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Contents

Farm Power and Agricultural Machinery Technologies

Development and Testing of Single Row Animal Drawn Groundnut Planter

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Abstract

This project was undertaken to develop and test the performance of a planter that capable of planting groundnut at predetermined spacing and depths. The planter, consisting of a frame, seed hopper, seed metering devices, seed tube/spout, adjustable furrow openers and covering device, and drive wheels. Physical properties of seeds involved in the study were investigated to optimize the design of planter's components. Field testing was conducted in two locations namely at Boko and Erer substations of different soil types. In this experiment, two types of sowing methods were used, the animal drawn planter and manual sowing. The animal drawn planter is simple in design and easily operated and can be maintained by farmers. Randomize complete plot with four replications were used with plot size of 20 x3m^2*. The data was analyzed by two sample t-test statistical analysis of mean values, t- values and probability levels at 95% confidence interval. The parameters observed were sowing time, depth of sowing, speed of sowing, row spacing and plant spacing. The results showed that there were highly significant differences between the animal drawn groundnut planter and manual for a parameter such as time for sowing, depth of sowing and speed of sowing. The animal drawn planter saves sowing time and labor requirements when compared to manual sowing. It also gave better average seeding rate for planter 82 kg/ha than that of manual treatment (93 kg/ha). Effective field capacity and field efficiency of the planter was 0.08 ha/hr. and 73% respectively. Hence, it is recommended that this efficient planter will be upgrade the planting rows in future design in multi row planter for increasing planting capacity per unit time.*

Key words: Ground nut, Animal drawn groundnut planter, single row planter

Introduction

Throughout the developing world and many developed countries, animals' traction is an inseparable part of agricultural practice, particularly in sub-Saharan Africa, the use of animal power for agriculture and rural transport is increasing every year (FAO, 2000).

In Ethiopia, development and adoption of improved agricultural technologies including farm implements and machinery has been a long term concern of agricultural experts, policy makers, and agricultural researchers and many others linked to the sector. However, evidence indicates that adoption rate of modern agricultural technologies in the country is very low (Kebede et al.1990).

The adoption of agricultural innovation in developing countries attracts considerable attention because it can provide the basis for increasing production and income. Small scale farmers' decisions to adopt or reject agricultural technologies depend on their objectives and constraints as well as cost and benefit accruing to it (Million and Belay, 2004). Therefore, farmers will adopt only technologies that suit their needs. In Ethiopia, about 69% of smallholder farmers own farmlands less than or equal to one hectare in size and average grain yield for various crop is less than one metric ton per hectare (CSA, 2013). It is very difficult for these farmers to own and operate costly agricultural machinery and equipment's that can establish the optimum plant population. Hence, in most part of the country, manual broadcasting method of sowing is still in use. This method of crop establishment adversely affects the seed requirement and production per unit area.

Animal drawn planting technology is particularly important to the traditional rain-fed farming in Ethiopia and to neighboring countries as many experts count. The technology constitute one of the major solutions to low productivity and the expansion of the production area associated with traditional hand tools used by the rural farmers (Mekki and Mohamed 2011), so as to solve the food security problem of the rural farmers. According to Philip *et.al* (1988), the use of animal drawn planting technology for agricultural practices is potentially useful and is also an appropriate means of improving the efficiency of the traditional farming system. Animal traction would increase crop yield through better and timely cultivation and planting. It would reduce labor requirement per unit area and allow an increase in the area under cultivation. Therefore the project was conducted with the objectives of developing and testing of animal drawn groundnut planter and evaluating its performance in the field.

Materials and Methods

Description of experimental site

Development and performance evaluation of the planter were done at FARC and tested at fades district on station and Babile district on Erer substation. Fadis station is located at the distance of 24 km away from Harar city in the south direction and it is located at the latitude of 9^0 07' 00" N and longitude of 42^0 04' 00" east, in middle and lowlands areas and at average altitude of 1702 m.a.s.l. with a prevalence of low lands. Babile was located at 9^0 10' 41.5" north of latitude, 42^0 15' 27.3" east longitude and elevation 1274 m.a.s.l.

Materials

Groundnut seeds were used to evaluate performance of the planter that developed at FARC metal work shop. Hence, the planting machine was designed to plant the seed.

Methods

Experimental treatments

The experimental land was well prepared for assessment of animal drawn planter, two treatments were used which are described below.

Animal drawn planter: (required two labor, one for guiding the animal and other to control the movement in the row)

Manual: Rrequired four labors, two for making the rows by hoe, one sowing the seed and one for covering seeds by soil).

Experimental site

The experiments were designed and conducted in the sandy loam and sandy clay loam soils. The experimental land size was 12×20 m^2 and divided in to four equal plots and accordingly for manual. Randomize complete plot with four replications were used with plot size of 20 x3 m^2. Local seed was selected and examined using the recommended cultural practices in the area.

Seeding rate and plant population

The optimum plant population per hectare can be calculated from recommended plant spacing (row spacing and distance between plants) for a given crop, as follows: -

$$P_{p.} = \frac{10{,}000m^2}{p_s{}^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (1)$$

Where: P_p= plant population per ha
P_s= area per plant (m^2)

Determination of physical properties of seed

The mean sizes of the seed, used in the study, were determined by randomly selecting 100 seeds from the representative samples and measuring their three principal diameters using digital caliper. The larger, intermediate and minor diameters of the seeds were designated as length, width and thickness, respectively. The mean sizes of the seeds were determined as geometric mean diameters. The volume and sphericity of individual seed was calculated using the measured length, width and thickness of the seeds and equations given below (Davies, 2009).

$$D_g = \sqrt[3]{L * W * T} \qquad (2)$$

$$V = \frac{\pi}{6}(L \times W \times T) \qquad (3)$$

$$S_{m=} \frac{\sqrt[3]{L \times W \times T}}{L} \qquad (4)$$

Where: D_g = Mean geometric diameter (mm), L= Mean length (mm); W= Mean width (mm); T = Mean thickness (mm); V = Mean volume (mm^3): S_m = Mean seed sphericity

Design and material selection of the planter components

The planter consists of frame, seed hoppers, metering mechanisms, furrow openers, seed covering devices, handles, drive wheels and rear wheel that used to press the soil. To achieve the best performance of planter, proper design and material selection of different components are important factor which optimize and suit planting mechanism at appropriate place as well as minimize seed damage.

Main frame design: The frame (Figure 1), which is the skeleton of the planter, supports all other component parts of the machine. The two design factors considered in the determination of the material required for the frame were weight and strength. In this design, mild steel angle iron of 30 mm x 30 mm and 3 mm was used to give the required strength and rigidity, so that it can with stand all types of load during operation. The frame was provided with holes on both ends for shaft bearings and support of drive/ground wheels that power to operate the metering devices during laboratory and field performance evaluations. Connections between the frame and other component parts of the planter were made using appropriate sizes of bolts and nut.

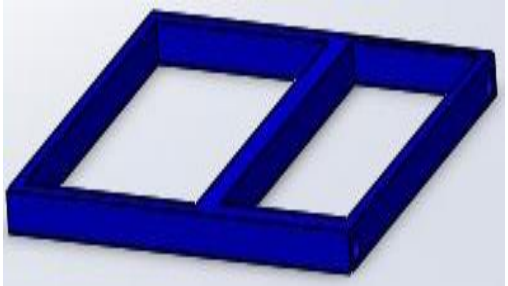

Fig1. 3D of main frame design

Hopper design

Hopper was designed to store and feed metering devices in vertical direction. The material used for the construction was sheet metal with thickness of 1.5 mm, which is readily available in the market and relatively affordable. The hopper has a shape of inverted frustum of rectangular pyramid truncated with rectangle bottom (5 cm x 20 cm) having a height of 22 cm) and rectangle top (20 cm x 30 cm). The bulk density of groundnut seed was 479.28 kg m^{-3}, and angle of repose 28^0 according to (Davies, 2009). The average seeding rate of groundnut is 84.5 kg ha^{-1}. Hence based this rates of seeding, the volume of the hopper was estimated using equation given by Olaoye and Bolufawi, (2001);

$$V=\frac{\boldsymbol{Sr}}{\boldsymbol{nBD}} \qquad (5)$$

Where: - S_r = seeding rate (kg ha^{-1}); n = number of refilling per hectare BD = bulk density of the seeds (kg m^{-3})

Volume of seed $=\frac{84.5}{20\times479.28} = 8.8\times10^{-3}\,m^3$

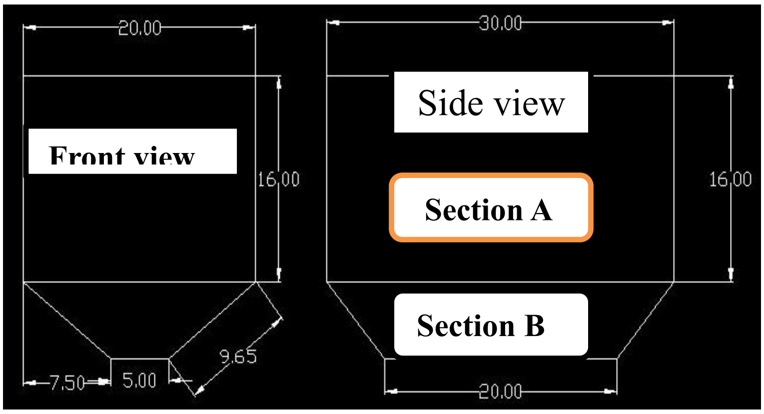

Fig. 2: Cross-sectional view of hopper

Section A: H_1 =Height of the box, L = Length of the box, W= Width of the box
Section B: a= Bottom width; H_2=Height; t=Distance and ϴ= angle of repose of the crop degree 28^0

The hopper has two kinds of shape that were rectangular shape at point A and trapezoidal shape at point B

Volume at section A $V_a = W x H_1 x\ L = 9600\ cm^3$ and Volume at section B was determined by

$$V_b = \frac{(a+b)\times h\times lb}{2} \qquad (6)$$

Where: v_b = volume of box with trapezoidal section
Therefore, volume of the hopper =Va+Vb
a=bottom width, b=top width of the box, L_b= length of the box but b= a+2t

$$\text{So}\quad V_b = \frac{(a+a+2t)\times h\times lb}{2}$$
$$= \frac{(2a+2t)\times h\times lb}{2}$$
$$\tan_{\Theta} = t/h \qquad (7)$$

The angle of repose for groundnut was about 28^o (Davies, 2009).

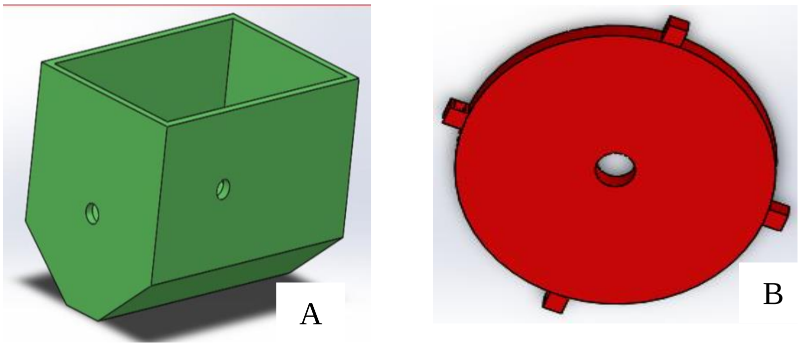

Fig. 3: Hoper (A) (B) Seed metering disk

The angle of the seed box must be greater than the angle of repose for easily seed flow. Therefore, $\alpha = 49^0$ was selected for designing of seed hopper.

Design of seed metering part

The metering devices were made from sheet metal of 3 mm thickness and 18cm diameter and four cups were made about its circumference at equal distance from each another. The size and number of cups on the plate depended on the size and shape of seeds. Seed metering device receive power from ground wheel through chain and sprocket mechanism. Hence the gear ratio of the bigger gear to the smaller is 2:1 that means as the ground wheel rotate once the seed metering device rotate twice of the ground wheel so that the distance covered in one revolution of the ground wheels were calculated so that seed metering device was designed to place the seeds at 20 cm plant to spacing.

The diameter and numbers of cells were determined on the basis of mean size of individual seeds, recommended intra-row spacing of seeds and economical and efficient size (diameter) of driving wheel. The plate had the size 3 mm x18 cm (thickness x diameter). The diameter of the ground wheels was 51 cm. The size of the cells on the plate was decided on basis size of the biggest seeds of a given crop. The number of cells and distance between consecutive cells on the seed metering plate were obtained using the following expressions;

$$M = \frac{\pi D2}{Irs} \tag{8}$$

$$t= \frac{\pi D1}{m} \tag{9}$$

Where: - D_1 = Diameter of seed metering roller (18 cm): D_2 = Diameter of ground wheel (51cm) m = Number of cells on a roller (minimum value): I_{rs} = Intra-row spacing of seeds and t = Distance between consecutive cells

The numbers of cups on seed metering plate were 4 and consecutive distance between each cups on seed metering plate was 14.13 cm. Hence the gear ratio of the bigger gear to the smaller is 2:1 that means as the ground wheel rotate once the seed metering device rotate twice of the ground wheel.

Gear ratio = $\frac{N1}{N2}$:- where N_1 number of teeth on the driving gear and N_2 the number of teeth on the driven gear. So N_1=36 and N_2=18 The distance covered in one revolution of the ground wheels were calculated so that seed metering device was designed to place the seeds at 20 cm plant to plant spacing.

Design of ground wheel for the planter

The planter’s ground wheel, with external diameter of 51 cm, was designed as an integral part of the seed metering mechanism connected to the seed metering device directly. The rim of wheel was made from mild steel flat iron 6 mm thick and 60 mm wide. Each wheel had eight spokes made from mild steel rods with diameter of 8 mm, and were welded to the rim and hub at the center of the wheel that served as bushing or shaft bearing, at equal interval Equation below (Thomas and Brown, 2005) was used to analyze the shear strength (τ) of the ground wheel considering the wheel as thin-walled vessels.

$$\tau=\frac{T}{2\times A_m \text{ x } t_w} \tag{10}$$

Where: T=Torque produced by the wheel (12.50 Nm) A_m = Area of the wheel calculated based on the median diameter of the wheel; t_w = Thickness of the wheel wall (0.006 m) and r_m = the median radius of the wheel r = the outer radius of the wheel (0.25m)

Therefore, the shear stress on the wheel

$$\tau= \frac{12.5}{2\times 0.006\times 0.019} = 54824\text{N m}^{-2} = 54.8 \text{ KN}$$

Thus the calculated shear stress was much less than the maximum allowable shear stress of the mild steel flat iron used in the construction of the ground wheel, 80.8MPa, hence the wheel is safe for operation.

Furrow opener

The design of furrow openers of seed planters varies to suit the soil conditions of particular region. Most seed planters are provided with pointed tool to form a narrow slit in the soil for seed deposition. The adjustable furrow opener permits planting at each variety's ideal ground depth. The type used for this work is the V -shaped type. These types of furrow openers are used for forming slightly narrow under sandy soils for placement of seeds at medium depths. The Furrow opener is thin mild steel. The mild steel flat iron was fabricated to shoe type like structure to facilitate an easy cut through the soil. Nut and both were used to fasten the device to the frame through a hole drilled on the frame for adjusting sowing depth according to crop.

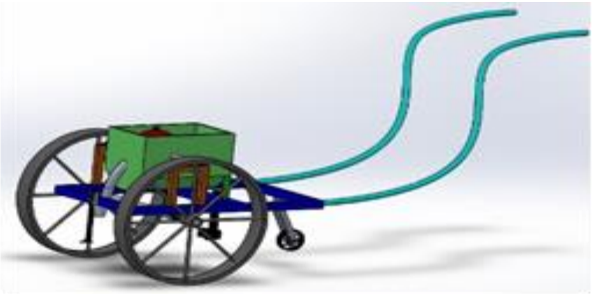

Fig . The developed planter

Data collection and statistical analysis

The data were collected from the parameters as described below:

Planting time: - The time taken for sowing by animal drawn planter and manual hr/ plot
Plant spacing: The distance between two consecutive plants
Row spacing: The distance between adjacent rows
Depth of planting: Depth at which furrow opener can open and was measured by ruler (cm)
Uniformity: The percentage of even distribution of plant per plot
Days to 50% seed emergency: The number of days from planting date to emergency.

Field test was conducted on a well prepared soil using tractor. The depth of planting was measured along the row the length of every 2 m at three randomly selected rows from each plot.

Field capacity and efficiency were determined in accordance to the recommendation made by Kepner (1978) and using relevant parameters that included effective operation time, turning time and time losses due to obstructions on the field. A plot of 12 m by 20 m requiring, on average, about 32 passes with inter-row spacing of 37.4 cm was used to assess field capacity and field efficiency. From the data gathered, working speed (km hr $^{-1}$), and effective field capacity (ha hr.$^{-1}$) and field efficiency (%) was estimated using the expressions below:

Actual field capacity was calculated:-$A_{FC} = \frac{A}{10{,}000T}$ (11)

Where: AFC=Actual field capacity (ha $hr.^{-1}$): A= Total area of the field (m^2) and T= Total time taken to finish the field (hr.**)**

Theoretical field capacity also calculated as : T_{FC}=0.0036WS (12)

Where: T_{fc}= theoretical field capacity (ha hr^{-1}.); W= width of planter (cm) and S = forward speed of the animal (m s^{-1})

Field efficiency is the ratio of actual field capacity to theoretical field capacity

$$FE = \frac{A_{FC}}{T_{FC}} \times 100 \quad (13)$$

Result and Discussion

Using an experimental plot of 20 m by 12 m with the help of measuring instruments and devices performance data was collected. Data collected during field test include; speed of the animals, depth and width of furrow opener, spacing between rows and plant numbers of seed per drop, operational time and other as described in table 1 and 2

Table 1: Experimental plot required and machine performance test

Length of the Field (m)	Width of the Field (m)	Time taken to Finish field (min)	Time lost by turning and stopping (min)	Theoretical field capacity ha hr^{-1}	Field capacity in ha hr^{-1}	Field efficiency %
20	12	15	3.2	0.11	0.08	73

The time taken to finish one hectare of land was 12:30 hr. that means by taking 8 hr. working time per day by farmer. Hence to time required accomplished 1 hectare of land planter was 1 ½ day. But for manual planting the time taken to finish one hectare was 50 hr which was about 6.25 days this indicates significant different among them. This result agreed with

On the other hand Table 2 result the proposed plant spacing was 20 cm and result obtained from the experiments was 22.78 cm so it is good in terms of plant spacing and plant spacing uniformity was about 86.7% which was acceptable.

