TFC).

\[
EFC = \frac{A}{T_T} \hspace{2cm} \text{(Eq. 9)}
\]

\[
TFC = \frac{A}{T_{net}} \hspace{2cm} \text{(Eq. 10)}
\]

\[
FE = 100 \left( \frac{e_{fc}}{T_{fc}} \right) \hspace{2cm} \text{(Eq. 11)}
\]

\[
TT = T_{net} + T_{refill} + T_{rep} + \text{etc} \hspace{2cm} \text{(Eq. 12)}
\]

Where EFC = actual field capacity, hahr⁻¹; FE = field efficiency, %; TFC = theoretical field efficiency, hahr⁻¹; TT = total time spent for the operation, hr; T_{net} = net time spent for the operation, hr; T_{refill} = time spent for refilling the hoppers, hr; T_{rep} = time spent for maintenance and repair during operation, hr;
Plant population density
For bean and maize trials, the plant population, or rather seed emergence, count were measured from the middle eight rows of each plot when the crops were at three to four leaves stage. When the count were made, two or more seeds emerged at a spot were considered as one (in case of maize and bean trials) because tinning work shall be performed eventually in order to avoid competitions among the germinated seeds. However, for wheat and sorghum trials, the plant population data were measured from five randomly selected (along the diagonal) spots of each plot using 1m² square quadrant.

Draft requirement
The draft requirement test of the planter was conducted on a 20m clean, dry concrete track and on actual field. The average moisture content of the field and its gradient were 19.23% and 5% respectively and the average angle of pull were 13.70° and 15.42° from the horizontal for the track and field tests respectively. The measurements were replicated five times for both cases.

Data analysis
All the data collected during the evaluations were analyzed using Statistix 8 software. Statistics 8 is a commercial software package developed by the United States Department of Agriculture (USDA). During the analysis, the confidence interval level used was 95% and the 4 observations done in seed spacing and seed per hill measurement for each plot were combined and analyzed together.

Result and Discussion

Seeding pattern and plant population
Maize and bean
Significant variations were observed on seed spacing between the treatments for both trials (Tables1 and 2). Seed bounce and variation of operation speeds could be the reasons for the planter not to perform as per the desired seed spacing; 10cm and 25cm for bean and maize crops respectively. Seed bounce created when there is variation between the forward speed of the planter and the seed velocity relative to the planter in the direction of motion/planting. When this happens, the seed will not have zero velocity relative to the ground/furrow. Improper setting of seed tube angle at seed outlet, creates such problem (Ajit K. et.al. 2012).

Inconsistent operation speed also affects the seed spacing between plants through varying the rotational speed of the metering unit, which leads to non-uniform initial/lauhching velocity of the seed. This causes the seed to have non-uniform transit time in the tube (Ajit K. et.al. 2012). Staggenborg et al. (2004) also determined that variation in maize planting speed adversely affected plant spacing uniformity performance in northeast Kansas. However, though significant variations were observed between the treatments, the seed spacing achieved by the planter were close to the recommended seed spacing of the crops and also they were within the quality feed index ranges.
Table 1. Seeding pattern and plant population of the planter on maize and bean crops

<table>
<thead>
<tr>
<th>Parameter</th>
<th>*Maize</th>
<th>*Bean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CMP</td>
<td>AMCP</td>
</tr>
<tr>
<td>Seed spacing (cm)</td>
<td>26.05±1.18a</td>
<td>19.64±5.34b</td>
</tr>
<tr>
<td>Seeds per hill,( count)</td>
<td>2.00±0.00a</td>
<td>2.67±0.58a</td>
</tr>
<tr>
<td>Seeding depth,( cm)</td>
<td>7.03±0.72a</td>
<td>8.17±0.47a</td>
</tr>
<tr>
<td>Fertilizer application, (kg/ha)</td>
<td>102.40±2.19a</td>
<td>108.15±4.28b</td>
</tr>
<tr>
<td>Missed/skipped spots (%)</td>
<td>-</td>
<td>7.16±9.48</td>
</tr>
<tr>
<td>Single seed</td>
<td>-</td>
<td>11.14±6.82</td>
</tr>
<tr>
<td>Double seeds</td>
<td>100</td>
<td>70.42±9.98</td>
</tr>
<tr>
<td>Multiple seed</td>
<td>-</td>
<td>11.46±6.16</td>
</tr>
<tr>
<td>Plant population (1000/ha)</td>
<td>43.4±2.3a</td>
<td>50.2±2.6a</td>
</tr>
</tbody>
</table>

* mean ± SD for n = 12, CMP = conventional planting, AMCP=Animal drawn multi-crop planter

In seed drop per hill, no significant variations between the treatments were observed for both trials. However, the capacity of the planter applying two seeds per hill (as per the adjustment made prior to the test) was found to be 70.42 ± 9.98% for bean and 69.92±10.82 for maize. The missed spots could be related with the variation of speed of operations. As the speed of operation increases, the probability of picking seeds from the hopper reduces. The multiple seed drop per spot could be due to the variation of seed sizes and geometry. In general, seed drop efficiency relates with the variation of seed sizes, geometry, and position at the picking zone and the speed of operation.

The good thing of the planter is that the volume of seed scooping cups on the metering unit is adjustable. This helps to easily maintain the required amount of seeds per spot through adjusting the volume/depth of the scooping cups.

Wheat and sorghum
In seed rate application and seeding depth, no significant variations between the means of the treatments were observed for both trials. However, in fertilizer application rates, there were significant variations, which could be the result of improper adjustment of metering units, size, and geometry of the fertilizer granules and operational speed variations of the planter. With proper scooping cups volume adjustment and maintaining uniform speed of operation, the planter could achieve the recommended fertilizer application rates. (Table 2). Here also the planter achieved the recommended seeding depths of both crops. This is due to the presence of depth adjustable furrow openers that helps to achieve relatively uniform depth of seeding.

Table 2. Seeding pattern and plant population of the planter on wheat and sorghum crops

<table>
<thead>
<tr>
<th>Parameter</th>
<th>*Wheat</th>
<th>*Sorghum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CMP</td>
<td>AMCP</td>
</tr>
<tr>
<td>Seed rate (kg/ha)</td>
<td>126.67±1.53a</td>
<td>127.23±5.69a</td>
</tr>
<tr>
<td>Fertilizer application, (kg/ha)</td>
<td>100.67±1.15a</td>
<td>110.33±5.69b</td>
</tr>
<tr>
<td>Seed depth (cm)</td>
<td>2.43±0.35a</td>
<td>2.93±0.45a</td>
</tr>
<tr>
<td>Plant population (1000/ha)</td>
<td>1860 ±302.3a</td>
<td>1890±214.7</td>
</tr>
</tbody>
</table>

Plant population
No significant variation was observed in plant population densities between the means of treatments in all the trials. However, though there was not significant variation, there was
differences between the two treatments which could be due to differences in seeding rate in case of wheat and sorghum crops and due to the variations from the recommended seed spacing in case of bean and maize crops. However, the plant population densities achieved by both treatments were lower than the expected theoretical amounts for each crop. This was mainly due to low amount and erratic distribution of precipitations during the trial year.

Field capacity
Significant variation was observed in field capacities between the treatments in all the four trials (Table 1 and 2). The lower performance of CMP could be related with successive operations of furrow making, seeding and soil cover which had to be done manually. The planter itself did all such operations in AMCP case. The number of turns of the planter at headlands per hectare was different for each crop due to the variation in row spacing of the crops. This, frequency of hopper refilling and the variation of speed of operations affected the field efficiencies of the planter.

Table 3. Field capacities and efficiencies of the planter on crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>* Field capacity (ha/r)</th>
<th>* Field efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CMP</td>
<td>AMCP</td>
</tr>
<tr>
<td>Maize</td>
<td>0.05±0.01a</td>
<td>0.173±0.01b</td>
</tr>
<tr>
<td>Bean</td>
<td>0.028±0.01a</td>
<td>0.161±0.02b</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.032±0.00a</td>
<td>0.143±0.02b</td>
</tr>
<tr>
<td>Sorghum</td>
<td>0.065±0.01a</td>
<td>0.169±0.01b</td>
</tr>
</tbody>
</table>

However, the time lost were insignificant and were compensated by the reduced turning radius of the planter due to cultural plow with elongated round pipe beam located at equidistance of the width of the planter which helped the operator could make sharp turns by engaging the plow against the soil firmly whenever he made turns at headlands. Besides the furrow openers designed to be placed on the rear side of the planter on a square solid bar whose ends were connected with the frame of the planter with ball bearings, it helped the operator to make turns easily at headlands without carrying the planter through raising only the handle which is connected with the solid bar the furrow openers are anchored with to disengage the furrow openers from the soil. The presence of the cultural plow in the planter also helps as a motion stopper, or rather a brake, to manipulate the speed of operation and to keep the draft animals on the right truck. The placing of furrow openers at rear side of the planter using solid bar and bearings also helps the operator to easily adjust the depth of operation through raising/lowering the handle.

Draft requirement
The field draft requirement of the implement in general found less than the draft output of a pair of local breed oxen (890N). The draft requirement was not large enough to induce stress on the pulling animals. This was the result of engaging wheels and their designed width dimension (10cm), which helped the planter to rotate over the surface of a ground without sinking into the soil.
Table 6. Horizontal draft force requirement of the planter

<table>
<thead>
<tr>
<th>Draft force (N)</th>
<th>Track test</th>
<th>Field test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>98</td>
<td>615</td>
</tr>
<tr>
<td>Maximum</td>
<td>112</td>
<td>667</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>107.10 ±4.15</td>
<td>637.50 ±18.22</td>
</tr>
</tbody>
</table>

Generally, the planter has shown excelled performance in many of the parameters over the conventional method of row planting which farmers are using. Its field performances on seed spacing, seeding depth, and fertilizer application are closer to the agronomic recommendations of the crops. Its seed per hill efficiency is almost as per the design and its field capacities are higher. Its draft requirement is below the average draft output of the power sources; a pair of oxen. Moreover, it is a multi-crop type which helps farmers to use it for various crops they grow just by adjusting the metering unit using screwdriver. However, it requires more study and modification works on the following issues:

- the dynamics of the seeds motions at picking zone and along the projectile trajectory (after thrown off) needs to be studied so that appropriate position of the outlet gates to be determined;
- if possible, higher than the existing gear ratio with appropriate reconfiguration of the scooping cups number on each metering unit should be employed so as to minimize the effect of the speed of the planter /the pulling animals/ on its seed spacing/rate achievement; and
- a better spring loaded speed brake mechanism should be integrated with the unit in order to have higher control of the seeding operation.

Acknowledgements
The authors would like to acknowledge the financial support of Ethiopian Institute of Agricultural Research, Agricultural Engineering Research Directorate. The authors also would like to acknowledge Laike Kebede, Assefa Birku, Dereje Alemu, Dereje Yihun, Tahir Tune, Kefyalew Weldesenbet, Tefera Mitiku, Eshet Belay and Tilahun Teka for their valuable comments and contributions during the prototype development, experiment execution and editorial work.

References
Performance of Ground Wheel Operated Boom Sprayer

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Abstract

Pests and weed problems, in crop production are serious both in rain fed and irrigated farms in Ethiopia. They are forced to spray insecticides, pesticides and herbicides frequently using manually operated machines, which are poor in application uniformity, laborious, time consuming, and dangerous in terms of operators' safety and health. The objectives of this research saw to manufacture and evaluate ground wheel operated boom sprayer. The sprayer was fabricated based on the manufacturing drawing. Then it was tested in both laboratory and field for the uniformity of application, discharge rate, field capacity and field efficiency. It has managed to achieve an application rate of 281.3 l/ha with coefficient of variation (CV %) of 2.80% among the nozzles. With discharge rate of 0.83 ha/hr., effective field capacity of 0.83ha/hrs. theoretical field capacity of 1.04 ha/hr. and field efficiency of 82.7%. As compared to the manually operated knapsacks sprayer of 0.4 ha/day field capacity and 56% field efficiency the prototype sprayer had improved the effective field capacity and field efficiency by 3 to 4 fold and 26.7% respectively. Based on the performance result the newly developed sprayer can cover one hectare of land within about an hour with a better spray uniformity.

Introduction

Now days, there are many types of pesticide sprayer already in market. Small and medium farmers mostly use knapsack sprayers to apply pesticides (FAO, 1994). Knapsack sprayers can be hand operated or motorized. More than 5 million hand-operated sprayers are sold annually in the world and most of them are sold in Southeast Asia and Africa (Matthews, 1992). Hand operated knapsack sprayers generally used by farmers involve continuous pumping by oscillating the lever with one hand while holding the sprayer nozzle with the other when spraying out the pesticide. The whole process of spraying is very tiresome, the constant pumping required operating results in muscular disorder and also leads to hand, back and neck pains with prolonged use with a heavy tank backload. Moreover, very small area is covered while spraying. So, more time are required to spray the entire land, which increases cost for spraying as well as the hazard of pesticide mist getting into the eyes.

The second type of spray pump used is fuel operated spray pump, which is heavier than hand operated backpack pump. This type of pump is running on petrol engine. The pump produces more vibrations, which is hazardous to users back muscles, and makes unwanted noise. In addition, we know that petrol is one of the costly fuel. Other options like tractor mounted boom sprayer could be a possible solution but it has become very difficult for farmers to easily access tractors even for the more laborious jobs of tillage. The cost of tractor hiring is very high and beyond the reach of the average farmer. According to Takeshima and Salau (2010) the minimum farm size for economic deployment of tractor is 50 hectares.

The quality of many of these sprayers, and their ability to be used to apply pesticides accurately and efficiently is of great concern due to their design and operation. It was estimated that about 50-80% of applied pesticides wasted due to poor spray machinery and inappropriate application
methods (Khan, et al., 1997). According to (Hastings and Quick, 1988) to attain a good result during spraying the distance between the nozzle and tops of the plants should be maintained at around 30 cm. According to some studies, a chance of overlap or missed areas was observed during swing of knapsack sprayers’ lance operation and the nozzle height was changed by 10% in each swing of lance (Garman and Navastor 1981). That means it is quite difficult to maintain a constant nozzle height during swing of the lance. Thus, taking the above into account a cycle wheel driven efficient, bigger swath boom sprayer that can alleviate drudgery of spray and better adaptable for small and medium level farmers was fabricated and evaluated at MARC.

Materials and Methods

Construction of the Sprayer
The sprayer was manufactured at Melkassa Agricultural Research Center workshop. It is an assembly of a sprocket and chain, pump, tank, adjustable sprayer boom, driving bicycle wheel and frame. A drum containing the solution is firmly attached to the frame of the bicycle. The reciprocating pistons are connected to the sprocket with linkage mechanism. Six spraying nozzles are connected to a boom and their direction and height are adjustable according to requirements.

The bigger sprocket is fitted to the wheel hub and the smaller sprocket is the driven one. The forward and backward movement of the bicycle through the chain and sprocket arrangement is transferred to a pump assembly, which pumps air into the tank to generate pressure for spraying through the sprayer boom nozzles. The flow of the liquid from the tank to the spray boom and vice versa can be adjusted with the help of control valve. The sprayer main parts were assembled with bolt and nuts, straps to secure in place and some clamps. In assembling the sprayer parts, only three different sized bolts and nuts were used. This makes easy maintenance and only few tools are needed.

Materials used
The materials listed in Table 1 with their dimensions were used to fabricate the machine. They were selected based on the manufacturing drawing, the availability, and the cost of the material.

<table>
<thead>
<tr>
<th>Part</th>
<th>Dimensions</th>
<th>Material used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural frame</td>
<td>(\frac{3}{4} \text{in} \times 164 \text{m} ), 2 piece</td>
<td>Round steel pipe</td>
</tr>
<tr>
<td>Tank</td>
<td>20 l, 150 x180 x360</td>
<td>Plastic</td>
</tr>
<tr>
<td>Piston pump</td>
<td>( \varnothing 34 \text{mm}, \text{stroke length} 65 \text{mm} )</td>
<td>Brass, plastic</td>
</tr>
<tr>
<td>Shaft</td>
<td>( \varnothing 24 \text{mm}, 200 \text{mm} )</td>
<td>Milled steel</td>
</tr>
<tr>
<td>Wheel</td>
<td>( \varnothing 65 \text{cm} )</td>
<td>Pneumatic spoke wheel</td>
</tr>
<tr>
<td>Hose</td>
<td>5m</td>
<td>Plastic</td>
</tr>
<tr>
<td>Boom</td>
<td>2, 1.5m each</td>
<td>Galvanized steel pipe</td>
</tr>
<tr>
<td>Nozzle</td>
<td>04 size</td>
<td>Tee Jet flat fan</td>
</tr>
<tr>
<td>Chain</td>
<td>1155.7mm, pitch 12.7</td>
<td>Standard</td>
</tr>
<tr>
<td>Sprocket</td>
<td>Teeth no 42, ( \varnothing 17.4 \text{ cm} )</td>
<td>Standard</td>
</tr>
<tr>
<td>Sprocket</td>
<td>Teeth no 14, ( \varnothing 5.6 \text{cm} )</td>
<td>Standard</td>
</tr>
</tbody>
</table>
**Performance evaluation**
Both the laboratory and field-testing of the sprayer were conducted in the research center using laboratory facility at the center. Sprayer performance evaluation is based on the uniformity of coverage and spray patterns (Ajit, et al., 2012). The sprayer was evaluated both in laboratory and field and accordingly the following data were collected and analyzed.

**Laboratory test Uniformity of nozzle discharge rate**
The discharge rate from each nozzle was measured to determine the amount and check the variation between the discharge rates of each nozzle within 5-meter intervals of 20m. In each 5m interval, the discharge from each nozzle was collected using a plastic bucket and measured using a measuring cylinder. The time taken to cover each interval also recorded to calculate the discharge rate. The trial for each interval was replicated three times and coefficient of variation (CV%) was used to analyze variation of discharge rate among the nozzles for each 5m interval.

**Spray overlap**
The spray overlap test was done on a test track using a dye. First, the test track was painted with light blue color and then a black dye was used as a water solution to get a good contrast between the track and the spray solution. The sprayer was tested for 50cm boom height and 50cm nozzle spacing spray and the measurement was taken within 30m distance at an interval of 5m.

**Field test**
**Application rate, field capacity, and field efficiency of the sprayer**
The field test were conducted on 0.25 ha trial field. In this test nozzle, discharge measurement was done to evaluate the amount of discharge from each nozzle and to check the variation in discharge rates among the nozzles within 30 meter. The discharge from each nozzle was collected by tying a plastic bag on each nozzle.

**Results and Discussion**
The results were as indicated in the following tables and figure.

**Table 2. Performance of the Prototype Sprayer**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional</strong></td>
<td></td>
</tr>
<tr>
<td>Number of nozzle and spacing, mm</td>
<td>6 x 500</td>
</tr>
<tr>
<td>Swath width, m</td>
<td>3.00</td>
</tr>
<tr>
<td>Mean pressure, bar</td>
<td>1.80</td>
</tr>
<tr>
<td>Discharge rate/nozzle, ml/min</td>
<td>882.00</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td></td>
</tr>
<tr>
<td>Quantity of solution sprayed, l</td>
<td>70.25</td>
</tr>
<tr>
<td>Effective time, (min)</td>
<td>14.75</td>
</tr>
<tr>
<td>Lost time, min</td>
<td>1.67</td>
</tr>
<tr>
<td>Total time, min</td>
<td>16.42</td>
</tr>
<tr>
<td>Field size or area treated, ha</td>
<td>0.25</td>
</tr>
<tr>
<td>Forward speed, km/hr.</td>
<td>4.00</td>
</tr>
<tr>
<td>Field capacity, h/hr.</td>
<td>0.83</td>
</tr>
<tr>
<td>Field efficiency, %</td>
<td>82.7</td>
</tr>
</tbody>
</table>
Laboratory test results

Uniformity of nozzle discharge
During the laboratory test on the test track, with in 20m and at an interval of 5m, the nozzles average discharge rate was 10.68 ml./s, 13.55 ml./s, 14.32 ml./s and 14.71 ml/sec in the 1st, 2nd, 3rd and 4th intervals respectively at an average bar pressure of 1.8 bars, Table 3.