Table 2: Performance testing of planter

Field Test	Unit	Symbol	Field value
Seed spacing*	cm	SS	22.78
Seed spacing standard deviation	cm	SSD	3.0
Seed spacing evenness=(SS-SSD)/SS	-	Eu	86.7%
Seeding depth*	cm	d^1	8.91
Seeding depth standard deviation	cm	d^1_d	0.8
Seeding depth evenness =$(d^1 - d^1_d)/d^1$	-	E_d	90.9%

Row spacing*	cm	HS	37.4
Row spacing standard deviation	cm	HSD	4.58
Row spacing evenness =(HS-HSD)/HS	-	E_h	87.7%
Number of seeds per row*	-	H	7.4
Number of seed standard deviation	-	hSD	1.54
Seeds per row evenness	-	E_n	79%

The proposed depth of planting for planter was about 6-10 cm and the result obtained according to (Tarig *et al*., 2013**)** was 6.1 cm for groundnut and the result from our planter was 8.91 cm which is acceptable depth in the dry land and the result obtained from the test was about 90.9% and depth of planting uniformity was 94% according to (Tarig *et al*. 2013**)** which was almost the same results when compared to the previous work. The proposed row spacing for groundnut planter was 40 cm and result obtained was 37.4 cm that is good results and its uniformity for row spacing was 87.7%.

Table 3: Effect of planter and manual on seeding rate

Location	Area(m^2)	Weight of seed sown (kg)	Seed rate (kg/ha)
Fedis planter	240	1.92	80.0
Erer planter	240	1.97	82.0
Erer manual	240	2.23	93.0

Manual planting slightly higher than single row animal drawn planter Table 3. In the other word the result confirmed that performance of planter was falls within the standard range of seed rate of the crop. In terms of work drudgery i.e. labor and time saving, this planter can significant amount of seed as 11kg, which can saw or cover 0.13 ha of additional land.

Table 3. Statistical analysis: Gen-stat 15th Edition statistical package was utilized to analyze by two sample t- test method

Treatment	Time of planting (min)	Speed of animal (m/s)	Spacing between row (cm)	Spacing between Plant (cm)	Planting depth (cm)
Planter	0.41	0.82	37.38	22.66	8.250
Manual	3.00	0.13	38.34	22.79	9.563
SE±	0.01	0.0166	2.358	1.553	0.220
T value	-2.98	41.40	-0.41	-0.08	-5.96
Level of significant	**	**	ns	ns	**

Note: ** and ns = significant at < 0.001 and not significant, for 95 confidence interval of difference in means values respectively. Planting time, speed of planting and depth of planting had significant effects among the treatments while plant spacing and row spacing had not significant effects with in the treatments

Conclusion and Recommendation

From the above result we can conclude that the donkey drawn planter is more suitable then manual sowing of groundnut under rain-fed condition on Erer and Fadis at sandy loam and sand clay loam soil respectively. Also, it was significantly reduced the sowing time and labor requirement for groundnut planting when compared to manual sowing. Manual placement of seeds required four persons: two to make rows one for seed placing and one for seed covering. But, row planter required only two persons one to guide the animal and one to control the movements in rows. The time required to plant one hectare of land using traditional method, with four persons, was 50 hours while using the planter, with two persons required only 12:30 hours-ha-1 to do the same works. Hence, one can note that the time requirement per hectare is reduced by one-fourth and labor requirement was reduced by half when the planter was used. In addition to time and labor the farmers can save about 11kg seed when compared to manual sowing. Then the machine was portable and can be easily operated and maintained by the farmers.

Recommendation

The performance evaluations made indicated that the planter can be used successfully on small farm holders. Form the test results the planter was better than manual planting interims of performance indicators, time and labor saved indicated that the planter can be used successfully at farmer’s level. The tested planter is single row; it is necessary to improve as large scale farmers by increasing number of rows of the planter to improve field capacity of planter.

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Improvement of Asella Wheat and Barley Thresher

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Abstract

Wheat and barley thresher was improved for its threshing capacity and suitability of operation and performance evaluation was done on wheat and barley crops. The size of previous wheat and barley thresher was increased and the feeding system that blows the dust outward to the operator was improved. The major components of the improved wheat and barley thresher include threshing unit, cleaning unit, feeding table, straw and chaff discharging unit and grain discharging unit. It was tested to thresh, separate and clean the wheat and barley seeds. The results showed that the machine had the maximum threshing capacity of 538 and 424 Kg/hr at feeding rate of 1000 Kg/hr and drum speed of 1100 rpm with grain straw ratio of 1:0.96 and 1:1.44 of wheat and barley crops respectively. The maximum threshing and cleaning efficiency of 98.95 and 99.93 %, 98.13 and 97.91 % and grain breakage of 0.52 and 1.06 % at above combination of 1100 rpm drum speed and 1000 Kg/hr feed rate for wheat and barley crops respectively. The maximum fuel consumption recorded were 0.73 and 0.60 liters per hour at moisture content of 12.5 and 11 % (d.b) at the combination of 1000 Kg/hr feed rate and 1100 rpm drum speed for wheat and barley respectively. The successful improvement of this machine is expected to reduce drudgery associated with the traditional method of threshing wheat and barley, and therefore increase productivity of farmers by reducing post-harvest losses.

Key words: *Threshing, capacity, efficiency, breakage, wheat, barley, drum*

Introduction

Crop production is the major part of agricultural production in Ethiopia and over 98% of this is produced by smallholder farming sector (UNDO, 2008). Barley and wheat usage ranges from being used as raw materials in industries for production of malt, beverages, beer, etc. to being consumed directly as food. Its post-harvest processing could be done through traditional method (manual) or modern method. However, manual system of threshing cereal failed to meet up with this growing demand of cereals and is labor intensive (Osueke, 2011). In this sector agricultural activities are done by traditional methodin the country as a whole. In addition to tiresome of the activities, farmers are losing substantial parts of their product at each production steps.

In this method, about 40% of the total labor required to produce crop is extended in harvesting and threshing activities. The person hour per output of the method is very low, varying between 40 and 50 person hour per ton for both animal and manual threshing

Johnson, (1992). However it is cheap, labor intensive and takes long time hence exposed to tremendous loss. The average post- harvest losses of food crops such as Teff, Wheat and Maize are annually 12.9%, 13.6% and 10.9% respectively Derege A. *et al*, (1989). Among this loss, threshing accounts for large place.

Threshing, the first major post-harvest operation, involves application of mechanical forces to detach grains from straws. The applied forces fall on the straws at random, breaking the straws stochastically, to free the enclosed grains. Some physical phenomena involved in threshing crops are: breakage of the grain pod which is dependent on the intensity of force, the orientation of the pod and moisture content; freedom of the grain from the straw and the passage of them through the concave Simonyan, (2006).

In order to address threshing problem of small- scale agriculture, many efforts have been made by different governmental and non-governmental organizations to replace traditional threshing with introduction of improved mobile threshers that can be locally developed or adopted. The development of mechanical threshers for the purpose has clearly an edge over conventional methods and has reduced the drudgery of work to a great extent. The use of these stationery threshing machines is based on the quick process, level of performance and economy. It is need of the hour to mechanize wheat threshing operation in order to recover better yield completing the operation timely (Ahmad, 2013). There are many factors affecting the performance of threshing machines such as cylinder peripheral speed, feeding rate and moisture content. (Mahmoud, 2007)

Different researchers try to design, develop, select, modify and evaluate many threshers for its performance based on evaluation parameters on cereal crops. Majumdar (1985), Morad (1997), Abdelghany and El-Sahar (1999), Gill *et al*. (2002), Behera *et al* (1990) and others are few of them.

Asella Rural Technology (AAERC) had modified and tested multi-crop thresher in 1982 and known as Asella wheat and barley thresher. The problem of this thresher is its durability and cleaning system. Birhanu Atomsa of HRTRC (FARC) is extensively working on cleaning efficiency and promising result was obtained. Asella agricultural mechanization research center currently Asella agricultural engineering had modified on durability and it was completely resolved but the size and dusting problem is not that much promising. This wheat and barley crop thresher pushes out ward the material when feeding. There is a full of dust that an operator face when working with the machine and it could not easily take in ward the material to be threshed because the feed inlet position is at the end center of threshing drum. Another problem is its low threshing capacity (200-300kg and 300-400kg) of wheat and barley respectively. Therefore, the aim of initiating this activity is to improve and evaluate for its performance of Asella wheat and barley thresher.

Material and Methods

Material

The material used for prototype production and performance evaluation were: angle iron, sheet metal, square pipe, pulleys, bearings, steel shaft, diesel engine, fuel, bolts and nuts, electrodes, flat iron, round bars, improved wheat and barley thresher, wheat and barley crops.

Instrument

The instruments used during performance evaluation and data collection were: digital balance, spring balance, tachometer, graduated cylinder for measuring fuel, oil and stopwatch.

Methods

Machine Description

Improved Asella wheat and barley thresher has the following components. These components are feeding table, threshing unit, cleaning unit, grain discharging unit, straw and chaff discharging unit. Threshing drum is made up of rolled sheet metal and steel shaft at the center. It has spike tooth and peg attached on the drum. Spike tooth type has attached on threshing drum with respective arrangement for facilitating straw motion and biting.

Figure1. Major parts of improved Asella wheat and barley thresher

The threshing Parts Modified

Threshing drum

The principal parameters of the threshing drum are the drum length, the drum diameter, number of beaters on the drum and the drum speed Soja *et al. (*2004).

$$Q = q_o \, x \, L \, x \, M \qquad (1)$$

Where:-Q = Feed rate of thresher (kg/s), q_o = Permissible feed rate (kg/s. m) and varies between 0.35 – 0.4, L = Drum length (m) and M = Number of (rows of) beaters.

The thresher was modified as follow: drum diameter increased from 200 mm to 300 mm, the number of beaters also increased from 36 to 48 and 26 to 35 for peg beater and chopper respectively. From equation 1, drum length and threshing capacity has direct relation between them so that increasing drum length and diameter increases the threshing capacity of machine.

Concave

Concave is the lower half of the drum which was served as the discharge through holes for the threshed crops. The clearance between threshing drum and concave was reduced from 45 to 25 mm. Length of the concave was also increased from 940 to 1000 mm. The upper half concave was served as the cover. It was made from rolled sheet metal and served as a cover for the crop material during threshed.

Fan

The air blast created by fan pushes the straw out of the thresher. The fan of wheat and barley thresher has four blades attached to fan shaft mounted on two bearings on each end side to allow free rotation. So, this fan will be improved based on aerodynamic properties of crop. Diameter of the fan increased from 250 to 350 mm and the length also increased from 975 to 995 mm. For agricultural applications, fan speeds are recommended to be between 450 and 1000 rpm (Adane, 2004).

Selection of Drive and Transmission

Selection of pulley diameters

The pulleys used in the drive system were made of cast iron. Pulley diameters were selected based on the need to reduce the engine speed to the required one. The following equation was used to determine pulley diameters.

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \tag{2}$$

Where: N_1 and N_2 are rpm of driving and driven pulleys

D_1 andD_2 are diameters of driving and driven pulleys

The values of D_1, D_2 and N_1 was 140 mm, 225 mm and 2500 rpm and the maximum determined value of N2 was equal to 1372.55 rpm

Selection of the drive

V-belt and pulley arrangements were used in this work to transmit power from the engine to the drum and fan shaft. The main reasons for using the v-belt drive was its flexibility, simplicity, and low maintenance costs. Additionally, the v- belt has the ability to absorb shocks there by mitigating the effect of vibratory forces (Khurmi and Gupta, 2005).

Determination of belt contact angle

The belt contact angle is given by the following equation (Khurmi and Gupta, 2005).

$$\varphi = Sin^{-1}\left(\frac{R-r}{C}\right) \tag{3}$$

The angles of wrap for the smaller and larger pulleys are determined by the following equation:

$$\alpha_1 = 180 - 2Sin^{-1}\left(\frac{R-r}{C}\right) \tag{4}$$

$$\alpha_2 = 180 + 2Sin^{-1}\left(\frac{R-r}{C}\right) \tag{5}$$

Where: R = radius of larger pulley, mm;
r = radius of smaller pulley, mm;
α_1 = angle of wrap for the engine pulley, deg;
α_2 = angle of wrap for the drum shaft pulley, deg;
C = is the center distance between the two center pulleys.

Therefore, by using the above equations the determined values of φ, α_1 and α_2 were 4.34^0, 171.32^0 and 188.68^0.

Determination of belt length

The length of belt appropriate to drive the system was calculated using the equation given below by Shigley and Mischike (2001).

$$L = 2C + \frac{\pi}{2}(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \tag{6}$$

$$L = 2*0.76 + \frac{3.14}{2}(0.255 + 0.14) + \frac{(0.255 - 0.14)^2}{4*0.76} = 2.144m$$

The closest standard length of the belt was selected from standard table and this value was 2101 mm. Since the belt is B type of V- belt we add to inside length 43 so, the exact length of v belt is equal to 2144mm. Then the exact center distance was determined by the following equation (Khurmi and Gupta, 2005):

$$C = \frac{K + \sqrt{K^2 - 32(D_2 - D_1)^2}}{16} \tag{7}$$

$$K = 4L - 6.28(D_2 + D_1) \tag{8}$$

Where: L = belt length, m;
C = center distance between pulleys, m;
D_2 = pitch diameter of driven pulley, m;
D_1 = Pitch diameter of driver pulley, m.

Since the calculated length of v belt is equal to the closest standard belt the exact center distance is also correct. Therefore, center distance was equal to 760 mm.Speed of the belt was calculated by using the following equation as given by Khurmi and Gupta (2005).

$$v = \frac{\pi D_1 N_1}{60} \tag{9}$$

$$v = \frac{3.14 * 0.14 mm * 2500 rpm}{60} = 18.32 m/s$$

This determined value was the highest for performing performance evaluation.

Bearing Selection

Bearing selection was made in accordance to American Society of Mechanical Engineers (ASME, 1995) standard as given by Hall *et al.* (1988). Therefore, UCP of 605 block bearing was selected.

Determination of Belt Tensions

To determine tensions on the tight and slack sides of the belt the following equations was used (Khurmi and Gupta, 2005).

$$T_1 = T - T_c \tag{10}$$

$$T = \sigma_{\max} a \tag{11}$$

$$T_c = mv^2 \tag{12}$$

Where: T_c and T= the centrifugal and maximum tension of the belts (N);
T_1 and T_2 = tension in the tight and slack sides (N)
$\sigma_{\max}$= maximum safe normal stress (N/mm^2);
a = is cross sectional area of belt (mm^2)
m = mass per unit length of belt (kg/m);
v = is speed of belt (m/s).

Values of $\sigma_{\max}$, a and m are taken from standard tables. So their values were: 2.1 n/mm^2, 81 mm^2 and 0.108 Kg/m respectively. Since the pulley is double line the number of belts used was also two. Therefore, the values of of T_1, T and T_c determined by equations 10-12 were equal to 267.70, 340.20 and 72.50 N. For the smaller pulley, tension on the drum was equal to half of the bigger Pulley tensions because the belt is single line. Therefore, the values of these forces were 133.85, 170.10 and 36.25 N.

Tensions on the tight and slack sides of the belt were estimated using the equation given Khurmi and Gupta, (2005):

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu \alpha_1 \operatorname{cosec} \frac{\beta}{2}} \tag{13}$$

Where: μ = coefficient of friction between a belt and a pulley
β = groove angle in deg. From design book = 40^0
α_1 = angle of wrap on small pulley in rad. It is determined by multiplying angle of wrap and π then divides to 180^0 so the result is equal to 2.9886.Finally the value of T_2 is equal to 160.67 N. again for the smaller pulley T2 was equal to half of the bigger pulley since the belt is single and it was equal to 80.34 N.

According to Khurmi and Gupta (2005) torsional moment (T_r) due to double belt and single belt tensions was determined using the following equation.

$$T_r = (T_1 - T_2)\frac{D_2}{2} \tag{14}$$

Where: T_1 = tension on tight side of a belt (N),
T_2 = tension on slack side of a belt (N),
D_2 = is the diameter of driven pulley (m).
Therefore, the determined value of T_r was equal to 13.65 Nm.

Shaft diameter determination

Shaft must have adequate torsional strength to transmit torque and not over stressed. The diameter of the threshing drum and fan shaft was determined using maximum shear stress theory. It was mounted on bearings and transmits power through v- belts and pulleys. The threshing drum shaft was supported by two bearings (R_1& R_2). On this shaft there was a load of threshing drum with beaters and crop materials that were uniformly distributed along the section of shaft (F). Pulleys (P) were placed at a specified distance to the left having specified weight each and tension forces due to belts.