Table 3. Discharge rate of individual nozzle on the test track within 20m at 5m interval

<table>
<thead>
<tr>
<th>Interval</th>
<th>Average discharge rate, ml/sec</th>
<th>Mean discharge in ml/s</th>
<th>CV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>10.55 10.66 10.94 11.00 10.66 10.27</td>
<td>10.68</td>
<td>3.20</td>
</tr>
</tbody>
</table>

N1-N2, N2-N3 … are the adjacent six flat fan nozzles fitted on the boom at 50cm spacing.

The coefficient of variation for the average discharge rates among the nozzles was found to be 3.20%, 2.19%, 1.31% and 1.32% in 1st, 2nd, 3rd and 4th intervals respectively. This was below acceptable variation of 10% as per the recommendation (Gomez and Gomez, 1984) and decreased from 3.20%, in the 1st interval to 1.32% in the last 4th interval, this shows the variability in discharge rate decreases significantly within 20m and attains an optimal discharge rate of 14.71 ml/s.

Spray overlap
During the spray overlap test the average percentage-overlap between the nozzles varied from 31.69% to 32.86 at boom height of 50cm and nozzle spacing of 50cm, which was within the acceptable range of 30 to 100%. The coefficient of variation (CV %) of percentage overlap between the adjacent nozzles were 1.73%, which shows very small variability of overlap between consecutive adjacent nozzles indicating a good uniformity of coverage as shown in Table 4.

Table 4. Spray overlaps between nozzles

<table>
<thead>
<tr>
<th>Data point (m)</th>
<th>Overlap (cm)</th>
<th>Mean average overlap</th>
<th>CV%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N1-N2</td>
<td>N2-N3</td>
<td>N4-N5</td>
</tr>
<tr>
<td>5</td>
<td>24.70</td>
<td>25.00</td>
<td>23.50</td>
</tr>
<tr>
<td>10</td>
<td>24.50</td>
<td>24.80</td>
<td>24.50</td>
</tr>
<tr>
<td>15</td>
<td>25.00</td>
<td>23.50</td>
<td>22.80</td>
</tr>
<tr>
<td>20</td>
<td>23.50</td>
<td>24.50</td>
<td>23.50</td>
</tr>
<tr>
<td>Average overlap</td>
<td>24.42</td>
<td>24.45</td>
<td>23.58</td>
</tr>
<tr>
<td>Average % overlap</td>
<td>32.83</td>
<td>32.86</td>
<td>31.69</td>
</tr>
</tbody>
</table>

N1-N2, N2-N3 … are the adjacent six flat fan nozzles fitted on the boom at 50cm spacing.
Field performance test result
Application rate, field capacity and field efficiency
During the field test, the average discharge rate between the nozzles varies from 44.50 to 45.61 lit/hrs with the mean average discharge rate of 46.94 lit/hrs at an average operating pressure of 1.8 bars and forward speed of 4 km/hr. The result in table 5, shows that the amount of fluid sprayed was 70.32 litters on 0.25 hectares of land, which gave an application rate of 281.3 l/ha.

Table 5. Discharge rate of individual nozzle in the field test

<table>
<thead>
<tr>
<th>Rep</th>
<th>Discharge from each nozzle in lit/hrs</th>
<th>Mean discharge (lit/hrs)</th>
<th>CV%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N1</td>
<td>N2</td>
<td>N3</td>
</tr>
<tr>
<td>1</td>
<td>46.44</td>
<td>46.44</td>
<td>45.29</td>
</tr>
<tr>
<td>2</td>
<td>49.07</td>
<td>46.91</td>
<td>46.91</td>
</tr>
<tr>
<td>3</td>
<td>48.53</td>
<td>48.53</td>
<td>47.45</td>
</tr>
<tr>
<td>Average</td>
<td>48.02</td>
<td>47.27</td>
<td>46.55</td>
</tr>
</tbody>
</table>

N1, N2 … N6 are six flat fan nozzles fitted on the boom at 50cm spacing

This sprayer is energy-efficient and easy to operate and maintain. As it is a flexible product with adjustable height and width of spraying boom there is greater flexibility for using it for various crops. Since the bicycle requires less space to move, it can be used in a more versatile manner as compared to power sprayers that are mounted on tractors. As a labor saving device, it can be used to spray 0.41 ha of land in 45 minutes thus covering more area compared to manual spraying. Easy to assemble and disassemble, it serves the dual use of sprayer cum bicycle.

Based on result above the sprayer has managed to maintain an average nozzle pressure of 1.8 bar during both the field and laboratory test at an average speed of 4km/hr. The average nozzles discharge rate variation along travel distance reduced and attained an optimum discharge rate among the nozzles within 15-20m distance. The sprayer is manufactured with tank capacity of 20 litters. A full tank can cover an area of 0.07ha, which needs a refilling of 14 times to cover one hectare with an application rate of 281 lit/ha an average discharge rate 13.04ml/sand effective field capacity of 0.83 ha/hr., it also has a good uniformity of coverage with an average percentage overlap of 32.53%.

The sprayer forward speed and spray application are synchronized, so that once the sprayer attained the optimal uniform discharge along all the nozzles it will maintain its uniformity until the next tank filling. Moreover, the sprayer applies the pesticide at about 3m away from the operator, which minimized the chances of exposure of chemical to the operator and alleviates carrying the chemical tank at the back of the operator's shoulder.

Though the sprayer has all the above advantages further improvements could be done to improve its capacity by increasing the capacity of tanker, pump, the boom length and number of nozzles, which could reduce the frequency of refilling and improving the field efficiency. The operation speed could also be enhanced by installing pressure relief valve, which help to regulate the pressure at the nozzles. Since the machine gets the power from the ground wheel, as the operation speed increases so do the pressure at the nozzles, Therefore, the pressure relief valve could solve this problem and allows the operator to operate even above the average human speed.
References

Ajit K, EG Carroll, PR Roger, and RB Dennis. 2012., Engineering Principles of Agricultural machines, 2nd edition, American Society of Agricultural and Biological Engineers: 2950 Niles Road, St. Joseph, MI 49085-9659 USA.


Performance Evaluation of Reaper Harvester

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Abstract

During harvesting season, often rain and storm cause considerable damage to standing crops. Rapid harvest facilitates extra days for land preparation and earlier planting of the next crop. The use of harvesting machines can also help to harvest at proper stage of crop maturity and reduce drudgery and operation time, which also generates spare time for education, social, cultural, and political activities, and human development especially for women headed household farmers. Thus considering the advantage of small and mid-level harvesting machines, walking behind vertical reaper harvester were evaluated on Kakaba and Digelu wheat varieties at Kulumsa and Ginir Woredas and on X-Jigna rice crop at Fogera area. Three treatments included walking behind harvester, brush cutter harvester, and manual harvesting with sickle. The results indicate that walking behind harvester has 0.23±0.03ha/hr field capacity while brush cutter harvester and manual harvesting using sickle have field capacity 0.035±0.04ha/hrs and 0.013±0.07ha/hr respectively on wheat crop. Labor (man-hrs. per ha) result which included the time taken to harvest, collect the harvested crop to one place and make a hip. Harvesting using walking behind harvester, brush cutter and manual harvesting method using sickle have taken 7.6 and 29 hrs./ha and, 82 hrs./ha respectively. Grain loss in wheat harvesting at 14.02 % (w.b.) moisture content (mc) were less than the acceptable level for all treatments around 3%. However, as the standing crop dries, the total machines losses became much higher beyond the recommendation. It also found that the variety of the crops matters the total machine loss and the overall performance of the harvesters. Generally, the performances of the three treatments were lower on rice crop than wheat.

Introduction

Harvesting of crop is one of the most labor-intensive operations in agriculture. Yet the most prevalent method of harvesting, for many of cereal crops in Ethiopia is done manually by cutting the standing crop with sickle. These traditional harvesting techniques are labor intensive, time consuming, have a lot of drudgery, and cause high losses. Crops after harvest are mostly windrowed for few days, transported to the threshing and shelling site; where they are stacked or stored until the threshing or shelling season reach. Then threshing is performed by beating with stick or treading with animals that causes a greater post-harvest loss due to the method being employed.

Moreover, during harvesting season, often rain and storm cause considerable damage to standing crops. Rapid harvest facilitates extra days for land preparation and earlier planting of the next crop. Thus the use of harvesting machines can help to harvest at proper stage of crop maturity and reduce drudgery and operation time, which also generates spare time for education, social, cultural and political activities and human development especially for women headed household’s farmers. Therefore, this paper was written with the aim to obtain actual data on machine performance, operating accuracy, work quality, and adaptability to varied
crops and field conditions in order to adapt and introduce the imported small harvesting technology.

**Methodology**

**Experimental site and duration**

The experiment on performance evaluation of two reaper harvesters was conducted at Ginir and Kulumsa for wheat harvesting and at Fogera for rice harvesting during a main season of 2006, 2007 and 2008 E.C.

The experimental machines

The experimental was undertaken to determine the field performance and field losses of Chinese made walk behind vertical conveyor reaper and a portable brush cutter harvester. A reaper is used for harvesting of wheat, barley, and rice. The machine consists of reciprocating cutter bar assembly, crop row dividers, vertical conveyor belts fitted with lugs, pressures springs, pulleys, and gearbox for the power transmission system. The crop row dividers are fitted in front of the cutter bar assembly and the star wheels are mounted over the crop row dividers. The machine is mounted in front of the tractor and it is powered by two-wheel tractor through V-belt and pulley.