The total bending moment was determined by using the following equation.

$$M = \sqrt{M_V{}^2 + M_H{}^2} \tag{15}$$

Where: M_V = vertical bending moment, Nm
M_H = horizontal bending moment, Nm

During force analysis the maximum bending moment of drum shaft was observed at bearing nearest to the single line pulley and the vertical and horizontal bending moment was equal to 37.04 Nm and 1 Nm respectively. Therefore, from the above equation bending moment was equal to 37.05 Nm.

According to (ASME) code (ASME, 1995); the diameter of threshing shaft was calculated using theory of maximum shear stress.

$$d^3 = \frac{16 fs}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t T_r)^2} \tag{16}$$

Where: - d = Shaft diameter, Ss = Allowable shear stress for shaft (42N / mm$^{2)}$ from design book, K_b = Shock factor for bending moment = 2, K_t = Shock factor for torsional moment = 2, M_b = Maximum bending moment (N. m), T= Maximum torque (N. m) and *fs* = factor of safety which is = 3 for agricultural equipment's.Finally a shaft diameter of 31 mm was determined and the standard shaft diameter selected was equal to 35 mm.

Working Principle

The crop material put on the feeding table is pushed into the inlet of drum when engine put on. The drum which gets power from an engine rotated in the concave is used to thresh the crop material. As the crop threshed, grain passes to grain outlet and straw to straw outlet.

The grain passed through a concave fall on grain collector and discharged to outside the machine. The straw, chaff and unwanted materials are passed to straw outlet by the help of air pressure created by blower and systems applied on the drum due to peg and chopper arrangements. Blower and drum shaft consist of pulleys at one of their end. Pulleys on each shaft are connected together with the help of belt to transmit power to each shaft.

Collected Data

Performance Evaluation

The following parameters were determined during performance evaluation of this improved Asella wheat and barley crop thresher. Some of these parameters were: threshing capacity, threshing efficiency, grain breakage, cleaning efficiency, grain loss.

Threshing capacity (kg/hr)

The weight of grains (whole and damaged) threshed and received per hour at the main grain outlet was called capacity. At the end of each test, total threshed grain was collected from the main grain outlet. The capacity will be calculated from the following expression:

$$T_c = \frac{W_g}{t} \times 60\,\mathrm{min}/hr \qquad (17)$$

Where: - Tc- threshing capacity (kg/hr),

W_g – Weight of threshed grain at main outlet (kg)

t – Recorded time of threshing (min)

Threshing efficiency (% TE)

Threshing efficiency is the ability of the thresher that separating the grain from the straw and the stuck correctly. It was calculated according to the following equation:

$$\%TE = \frac{T_G - Un_G}{T_G} \times 100 \qquad (18)$$

Where: T_G= Weight of total grains input per unit time, kg.

Un_G= Weight of un-threshed grains per unit time, kg.

Cleaning efficiency (% CE)

It is the ability of the thresher that can separate grain from the chaff and straw and calculated according to the following equation

$$\%CE = \frac{W}{W_O} \times 100 \qquad (19)$$

Where: W = Weight of grains from the main output opening after cleaning, kg.

W_O= Weight of grains and small chaff from the main output opening, kg.

Broken/damaged grain (% GB)

Damage due to mechanical threshing was determined as the ratio of weight of the actual damaged kernels to the weight of a sample taken.

$$\%GB = \frac{W_b}{W_s} x100 \qquad (20)$$

Where: W_g – percentage of broken grain, W_b – weight of broken (damaged) grains (g)
W_s – Weight of sample taken (g)

Grain-Straw Ratio

Grain-straw ratio was determined by taking the sample of material that was threshed. The samples is placed in sealed plastic containers and taken to the laboratory where the grains and straw are separated by hand. The straw and grains from each sample was kept paired. After weighing, the samples was dried to specific hours and then reweighed.

Experimental Design

The experimental design was a split-split plot design according to the principle of factorial experiment with three replications. The two levels of crop types was assigned to main plot, the three levels of threshing drum speed was assigned to sub plot, while the three levels of feeding was assigned to sub-sub plot, each with three replications. The experiment design was laid as 2*3*3 with three replications and had total of 54 test runs (2*3*3*3 = 54)

Statistical Analysis

The data were subjected to analysis of variances following a procedure appropriate for the design of the experiment (Gomez and Gomez, 1984) and using GenStat 15th edition statistical software. The treatment means that were different at 5% levels of significance were separated using least significant difference (LSD 5%) test. The least significant difference (LSD) test was performed for the mean values of threshing capacity, threshing efficiency, cleaning efficiency, percentage of visible grain breakage and percentage of grain loss in relation to crop type, threshing drum speed and crop feeding level.

Results and Discussion

This study was undertaken to improve and evaluate the performance of a thresher prototype capable of threshing wheat and barley crops at three level of drum speed and three feeding level. Performance indicators such as threshing capacity (TrC), threshing efficiency (TrE), cleaning Efficiency (ClE), percentage of visible grain breakage (GrB) and percentage of grain loss were used to assess functional fulfillment of the improved thresher. The result obtained were analyzed and discussed under the following heads.

Effects of Drum Speed and Feed Rate on Performance Parameters of Improved Thresher

Threshing Capacity

Table 1 and Fig. 2 showed the relation between drum speed and threshing capacity in wheat and barley crop at drum speed of 900 rpm, 1100 rpm, and 1300 rpm and feed rates of 800, 900 and 1000 Kg/hr. The maximum threshing capacity was observed to be 538 and 424 Kg/hr at drum speed of 1100 rpm and feed rate of 1000 Kg/hr and minimum threshing capacity was 408 and 316 Kg/hr at drum speed of 900 rpm and feed rate of 800 Kg/hr for wheat and barley crop respectively. As the feed rate increased from 800 to 1000 Kg/hr, the threshing capacity increased from 408 to 514.67 Kg and 316 to 408 Kg at 900 rpm drum speed for wheat and barley respectively. Similarly for the same range of feed rate the threshing capacity increased from 410.67 to 538 Kg and 326.67 to 424 Kg; 408 to 536 Kg and 322.67 to 426 Kg at drum speed of 1100 rpm and 1300 rpm, for wheat and barley respectively and which is similar to the finding of Behera *et al* (1990) and Chukuwa (2008).

Table 1. Effect of drum speed and feed rate on performance evaluation of improved thresher on wheat and barley crop (moisture content 12.5 % and 11 % and grain straw ratio of 1:0.96 and 1:1.44 respectively)

Drum speed (rpm)	Feed Rate (Kg/hr)	Threshing Capacity (Kg/hr)		Threshing Efficiency (%)		Cleaning Efficiency (%)		Grain Breakage (%)		Fuel consumed (Lit)	
		Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley
900	800	408	316	99.81	99.84	96.27	90.26	0.0955	0.07	0.60	0.54
	900	462.67	364	99.91	99.87	97.23	93.02	0.41	0.32	0.62	0.60
	1000	514.67	408	99.93	99.91	97.7	93.05	0.5	0.41	0.77	0.72
1100	800	410.67	326.67	99.85	99.87	96.67	96.97	0.14	0.53	0.53	0.48
	900	485.6	372	99.93	99.91	97.78	97.51	0.44	0.82	0.59	0.55
	1000	538	424	99.95	99.93	98.13	97.91	0.52	1.06	0.73	0.60
1300	800	408	322.67	99.83	99.85	97.37	94.77	0.233	0.83	0.56	0.56
	900	478.67	369.33	99.92	99.89	98	96.05	0.467	1.31	0.62	0.63
	1000	536	416	99.95	99.92	98.4	96.41	0.597	1.62	0.70	0.70

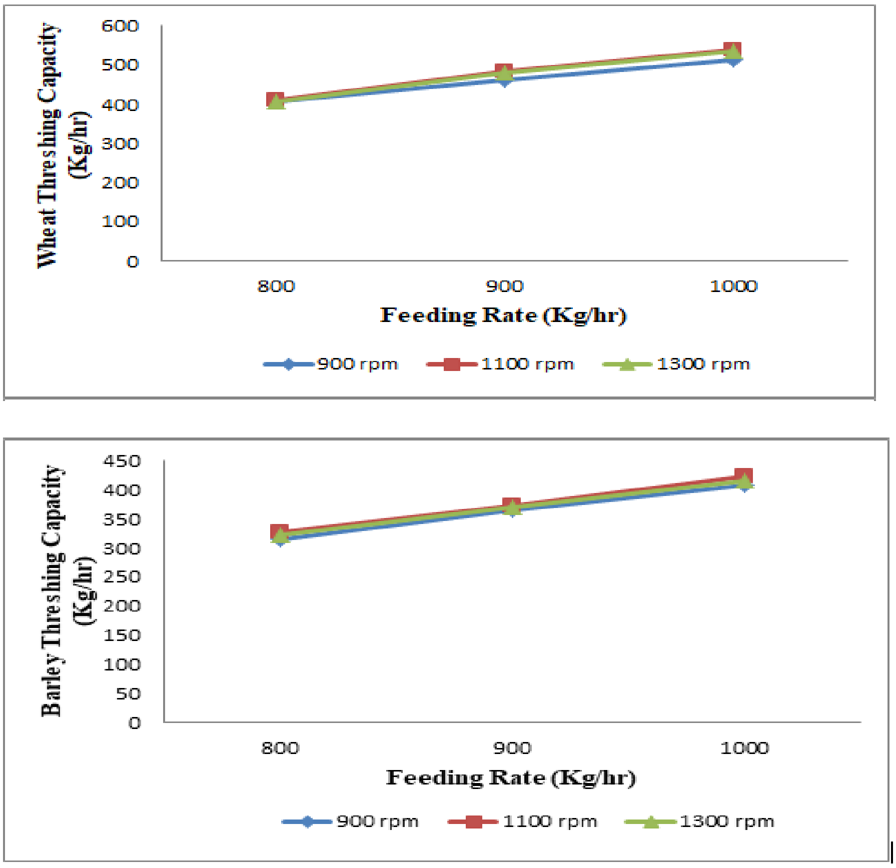


Figure 2.The effect of feeding rate and drum speed on threshing capacity of wheat and barley

Results of the analysis of variance (ANOVA) revealed that the feed rate and crop type had significant effect ($p < 0.05$) whereas drum speed, interaction of crop type and drum speed, interaction of crop type and feed rate, interaction of drum speed and feed rate, and interaction of crop type, drum speed and feed rate had no significant effect ($p > 0.05$) on threshing capacity.

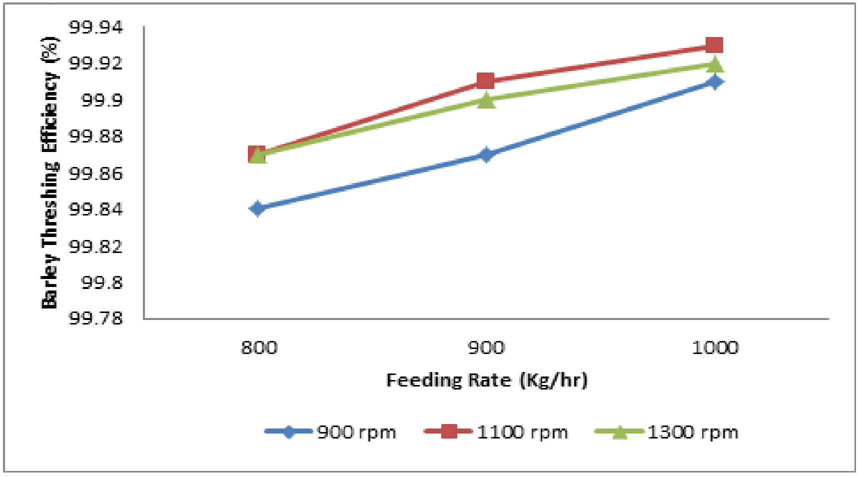
Table 2 show the effect of threshing drum speed, feeding rate, crop type and the combined effect of drum speed and feed rate on mean threshing capacity.

Parameter	Source of variation				Measure of differences	
	Drum Speed (DrS)		Crop type (CrT)			
			Wheat	barley	LSD (5%)	SE(M)
TrC (Kg/hr)	900		461.8^{a}	362.7a	15.13	4.80
	1100		482.5^{b}	368.7a		
	1300		474.2ab	369.3a		
	Feeding rate (FR)		Wheat	barley	12.65	4.27
	800		413.3^{a}	321.8^{a}		
	900		475.6^{b}	362.9^{b}		
	1000		529.6^{c}	416.0^{c}		
	Interaction(DrS*FR)				17.07	5.90
		800 Kg/hr	900 Kg/hr	1000 Kg/hr		
	900 rpm	362.0^{a}	413.3^{b}	461.3^{c}		
	1100 rpm	375.3^{a}	420.5^{b}	481.0^{d}		
	1300 rpm	365.3^{a}	424.0^{b}	476.0^{cd}		

Means followed by the same letters do not have significant difference at 5% level of probability

Threshing Efficiency

The test result of feed rate and drum speed on threshing efficiency for wheat and barley has been given in the Table 1 and shown in Fig 3. It is evident from the figure that the maximum threshing efficiency 98.95 % and 99.93 % was obtained at the 1000 Kg/hr of feed rate and 1100-rpm speed for wheat and barley respectively. While the minimum threshing efficiency of 99.81 % and 99.84 % was obtained at the feed rate of 800 Kg/hr and drum speed of 900 rpm for wheat and barley respectively. As the feed rate increased from 800 to 1000 Kg/hr, the threshing efficiency increased from 99.81 % to 99.93 % and 99.84 % to 99.91 % at 900 rpm drum speed for wheat and barley respectively. Similarly for the same range of feed rate the threshing efficiency increased from 99.85 % to 99.95 % and 99.87 % to 99.93 %; 99.83 % to 99.95 % and 99.85 % to 99.92 % at drum speed of 1100 rpm to and 1300 rpm, for wheat and barley respectively and which is similar to the findings of Behera *et al* (1990).



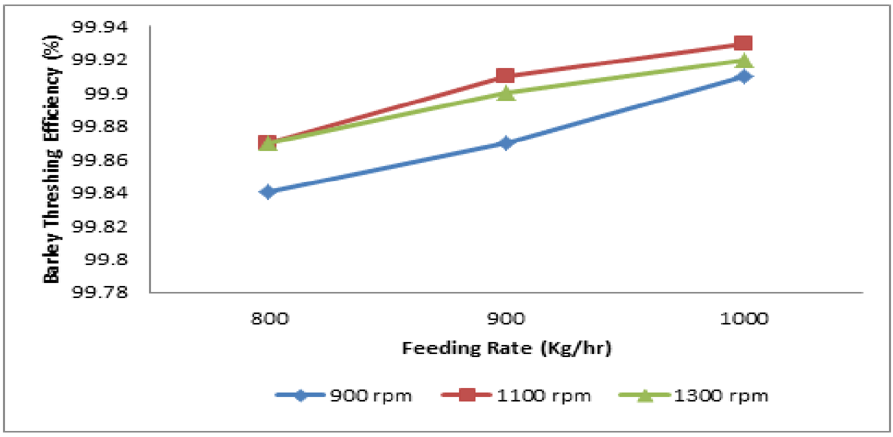


Figure 3.The effect of drum speed and feeding rate on threshing efficiency of wheat and barley

The analysis of variance (ANOVA) revealed that drum speed and feeding rate had significant effect ($p < 0.05$) whereas crop type and the interaction of crop type and drum speed, interaction of drum speed and feed rate, interaction of crop type and feed rate and interaction of crop type, drum speed and feed rate had no significant effect ($p > 0.05$) on threshing efficiency. Table 3 show the effect of drum speed, feeding rate, crop type and the combined effect of drum speed and feed rate on mean threshing efficiency. Figure 3 shows the relation between drum speed and feeding rate on mean threshing capacity.

Table 3. Means of threshing drum speed, feeding rate, crop type and their interaction on threshing efficiency

Parameter	Source of variation				Measure of differences	
	Drum Speed (rpm)		Crop type			
			wheat	Barley	LSD (5%)	SE(M)
TrE (%)	900		99.8178a	99.8756a	0.05919	0.01420
	1100		99.9100b	99.9044a		
	1300		99.8989bc	99.8878a		
	Feeding rate (Kg/hr)		wheat	Barley	0.05677	0.01665
	800		99.8333a	99.8567a		
	900		99.8511a	99.8911ab		
	1000		99.9422b	99.9200b		
	Interaction(drum speed*feed rate)				0.04357	0.01510
		800 Kg/hr	900 Kg/hr	1000 Kg/hr		
	900 rpm	99.8283ab	99.7900b	99.9217c		
	1100 rpm	99.8633a	99.9200c	99.9383c		
	1300 rpm	99.8433a	99.9033c	99.9333c		

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability.

Cleaning efficiency:

The relationship between feed rate, drum speed and cleaning efficiency is presented in the Table 1 and shown in Fig. 4. The maximum cleaning efficiency of 98.40 % and 97.91 % was obtained at 1000 Kg/hr feed rate and 1300 and 1100 rpm of drum speed for wheat and barley crops respectively, whereas a minimum cleaning efficiency of 96.27 % and 90.26 % was obtained at 800 Kg/hr feed rate and 900 rpm of the drum speed for wheat and barley respectively. As the feed rate increased from 800 to 1000 Kg/hr, at drum speed of 900 rpm, the cleaning efficiency increased from 96.27% to 97.23 % and 90.26 % to 93.05 % for wheat and barley respectively. Similarly for the same range of feed rate the cleaning efficiency increased from 96.67 % to 98.13 % and 96.97 % to 97.91 %; 97.37 % to 98.40 % and 94.77 % to 96.41 % at drum speed of 1100 rpm and 1300 rpm, for wheat and barley respectively. Above results revealed that for all set of observations minimum and maximum cleaning efficiency were obtained at the feed rate of 800 and 1000 Kg/hr respectively. The cleaning efficiency increased with increasing in speed of the drum from 900 to 1300 rpm for wheat and increased from 900 rpm to 1100 for barley. However, at 1300 rpm drum speed, cleaning efficiency is below drum speed of 1100 rpm for barley.