The cutter bar of the walk behind reaper was 1.2 m wide. It cuts and lays the cut crop into a windrow. The crop row dividers helped the standing crop to enter the machine, and the star wheel kept the cut crop in upright position towards crop conveyors. The reaper harvester consisted of 3hp engine to drive the cutter bar, conveying system and rubber wheels to move forward. It was provided with one forward, neutral and one reverse gear mechanism. It was steered by hand-operated brakes for turning left or right. As its name indicates, it has the handles for operator, controls, fuel throttle and clutch used to steer the machine easily during operation or moving forward. It takes two kinds of fuels: petrol fuel is used for starting purposes and kerosene is used for field operation. The fuel tank has two compartments and a knob to change the fuels.

The major components of the brush cutter h include, a small engine carried at the back of the operator, a belt for buckling up the engine on the shoulder during the operation, disc cutter and long propeller shaft to transmit the power from the engine to the disc cutter inside the compartment pipe. Like walking behind harvester, it cuts and lays the cut crop into a windrow. It has fuel tank but do not has oil tank so that the fuel and oil added with the ratio according to the user manual of the company produced the Brush Cutter. While cutting the crop the operator swing the handle right and left to cut and windrow the crop.

**Experimental procedures**

**Field capacity**

Effective field capacity was measured by the actual area covered by the reaper-, based on its total time consumed and its width. Effective field capacity was determined by the following relationship.

\[
\text{Effective field capacity (ha./hrs.)} = \frac{\text{Area covered (ha)}}{\text{time taken (h)}}
\]
Labor requirement
The number of labors required and time taken for harvesting, collecting, and piling harvested crop were recorded.

Fuel consumption
The fuel consumption was measured by filling the tank before and after operation and noting the difference.

Loss determination
Five (1mx1m) areas were selected randomly from each trial plot to determine plant characteristics such as, pre-harvest shattering losses, and after harvest operating losses.

Experimental design and treatments
Walking behind vertical reaper harvester, brush cutter and manual harvesting with sickle as a control were compared on a plot size of 10m x 30m on wheat and rice crop following standard test procedure (Philippines Agricultural Engineering Standard PAES 213: 2004). The experiment was done in Randomized Complete Block Design (RCBD) with three replications. Parameters recorded and analyzed were actual working time, turning time, and break downs, field capacity (ha/hrs), speed of operation (km/hr.), width of cut (m), labor input (hrs/ha), crop moisture content (%), yield (kg/ha), grain losses (%) and fuel consumption(l/hrs).

Results and Discussions
Tables 1 and 2 show the field performance of walking behind reaper and brush cutter harvesters along with the corresponding manual harvesting system. The results showed that walking behind harvester performed 17.7 and 6.34 times greater field capacity than manual harvesting using sickle, and brush cutter harvester respectively. Depending on crop type and moisture content of the standing crop, labor input (man-hrs. per ha) result to harvest the standing crop, varied from 4.5 to 8.2 30.8 to 40.8 and 164 to 200 hrs./ha using walking behind reaper harvester, bush cutter and manual harvesting method using sickle respectively. The walking behind harvester has shown excellent performances in most of the parameters both on wheat and rice crops (Tables 1, 2 and Figure 3). The brush cutter harvester had clogging problem when standing crop is not uniformly matured and when not operated in a weedy plot which created clogging of rotating disc. In addition crop harvesting using bush cutter at crop moisture content higher than 14% (w.b.) resulted greater uncut crop. Besides, while harvesting with brush cutter harvester, width of cut above one meter caused the engine torque to drop and consequently leaving uncut crop. Furthermore, the operator needs to operate the implement holding it closer to the ground and swipe it right and left to cut the standing crop which causes higher drudgery.
Table-1: Performance of a walk behind reaper and brush cutters harvesters on wheat crop at Ginir in 2007 and Kulumsa Wereda in 2008 E.C.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kulumsa</th>
<th></th>
<th>Ginir</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBH</td>
<td>BCH</td>
<td>MSH</td>
<td>WBH</td>
</tr>
<tr>
<td>Crop moisture content, wb %</td>
<td>14.02</td>
<td>14.02</td>
<td>14.02</td>
<td>8</td>
</tr>
<tr>
<td>Operating speed , m/s</td>
<td>0.586</td>
<td>0.072</td>
<td>0.037</td>
<td>0.65</td>
</tr>
<tr>
<td>Effective width of cut, cm</td>
<td>120</td>
<td>146.6</td>
<td>40.00</td>
<td>112.7</td>
</tr>
<tr>
<td>Fuel consumption, l/ha</td>
<td>9.44</td>
<td>34.8</td>
<td>NA</td>
<td>7.28</td>
</tr>
<tr>
<td>Total machine loss, %</td>
<td>3.47</td>
<td>3.29</td>
<td>2.43</td>
<td>6.06</td>
</tr>
<tr>
<td>Actual field capacity, ha/hrs.</td>
<td>0.22</td>
<td>0.033</td>
<td>0.005</td>
<td>0.19</td>
</tr>
<tr>
<td>Theoretical field capacity, ha/hrs.</td>
<td>0.25</td>
<td>0.038</td>
<td>0.0052</td>
<td>0.25</td>
</tr>
<tr>
<td>Field efficiency, %</td>
<td>88</td>
<td>86.8</td>
<td>96.15</td>
<td>76</td>
</tr>
<tr>
<td>Labor, man-hrs./ha</td>
<td>4.5</td>
<td>30.8</td>
<td>68.5</td>
<td>5.2</td>
</tr>
</tbody>
</table>

MSH = manual harvesting with sickle, BCH = brush cutter harvester and WBH= walk behind harvester

Table-2: Performance of a walk behind reaper and brush cutter harvester on paddy rice at Fogera Wereda in 2008 E.C.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>WBH</th>
<th>BCH</th>
<th>MSH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content of the crop, w.b. %</td>
<td>17.02</td>
<td>17.6</td>
<td>16.87</td>
</tr>
<tr>
<td>Operating speed , m/s</td>
<td>0.62</td>
<td>0.092</td>
<td>0.038</td>
</tr>
<tr>
<td>Effective width of cut, cm</td>
<td>110.7</td>
<td>111.3</td>
<td>40.00</td>
</tr>
<tr>
<td>Fuel consumption, l/ha</td>
<td>10.28</td>
<td>40.89</td>
<td>NA</td>
</tr>
<tr>
<td>Total machine loss, %</td>
<td>7.12</td>
<td>6.29</td>
<td>4.95</td>
</tr>
<tr>
<td>Actual field capacity, ha/hrs.</td>
<td>0.16</td>
<td>0.045</td>
<td>0.0052</td>
</tr>
<tr>
<td>Theoretical field capacity, ha/hrs.</td>
<td>0.25</td>
<td>0.068</td>
<td>0.0049</td>
</tr>
<tr>
<td>Field efficiency, %</td>
<td>64</td>
<td>66.17</td>
<td>94.5</td>
</tr>
<tr>
<td>Labor, man-hrs./ha</td>
<td>8.2</td>
<td>40.8</td>
<td>192</td>
</tr>
</tbody>
</table>

MSH = manual harvesting with sickle, BCH = brush cutter harvester and WBH= walk behind harvester

The difference in grain loss between treatments were not significant (p<.05) and it is less than acceptable level of 3% for all treatments. Crop loss were affected by crop moisture content as observed from wheat harvesting in 2007 and 2008 crop season (Table 2 and Figure 5). As compared to the both motorized harvesters, manual harvesting with sickle method relatively performed better in terms of providing less grain loss at both levels of moisture content, i.e. 14.02% and 8% (w.b.). Rice harvesting at standing crop moisture contents (17%) (Table 3) resulted 7.29, 6.29 and 4.95 grain loss with the use of vertical reaper, brush cutter and manual harvesting using sickle respectively. This shows that rice crop is very sensitive for shattering than wheat and need to be harvested before the standing crop dried.
The performance of walk behind reaper and bush cutter with respect to field capacity, field efficiency, fuel consumption, harvesting losses and labor requirement were studied and compared with manual harvesting method, the following conclusions are drawn. Walking behind harvester excelled in all conditions except the grain losses. Therefore, it is better to use at appropriate maturity stage in order to minimize losses. The Brush cutter harvester performance was affected by weed intensity and non-uniform crop maturity. While cutting the crop the disc of the harvester clogs easily by weed and wet crop and also sometimes left uncut crop on the field; and Brush cutter harvester needs some modification on the side trap and on the discs and clutch to get maximum torque during harvesting.

References

AMA, 1992. Vol.23, no.2
Performance evaluation of Metal Silo and Purdue Improved Cowpea Storage Bag

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Abstract

Inadequate storage facilities have contributed to severe postharvest losses of major grain crops grown in Ethiopia. This study determined the postharvest loss of maize, sorghum, wheat, and haricot bean crops stored in hermetic storage methods for a storage period of six months. The storage types include metal silo with 300 kg capacity, Purdue Improved Cowpea Storage (PICS) bags of 50 kg capacity, and the control storage method using 50 kg capacity polypropylene woven bags. Selected quantitative loss parameters including grain moisture, temperature, germination ability, were measured at beginning and after 3 & 6 months of storage period. Observations revealed that temperature variation were similar in all storage types. MC showed slight reduction in all stores during the 1st three months with little variation between the hermetic and control stores. During the 2nd half of the storage period, MC reduced sharply in all stores but metal silo and PICS bag storage showed more reduction than the control store. Level of insect infestation found were almost nil from metal silo and PICS bag storage methods while presence of insect were extremely high on conventional sack storage. There was good seed germination for both hermetic storage methods, which ranged from 96 to 100% in metal silo and 84 to 100% in PICS bag. Whereas, except in one occasion, grain samples from the conventional storage method showed very poor germination rate. Depending on crop type, it ranged from 22 to 41.7%. In all stores wheat followed by maize, were observed to have better performance while the least was sorghum which showed the existence of moderate to severe mold specially in the control store. In overall metal silo and PICS bag are superior for proper storage of grains for food and as seed. Thus, this research recommends the use of metal silo and PICS bags depending on the income of the small holders.

Introduction

The importance of post-harvest losses in developing countries like Ethiopia has been recognized worldwide. A report by the World Bank (World Bank, 2011) revealed that, each year, significant volumes of food are lost after harvest in sub-Saharan Africa (SSA), the value of which is estimated at USD 4 billion for grains alone. Based on these reasons, experts now agree that investing in postharvest losses (PHLs) reduction is a quick impact intervention for enhancing food security. Reducing food losses therefore offers an important pathway of availing food, alleviating poverty, and improving nutrition. Moreover, reducing PHL has positive impacts on the environment and climate as it enhances farm-level productivity and reduces the utilization of production resources or expansion into fragile ecosystems to produce food that will be lost and not consumed (Hodges et al., 2011).

There are many challenges facing small-scale farmers that lead to grain post-harvest losses. Inadequate traditional storage facilities in developing countries are amongst these leading to 20-30% grain losses, particularly due to post-harvest insect pests and grain pathogens (Tefera, Kanampiu et al. 2011). Safe storage of grains at farm level is very crucial for minimizing
postharvest losses. It was from this backdrop that the metal silo and Purdue Improved Cowpea Storage (PICS) bags technology with the application of hermetic storage principles have been introduced to the rural communities who practice subsistence agriculture.

Hermetic storage technology is an alternative, often pesticide-free method that eliminates insects and molds by depleting oxygen levels and producing carbon dioxide within the storage unit. An airtight enclosure effectively suffocates insects by forcing them to use up the available oxygen. Hermetic principles may be applied to hard containers such as metal silo or flexible materials, like PICS bags.

The technology promotes safe on-farm grain storage which extends the storage period and reduces after harvest crop loss significantly thereby encourage farmers to maintain their harvest beyond the low price glut period either for food or to trade later when the prices are fair. Introducing these storage facilities offer the opportunity to smooth hunger between staple crop harvests and give freedom for small-scale farmers to decide when to bring their surplus harvest to market. The paper therefore presented the comparative storage performance of metal silo, Purdue Improved Cowpea Storage (PICS) bags & traditional storage (farmers’ practices) for maize, wheat, haricot bean, and sorghum grains in the four major regions of Ethiopia.

**Materials and Method**

**Description of technology**

PICS bag is a storage unit of 50 kg capacity suitable for hermetic storage of dry grains Fig. 1. They are made up of three nested plastic bags; the inner two hermetically seal when closed properly. The outer bag resembles more commonly available storage bags with tightly woven plastic strips. PICS bags were identified as a potentially impactful intervention in terms of reducing post-harvest loss from pests and moisture. PICS bag storage technology is well accepted and proved successful wherever it has been tried but rodents are a big challenge to farmers who do not follow instructions on how to use and store.

The metal silo storage facility is a 300 kg capacity cylindrical structure, constructed from a galvanized iron sheet of 0.5mm thickness. Artisans selected and trained from the four major regions of Ethiopia fabricate it. Fig. 1 shows the isometric view of this storage technology. It is aluminum painted for additional protection of the sheet against corrosion and to improve silo’s appearance. During fabrication, the silos were sealed and checked for their hermetic performance by burning a candle. Wooden pallet is used to place MS. Conventional storage (CS) is characterized by using locally available polypropylene woven bags of 50 kg capacity (Figure 1).
Experimental setup
The trial initially involved 36 experiment hosting farmers selected from 9 districts in the four major regions of Ethiopia. They were selected in consultation with the district agricultural office based on their willingness and location accessibility. Later on, few farmers were dropped out from the trial and consequently actual data were taken from 26 farmers. Right after an introductory orientation on metal silo and PICS bag working principles and applications, detailed briefing and discussion about the experimental setup were given to participant farmers. The experiment was carried out employing a total of 4 grain crops (maize, sorghum, wheat and bean) for six months, June -December 2016. Details of crop type and the varieties used in the different location were shown in Table 1.

Table 1 Crop types and varieties tested by the participating farmers across the main four regions

<table>
<thead>
<tr>
<th>Crop and varieties</th>
<th>Test locations</th>
<th>No of farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Ogolcho, Gedebs Assasa</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Kekeba, Debre-Elias and Sorro</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Hidase, Offla</td>
<td>2</td>
</tr>
<tr>
<td>Maize</td>
<td>BH660, Debub Achefer</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>BH-540, Adami-Tullu</td>
<td>2</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Degalit, Alamata</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Teshale, Fedis</td>
<td>3</td>
</tr>
<tr>
<td>Beans</td>
<td>Nasir, Adami-Tullu</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Red, Loka-Abaya</td>
<td>1</td>
</tr>
</tbody>
</table>

The treatments: conventional storage (poly bag), metal silo (MS) and Purdue Improved Cowpea Storage (PICS) bags were arranged in RCB design considering farmers who stored same crop type as replicates and district as blocks.

Performance evaluation and measurements
The storage units were placed and evaluated side by side at trial hosting farmer's storage room/area in all locations. The grains were properly dried to less than 13% moisture content and loaded in the treatment stores. After filling grain, a burning candle was left inside the metal silo storage unit before sealing with rubber band. Farmers were visited in two phases, just after the 3rd and 6th months thus storage units were monitored for grain condition. Grain sampling of about 100g per treatment was done for determination of grain quality, insect count, and insect
damage. Samples were collected from top (0-25 cm), middle (25-50 cm) and bottom (50-75 cm) part of all storage units (treatments). Data generated include grain moisture content, number of bored grains, number of live and dead insects and germination rate.

**Results and Discussion**

The variables considered in monitoring of stored grain condition include variation of grain moisture content, percent germination, and count of live and dead insects per sample.

**Levels of insect infestation**

Insects, mainly weevils, were separated from sample grain crops collected from all locations. The level of insect infestation estimated in terms of number of live and dead insects per gram of grain were shown in Table 2. In all crops significant differences were found between the storage methods. There was almost nil live insect manifestation observed in maize, sorghum and wheat stored in metal silo and PICS bag storage methods. Relatively a very small number of live insect counts were found in beans (less than 20 per kilogram) stored in the hermetic storage methods. On the other hand presence of live insects in the control bags in the case of beans is extremely higher than the treatment stores. In all hermetic stores, most of the insects were dead. It has been found that the number of dead and live insects for the traditional storages, were quite high. The greatest density of dead insects was 32 in MS, 149 PICS bag and 1178 in conventional sack storage for the bean crop. This implies greater ability of the hermetic storages to protect grain from insects, less chance of deterioration and hence better quality and selling price.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Storage</th>
<th>N</th>
<th># of seed with egg/kg</th>
<th># of dead insects/kg</th>
<th># of live insects/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bean</td>
<td>Metal Silo</td>
<td>9</td>
<td>214b</td>
<td>32b</td>
<td>8b</td>
</tr>
<tr>
<td></td>
<td>PICS bag</td>
<td>9</td>
<td>70b</td>
<td>149b</td>
<td>11b</td>
</tr>
<tr>
<td></td>
<td>Poly bag</td>
<td>9</td>
<td>4580a</td>
<td>1178a</td>
<td>646a</td>
</tr>
<tr>
<td></td>
<td>Metal Silo</td>
<td>6</td>
<td>20b</td>
<td>0b</td>
<td>0</td>
</tr>
<tr>
<td>Maize</td>
<td>PICS bag</td>
<td>6</td>
<td>40b</td>
<td>0b</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Poly bag</td>
<td>6</td>
<td>380a</td>
<td>70a</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Metal Silo</td>
<td>18</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
<tr>
<td>Sorghum</td>
<td>PICS bag</td>
<td>18</td>
<td>40b</td>
<td>0b</td>
<td>0b</td>
</tr>
<tr>
<td></td>
<td>Poly bag</td>
<td>18</td>
<td>6450a</td>
<td>110a</td>
<td>80a</td>
</tr>
<tr>
<td></td>
<td>Metal Silo</td>
<td>30</td>
<td>10b</td>
<td>0b</td>
<td>0b</td>
</tr>
<tr>
<td>Wheat</td>
<td>PICS bag</td>
<td>33</td>
<td>0b</td>
<td>0b</td>
<td>0b</td>
</tr>
<tr>
<td></td>
<td>Poly bag</td>
<td>33</td>
<td>4580a</td>
<td>620a</td>
<td>350a</td>
</tr>
</tbody>
</table>

*Means within each column followed by the same letters are not significantly different at (p<0.05), N= number of observations; NDI = number of dead insects, NLI= number of live insects SWE = seeds with egg

In some samples, there was high variability of dead and live insects as well as egg count observed within crop type as well as storage method. Wheat samples collected from conventional storage for instant at Gedeb Assasa showed no insect infestation in the case of one farmer in contrast to highly infested samples of other farmers. This pronounced variation could be due to initial condition of crop prior to storage, environmental differences between sites and varietal difference.
The grain used for the trial was purchased from the market and hence considerable number of live insects was observed in sampled grains at the beginning of the trial. However, both hermetic storage technologies were proved to be effective in completely killing of the storage pests thereby hampered further grain damage that could have been observed as in the case of the traditional storage. Generally this observation suggests that both hermetic storages technologies (metal silo and PICS bag), are effective on controlling insect infestation in sorghum, bean, wheat and maize storage. Besides storage losses of maize, sorghum and beans are serious, while losses in wheat were found relatively lower, indicating the variability in level of insect infestation due to crop type.

**Moisture content variation in storage**

The moisture content of grain samples taken from the stores at the beginning of storage across locations ranged from 10.3 to 12.9% for wheat, 11.4 to 12.4% for maize, 10.8 to 11.7% for sorghum and 10.4 to 11.9 % for beans. These moisture contents were at safe level of < 14%. Fig 2 shows variation in percent moisture content for each grain types during the storage period of six months between June and December 2016. The highest decrease in moisture content during this period was in maize (4.56%) followed by wheat (3.54%), sorghum (1.77%) and beans (1.01%).