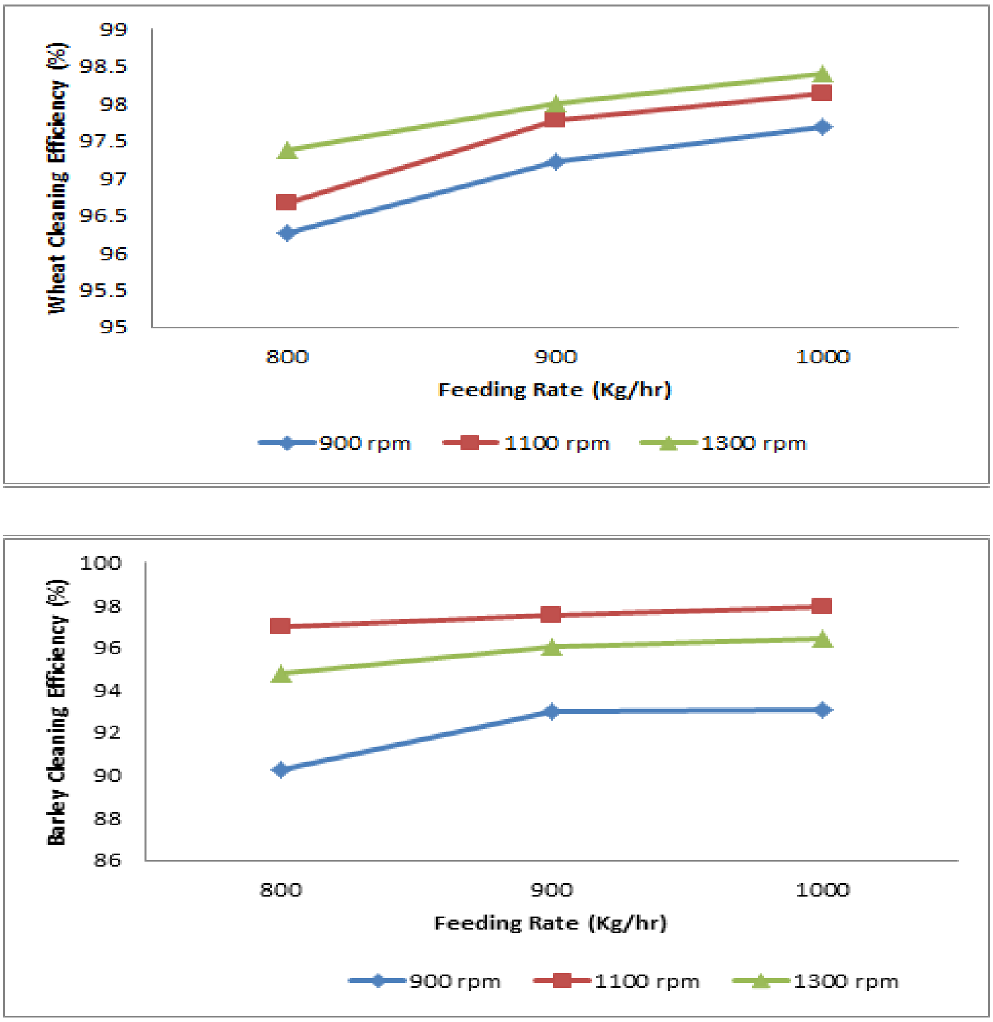


Figure 4.Effect of threshing drum speed and feeding rate on cleaning efficiency of wheat and barley

As evident from the Fig. 4 that with increased in drum speed the cleaning efficiency increased. Since the speed of blower increased with drum speed, the cleaning efficiency was also affected considerably. The increase of the drum speed causes increase of blower speed, resulting high air blast, thereby increased the cleaning efficiency.

Result of the analysis of variance (ANOVA) revealed that drum speed, feeding rate and the interaction of crop type and drum speed had significant effect ($p < 0.05$) on cleaning efficiency. On the other hand crop type and the interaction of crop type and feed rate, interaction of drum speed and feed rate, interaction of crop type, drum speed and feed rate had no significant effect ($p > 0.05$) on cleaning efficiency.

Table 4 show the effect of cylinder speed, feeding rate, crop type and the combined effect of drum speed and feed rate on mean cleaning efficiency. Figure 4 shows the relation between cylinder speed and feeding rate on mean cleaning efficiency.

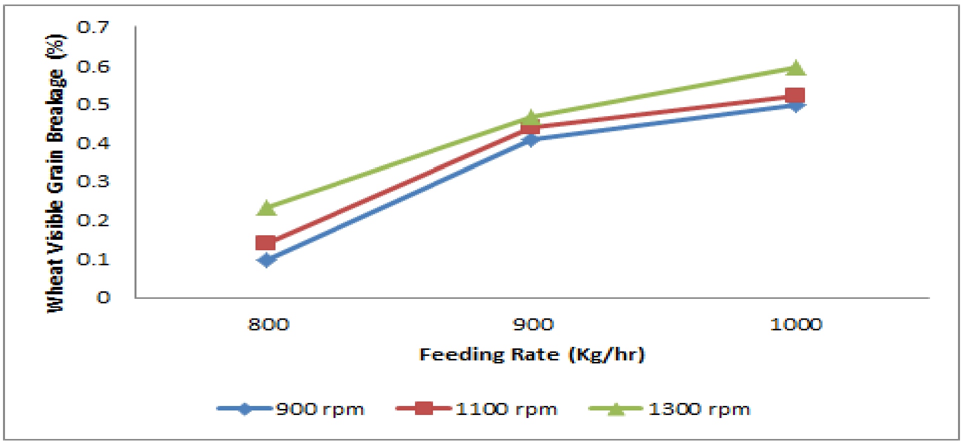
Table 4. Means of threshing drum speed, feeding rate, crop type and their interaction on cleaning efficiency

Parameter	Source of variation				Measure of differences	
	Drum Speed levels (rpm)		Crop type			
			wheat	barley	LSD (5%)	SE(M)
ClE (%)	900		97.07^{a}	92.11^{a}	1.018	0.319
	1100		97.53^{a}	97.46^{b}		
	1300		97.92^{a}	95.74^{c}		
	Feeding rate (Kg/hr)		wheat	barley	1.053	0.354
	800		96.77^{a}	94.00^{a}		
	900		97.67^{a}	95.53^{bc}		
	1000		98.08b	95.79^{c}		
	Interaction(drum speed*feed rate)				1.253	0.435
		800 Kg/hr	900 Kg/hr	1000 Kg/hr		
	900 rpm	93.27^{a}	95.13^{d}	95.38^{d}		
	1100 rpm	96.82^{bc}	97.64^{b}	98.03^{b}		
	1300 rpm	96.07^{cd}	97.03^{bc}	97.40^{b}		

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability.

Grain Breakage

Table 1 and Fig. 5 showed the relation between drum speed, feed rate and grain breakage in wheat and barley crops at the drum speed of 900 rpm, 1100 rpm and 1300 rpm and feed rate of 800, 900 and 1000 Kg/hr. The maximum breakage observed to be 0.597 and 1.62 % at higher drum speed of 1300 rpm and feed rate of 1000 Kg/hr for wheat and barley crops respectively. There was moderate breakage at drum speed of 1100 rpm and minimum breakage of 0.0955 and 0.070 % were obtained at drum speed of 900 rpm and feed rate 800 Kg/hr for wheat and barley respectively. More grain breakage at higher speed was due to greater impact by pegs of drum to detach the grain from ear heads, which reflected in the increase of breakage percentage at higher speed.



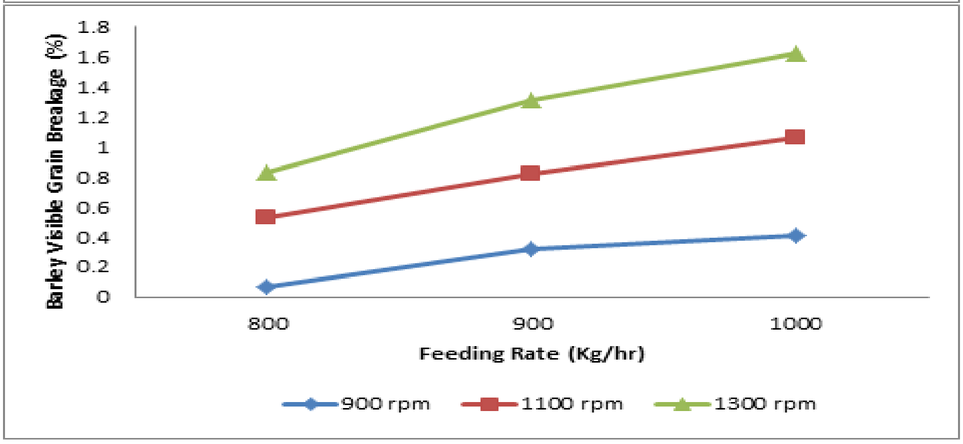


Figure 5.Effects of threshing drum speed and feeding rate on grain breakageofwheat and barley crop

Result of the analysis of variance (ANOVA) revealed that drum speed, feeding rate and the interaction of crop type and drum speed had significant effect ($p < 0.05$) whereas crop type, interaction of crop type and feed rate, interaction of drum speed and feed rate and interaction of crop type, drum speed and feed rate had no significant effect ($p > 0.05$) on threshing efficiency. Table 5 show the effect of drum speed, feeding rate, crop type and the combined effect of drum speed and feed rate on mean grain breakage. Figure 5 shows the relation between drum speed and feeding rate on mean grain breakage.

Table 5. Means of threshing drum speed, feeding rate, crop type and their interaction on Grain Breakage

Parameter	Source of variation				Measure of differences	
	Drum Speed level (rpm)	Crop type				
		wheat	barley		LSD (5%)	SE(M)
GrB (%)	900	0.327^{a}	0.266^{a}		0.1732	0.0513
	1100	0.366^{a}	0.802^{b}			
	1300	0.432^{a}	1.251^{c}			
	Feeding rate (Kg/hr)	wheat	barley		0.1925	0.0637
	800	0.147^{a}	0.474^{a}			
	900	0.439^{b}	0.816^{b}			
	1000	$0.539b^{c}$	1.029^{c}			
	Interaction(drum speed*feed rate)				0.2078	0.0721
		800 Kg/hr	900 Kg/hr	1000 Kg/hr		
	900 rpm	0.070^{a}	0.363^{b}	0.455^{bc}		
	1100 rpm	0.332^{b}	0.632^{ce}	0.788^{de}		
	1300 rpm	$0.530b^{c}$	0.887^{d}	1.108^{f}		

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability.

Conclusion and Recommendation

Conclusion

The performance evaluation of improved wheat and barley thresher was conducted under farmers' field. The following are the main conclusions drawn from the study. The grain straw ratio of wheat and barley crops at which performance evaluation of the thresher performed is 1:0.96 and 1:1.44 respectively. The maximum threshing capacity was found 538 and 424 Kg at drum speed of 1100 rpm and feeding rate of 1000 Kg/hr for wheat and barley crop respectively. The threshing and cleaning efficiency were 98.95 and 99.93 %, 98.13 and 97.91 % for wheat and barley crops respectively and grain breakage were 0.52 and 1.06 % at above combination of speed and feed rate for wheat and barley crops respectively. As compared to the previous thresher the improved one had more than 200 Kg/hr threshing capacity. The maximum fuel consumption of the engine was equal to 0.77 and 0.72 liter for wheat and barley at the maximum drum speed and feed rate respectively.

Recommendation

From the study result improved wheat and barley thresher was more effective and efficient than the previous thresher for its capacity and suitability of operation.

Farmers must used combination of 1100 drum rpm and 1000 Kg/hr feed rate in order to get high values of threshing capacity, threshing efficiency and cleaning efficiency based on crop moisture.

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Adaptation and Performance Evaluation of Engine Operated Reaper

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Abstract

This harvesting machine targets the small scale farmers who have small land holding of less than 2 hectares. It has cutting blades which cut the crop in a scissoring type of motion. It runs on petrol engine of 5HP, this power from engine, is provided through pulley and chain-sprocket combination to the cutter. A collecting mechanism is provided for the collection of crops to one side after cutting. This mechanism is also powered by pulley arrangement. This compact reaper harvester is manufactured using locally available spare parts and thus, it is easily maintainable. The reaper might be the solution to the problems faced by a small scale farmer regarding cost and labour implementation. Field performance evaluation result shows that, 0.075 ha/hr and 67.57% of effective field capacity and field efficiency respectively. It took 13.33 hr to harvest 1 ha area and the fuel consumption was 13.99 l/ha or 1.05 lit/hr. After testing the reaper machine in farm it is found that the cost of harvesting using this reaper harvester is considerably less as compared to manual harvesting.

Key words: *Harvester, reaper, scissoring action etc*

Introduction

Today agriculture plays an important role in countries like Ethiopia. Wheat is one of the most important crops and staple food of millions of people which is grown in many countries of the world includes our country. In Ethiopia wheat production is increasing but in most parts of the country the harvesting of wheat is still being done manually. Manual harvesting requires about 25% of the total labour requirement of the wheat cultivation. Depending upon the crop yield, 120 to 250 man-hour required for cutting, bundling and on farm stacking of one hectare of wheat field by using traditional sickle (Nadeem, 1983).

Labour scarcity during peak period of harvesting leads to delay in harvesting and field grain losses. Also high labour wages during peak period adds extra cost in total cost of wheat cultivation. Mechanized harvesting is an alternative solution to tackle this problem. Farm machineries are needed for timely completion of various agricultural operations and to reduce the work drudgery. Appropriate and selective mechanization is needed for post-harvest management. While mechanization would augment the post-harvest management could add 5-10% more by reducing losses (Singh, 2000a). Farm mechanization will also result in lesser cost of operation.

As a step towards mechanization of the harvesting operation for cereal crops, the farmers want to recover both grains as well as the straw from cereal crops, because they need straw for their cattle's. An alternative straw handling and disposal technology may have to be developed and promoted where farmers have adopted combines for harvesting as throwing away of straw and farmers are losing valuable animal feed material. Reapers on the other hand are other alternative harvesting equipment provided straw is considered as economic by-product for animal feed and/or industrial applications (Singh, 2002). Hence, keeping these facts in view, this project was initiated to adapt and develop engine operated reaper to minimize the cost of harvesting of wheat crop through farm mechanization.

Materials and Methods

Materials

The construction materials were selected on the basis of strength requirement of various components of the machine working mechanism.

Table 1. Material used for various components

Sr. no.	Component	Material used
1	Frame	Mild steel
2	Ground wheel	Mild steel and rubber
3	Shafts :- Ground wheel shaft Idle shaft (v-belt pulley shaft) Rotating disc shaft Rotating pulley shafts	High carbon steel
4	Crop divider	G.I. sheet
5	Star wheel	Plastic
6	Cutter bar	High carbon steel
7	Handles	Mild steel
8	Chain	High carbon steel
9	Belt	Rubber
10	Shaft pulley	Cast iron and aluminum
11	Sprocket	Gun metal & Mild steel
12	Bearing	Standard

Methods

This section deals with the procedures adopted to develop different functional parts of the reaper, operational parameters on the performance of the developed machine. It also describes the crop conditions. The field experiments for the evaluation of the machine were carried out at farmer's wheat field. Range of variables for the study was conducted based on the literature reviewed and preliminary test trials conducted on the machine.

Machine Description

The developed reaper consists of the header, conveyor unit, power unit, transmission system, frame and wheels. The header carries the cutter bar and the driven-shaft of the conveyor unit (Fig. 1). When the reaper started to walk through the wheat field, the cutter bar reaps the straw using slider crank mechanism to reciprocate sets of knives moving between ledgers; the reaped straw falls on the ground.

Figure 1. The developed engine operated reaper and during harvesting

Design Assumptions and Considerations

Empirically recommended design parameters were used to design reaper functional elements. Critical speed and capacities for different elements were used in the designing process. The important functional elements in which speeds and capacities were the major design factors.

Determination of crop cutting unit

Width of cutting (length of cutter bar) (*Lc*):- based on the standard the row to row spacing of cereal crops (wheat row to row spacing: - 20 cm). Therefor the length of cutter bar selected on the base of above condition Lc = 0.5 m selected

Type of cutter bar: - a reciprocating type cutter bar having 76.2 mm stroke length and two cuts per stroke is generally used.

$$No.of\ knife\,\text{section} = \frac{L_C}{Size of\ knife\,\text{section}} \quad (1)$$

$$No.of\ knife\,\text{section} = \frac{500}{76.2} = 6.56 \approx 7$$

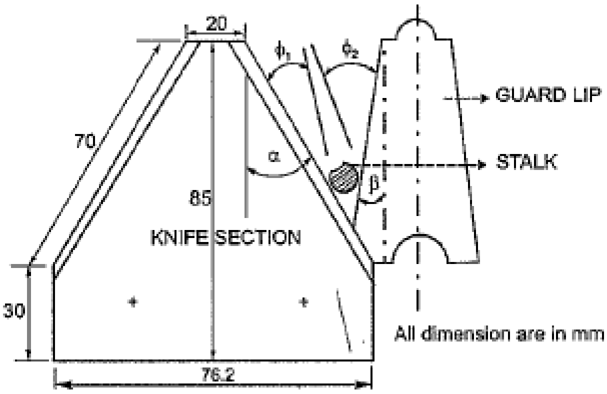

Figure. 2 Standard dimension of knives' section

The velocity of knife section is a function of forward speed of the machine expressed as:-

$$V_K = R \times V_f \qquad 2$$

Where, V_K = average knife velocity, m/s

V_f= forward speed of the machine, m/s

R = velocity ratio

According to Klenin (1985) and Bansal (1989) for α of 31^0 the knife velocity should be 1.5 m/s the value of R falls between 1.3 to 1.4 with available cutter knives.
Let take R=1.4 and forward speed of machine (V_f) of 0.75 m/s and putting the value in the above equation, we get:-

$$V_K = 1.4 \times 0.75 = 1.1 m/s$$

Also we know that: - $V_K = X \times \frac{N_K}{30}$ 3

Where, X= stroke length or standard knife section 76.2 mm

N_K= Rotational speed (rpm) of knife section (rotational speed)

V_K = average knife velocity, m/s

Therefore, $N_K = V_K \times \frac{30}{X}$

$$N_K = 1.1 \times \frac{30}{0.0762} = 433 rpm \approx 450 rpm$$

Based on the above discussions on design parameters, the dimensions of different components of crop cutting units selected are summarized in table 2.

Table 2. Specification of selected crop cutting unit of the reaper

Particulars	**Specifications**
Type of cutter bar	Reciprocating knife sections
Material	High carbon steel
Length of cutter bar	500 mm
Knife section	Standard
Types of blade	Serrated
stroke length	76.2 mm
Angle between cutting edge &axis of knife section (α)	31^0

Shafts

Four shafts were used as parts of the components for the construction of the reaper machine. They are: the shaft to drive the machine wheel and the shaft to drive the conveyor-roller and the driven-shaft; and the shaft to transmit power away from the petrol engine.

Slider crank mechanism

The slider crank mechanism is used to convert rotary motion to linear sliding motion. Scissoring action is obtained due to reciprocating movement of cutter blade over stationery blade is used to cut the crops.

Star wheel

The cut crop is conveyed with the help of star wheel at one side by the lugged belt conveyer for easy collection and bundling. The star wheel was designed on the basis of minimum required speed of star wheel. According to Datt, P. and Prasad, J., (2000) for good performance of the machine the optimum inclination of the star wheels should be 22° with the horizontal.

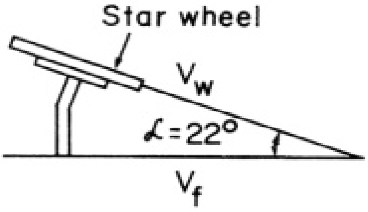

Figure3. Side view of star wheel

The horizontal component of star wheel velocity should be greater than or equal to forward speed of machine (Datt, P. and Prasad, J., 2000) and the velocity of star wheel (Vsw) is given by:-

$$\frac{V_f}{\cos\alpha} \angle V_{sw} \qquad 4$$

Where: V_{sw} = average speed of star wheel, m/s
V_f = forward speed of machine, m/s
A = angle of inclination of star wheel.

The normal walking speed of human is about 0.7- 0.8 m/s. therefore; 0.75 m/s forward speed of machine is selected. Thus, for a 22°angle the above expression simplifies to: $V_{sw} > 1.08\ V_f$

Therefore, $V_{sw} = 1.08 \times 0.75 = 0.81$ m/s

Table 3. Selected standard star wheel specification

Particular	Specification
Outside diameter (Do)	300 mm
Inside diameter (Di)	150 mm
Internal diameter of star wheel (d)	15 mm
Material of star wheel	Plastic

The star wheel which is driven by the conveyor belt lug has a linear speed at the tip equal to the conveyor belt. The star wheel rotates with their own axis and the angular speed of the star wheel can be calculated as:-

$$\omega_{sw} = \frac{V_{sw}}{R_{sw}} \qquad 5$$

Where: -R_{sw} = radius of star wheel and equal to 150mm.
V_{sw} = linear speed of star wheel and equal to the speed of belt conveyor.
ω_{sw} =Angular speed

$$\omega_{sw} = \frac{0.81}{0.15} = 5.4 rad/\sec = 52 rev/\min$$

The star wheels have outer diameter of (Do = 300 mm) and inner (Di = 150 mm). The length of star wheel wing can be calculated from the relation of its star wheel diameter.

$$L_s = \frac{D_O - D_i}{2} \qquad 6$$

Where - L_s =length of star wheel wing

$$L_s = \frac{300-150}{2} = 75mm$$

Crop conveyor

The cut crop by the machine is conveyed to one side by the lugged belt conveyor at an angle of 90 for easy collection and bundling. For this purpose the conveyor of the machine must convey the bunch of cut crop on a vertical platform continuously without blockage. Therefore, the rate of cut crop conveyed by the conveyor should be greater than the crop cut by the cutting unit of the reaper. The speed of lugged belt conveyor is given by:-

$$V_b = 1.4 \times V_f \qquad 7$$

Where, P = Peripheral speed of flat belt (m/s)
V_f = Machine forward speed (m/s)

Therefore, $V_b = 1.4 \times V_f$
$V_b = 1.4 \times 0.75 = 1.05$ m/sec

Working principle

The machine will be a walking behind type of reaper which is powered by the engine. The engine power is transmitted to cutter with the combination of V-belt and chain-sprocket mechanism. Reciprocating cutter blade slides over fixed blade and creates scissoring action responsible for cutting the crops. After cutting, the cut crop is conveyed with the help of star wheel at one side by the lugged belt conveyer for easy collection and bundling.

Performance evaluation of the machine

Performance evaluation was conducted based on FAO (1994) standards of agricultural machineries performance evaluation procedures. The performance data were categorized as data for test conditions and data for performance measures. The data for test conditions included, crop parameters, condition of the field, and condition of the machine and operator. Performance measures were harvesting capacity, harvesting efficiency, harvesting losses and labour requirements.

Crop parameters

Condition of the crop include crop kind, crop variety, susceptibility to shattering, ripening stage, plant density, lodging angle of the crop plant, moisture content of the stem and the grain at the time of harvesting as well as potential yields per hectare. The crop conditions have influence on the performance of harvesting machine.

Height of plant

Plant height was measured from the base of stem to the tip of the top most panicle at five randomly selected places of each test plots by measuring tape.

Plant population

The populations of the harvested crops were counted within 1 m^2 square frame at five random places in the plot. The number of plants from these places gave plant population per meter square.

Height of cut

The height of cut both for reaper harvesting and manual harvesting were measured from the base of stem to the tip of the top cutting tip at five randomly selected places of each test plots by measuring tape.

Moisture content

During the field testing of the machine, the grain sample was placed in an oven for 24 hours at 105^0C. The straw samples were chopped in small pieces and samples were weighed and dried as described for grain. The moisture content was calculated as follows:-

$$\text{Moisture content},\% = \frac{W_1 - W_2}{W_2} x100 \qquad 8$$

W_1 = initial weight of the grains,
W_2 = final weight of the grains after drying.

Machine performance parameters

Performance of the machine includes the operational speed, field capacity (ha/h), percentage of grain losses, fuel consumption per hour (L/h) and man-hours required of machine harvesting and conventional method which was harvesting by sickle. The field performance evaluations of the machine were conducted as per FAO test standards (FAO, 1994).

Speed of operation

The working speed was determined by marking the length of 20m and the reaper was operated in the marked run length. A stop watch was used to record the time for the reaper to travel the marked run length so that the speed of travel was computed in ms^{-1}.

Theoretical field capacity

Theoretical field capacity is computed from the rate of field coverage of the machine, based on hundred percent of time at the rated speed and covering hundred percent of its rated width. The theoretical field capacity was determined by using the following relationship:-

$$\text{Theoretical field capacity, ha h}^{-1} = \frac{\text{Width (m)} \times \text{Speed (km/h)}}{10} \qquad 9$$

Effective field capacity

Effective field capacity is computed from the actual area covered by the reaper based on its total time consumed to harvest a given plot and computed by the following relationship:-

$$\text{Effective field capacity, ha h}^{-1} = \frac{\text{Total area covered, ha}}{\text{Total time taken, h}} \qquad 10$$

Field efficiency

Field efficiency is computed from the ratio of effective field capacity and the theoretical field capacity. It takes into account the time losses encountered in the field due to various reasons. It was calculated as follows.

$$\text{Field efficiency, \%} = \frac{\text{Effective field capacity, (ha/h)}}{\text{Theoretical field capacity, (ha/h)}} x100 \qquad 11$$

Fuel consumption

The fuel consumption was having direct effect on economics of the machine. The fuel consumption was measured by refill method. The fuel tank of the reaper-binder was filled at its full capacity. The machine was run in the field at constant speed. After completion of harvesting operation, the fuel was refilled in the tank up to the top level. The quantity of refilled fuel was expressed as l h^{-1} and l ha^{-1}.

Harvesting losses

Harvesting loss is the amount of grains and ear heads fallen on the ground due to harvesting actions. After harvesting, grains and ear heads which has been fallen within 1m^2 metal frames was recorded. This harvesting loss (W_2) was repeated at seven different places chosen randomly within a plot.

Conveying loss

Conveying loss is the amount of grain and ear heads fallen during harvesting and bundling of the crop. To measure this loss a 2 m long and 1 m wide polythene sheet was laid adjacent to the standing crop. The harvest crop fell on the polythene sheet was picked the grain and ear heads remaining on the polythene sheet were recorded as conveying loss (W_3) in g/m^2. Thus, the total harvesting losses were calculated described as follows (Mohammad Reza *et al.,* 2007).

$$W_t = W_1 + W_2 + W_3 \qquad 12$$

Where; W_t = Total losses, g m^{-2}
W_1 = Pre-harvest losses, g m^{-2}
W_2 = Shattering losses, g m^{-2}
W_3 = conveying losses, g m^{-2}

Percentage of harvesting losses

After measuring the amount of losses at different stages, the percentage of harvesting losses was determined by the following equation:-

$$H = \frac{W_t - W_1}{Y_g} x100 \qquad 13$$

Where: H = Percentage of harvest losses, %

W_1 = Pre harvest losses, g m^{-2}

W_t = Total harvest losses, g m^{-2}

Y_g = Grain yield, g m^{-2}

Harvesting Cost

Harvesting cost for both manual and reaper were determined. In machine harvesting, the costs included labour, machine depreciation, machine repair, fuel and lubricants. Labour cost included wages for the machine operator and the assistant operator. The harvesting cost for reaper calculated on the basis of fixed and variable costs.

Fixed Costs

Fixed cost of the machine is the cost which is involved irrespective of whether the machine is used or not. These costs include; depreciation cost, interest on investment and taxes, shelter and insurance. Depreciation cost was calculated by straight line method. Useful life of reaper considered to be 10 years. The salvage value was also considered to be 10% of purchase price.

$$\text{The annual Depreciation, D} = \frac{P - S}{L} \qquad 14$$

Where, P = purchase price (Birr),

S = selling price (Birr),

L = Useful life, yr.

Interest on Investment is an actual cost in agricultural machinery was calculated by Straight Line Method.

$$\text{Interest on Investment, I} = \frac{P + S}{2} i \qquad 15$$

Where, P = Purchase price, Birr.

S = Resale value, Birr.

i = annual interest rate

Shelter, Tax and Insurance cost of the machine were annually estimated as follows:-

$$\text{Shelter, Tax and Insurance, STI} = 2.5\% p \qquad 16$$

$$\text{Total Fixed Cost}\left(\frac{\text{Birr}}{\text{Yr}}\right) = D + I + \text{STI} \qquad 17$$

$$\text{Fixed Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = \frac{\text{Total Fixed Cost}\left(\frac{\text{Birr}}{\text{Yr}}\right)}{\text{Total Area Coverage}\left(\frac{\text{ha}}{\text{Yr}}\right)} \qquad 18$$

Variable Costs

Fuel, oil, labor, repair and maintenance cost were considered as variable costs of the machine and determined by the following formulas:-

$$\text{Fuel Cost}\left(\frac{\text{Birr}}{\text{ha}}\right)=\frac{\text{Fuel consumed}\left(\frac{\text{Litre}}{\text{Day}}\right)\times \text{Pr}ice\left(\frac{Birr}{Litre}\right)}{\text{Area Coverage}\left(\frac{\text{ha}}{\text{Day}}\right)} \qquad 19$$

$$\text{Oil Cost}\left(\frac{\text{Birr}}{\text{ha}}\right)=15\%\text{ of fuel cost} \qquad 20$$

$$\text{Loubor Cost}\left(\frac{\text{Birr}}{\text{ha}}\right)=\frac{\text{Sum of wages of loubors}\left(\frac{\text{Birr}}{\text{Day}}\right)}{\text{Area Coverage}\left(\frac{\text{ha}}{\text{Day}}\right)} \qquad 21$$

$$\text{Repaire and Maintenanc, R \& M}\left(\frac{\text{Birr}}{\text{Yr}}\right)=3.5\%\text{ of purchase price} \qquad 22$$

$$\text{Total Variable Cost}\left(\frac{\text{Birr}}{\text{ha}}\right)=\left(\text{F}+\text{O}+\text{L}+\text{R \& M}\right)\frac{Birr}{ha} \qquad 23$$

$$\text{Total cost of Harvesting}\left(\frac{\text{Birr}}{\text{Yr}}\right)=\text{Fixed cost}\left(\frac{\text{Birr}}{\text{ha}}\right)+\text{Variable cost}\left(\frac{\text{Birr}}{\text{ha}}\right) \qquad 24$$

Break-even point

The break-even point is that area in which the harvesting cost per unit area is equal for machine and manual, determined by the following equation described by Alizadeh*et al.*, (2013).

$$\text{Break - even point, B}=\frac{F}{V_a-V_m} \qquad 25$$

Where,B= Break – even point (ha/year),
F= Fixed costs of machine harvesting (Birr/year)
V_a= Variable costs for manual method (Birr/ha)
V_m= Variable costs for machinery method (Birr/ha)

Results and Discussion

The reaper was evaluated for its performance by harvesting of wheat during 2018/19 harvesting season. The experiments were carried out in the extent of 0.24 ha at farmer's wheat field. The performance evaluation of the reaper was obtained during the field tests by harvesting of wheat crop. The performance of the reaper was based on average height of cut, forward speed, actual width of cut, actual field capacity, field efficiency, fuel consumption, labor and the loss occurring in the field while harvesting is shown in table 4 and 5.

Crop parameters

The results of field performance based on test conducted are summarized in Table 4. The mean values of plant height, number of tillers, plant population and height of cut were 109.67 cm, 5,270/m^2 and 16 cm respectively.

Table 4. Details of crop parameters

Particulate	Harvesting Methods				
	Reaper harvesting				Manual harvesting
	Trial			Mean value	
Crop	Wheat				Wheat
Height of plant , cm	113	99	117	109.67	107.2
Number of tillers	5	4	6	5	5
Plant population per sq. m	260	286	264	270	268
Height of cut, cm	15	17	16	16	35
Condition of crop	erect	erect	erect	-	erect
Grain moisture content, %	10.29	10.60	9.89	10.26	10.35
Straw moisture content, %	9.32	8.97	9.28	9.19	9.42

Machine Performance parameters

Table 5: Test results of reaper harvester compared with manual harvesting by sickle

Parameter	Harvesting Methods				Manual harvesting
	Mechanical harvester				
	Trial				
	1	2	3	Average	
Actual area covered (ha)	0.03	0.03	0.03	0.03	0.03
No. of Labours	1	1	1	1	5
Total time of operation (min)	25.02	23.00	24.20	24.07	44.40
Effective working width (cm)	50	50	50	-	-
Operating speed (km/hr)	2.21	2.25	2.17	2.21	-
Theoretical field capacity (ha/hr)	0.111	0.113	0.109	0.111	-
Effective field capacity (ha/hr)	0.072	0.078	0.075	0.075	0.008
Field efficiency %	64.86	69.03	68.81	67.57	-
Labour requirement, man-hr/ha	13.89	12.82	13.33	13.35	125
Fuel consumption (lit/hr)	1.02	1.13	0.99	1.05	-
Fuel consumption (lit/ha)	14.20	14.53	13.25	13.99	-
Potential grain Yield (gm/m^2)	632.46	672.67	619.06	641.4	641.4
Harvesting losses (g/m^2)	19.60	18.30	19.50	19.13	14.50
Harvesting losses (%)	3.10	2.72	3.15	2.98	2.26
Conveying loss (g/m^2)	6.40	6.86	6.32	6.53	6.67
Conveying loss, %	1.01	1.02	1.02	1.02	1.04
Total harvesting loss, %	4.11	3.74	4.17	4.00	3.30

Table 5 presents the field performance results of reaper for wheat crop. The mean values of the performance parameter that include cutting width, cutting height, operating speed, theoretical field capacity, effective field capacity and field efficiency are presented in Table 4 and 5. The cutting width was 0.5 m and the operating forward speed of the machine was found 2.21 km/h. The actual field capacity of the reaper for wheat crop was 0.075 ha/hr. The theoretical field capacity of the machine is a function of speed of travel and cutting width and computed result is 0.111ha/h. Field efficiency of reaper harvesting machine was 67.57%. In manual harvesting with sickle, on average one person can harvest 80m^2 /hr, but this amount can be differ with respect to crop condition, laborer ability and weather condition. The required time for harvesting one hectare of wheat in manual harvesting was 125 man-h/ha compared to 13.35 man-h/ha for the reaper (Table 5). The reaper was 9.36 times faster compared to manual harvesting.

Harvesting Losses

The amount of grain loss due to harvesting, conveying losses, windrowing, collection and bundling for reaper and manual harvesting with sickle are shown in table 5. The mean percentage of conveying losses in reaper and manual harvesting for wheat crop were 1.02% and 1.04% respectively and that of harvesting losses were 2.98% and 2.26% respectively. The percentage of total grain (conveying and harvesting) losses in reaper harvesting was recorded 4%. Similar results were reported by Singh *et.al.* (1988).The higher harvesting loss may happen due to unleveled field. Devani and Pandey (1985) designed and developed a vertical conveyor belt windrower for harvesting wheat crop. They concluded that, the total harvesting losses were in the range of 4 to 6 % of grain yield when grain moisture content was 7 to 11 %.