**Germination rate**

The germination rate of grain varied significantly with store type. After six months of storage period, germination rate of the four crops ranged from 96 to 100 percent, 84 to 100 percent, and 33 to 78 percent respectively for metal silo, PICS bag and traditional polypropylene woven bag with the lowest for sorghum and highest for wheat. The traditional polypropylene woven bag storage, except in one occasion gave the worst with the existence of moderate to severe mold.
growth particularly in sorghum samples. This indicates traditional polypropylene woven bag storage for longer period can affect the germination if a farmer intends to use the stored grain as a seed. The stores with the lowest infestation levels had highest germination rates indicating a positive correlation between germination rate and insect infestation levels. Apart from the existence of insect pests, it was found that there was mold growth that affected viability of the seed samples from traditional polypropylene bag storages particularly with sorghum.

Table 2. Effect of method of storage on germination

<table>
<thead>
<tr>
<th>Storage</th>
<th>Germination rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bean</td>
</tr>
<tr>
<td>Metal Silo</td>
<td>98.9a</td>
</tr>
<tr>
<td>PICS bag</td>
<td>100a</td>
</tr>
<tr>
<td>Poly bag</td>
<td>33.3b</td>
</tr>
<tr>
<td>CV</td>
<td>31.6</td>
</tr>
</tbody>
</table>

This study reveals the performance of two hermetic storage methods PICs bag (triple-layer sacs) and metal silo for wheat, maize sorghum, and bean storage. Both methods significantly reduced grain post-harvest insect densities when compared to the control polypropylene bags. Grain stored in these storage methods was free or with very few insect after six months of storage. The initial grain quality observation showed some extent of infestation; requiring strategies to reduce pre-storage infestation such as prompt harvesting and adequate drying. The present study demonstrated that hermetic treatment is a valid and efficient way to kill grain storage pests. Therefore, farmers need to be advised to choose the technology based on its effectiveness against storage insects and consequently on the benefit of delayed selling of their grains until later in the season when prices are improved.

Acknowledgements

The authors would like to acknowledge the financial support received from the Food and Agriculture Organization of the United Nations (FAO) to conduct this research through Ethiopian Institute of Agricultural Research, Agricultural Engineering Research Directorate. The authors also would like to acknowledge the valuable contributions of Mr. Desseye Belay, Mr. Tefera Miteku, and Mr. Belete Gashu from Agricultural Engineering Research Directorate at Melkassa, Mr. Arsawum Mengesha from FAO and Mr. Sibhat Temesgen from the extension directorate in the Ministry of Agriculture.

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Introducing Naturally Ventilated Potato Storage Structure

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Abstract

A study was conducted on increasing the shelf life of potato using naturally ventilated potato storage structure. The storage structure was constructed from locally available material with a thatched roof, a 1.5 meter square slated floor, a wall height of 1.80 meter on one side to 2.2 meter on the opposite side. The storage floor is placed at 120 cm above ground which is kept open at night for letting air flow into the store to take advantage of the night cool air ventilation. Maximum and minimum temperatures were monitored both inside and outside the store. The store was used as a ware store and later as a seed store, where different data sets were considered. The potato store showed a good achievement of capturing the nighttime ambient temperature, but failed in inhibiting sprouting at the time of storage. With extended period of storage, to observe the performance on the quality of sprouting, less than 5 sprouts, significantly different were observed in the store than in the control. Under the Melkassa condition, the potato store was found satisfactory for storage of seed potato.

Introduction

Potato is harvested using hand tools and using traditional oxen plough. It was reported that a substantial mechanical damage was encountered while using Maresha. Once a product is bruised or wounded during harvesting, deterioration sets on immediately. Temperature enhances respiration. Tuber respiration during storage results in dry matter loss. At a storage temperature of 10° C the loss represents approximately 1 to 2 percent of fresh weight during the first month and about 0.8 percent per month thereafter, but rising to about 1.5 % per month when sprouting is well advanced (Booth and Shaw 1981)

Low-temperature storage is the major weapon that the postharvest operator uses to maintain quality and extend life of harvested products. Low temperatures, not only reduces respiration rate, but also water loss through transpiration, nutritional loss, postharvest decay and ethylene production. With proper management and at a temperature of 10-16 °C, potato could be stored up to 14 days if it is properly cured and if the temperature is held between 4.5-13 °C it could be stored for more than 5 months (Kitonja and Kader 2003).

Methodology

The methodology encompasses the material selected and methods followed to address the specific objectives

The storage structure

The potato storage structure is 1.5 meter square floor size and is 1.80 meter on one side to 2.2 meter on the other side. The storage floor is placed at 120 cm above ground. It has a slatted
floor and the walls below the floor have a slate opening which is kept open at night for letting air flow into the store for ventilating the product. It has a thatched roof and about 10 cm straw filled ceiling below the roof. The sides of the store are made with wooden board leaving 20-40 cm opening with wire mesh below the roof. The side of the store is insulated with 10 cm straw held in place with loosely netted sack kind of material. The product is filled in the chamber, with enough room above for air exchange (Figure 1). The lower flaps are kept closed during the day time and are open at night to keep advantage of the night cool air ventilation. Maximum and minimum temperatures were monitored both inside and outside the store (Table 1.). The store was used as a ware store and later as a seed store, where different data sets were considered (Tables 2 and 3).

![Figure 1. Schematic drawing of naturally ventilated store](image)

**Testing without load**
The structure was tested under no load and loaded condition. Mainly minimum and maximum temperatures between the ambient and inside the store were monitored. At night, the door on one side below the store floor was left open to take advantage of the night cool air temperature. During the daytime, the flaps were kept closed. The daily maximum and minimum temperature were recorded every day for 10 days (Table 1).

**Testing under load**
Three crates of cleaned potato were stored in the store and in the laboratory as a control. Data on weight loss, spoilage, and sprouting were taken for 50 days for the ware potato. Then the test was extended for another two months to assess the quality of the structure as a seed potato store (Table 2). Data on weight loss, damage and sprouting were recorded as a ware potato store for fifty days of storage. After fifty days for extended period of storage, the performance of the store as a seed store was examined. During this period, the number of sprouts, single sprout, 3-5 sprouts and > 5 sprouts were recorded in the store as well as in the control (Table 3). SAS was used for the analysis.

**Results and Discussion**

Potato weight loss and degree of sprouting in storage were shown in the following figures. Detailed information were also presented in Tables 1 and 2. The potato store captured the night
cool ambient temperature, but failed in inhibiting sprouting at the time of storage. As the material is bought from market, it was hard to know, whether it is from the prior history of the crop or the failure of the structure. Some losses were recorded between the crop stored both in the room and the storage structure, but no significant difference was recorded between the control and the potato stored in the storage structure, which could be attributed due to the storage period, which was conducted in the months of August September and October.

After studying the keeping quality, the storage period was further extended to observe the performance on the quality of sprouting, sprout number, dominance and optimum size and number of sprout (3-5 sprouts) between the storage structures. More than 5 sprouts, significantly different were observed in the potato stored in the room, which is not desirable. The optimum number of sprouts 3-5, which is desirable was higher in the store than in the room. In this case a significant difference was recorded between the storage structures with the desired sprout number and quality observed from the naturally ventilated storage structure (Figure 2).

The degree of spoilage was lower compared to the control, but the difference as not significant in the ware potato. As a seed store, the number of sprouts, especially higher number of potatoes with greater than 5 sprouts were recorded in the control, which was also significant (undesirable) From this preliminary result the structure could be a better choice as a potato seed store under conditions similar to the test period and place.

![Figure 2. Potato weight loss (left) and degree of sprouting (right) in the storage and control room](image)
Table 1. Potato test data on degree of spoilage and sprouting during a storage period from 18/10/2009 to 21/1/2010 (EC)

<table>
<thead>
<tr>
<th>Storage structure</th>
<th>Wt. Before Sprout Spoiled (wt.)</th>
<th>Wt. At the time</th>
<th>Room Wt. Before Sprout Spoiled (wt.)</th>
<th>Weight</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Clean</td>
<td>Total Clean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>-</td>
<td>28 28 30</td>
<td>29</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>-</td>
<td>28 28 30</td>
<td>29</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>-</td>
<td>29 29 30</td>
<td>29</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>-</td>
<td>3kg 25 29</td>
<td>2 (2 sprouts) 2</td>
<td>28</td>
<td>26</td>
</tr>
<tr>
<td>28</td>
<td>-</td>
<td>2kg 26 29</td>
<td>3 (2 sprouts) 5</td>
<td>28</td>
<td>23</td>
</tr>
<tr>
<td>29</td>
<td>2 (1 dominant) 2.5kg 27 24.5 29</td>
<td>- 2</td>
<td>2</td>
<td>28</td>
<td>26</td>
</tr>
<tr>
<td>Mean</td>
<td>2.5</td>
<td>25.2 29</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>6 (2 places) 3.03 25 21.97 28 5</td>
<td>2.07</td>
<td>26</td>
<td>23.93</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>5 (one) 2.00 26 24 28 9 3</td>
<td>3</td>
<td>22</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>24.5</td>
<td>5 (2 places) 2.00 26 24 28 3 3.97</td>
<td>25 21.03</td>
<td>8-12-09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.54</td>
<td>23.32</td>
<td>3</td>
<td>21.32</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5.04</td>
<td></td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Degree of spoilage inside the potato storage structure and control room starting 18/10/2009 (EC)