Cost Analysis

The estimated production cost of the reaper including engine costs are 34,541birr. The annual fixed and variable costs of the reaper were computed as 21,303.75 birr and 15,886.92 respectively. The working hour of the reaper was considered 240 hours per year. The fixed cost and variable costs for both reaper and manual harvesting are presented in Table 6. In this study, manual harvesting required 16 man-days to harvest one hectare of wheat field. Considering the labor cost as 150birr per day, 2400 birr/ha was required for manual harvesting, whereas 1021.52 birr/ha was calculated for reaper harvesting (Table 6).

Net savings per hectare area (Table 7) of 839.70Birr/ha could be saved as compared reaper harvesting against manual harvesting. This net saving comes because of higher field capacity of reaper than manual harvesting. In a previous study, net savings (1770 Bhat/ha) was found by Bora and Hansen (2007) who harvested rice by a reaper (40 Bhat = 1US$).

Table 6: Estimated total cost of reaper and manual harvesting for wheat

Machine Harvesting Cost				Manual harvesting cost	
Cost items	Birr/Year	Birr/ha	Birr/hr	Birr/ha	Birr/hr
Fixed cost					
Depreciation	3,108.69	205.60	12.95	2400	19.20
Interest	949.88	62.82	3.96		
Taxes, insurances and shelter	863.53	57.11	3.60		
Total fixed cost	4,922.10	325.53	20.51		
Variable cost					
Fuel	4,186.42	276.88	17.44		
lubrication	627.93	41.53	2.62		
labor	4,500.01	297.62	18.75		
Repair and maintenance	1208.94	79.96	4.98		
Total variable cost	10,523.30	695.99	43.79		
Harvesting cost	15,445.4	1021.52	64.30	2400	19.20

Table 7**:** Comparison of savings by the reaper harvesting per hectare

Particulars	Calculation	Amount (Birr)
Cost of manual harvesting (16 man-days/ha)	16×150	2400
Cost of machine harvesting/ha	1021.52	1021.52
Gross savings	2400−1021.52	1,378.48
Cost of total output (6414 kg/ha @ 12 birr/kg)*	12×6414	76,968
Loss in reaper harvesting, (4.00%)	76,968 ×0.04	3078.72
Loss in manual harvesting (3.3%)	76,968 ×0.033	2539.94
Excess loss due to manual harvesting	2539.94 - 3078.72	-538.78
The net savings per hectare	1,378.48+ (-538.78)	839.70

*Considered the production of wheat 64.14 quintal per hectare

Break-even Point Analysis

Harvesting cost by a reaper is found to be decreased gradually with the increase of harvesting area. However, break-even point is 3 ha of land where same cost will be found for both of reaper and manual harvesting. This break-even point indicates that the reaper would be beneficial to the farmers when the area of the harvesting land is more than 3 hectare of land per year. From this analysis, it was found that reaper would be beneficial to the farmers when the harvesting area exceeds the break-even point.

Conclusions and Recommendations

Conclusions

Wheat crop was harvested using engine operated reaper. Based on the field performance evaluation was observed that the actual cutting width of the reaper was 50 cm. The effective field capacity of the reaper was 0.075 ha/hr with a field efficiency of 67.57%. It took 13.33 hr to harvest 1 ha area and the fuel consumption was 13.99 l/ha or 1.05 lit/hr.

The labour requirement was found to be 13.35 man hours per hectare without including manual collection and bundling of the harvested crop compared to 125 man hours of labour per hectare in manual harvesting, without collecting and bundling of the crop. Thus, it saved 111 man hours of labour per hectare.

From the study, it can be concluded that the engine operated reaper could be used successfully with a labour saving of 111 man hours per hectare and reducing the drudgery of labours. The area of 0.60 ha can be harvested per day if the field capacity is kept as 0.075 ha/hr. considering the two months harvesting season, the maximum area that can be harvested using the engine operated reaper will be 18 ha.

If the machine is used for the maximum usage of 18 ha in a year, the cost of mechanical harvesting will be 1021.52 birr/ha as compared to 2400 birr/ha in case of manual harvesting. Thus it is feasible to minimize the cost of operation of wheat harvesting. Thus mechanization in wheat harvesting is a feasible solution for reducing the cost of harvesting of wheat crops.

Recommendations

From the study it was found that the use of reaper was more beneficial than manual harvesting for harvesting of wheat. Based on the advantages of mechanization provided by reaper, there is the need to improve and explore its full potential. Thus, the following are recommended for the future improvement of the reaper:

i. Grain loss in reaper should be minimized by improving its ground wheel from metal wheel to tire and land leveling should be considered, so as to avoid grain losses.

ii. Further studies should be conducted to determine the performance measure of the reaper in different cereal crops such as barley and rice harvesting as well as determining reaper performance at different speeds.

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Development and Evaluation of Small Size Engine Driven Rice Thresher

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Abstract

The development of rice threshing machines are the major effort made to increase the production of rice and encourage the government policy. Hence, to do this the appropriate rice threshing machines should be needed.the performance parameter of the machine such as: maximum threshing capacity 449.84kg/hr, maximum threshing efficiency 99.9%, and maximum cleaning efficiency 99.84% was very much acceptable. But, the maximum percentage damage 10.51% and maximum scatter loss 6.07% was recorded at maximum speed 1139rpm. Therefore to minimize this values, some adjustment on the machine should be done before release to the farmer or minimize the speed of the machine to medium which means 980rpm.

Key words: *Rice thresher, Threshing capacity, threshing efficiency, cleaning efficiency*

Background and Justification

Cereals are the first cultivated grasses belonging to the Poaceae family. The popular cereal crops of the world include wheat, barley, oats, rice, maize, sorghum and millets, but the major cereals of the developing countries are maize, rice, sorghum, and millet Okaka (1997).

Rice is a cereal cultivated mainly for the human consumption and also finds use in manufacturing of alcohol, starch, glucose acetic acid vinegar acetone, oil and pharmaceutical products and diet foods. The rice ball is developed like fuel and ashes which are reuse in the form of organic manure Pirot (1998). More than 40 percent of the rice consumption in West Africa is imported, which represents 2.75 million tons per year Barris et al. (2005). Since 2006, Ethiopian rice production trends show increases in both area and productivity. Even though rice is not a traditional staple food in Ethiopia, it is considered a high potential emergency and food security crop. In Southwestern Oromia the production of rice is high especially in Jimma and Illuababor zones like Shabe, Limu Saka, Chora Botor, Gomma and Gera woredas of Jimma zones and Chewake of Illuababor zone.

Post-harvest grain loss is the loss of grains (quality and/or quantity) between the moments of harvest and consumption. Reduction in food losses is sometimes considered as the ‘third dimension’ to the world food supply equation, i.e., in addition to increase in food production and increases in population (Toma,et al., 1990). Estimates suggest that the magnitude of post-harvest loss in Ethiopia was tremendous ranging from 5% to 26% for different crops Dereje (2000). This figure is quite large especially for Ethiopia where agreat majority of people are food insecure.

The traditional threshing of rice is generally done by hand:bunches of panicles are beaten against a hard element (e.g. a wooden barlog, bamboo table,or stone). In many countries in Asia and Africa, and in Madagascar, the crop is threshed by being trodden under foot (by humans or animals); this method of ten results in some losses due to the grain being broken or buried in the earth (FAO, 1995). According to Hailu (1971), in traditional methods of crop production, 40% of the total labor required to grow crop is expended in threshing. The output per person or per animal-hour is very low, and varies between 25 and 50 person-hours per ton for manual threshing, and 30 to 50 animals - hours per ton for trampling.

The rice threshing in the areas of Jimma and Illuababor can be done by manually especially women and children are threshing by stick, under the foot of animals and by the threshing machine. Thus, the threshing of rice by hand and by animals has its own effect on the quality and loss of the product. When it is threshed by hand the rice grain is spreading and the seed is broken by stick and by animal foot. Manual rice threshing is labor-intensive and back-breaking, and mainly carried out by women farmers. According to Tamiru and Teka 2015, the three threshing machines (Asella WB thresher, Jimma multicrop thresher and Votex) were evaluated for rice threshing, the result shows that the Asella WB thresher were selected based on %age of breaking. But the cleaning efficiency, threshing capacity and %age of breaking of this machine was 68.28%, 220.57kg/hr ,0.26% respectively on average. This indicate that the machine required improvement or design other machine for rice threshing. So to overcome the above problems, this study was initiated with the objectives of developing and evaluating small size engine operated rice thresher

Materials and Methods

The production of prototype was done according to the design in the Jimma Agricultural Engineering Research Center (JAERC). After the prototype produced the preliminary work and the laboratory tests were done in the center. Finally, the performance of the thresher was evaluated and each performance parameters such as threshing efficiency, threshing capacity, separation efficiency, losses and other parameters were tested.

Description of the Machine Components

The main components of the rice thresher include feed table, cylinder, concave, fan, delivery unit and frame (Figure 1).

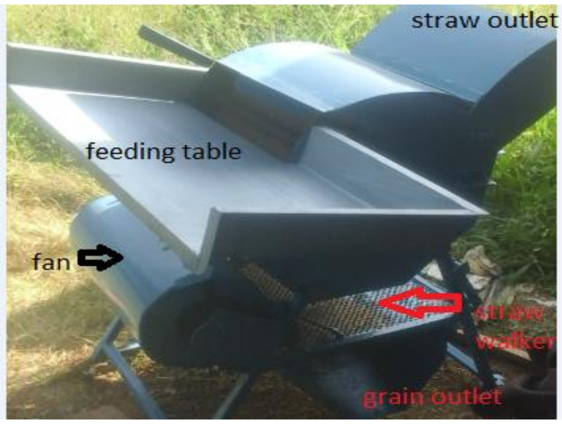

Figure 1. Description of rice threshing machine

Table 1 specification of engine driven rice thresher

No.	Particulars	Specifications	
1	Type of machine	Engine operated	
2	Overall dimensions (cm)	Length	146
		Width	116
		Height	165
3	Weight (kg)	145	
4	Thresher cylinder dimensions (mm)	Length	510
		Dia.	410
5	Concave clearance (mm)	Inlet	30
		Outlet	15

Method of data collecting and analyzing

Data to be collected

The data was collected during performance testing: before testing, during testing and after testing. The data collecting from field testing and from laboratory testing based on the measurement or test required. The data collected from laboratory and field test were:

Machine parameters	Crop Parameters	Machine performance indicators
➢ cylinder speed ➢ cylinder diameter ➢ cylinder length ➢ cylinder-concave clearance ➢ fan length and size, etc.	❖ moisture content ❖ bulk density ❖ mean diameter ❖ geometric diameter ❖ angle of repose ❖ static coefficient of friction ❖ straw-grain ratio, etc.	➢ threshing efficiency ➢ threshing capacity ➢ cleaning efficiency ➢ percent of breakage ➢ scattering loss

Power Required for Running the Thresher

Power delivered by shaft

$$P = T_t . \omega$$

$$\omega = {}^{2\pi N}/_{60}$$

$$T_t = m_c r (g + \frac{2V^2}{d})$$

Where: T_t = Torque (Nm)

m_c = total mass of cylinder (kg)

r = radius of the driven pulley of the cylinder (m)

d = effective diameter of the cylinder (m)

Power required to drive the shaft was calculated

$$p = \frac{2\pi N T_t}{60}$$

Power required driving fan

$$p = (T_1 - T_2) r$$

Performance parameters determination

Threshing efficiency: was used to determine how effectively the thresher was in carrying out its primary function of threshing the rice. It is defined as the percentage ratio of the threshed grain to the total quantity of sample grain after threshing process. The threshing efficiency would be calculated according to Gbabo et al., (2013) as:

$$threshing\ efficiency, (\%) = \frac{weight\ of\ threshed\ grain}{total\ weight\ of\ grain} * 100$$

Figure 2. During threshing the rice on the field

Cleaning efficiency

The cleaning efficiency was used for the evaluation of the ability of the thresher to clean the crop effectively. The cleaning efficiency is the ratio by weight of the grains collect at grain outlet to the total weight of the chaff and grains collect at the same outlet expressed as a percentage. It would be calculated according to the Gbabo et al., (2013) as:

$$cleaning\ efficiency, (\%) = \frac{W}{W_O} * 100$$

Where: W = Weight of grains from the main output opening after cleaning, kg.
W_o = Weight of grains and small chaff from the main output opening,kg.

Threshing capacity

The threshing capacity was used to evaluate for how fast the developed rice thresher can perform its given task of threshing. It is the amount of the actual cleaned grain that a machine is able to thresh per time and calculated as Mohammed (2009):

$$T_c = \frac{Q_s}{T}$$

Where: T_c-threshing capacity (kg/hr), Q_S-amount of threshed grain (kg), T-time taken (hr)

Mechanical damage

Mechanicalgrain damage was used to determine the quantity of visible physical damage to grains that can be owed to the thresher. It given by Mohammed (2009) as:

$$M_d = \frac{Q_b}{Q_t} * 100$$

Where: M_{d-} mechanical damage of grain (%)
Q_b-quantity of damage grains (kg)
Q_t- total weight of grains in the sample (kg)

Scatter Loss

During the threshing operation, some grains were lost as scatter loss from the thresher and were not collected with others at the grains outlet. this was evaluated from an equation Gbabo et al., (2013) give as:

$$S_l = \frac{Q_1}{Q_t} * 100$$

Where: Q_1 = the quatity of grain scattered
Q_t= the total quantity of grain in the sample

Method of data analyzing

The collecting data was analyzed using a split plot design method. The treatments under study were the feeding rate and the speed of cylinder. To test the thresher, three cylinder speeds was selecting that is minimum, medium and high speed and the three feeding rate was applied at three replications and the statistix 8. soft ware would be used to analysis the result.

Result andDiscussion

Power requirement determination

The power required to operate the threshing machine can be divided in to four parts;

- power required to thresh the rice,
- power required to drive the cylinder shaft,
- power required to drive oscillating sieve and
- power required to drive the fan

In general, the total power required was about 6.275kw

Physical Properties of Rice Kernel

Measurements made on pertinent physical properties of rice kernels revealed that the mean major, intermediate and minor diameters for the kernels were 8.5, 2.7 and 1.95 mm respectively. The mean geometric diameters, arithmetic mean diameter, dry volume of grain, percent of sphericity, static coefficient of friction and angle of repose were 3.55mm, 4.38mm, 23.43m3, 0.24, 0.258 and 38.66^0 respectively. The straw to grain ratio was calculated about 0.416 as shown in the table below.

Table 2. Physical properties of Jegna variety of rice

Parameters	**Value**	**parameters**	**Value**
Length (mm)	8.5	Geometric mean diameter (mm)	3.55
Width (mm)	2.70	Arithmetic mean diameter (mm)	4.38
Thickness (mm)	1.95	Dry volume of grain (mm3)	23.43
Thousand kernel weight	27.50	Percent Sphericity	0.24
Bulk density(g/cm^3)	0.58	Angle of repose (deg.)	25.16
Static coefficient of friction	0.258	**Straw/grain ratio**	0.416
Moisture content (%)	9.21		

Performance parameters determination

In order to determine the effect of cylinder speeds and feed rates on the performance of the prototype machine, threshing capacity (thr), mechanical damage (MD), threshing efficiency (T.Eff), cleaning efficiency (CE) and scattering loss (SL) were calculated using the above equations.

Threshing efficiency

The mean percent threshing efficiency of the rice thresher and analysis of variance are given in Table 3 below. Analysis of variance revealed that the threshing efficiency of the machine is not affected by feeding rate while the speed of cylinder was affecting the threshing efficiency of the machine as ($p < 0.05$). The combined effect of cylinder speed and feed rate were not significantly different from one another except on low speed. As can be seen from Table 3., increase in the cylinder speed resulted in increased threshing efficiency. This could be due to the very fact that at higher cylinder speed the energy imparted to rice was high hence causing higher threshing. This result has the same trend as that of Raji and Akaaimo (2005) and Chukwu (2008).

The maximum threshing efficiency 99.9% was observed when the cylinder was operated at velocity of 1139 rpm and at 10kg/hr feed rate; whereas the minimum threshing efficiency of 89.30% was observed when the cylinder speed was 665 rpm, and at feed rate was 8kg/min as can be seen from Table 3.

Table 3. Mean threshing efficiency (in %) of rice thresher at different cylinder speeds and feed rates

Feeding rate x speed		**Speed (rpm)**			**Speed (rpm)**	**mean**	**Feed (kg/min)**	**Mean**
		665	980	1139				
Feeding rate (kg/min)	6	89.64^{c}	99.80^{a}	99.70^{a}	665	89.47^{c}	6	96.55^{a}
	8	89.30^{c}	99.80^{a}	99.83^{a}	980	99.81^{a}	8	96.43^{a}
	10	89.47^{c}	97.53^{b}	$\mathbf{99.90^{a}}$	1139	99.04^{b}	10	96.49^{a}
SE	8.862E-03				2.131E-03		5.11E-03	
LSD	0.6724				0.000		0.6664	
CV	1.13							

Cleaning efficiency

Table 4 give results of cleaning efficiency investigation made and analysis of variance on cleaning efficiency of the rice thresher machine. From ANOVA it was learnt that cylinder speed and feed rate had significant ($P < 0.05$) effect on cleaning efficiency of the machine under study. The maximum cleaning efficiency 99.84% was obtained when the cylinder was operated at speed of 665rpm, and feed rate was 6 kg/min; whereas the minimum cleaning efficiency of 99.68% was observed when the cylinder was operated at speed of 665 rpm, and feed rate was 10 kg/min (Table 4). Tamiru D. and Teka T.(2015) study three threshers for rice threshing such as Asela multicrop thresher, Jimma multicrop thresher and Votex. according to their result, they were recommended Asela multicrop thresher which has cleaning efficiency at low, medium and high speed were 62.33%, 82.9% and 59.6% respectively. Increase in feed rate have increased the weight of the material being handled by the air stream and decrease in cleaning efficiency must have resulted from inadequacy of the air pressure supplied to convey the materials away.