<table>
<thead>
<tr>
<th>Wt. before</th>
<th>Wt. at the end of</th>
<th>Sprout</th>
<th>Spoiled (wt.)</th>
<th>Clean</th>
<th>Wt. before</th>
<th>Wt. at the end of</th>
<th>Sprout</th>
<th>Spoiled (wt.)</th>
<th>Clean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single 3-5 &gt;5</td>
<td>Quantity</td>
<td>Weight</td>
<td></td>
<td>Single 3-5 &gt;5</td>
<td>Quantity</td>
<td>Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>22 64 98 26</td>
<td>39</td>
<td>3.5 30 18</td>
<td>12</td>
<td>61 89</td>
<td>0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>21 41 100 27</td>
<td>18</td>
<td>1.5 30 20</td>
<td>36</td>
<td>77 130</td>
<td>6 0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>21 57 99 30</td>
<td>40</td>
<td>4 30 20</td>
<td>38</td>
<td>92 62</td>
<td>22 1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21.33</td>
<td>54 99 27.6</td>
<td>19.3</td>
<td>28.6 76.3</td>
<td>93.6</td>
<td>N.S N.S  S</td>
<td>N.S N.S S</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N.S</td>
<td>N.S  N.S S</td>
<td>N.S</td>
<td>N.S  S</td>
<td>N.S</td>
<td>S</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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References


Evaporative Cooling Structures for Storing Horticultural Crops

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Land and Water Research Directorate, Ethiopian Institute of Agricultural Research, Holetta Agricultural Research Center, P.O.Box 436, Adama, Ethiopia

Abstract

A study was conducted on minimizing losses and increase the shelf life of some common vegetables and fruits through the introduction of improved postharvest handling technologies. The study focused mainly on evaporative cooling storage structures. Three kinds of storage structures made of charcoal; scoria, filla, and RHB as control were built and compared by watering the walls three times a day. A 10 degree centigrade reduction from the ambient temperature and up to 90 % relative humidity was attained inside the scoria and charcoal walled evaporative cooling structures. A longer shelf life and delayed ripening was observed in banana compared to the open space storage. No satisfactory result was recorded in the case of carrots, which could be attributed to the difficulty of attaining the required environmental condition under the set up. The evaporative cooler is good enough for tropical fruits and need to be further tested by changing the frequency and watering regime on some other crops, which were not considered in the present study.

Introduction

There is a major crop post-harvest loss in all the sectors, but the loss recorded in the case of fruits and vegetables is substantial. Despite their nutritional value and health importance, there are substantial losses starting from harvesting, subsequent handling and have short storage life, which need careful handling at each stage.

Field observations over the past 40 years have revealed that 40-50% of horticultural crops produced in developing countries are lost before they are consumed, mainly because of high rate of bruising, water loss, and subsequent decay during post-harvest handling (Kitinoja 2002; Ray and Ravi 2005). In Ethiopia, about 20% loss is estimated, though not properly documented (personal communication with growers and unions in Meki Ziway area).

In Meki Ziway area, tomato is harvested up to three times; the first two harvests are usually picked by contract buyers directly from the field, but the third harvest is usually left in the field, because the farmers’ do not have the means to store the product and is prone to spoilage. Growers have always underlined the necessity of a scheme to extend the shelf life of their produce.

In horticultural crops in general, deterioration commences at harvest; postharvest technologies are designed to slow the rate of ripening and hence quality decline. Harvesting removes the product from its source of minerals and water (from roots) and in most cases from its source of energy. Freshly harvested horticultural products remain alive, very active metabolically, as...
reflected in their relatively high respiration rate. Physical damages occur from harvest to consumption. Bruises, cuts, abrasions, and fractures occur as a result of poor handling or inadequate packaging. Damage dramatically increases water loss and susceptibility to infection by postharvest fungi and bacteria. In addition, respiration and ethylene production are enhanced in wounded tissue.

All living things respire to generate energy for continued metabolism. Respiration is highly temperature dependent. The lower the temperature (down to 0±C) of harvested fruit and vegetables the lower is the respiration rate. Lowering respiration, results in reduction of carbohydrate loss, decreased rate of deterioration, increased storage and shelf life (CIGR 1999). Low-temperature storage is the major weapon that the postharvest operator has to maintain quality and extend shelf life of harvested products. Low temperatures not only reduce respiration rate, but also reduce water loss through transpiration, nutritional loss, postharvest decay, and ethylene production. Automated cold storage is utilized in big operations and where electricity is available, while as in areas of small-scale production different methods are utilized where evaporative cooling method is one.

The evaporative cooler is designed to provide an environment, which is both lower than the ambient temperature and at a higher level of relative humidity for the storage of fresh produce. It works on the principle of porous structure to which water is added, as air flows across the wet well the air temperature is decreased due to the loss of heat through the evaporation of water. The temperature is normally lowered by about 5 to 10 degree centigrade depending on the relative humidity of the ambient air. Evaporative coolers can be used for all types of fruit, but subtropical fruits respond best because their optimum storage temperature are closer to those achieved by Evaporative coolers.

**Materials and Methods**

Three evaporative cooling structures made from locally available materials were constructed and evaluated for their performance in association with the current mode of storage as a control.

**Design**

The work on the evaporative cooler has been going on for some time. Preliminary studies on water holding capacity and degree of difference in temperature between the ambient and the one inside the walling material has been studied using single strap and double strap filla material and on scoria. Encouraging results were recorded in all cases.

Four different types of cooling structures using charcoal, scoria, RHB and filla were constructed. The size of each structure is 200cmX 150cm inside with the overall dimension of 228 cmX178cm. The height of the structure is 2.2 meter on the longer side and 1.8 meter on the shortest side. Each was filled with the walling material up to a height of 20 cm below the roof with this space being left open to allow air circulation. The fourth structure, the control was made from RHB. The poles have a minimum of 10 cm diameter with perlins nailed both on the inside and outside. Before wall filling the walling material the structures were constructed from
- 5 poles of 100mm diameters and 3m length;
- timber 2mm ×50mm timber of total 56 m long;
- wire mesh (40m×1mm) for walling;
- plastic sheet (2m ×4m ) for doors;
- cement for floor; and
- seven timbers of 50m×50mm×6m and thatched grass for roofing.

Each except the RHB is covered with a net wire to keep the fill, walling material in place. Each was completely saturated with water before the produce is introduced into the store and will be regularly wetted by fitting the structure with a water tank and perforated plastic hose running around the top of the structure (Figure 1). The selected site is shaded from sunlight most of the day and is along a corridor with wind speed ranging up to 3km/min.

![Figure 1. Evaporative cooling structures](image)

**Testing procedure**
Testing was conducted at no load and loaded condition. In both cases the sides of the structures were wetted using 100 liters at a time. Twenty minutes after watering, temperature and humidity were measured both inside and outside the stores using thermometer and humidity meter. Such measurements were taken three times a day at 2 hours and 30 minutes interval each time after watering the walls.

**Monitoring under loaded condition**
Tomato
Tomato from field were collected, washed and sorted for uniformity and were placed in 12 crates weighing 30kg each and counted at the same time. The 12 crates were randomly assigned to the four storage structures, three crates per structure. The three structures were wetted as described above, temperature and humidity were measured and the crates were introduced into the structure. After two hours and thirty minutes, the structures were wetted and twenty minutes after wetting, temperature and humidity were measured both inside and outside the stores and recorded. The routine continued during the whole storage period. Every week data on the condition of the stored products, skin color (green, ripened), spoiled (shriveled, wilted) and weight loss were recorded.

Banana
A test was conducted on keeping quality of the three evaporating storage structures for fifteen days using banana dwarf cavendish variety. The experiment was conducted from 14/02/09 to
01/03/09 (E.C). Plastic crates were used for the study. In each store three crates of banana were used for the study. The charcoal, scoria and filla stores were watered three times a day with 100 liters of water at 2hrs 30 minutes interval. Throughout the storage period, temperature and humidity of the stores including the outside condition were monitored as well.

Results and Discussion

The results are shown in Table 1 and 2

Table 1. Temperature and humidity difference between the ambient and inside the cooling structure during the storage of tomato

<table>
<thead>
<tr>
<th>Structure</th>
<th>Temp( °C)</th>
<th>Humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hollow Block</td>
<td>4.00b</td>
<td>2.5b</td>
</tr>
<tr>
<td>Filla</td>
<td>4.5b</td>
<td>2.625b</td>
</tr>
<tr>
<td>Charcoal</td>
<td>5.5ab</td>
<td>7 a</td>
</tr>
<tr>
<td>Scoria</td>
<td>7.125 a</td>
<td>8.5 a</td>
</tr>
</tbody>
</table>

Table 2. Degree of weight loss and spoilage on tomato seed under evaporative cooling structures after 15 days of storage

<table>
<thead>
<tr>
<th>Structure</th>
<th>Weight loss (kg)</th>
<th>Spoilage (kg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hollow Block</td>
<td>0.7273</td>
<td>0.6850</td>
</tr>
<tr>
<td>Filla</td>
<td>0.5950</td>
<td>0.5797</td>
</tr>
<tr>
<td>Charcoal</td>
<td>0.5457</td>
<td>0.3520</td>
</tr>
<tr>
<td>Scoria</td>
<td>0.4247</td>
<td>0.2100</td>
</tr>
</tbody>
</table>

As indicated above in all the trials a significant difference among the structures were exhibited, in terms of temperature and humidity. The scoria and charcoal structures exhibited higher humidity and lower temperature than the filla and the hollow block. Lower weight loss and spoilage were recorded in the two charcoal and scoria structures than the filla and hollow block, though the difference was insignificant. In the case of banana, a delayed ripening was exhibited in the scoria and charcoal structures (Figure 1). After fifteen days of storage, the green colour was still pronounced in the two structures than in the filla and RHB. This was authenticated by the degree of reflectance shown in the histogram generated using Illwis, the GIS software. More pixels are observed in the darker score, while the brighter color, which is a manifestation of ripeness were exhibited in the other two stores. The charcoal and scoria evaporative cooling structures showed a remarkable reduction of temperature and Relative humidity, which has the potential to increase the shelf life of fruits like banana and vegetables like tomato.