Table 4 .Mean cleaning efficiency (in %) of rice thresher at different cylinder speeds and feed rates

Feeding rate x speed		**Speed (rpm)**			**Speed (rpm)**	**mean**	**Feed (kg/min)**	**Mean**
		665	980	1139				
Feeding rate (kg/min)	6	**99.84^{a}**	99.80^{b}	99.82^{b}	665	99.77^{a}	6	99.82^{a}
	8	99.80^{bc}	99.75^{d}	99.79^{c}	980	99.76^{b}	8	99.78^{b}
	10	99.68^{f}	99.72^{e}	99.72^{e}	1139	99.77^{a}	10	99.70^{c}
SE	4.014E-05				2.458E-05		2.317E-05	
LSD	0.0000				0.0034		0.0000	
CV	0.00							

Threshing capacity

The mean threshing capacity and analysis of variance are presented in Table 5 The statically analysis, ANOVA, clearly indicated that the threshing capacity of the rice thresher was significantly ($P < 0.05$) affected by cylinder speed and feed rate. The combined effect of cylinder speed and feed rate was also significant at the same level. The maximum threshing capacity of 449.84 kg/hr was recorded when the cylinder speed was 1139 rpm, the feed rate was 10 kg/min. this indicate that, the threshing capacity of the machine was increased significantly as the feeding rate and cylinder speed increased as shown in the table 5 which agreed with the result obtained by M.H.M.A. Bandara and M. Rambanda (2011). As Tamiru D. and Teka T.(2015) study three threshers for rice threshing such as Asela multicrop thresher, Jimma multicrop thresher and Votex. According to their result, they were recommended Asela multicrop thresher which has the threshing capacity at low, medium and high speed were178.4kg/hr,229.15kg/hr,264.17kg/hr respectively which indicated that the threshing capacity was very low when compared to the new one.

Table 5 Mean threshing capacity (in Kg/hr) of rice thresher at different cylinder speeds and feed rates

Feeding rate x speed		**Speed (rpm)**			**Speed (rpm)**	**mean**	**Feed (kg/min)**	**Mean**
		665	980	1139				
Feeding rate (kg/min)	6	250.12^{cd}	287.59^{c}	358.44^{b}	665	243.17^{c}	6	298.72^{b}
	8	251.80^{cd}	265.08^{cd}	409.46^{a}	980	294.95^{b}	8	308.78^{b}
	10	227.59^{d}	332.18^{b}	449.84^{a}	1139	405.91^{a}	10	336.54^{a}
SE		19.016			7.487		10.979	
LSD		0.0130			0.0001		0.0055	
CV		7.40						

Means followed by the same letters are not significantly different at 5% level of probability

Mechanical damage

Mean percent mechanical damaged (MD, %) of rice kernel at various cylinder speeds and feed rates were given in Table 6. The analysis of variance and significance levels of the variables were indicated in Table 6. The analysis of variance, on percent kernels mechanical damaged, indicated that cylinder speed, feed rate and the combined effect of cylinder speed and feed rate and had highly significant $P < 0.05$. The least percent kernel mechanical damage, almost 0.00%, was recorded at low cylinder speed (665 rpm) and at all feeding rate. Maximum percent kernel mechanical damage, 10.52% at cylinder speed of 1139 rpm and at feed rate of 10 kg/min. The increase in cylinder speed due to the increasing of the impact force exerted by the threshing drum to detach the paddy grains from the ear heads which is reflected in the increase of breakage was the reason.

Table 6 Mean mechanical damage (in %) of rice thresher at different cylinder speeds and feed rates

Feeding rate x speed		**Speed (rpm)**			**Speed (rpm)**	**mean**	**Feed (kg/min)**	**Mean**
		665	980	1139				
Feeding rate (kg/min)	6	0.02^{d}	5.40^{bc}	5.60^{bc}	665	0.03^{c}	6	3.67^{b}
	8	0.03^{d}	5.26^{bc}	7.18^{b}	980	5.24^{b}	8	4.16^{b}
	10	0.05^{d}	5.06^{c}	**10.51^{a}**	1139	7.76^{a}	10	5.21^{a}
SE	5.729E-03				5.304E-03		3.308E-03	
LSD	0.003				0.0003		0.0147	
CV	21.86							

Scatter Loss

The analysis of variance (ANOVA) result for scatter loss from the performance evaluation of the developed rice thresher was presented in the table 7. the result indicated that the feed rate, the speed of operation and the combined effect of the two were significant effect at 5% level of confidence. As shown in the table 7 , as speed of operation increased, the scatter loss was also increased and also the same to the feed rate.

Table 7. Mean scatter loss (in %) of rice thresher at different cylinder speeds and feed rates

Feeding rate x speed		**Speed (rpm)**			**Speed (rpm)**	**mean**	**Feed (kg/min)**	**mean**
		665	980	1139				
Feeding rate (kg/min)	6	1.16^{e}	2.04^{de}	3.70^{bc}	665	1.51^{c}	6	2.30^{c}
	8	1.40^{e}	3.14^{cd}	4.85^{ab}	980	3.11^{b}	8	3.13^{b}
	10	1.96^{de}	4.14^{bc}	6.07^{a}	1139	4.87^{a}	10	4.06^{a}
SE	0.6176				0.3198		0.3566	
LSD	0.4657				0.0012		0.0013	
CV	23.91							

Conclusion and Recommendation

Conclusion

Based on the results obtained, the performance parameter of the machine such as: threshing capacity (kg/hr), threshing efficiency (%), percentage damage (%) and cleaning efficiency (%) was very much acceptable.

In general,

- The feeding rate of the machine is vary based on the person who feed it because the machine has no mechanical feeding mechanism and also on the speed of cylinder.
- the threshing efficiency of the machine is based on the feeding rate and speed of the cylinder
- the threshing capacity of the machine is based on the straw to grain ratio and speed of the cylinder and also on feeding rate

Recommendations

The prototype rice thresher developed for use rice appears to be most efficient at cylinder speed of 980 rpm, pods moisture content 9.21% (db) and at almost all feed rate. Nonetheless, it is recommended that:

- the thresher was evaluated on one moisture content but it should be evaluated on different moisture content
- the concave of the machine should be constructed from round bar rather than deformed bar to minimize the straw pass with the grain on the sieve and resist the feed back to the feeding table so the inclination of the feeding table should be increased
- after the above minor adjustment made it is possible to use the thresher

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Evaluation of FARC Multi-action Thresher for Finger Millet Threshing

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Abstract

Finger millet is a cereal crop grown in most parts of Ethiopia, used for food, in different forms and as an input in preparing tradional alcoholic drinks in some areas. The traditional methods of finger millet threshing are the only method available in most parts of the country, including the major producer western part of Oromia. Hence, this activity is aimed to evaluate an engine powered smaller crops and spice Grains multi-action thresher for finger millet threshing then determine baseline data for modification/development of thresher for the crop. The experimental was conducted in a split- plot design having drum speeds (V1 = 600rpm, V2= 700rpm and V3 = 800rpm) in main plots and concave clearance (20 and 25mm) in sub-plots with three replications as block. The maximum threshing capacity of 82.74 kg/hr was recorded at combination effect 800 rpm and 27 mm drum speed and concave clearance respectively. At this optimum threshing capacity, cleaning efficiency, percentage of loss and threshing efficiency is 48.81, 7.14 and 93.81% respectively. Based on the results obtained, regarding to performance indices like low threshing capacity and cleaning efficiency and to reduce percentage of loss, it is recommended that machine requires a modification.

Key words: Multicrop thresher, finger millet, threshing

Introduction

Finger millet (*Eleusine coracana (L.) Gaertn. ssp. coracana),* is an important crop grown in low input farming systems in western and south western Ethiopia (MA Mgonja, et al.,2007). Finger millet is a highly tillering annual crop, whose average height can reach as high as 1.0 m, but 1.6 m Tillers come from the base of the plant and axillary buds along the stem. Each tiller produces a panicle. Leaves are generally 30 to 40 cm long, but can reach 70 cm and are narrow (1.5 to 3 cm) (Silas T.A.R. Kajuna, 2001). Panicle branches commonly come from the same place giving a finger like appearance. The number of branches ranges from 4 to 19; they can be straight (3 to 10 cm long) or they can be curved like a hand with fingers partially closed (hence the name finger millet). Seeds are formed in florets generally arranged in two rows along the panicle branch. The seeds are generally dark brown, red brown or purple, although light brown and cream colored seeds are found. Seeds are hard and very small, up to 2 mm in diameter (Cristina Apetrei, 2012).

Finger millet is a cereal crop grown in some parts of Ethiopia, used for food, as porridge and meal food, besides its importance as a staple food crop, finger millet contributes greatly to the incomes of rural households, particularly women. It is brewed into local beer for sale or is sold directly as grain in local markets where there is ready demand. In Ethiopia, it is grown on approximately 456,057.31 ha, with yield 22.60 Qt/Ha (CSA, 2018).

Finger millet threshing is the most difficult in post harvest threshing activity like some cultivars of east African enclosed head sorghums, mainly due to their nature of the grain firm attachment to florets and to its glumes in the latter (Mary Tamale, 2001, MA Mgonja, et al., 2007). It is done manually by women and men by beating its heads with sticks or clubs repeatedly until almost all the grains are detached from the heads on a mat, canvas or bare ground and animal trampling. In order to ease grain collection after beating, sometimes the heads of millets may be stuffed in to bags, prior to beating. The straw that remains after threshing may be used as a source of fuel or used as mulch as well as animal feed. However, on the outset the level of mechanization in finger millet farming systems is almost negligible in east African countries; no one knows how farmers are trying to cope with labor drudgery (*Ambitsi N, 2011).* Thus, as the traditional methods of finger millet threshing is the only method available in most parts of the country, including the major producer area, the western oromia. The long hours of day labour of these “human threshers” is not anything to write home about as an average woman can only thresh about 10 kg per day (www.fao.org/docrep). Thus, the traditional methods are arduous and slow.

So that, availing the necessary mechanical threshing is a means to overcome the problems and searching for machines that can thresh the finger millet is mandatory priority of the solution. Additionally, the finger millet threshing machinery data is not also available in the country, so that, searching for thresher that might be developed for another crops of closely resembles the physical characteristics of finger millets grains which is enclosed within the florets is an option.

Accordingly, the center (BAERC) search and select FARC engine operated Multi-thresher for smaller crops and spice Grains. In addition to the sorghum, the machine was evaluated for threshing of Black-cumin, Linseed & Niger seed. The result analysis of its output for some crops with similar threshing characteristics is reported in 2013 by the center as; 100% threshing and cleaning efficiency with no grain breakage for muira and fandisha sorghum threshing, with less than 1% seed in glumes at optimum speed 600rpm and 650kg/h feed rate. In Black cumin, threshing and cleaning efficiency are 100% (but with inclusion of sieve), with no grain breakage and less than 1% seed in pods and its output 400-500kg/h.

The machine is combined threshing systems of beating, rubbing and chopping with specially designed beater chopper with spiral bar and axial flow system. Since, the machine has with the above performances results of crops of finger millet type threshing characteristics might be suitable for the finger millet threshing. Hence, this activity is aimed to evaluate the engine powered smaller crops and spice Grains multi-thresher for finger millet threshing then determine baseline data for modification/development of thresher for the crop.

Picture1. Traditional threshing (left) and threshing parts of FARC thresher (right)

Materials and Methods

A prototype production, according to FARC motorized small crops and spice Grains Multi-thresher, and its evaluation were done at Bako Agricultural Engineering Research Center (BAERC), which is located in West Shoa zone of Oromia National Regional State, Ethiopia.

Descriptions of the Machine

The machine consisted mainly a frame, threshing drum, blower, concave and feeding table. The threshing drum was fixed with short peg-tooths followed by blades from inlet to out let and rod coiled on water pipe. The concave was made of mild steel rods with spacing of 6 mm. The concave clearance between the threshing drum and concave was adjustable. The power from a diesel engine (10hp) was transmitted to the threshing drum by V-belts.

Figure 2. A prototype and its basic parts

Performance Evaluation of the prototype

Three levels of engine crank shaft speed and two levels of concave clearance were used to evaluate the performance of the machine. The performance of the machine was evaluated in terms of threshing capacity (kg/h), threshing efficiency (%), cleaning efficiency (%) and percentage of loss (%) using the following equations; Ndirika (1994) and Gbabo *et al.*, (2013).

Threshing capacity (kg/h) $= \frac{Q_t}{T_m}$

Threshing efficiency (%) $= \frac{Q_t}{Q_t + Q_{ut}} X100$

Cleaning efficiency (%) = $\frac{Qt}{Q_{t+cf}} \times 100$

Percentage of loss (%) = $\frac{Q_{ut} + Q_{tch}}{Q_t + Q_{ut} + Q_{tch}} X100$

Where: Qt – Mass of threshed grain at grain outlet (kg); Tm – time of threshing operation (h); Qut – quantity of unthreshed grain(kg); Qt+cf - quantity of threshed grain and chaff at grain outlet (kg), W_{hw} – quantity of winnowed husk (kg); Qtch – quantity of threshed grain in chaff (kg)

Experimental Design

The experimental was conducted in a split- plot design having drum speeds in main plots, concave clearance in sub-plots with three replications as block.

- The details of the treatments were: three levels of drum speeds were used by adjusting fuel control throttle valves of the engine (V1 = 600rpm, V2= 700rpm and V3 = 800rpm), Akintayo A. , 2015 and two levels of concave clearance C1 = 20mm and C2 = 25mm
- Full feeding rate (the batch that can full the inlet area) that make the farmer easy while using the machine and 7% measured mean grain moisture content that is close to the recommended to be threshed (Akintayo A. , 2015) were used

Statically Analysis

Data were subjected to analysis of variance using statically procedure as described by Gomez and Gomez (1984). Analysis was made using Gen Stat 15th edition statistical software.

Result and Discussion

Performance of the prototype machine was evaluated interims of the following parameters and discussed below.

Threshing capacity (Kg/hr)

Table 1. Effect of drum speed and concave clearance on threshing capacity

Source of Variation							
Combination Effect of (VXC)			***Main Effect***				
Velocity (rpm)	Con. Clearance (mm)		Velocity (rpm)	Mean	Clear.(mm)	Mean	Grand mean
	20	25					
600	57.18	58.72	600	57.78	20	65.04	
700	66.67	67.75	700	67.21	25	69.61	
800	71.27	82.74	800	76.99			67.32
SE (M)	1.181		0.835		0.682		
LSD (5%)	3.280		2.319		1.893		
CV (%)	2.1						

The maximum threshing capacity of 82.74 kg/hr was recorded at combination effect 800 rpm and 27 mm drum speed and concave clearance respectively. It has direct relationship with drum speed and concave clearance, Gbado *et al*., (2011) reported that throughput capacity would increase with an increase in the operating speed of a thresher. The machine threshing capacity is low due to the intake, chopping and threshing unit problems. Akintayo A., 2015, reported that throughput of 46.7 kg hr-1 was obtained at 9.7 % moisture content , 300rp cylinder speed and 5mm concave clearance.

Cleaning Efficiency (%)

Table 2. Effect of drum speed and concave clearance on cleaning efficiency

Source of Variation							
Combination Effect of (VXC)			***Main Effect***				
Velocity (rpm)	Con. Clearance (mm)		Velocity (rpm)	Mean	Clear. (mm)	Mean	Grand mean
	20	25					
600	46.57	45.56	600	46.06	20	50.20	
700	53.15	45.94	700	49.54	25	46.77	
800	50.87	48.81	800	49.84			48.48
SE (M)	1.391		0.983		0.803		
LSD (5%)	3.861		2.730		2.29		
CV (%)	3.5						

The maximum cleaning efficiency of 53.15% was recorded at combination effect 700rpm and 20mm drum speed and concave clearance respectively, while the minimum was obtained at 600rpm and 25mm drum speed and concave clearance. Even though, the cleaning efficiency of the machine is poor and requires modification Ndirika (1994) plotted a similar graph where cleaning efficiency of millet increased with cylinder speed. Abarchi (2011) got a straight line graph when he plotted cleaning efficiency against speed of revolution of millet thresher and Abolaji (1980) result for a similar plot was not different from these results.