This technology is promising and needs to be scaled out and further tested with tropical fruits which have not been considered in the current study and have a better keeping quality up to a temperature of 15 °C.
Figure 2. Degree of de-greening in banana stored in different storage structure

References


Modification of the AIRIC Enset Corm Pulverizer Using Engine as a Power Source

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Abstract

The processing of Enset, both the root and the pseudo stem has been a back breaking exercise, which imparts physiological stress on the operators, who are usually women. To overcome these problems, a number of efforts have been made by individuals and organizations. Among many, the Agricultural Mechanization Research division of EIAR made major improvements on the clamping component of the pseudo stem decorticating device and Amicho pulverizer. The former manual operated Amicho pulverizer has dramatically cut down the time required to less than an hour for the whole corm compared to three hours taken in squatting position in the traditional way of pulverizing. The device runs smoothly on smaller diameter and softer varieties, while harder varieties were found tiresome as the machine was manually operated. To alleviate these problems, further improvement was made by making it engine driven and has now a provision for ease of mobility within a field. The new corm pulverizer recorded a capacity of 320-360 kg/hr which is more than 150 times compared to the traditional practice and nearly 2.5 times the former design. The technology is satisfactory and needs to be scaled out to the end users.

Introduction

Work on Enset processing devices started at the EIAR farm implements research section in the late 1970s. During the 1984 and 1985 research season, effort was made to improve the traditional Enset decorticating devices. The original corm grater has some resemblance to that of the carpenter’s jack plane and comprised a set of thin plates in front of the main blade. The efficiency of this device was three times that of the traditional tool, but the sliced material varied in size which made pulverization difficult. Further effort was made to refine the operation and finally an adjustable rotary type blade pulverizer was developed, which was much better than its previous predecessors (Friew 2012).

In the consecutive studies made by the department, it was learnt that people use hired labour to process Enset at a rate of two birr per pseudo stem and two birr per three corm including the provision of the necessary daily maintenance i.e. food, coffee for the operation day on top of the two birr she was paying per head. The operators complained that it was indeed a back breaking exercise as the women had to squeeze in a cramped position for the whole day and there was no question on the needed improvement on the decorticating devices. The corm grating device, gebangeba was reported to be tiresome and in efficient. Women said that any improvement on the devices should have a provision for sitting arrangement during operation. Taking the above into account, the Agricultural mechanization research program proposed to revisit the previous activities on Enset and come up with a better processing technology.
The capacity of the first generation corm pulverizer was not more than 95.4 kg/hrs., which was about 40 minutes for a 20 kg corm and about 26% unpulverized corm, was exhibited in most cases (Friew 2012).

Despite the different designs forwarded to the users, farmers opted for a machine that takes up the whole corm in one piece. A thorough study was conducted to set the optimum feeding rate, which lessens the load on the operator. A feeding mechanism that delivers a feeding rate of 4 mm per revolution of the cutting disc was designed. The equipment was fabricated in the workshop and tested on station and at Areka Research Center in collaboration with the Enset Research team. It was also demonstrated at Chencha in collaboration with World Vision Ethiopia. It was also demonstrated to women group at Buee with SELF HELP group. It was found operational and acceptable. The equipment was able to handle a corm up to 0.45m in diameter and of 0.60m length in less than an hour. Though the pulverizer was found efficient in all the tested areas, farmers still complained on the weight of the equipment and operation technique, as it was different from the way they are used to. They even suggested it to be motorized and suggested some kind of a wheel for ease of mobility within farms (Friew 2012). Taking the above into account the study was continued to meet the above stated challenges.

Methodology

The methodology encompassed material selection and methods followed to address the specific objectives. Major considerations were given to engine selection and power transmission system. The corm clamping system and the mobility were given due considerations as well.

Design procedure

Engine drive and transmission

A 5hp engine already available in the workshop was used for this study. Focus was given to the power transmission system. Taking 5hp as the design horse power and 3000 rpm as the fast shaft speed an A type belt was selected using the BALDOR.MASKA quick selection guide for V-belts. (Figure 1).

![Design Factors](source: BALDOR. MASKA)
Number of belts
The first attempt was a direct drive using the engine pulley as the driver and fitting the cutting disc directly on the driven pulley. In the second case another pulley in between the two was added for speed reduction. The required number of belts for these arrangements was selected using the BALDOR belt drive selection guide (figure 1.)

Number of belts and other parameters with direct drive arrangement
The engine was already bought, thus the design horse power and fast shaft speed were 5hp at 3000 rpm. The driven shaft expected to run at 1000 rpm, the closest pertinent data read from the table for the given ratio and smaller sheave size (30/10, and 10cm smaller sheave size) were

- (ratio is 3.12, pulley size 4, rpm 1123, corrected hp/belt 6.13
- Arc length correction factor 0.9

Corrected horse power rating is the horse power/belt X correction factor 6.13x0.9=5.517

The number of belts=design hp/corrected hp= 5/5.517, which is 1
Face width 0.75 inches (19.1 mm)

With intermediate drive

- The driven shaft is expected to run at 1000 rpm, the closest read from the table was 1008, which gives:
  - Speed ratio 2.4
  - Smaller sheave diameter 10 cm
  - Bigger sheave diameter 24cm
  - From the BALDOR table the belt power registered in the table is 5.98
- Number of Belts (N)
  \[ N = \frac{Design \, HP}{Belt \, HP} \]
- The belt size for 40cm center distance A52
- Arc length correction factor 0.9
- Corrected horse power rating is the horsepower/belt X correction factor 5.98x0.9=5.382
- The number of belts=design hp/corrected hp= 5/5.382, which is 1
- Thus one belt was is good enough for this arrangement as well
- Face width 0.75 inches (19.1 mm)

Sprocket drive
The sprocket is used to transmit power from the cutting disk pulley to the load conveying nut screw assembly. The engine delivers 3Kw power at a speed of 3000 rpm. As this reaches the load conveying arrangement, the speed is reduced to 1000 rpm. Though part of the energy is consumed in the cutting unit assuming the whole 3kw to be used in the conveying unit, the chain and sprocket were selected as follows:
- Power 3kw
- Speed of driver 1000 rpm
- Chain and sprocket from table RS 140 with 13 teeth
- The next driven will be 13X 3 = 39 tooth sprocket
  Thus 39 and 13 teeth sprockets were selected for the load delivery arrangement

**Modification of table**
The original table was rigid where the legs were welded to the main frame. In the new design, the legs were modified to be detachable. This made it easier to load the equipment on any vehicle for long distance transportation.

**Clamping mechanism**
The corm is not uniform but has a variable diameter along the length. Thus, three wooden clamps with metal brackets attached with bolts were designed and fabricated. These were attached to the table in adjustable slots based on the diameter of the corm at the three contact points. The spring between the clamp and the bracket, recoil or relax depending on the variable geometry of the corm along its length).

**The load delivery mechanism**
The load delivery mechanism was a screw nut arrangement. The nut pitch was 4mm, where for a rotation of the shaft, the load advanced by 4 mm, which was not difficult for the cutting disk. The cutting disk had to rotate 27 times for cutting a pitch equivalent of load. The main driving power was delivered from the engine, through a sprocket chain speed reduction arrangement, which was about 30-40 rpm. As the shaft rotated once the nut which drives the load delivery board moved 4mm, which is equivalent to the pitch.

**The transport mechanism**
A dead axle with free rotating wheel was designed and fabricated for in field transportation. The wheel is detached from the main body during operation. A twin handle is provided like a wheel barrow to move the equipment from one location to another.

**Testing**
The new version was tested on station by bringing *Enset* from Kulumsa and Butajera. The corm was separated from the other plant parts, cleaned. The diameter was measured at three different parts, representing minimum diameter, maximum, and the central diameter. The length and weight of the corm were also recorded. The corm was loaded on the pulverizing table as close as possible to the pulverizing disc. The engine was turned on, time was recorded, and the pulverized and left over material were recorded at the end.
Results
The equipment
As indicated above, the critical components like the engine and transmission system, the clamping and transportation parts were designed, fabricated, which gave the current assembled engine operated mobile corn pulverizer (Figure 2). The new equipment is engine driven and mobile which is more efficient compared to the previous designs. The test results indicated the new equipment with the new clamping mechanism has more than a 150 fold capacity compared to the traditional practice and around 2.5 times its immediate predecessor, with the older clamping mechanism, (Tables 1 and 2 ). This equipment is mobile and engine driven which is responsive to the issues raised on the previous designs.

![Figure 2. The newly redesigned fabricate corn pulverizer](image)

Test results

Table 1. Test results before arranging the clamping mechanism

<table>
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<th>Date</th>
<th>Length (cm)</th>
<th>Diameter (cm)</th>
<th>Weight (kg)</th>
<th>St time</th>
<th>Actual working time</th>
<th>Pulverized amount</th>
<th>Rate (kg/hrs)</th>
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<td>11</td>
<td>132</td>
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</tbody>
</table>

Table 2. Test results after arranging the clamping mechanism

<table>
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<th>Trial No</th>
<th>Date</th>
<th>Length (cm)</th>
<th>Diameter (cm)</th>
<th>Weight (kg)</th>
<th>Actual working time</th>
<th>Pulverized</th>
<th>Rate (Kg/hr.s)</th>
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</thead>
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<td>320</td>
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<td>31</td>
<td>16</td>
<td>3</td>
<td>320</td>
</tr>
</tbody>
</table>

Discussion
As indicated in the tables, a better performance is recorded in the improved technology compared to the traditional practice. The equipment recorded a capacity of 320-360 kg/hrs. compared to the traditional practice, which was not more than 60-70kg/day, which is less than 1.5 kg/hr. The rest period and maintenance requirement of the manual operators, which is taken care of by the client will not be an issue once this technology is adopted. The technology
is promising and needs to be scaled out to the end users. As the equipment is engine driven the mode of delivery or service delivery system, establishment of service providers need to be worked out as well.

Acknowledgments
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References

V-Belt Drive Selection Handbook. https://www.baldor.com/mvc/DownloadCenter/Files/MS4050V