Percentage of loss (%)

Table3. Effect of drum speed and concave clearance on percentage of loss

Source of Variation							
Combination Effect of (VXC)			***Main Effect***				
Velocity (rpm)	Con. Clearance (mm)		Velocity (rpm)	Mean	Clear.(mm)	Mean	Grand mean
	20	25					
600	5.54	7.99	600	6.77	20	5.36	
700	6.02	8.77	700	7.39	25	7.97	
800	4.53	7.14	800	5.84			6.67
SE (M)	0.149		0.105		0.086		
LSD (5%)	0.413		0.292		0.238		
CV (%)	2.7						

The maximum percentage losses of 8.77% was recorded at combination effect 700rpm and 25mm drum speed and concave clearance respectively, while the minimum 4.53% was obtained at 800rpm and 20mm drum speed and concave clearance. The loss is due to unthreshed head and grain with chaff. Study on millet threshing carried out by Kamble et al., (2003) gave the obtained highest threshing efficiency as 98.6 % and 2.1 % total grain loss

Threshing efficiency (%)

Table 4. Effect of drum speed and concave clearance on threshing efficiency

Source of Variation							
Combination Effect of (VXC)			***Main Effect***				
Velocity (rpm)	Con. Clearance (mm)		Velocity (rpm)	Mean	Clear.(mm)	Mean	Grand mean
	20	25					
600	96.28	94.97	600	95.94	20	95.94	
700	94.94	92.34	700	93.64	25	93.71	
800	96.62	93.82	800	95.22			94.83
SE (M) 0.299			0.211		0.173		
LSD (5%) 0.830			0.587		0.479		
CV (%) 0.4							

The maximum threshing efficiency of 96.62% was recorded at combination effect 800rpm and 20mm drum speed and concave clearance respectively, while the minimum was obtained at 700rpm and 25mm drum speed and concave clearance. Akintayo A., 2015, reported that threshing efficiency at 7.8 % moisture content increased from 94.7 % at 60 kg hr-1 feed rate to 95.6 % at 150 kg hr-1. Generally, threshing efficiency increase with increasing drum speed. Ndirika (1994), Abolaji (1980) and Abarchi (2011) plotted and got a similar trend where the threshing efficiency of threshed millet increased with cylinder speed.

Conclusion and recommendations

Finger millet has been threshing, in Ethiopia at present, is done manually by women and men by beating its heads with sticks or clubs repeatedly until almost all the grains are detached from the heads on a mat, canvas or bare ground and animal trampling. The long hours of day labour of these “human threshers” is not anything to write home about as an average woman can only thresh about 10 kg per day (www.fao.org/docrep).

In an effort to alleviate some of the problems associated with primary processing of finger millet, based on closely resembles physical characteristics of finger millets grains , motorized FARC small crops and spice grains multi thresher was selected and evaluated**.** Based on the results obtained, regarding to performance indices like low threshing capacity and cleaning efficiency and to reduce percentage of loss machine requires a modification.

Recommendations

Although, the physical properties of finger millet is similar to small crops and spice grains, finger millet should be threshed by more impact/biting load rather than rubbing because of its tillers are long and much number of tillers like teff. However, FARC small crops and spice grains multi thresher has few and short active part that apply the impact loads to thresh it. Additionally, at feeding area the drum has not blades that create active/rapid feeding mechanism. Because of these reasons, the threshing capacity of the machine was low.

Therefore, the drum should be wire loop in order to replace short pegs on it and then blades to have many impact loaders and more contact threshing part. This is to give room for the feeding of the thresher at greater rates than those used in the evaluation of the thresher. The machine also has no mechanical and efficient aerodynamic cleaning unit for this crop, poor cleaning efficiency is happened. So, the cleaning unit should be worked to improving the cleaning efficiency already achieved on the thresher.

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Improvement and on-farm evaluation of spiral water pump

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Abstract

Agriculture in Ethiopia is dominated by smallholder rain-fed systems but, low and erratic rainfall limits productivity and food security. Consequently, investment in small-scale irrigation has been identified as a key poverty reduction strategy. The Spiral Coil pump is a non-conventional water pump, which could be powered by flow energy of river water without electricity or fuel. It is very useful especially in rural areas for farming and irrigation purposes. Spiral Coil pump comes under the category of a low to moderate lift pump.

The experiment was tasted at Seka and karsa wereda of Jimma Zone on Gibe and Bulbul River respectively. Increasing hose diameter leads to better coil pump performance. The pump was proven to be capable of delivering over 12 L/min of water under pressure heads of up to 12-m. The discharge of pump at different heads was seen that as the head increases the discharge decreases. For the coil pump to be truly sustainable over time (applicable) for demonstration, special care must be taken in fabricating the rotating joint, depend on the site including floating structure is better.

Key Words: Spiral coil pump, revolution versus head, discharge of pump, pump efficiency

Introduction

Agriculture in Ethiopia is dominated by smallholder rain-fed systems but, low and erratic rainfall limits productivity and food security. Consequently, investment in small-scale irrigation has been identified as a key poverty reduction strategy (Mitiku, Ramayya and Shunki, 2016). Recent estimates indicate that the total irrigated area under small-scale irrigation in Ethiopia has reached to 853,000 hectares during the last implementation period of PASDEP-2009/10 and the plan set for development of small scale irrigation is 1850,000 hectares, which is planned to be achieved by the end of the five years growth and transformation plan (GTP) (Mitiku, Ramayya and Shunki, 2015).

In noting that farming is the primary occupation in rural areas, many organizations have worked to increase crop yield through improved irrigation techniques. Reliable irrigation techniques have been shown to increase crop yields between 100%-400%. The resulting increase in grain volume translates to increased sales and income, and allows farmers to cultivate higher-value crops, adopt new technologies, and increase financial returns. Despite the benefits of irrigation, too few farmers have a steady source of irrigation due to the financial limitations of acquiring commercial irrigation technologies.

In southwestern Oromia, flow of river is potential. Even though Diesel pumps are effective for irrigation with topographic problem of the area, yet the capital cost and fuel costs are too high for diesel pumps to be commonplace.

The Spiral Coil pump is a non-conventional water pump, which can be powered by wind energy or flow energy of river water. It can also be hand driven. It is very useful especially in rural areas for farming and irrigation purposes. Spiral Coil pump comes under the category of a low to moderate lift pump. In the present study, the hand operated experimental setup is designed and constructed to analyze the performance of the spiral coil pump under different parameters (Patilet al.,2013).

A spiral tube water pump is a method of pumping water by using an undershot water wheel which has a scoop connected to a spiral tube. As the wheel turns, the scoop will alternatively introduce either water or air into the spiral tube. The pressure from the hydrostatic head generated from the column of water introduced by the scoop, is added to the pressure from previous scoops, and so as the wheel turns it will increase the water pressure with every turn of the spiral. The main characteristic of the spiral water pump is that it can pump water without the input of electricity or fuel. It works with the power of the water flow. Once built, the spiral water pump is able to push water up to 30 meters high (vertical push) and up to 70 meters away (horizontal push). The water push (how far water will be pushed horizontally and vertically) depends on how big the wheel of the Spiral Water Pump is built, and how much tube is put around the wheel. The spiral tube water pumps were installed with the aim to provide irrigation water from rivers to higher-level crop fields. The type, size and thus material costs of a spiral water pump will depend on two parameters: first, the irrigation needs (how far the water needs to go and how much is used per day) and second, the available water flow (the velocity and depth of the water source). There is only an initial investment in material for the water wheel, after that the pump should work without any further costs incurred. So the aim of the research is to improve and evaluate existing spiral water pump for using the available water potential for irrigation.

Material and methods

Material

Pump manufacturing material – sheet metals, square pipes, different diameter plastic water pipes, bolt and nuts.

Instruments for data collection – stopwatch, 22lt container, tachometer

Important Parameters related to Spiral Tube Water Wheel Pump performance:

River flow: The speed of the water is directly proportional to the rotational speed of the water wheel.

Blade: It is a flat surface attached at the tip of the spoke of water wheel. The force exerted by the water on the flat plate makes the water wheel to rotate. The size of the plate is directly proportional to the force exerted on blade keeping velocity constant. More the number of blades, greater is the torque on the water wheel. But after a certain number of blade, the torque decreases due to blockage of water by the subsequent blade. Therefore the number of blades should be arranged in such a way that only one blade is fully immersed at a time.

Diameter of wheel: Diameter of the Water wheel is one of the primary part; it uses the energy of the flowing water to some useful energy. Larger the diameter of wheel, greater the head generated.

Number of coils: Number of coils is directly proportional to the head generated.

Spoke: It is a long bar connecting the center of the wheel and it supports the frame of the blade. The main function of spoke in water wheel is to support.

Hollow shaft: It acts as a supporting device and it helps in rotating the spiral wheel. Water collected by the spiral tube is discharge at the outlet with help of hollow shaft,

Spiral tube: It is a long tube coiled eccentrically on the hollow shaft, which collects water at each rotation.

Scoop: Scoop is typically made from a larger diameter pipe and can be used to vary the amount of water taken in with each revolution. The scoop should be enclosed in wire mesh to prevent debris from entering the coils.

Rotary Joint: The spiral wheel hollow shaft which collects water from spiral tube continuously rotated and it is not possible to rotate the whole delivery pipe. So there is a need of a joint between the hollow shaft and the delivery pipe which can provide a frictionless surface to rotated the outlet of the tube smoothly and air tight chamber to prevent leakage of water.

Working Principle of a Spiral Pump

A spiral pump is basically used to pump water from a lower head to a higher head region. This pump uses a rotating pipe coil to pump water. The spiral tubes are fixed to the wheel so that the spiral pipes rotate, as the wheel itself rotates. The water collector connected to the outermost end of the spiral tube gulps in a good quantity of water and delivers this into the spiral tube as it rises above. This core of water passes through the spiral followed by a core of air as the wheel rotates. A new core of water is formed on every revolution, and a new core of air. Thus a series of cores of water and air are formed within each spiral pipe as the wheel rotates. Both spiral tubes deliver their water and air into the axle of the wheel and there it is led off through a water seal to a static rising pipe, which delivers water to the header tank. As the wheel revolves a pressure head develops within each coil of the spiral tube, water in the rising coils being higher than in the descending coils. These cores of water in the spiral tube compress the air between them as they travel around the spirals and both water and air are expelled under pressure into the axle. The flow of water up the static rising pipe is also accelerated by the compressed air escaping and expanding from the outlet at the axle of the wheel. This effect also helps to lift water to the header tank.

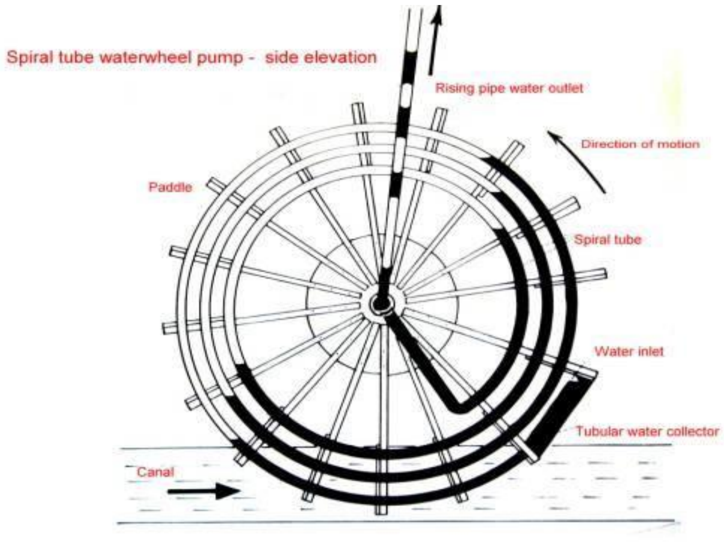

Fig 1. Cross section of spiral pump

Methods

Possible modifications undertaken

- ✓ The length of the blade wheel reduced to 0.75 meter for portability
- ✓ Increasing the number of turbine blade
- ✓ Winding the spiral tube at both right and left side for increasing pump discharge.
- ✓ The prototype was manufactured from metallic material instead of wood

Fabrication of the water wheel

The water wheel consists of two flanges made of Mild Steel of 32 cm diameter and 0.6cm thickness with an inner hole drilled to 5cm which was connected to a shaft. 10 spokes of Mild Steel square pipe of 1x25x40 mm dimension and length of 84cm are bolted together to the flanges at the centre from one side. Flat bars of 60 cm length and 2 mm thickness are bolted to the spokes in between for support. Mild steel plates of dimension (0.2X0.75) m^2 are welded to a frame by arc welding to form the blades which are fitted to the spokes with nut and bolt.

Fig 2: Shows fabrication processes

Parameters measured:

- Time taken to fill the known volume of container
- Number of rotation(RPM) of the spiral wheel
- Total head
- River flow

Parameters estimated:

- Pump discharge

The Discharge was calculated for two level of pipe diameter (0.5 and 1inch) Winding the spiral tube at both right and left side. The pump discharge in m^3/s calculated by dividing the amount of water filled to the known volume by the measured time. The discharge or capacity of the pump was calculated by

$$Q = {}^{V}\!/_{T}$$

Where: Q =V/T discharge of the pump, L/s
V = volume of water to fill the measuring drum, L
T = time required to fill the drum, s

Efficiency of the water pump (η) is equal to the Power output (the power gained) by the fluid from a pump divided by Maximal power of the flow (Power input in a water wheel).

$$Pi = (1/2)\,\rho A v^3$$

Where: Pi = power input,
ρ = density of water =1000 kg/m3
A = area of the blade,
V = velocity of the flowing water (From our experiment data)
Area of the blade A= L*W
Length of the blade (l) = 0.75m
Width of the blade (w) = 0.2m
The radius of water wheel turbine blades (R) = 0.931m

Calculated rotational speed of the water wheel (RPM_c) = V / R
The Power output (the power gained) by the fluid from a pump

$$Po = \rho\, Q\, g\, h$$

Where: ρ = density (kg/m^3)
Q = volume flow rate (m^3/s)
h = head (m)
g = acceleration of gravity (9.81 m/s^2)

Result and Discussion

Testing at Gibe River

For the selection of the best performing arrangement, testing was carried out in Jimma zone Saka chokorsa wereda at Gibe River with river flow rate of 0.79 m3/s. Different pipe size and winding side of coiled pipe configuration as an option was tried with the same river flow rate and pumping head of 3 meter and horizontal distance of 42 meter with half inch pipe diameter.

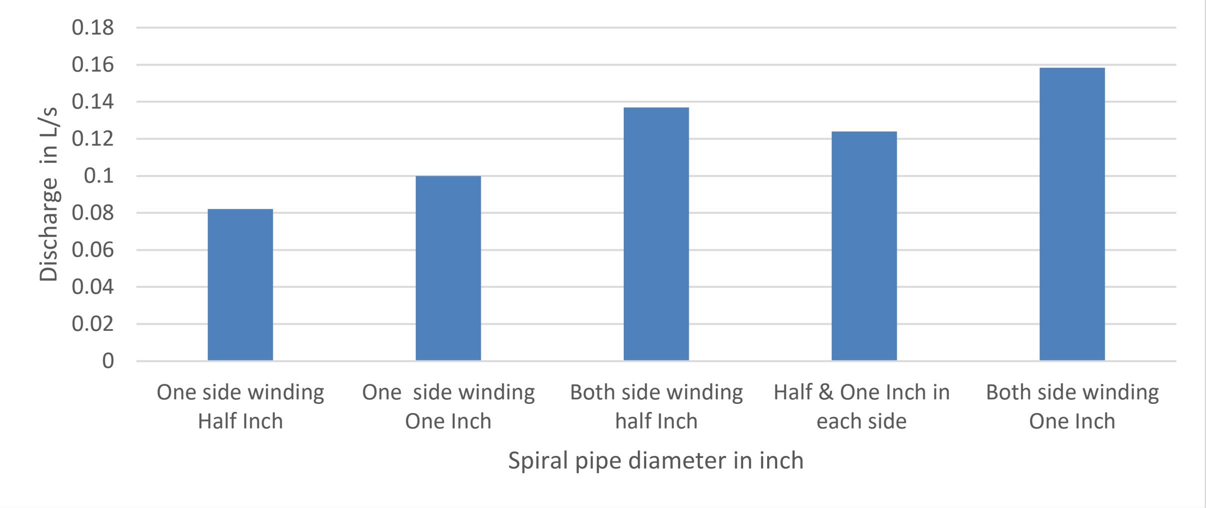

Fig. 3 Spiral pipe diameter versus Discharge

As shown in the figure when the coil pipe diameter increases from half to one inch diameter the water discharge in litter per second increases. Similarly, both left and right side winding is better. According to (Kassab et al., 2006) increasing the hose diameter increases the pump flow rate, which is collected at different heights. For small values of hose diameter, changes in pump discharge and head are small relative to those obtained in the case of large inch hose diameter. Therefore, the use of a larger size hose is one of the major important design parameters for coil pump.

An improvement in the coil pump performance with the increase of the coil hose diameter can be attributed to two effects: First, increasing the diameter of the coil tube results in a reduction in the friction loss within the hose and leads to a better pump performance. Second, increasing the diameter of the coil increases the pump inlet area as well as the mean pump outer diameter. This leads to an increase in the amount of air and water inter to the pump, which leads to improve the pump performance.

Using multi- layers coil pump with the pump intake placed at the top end of the upper layer improves the pump performance. This effect is the same as increasing the outer diameter of the case of only one layer. In both cases, the circumferential distance of the pump inlet increases due to the increase of the pump outer diameter. Consequently, the period for both air and water intake increases which has a positive improvement in the coil pump performance. The increase in the air intake results in an increase in the effective motive pumping power, and consequently the pressure head. While increasing the amount of water intake results in an increase in the flow rate. Both effects add to each other and produce better pump performance. In addition, it is important to point out that the effect of increasing the coil inner diameter has the same effect as the other two previously mentioned parameters and due to the same reasons in addition to the effect of reduced friction to the flow within the coil.

Testing at Bulbul River

By taking different height of the output, other parameters are measured. The average rpm of the wheel is measured by tachometer and it is found to be 5.28, 6.94 and 7.53 rpm on water wheel during the load condition. To measure the discharge rate, a procedure is followed to count the time required to fill a 22 liters bucket at 12.75, 6.5m and at the shaft level. As shown in fig.3 result of pump testing at Karsa wereda of Bulbul River with river flow rate of 2.04 m3/s, increasing the pumping head decreases the spiral pump revolution per minute (rpm) and discharge in liter per second.

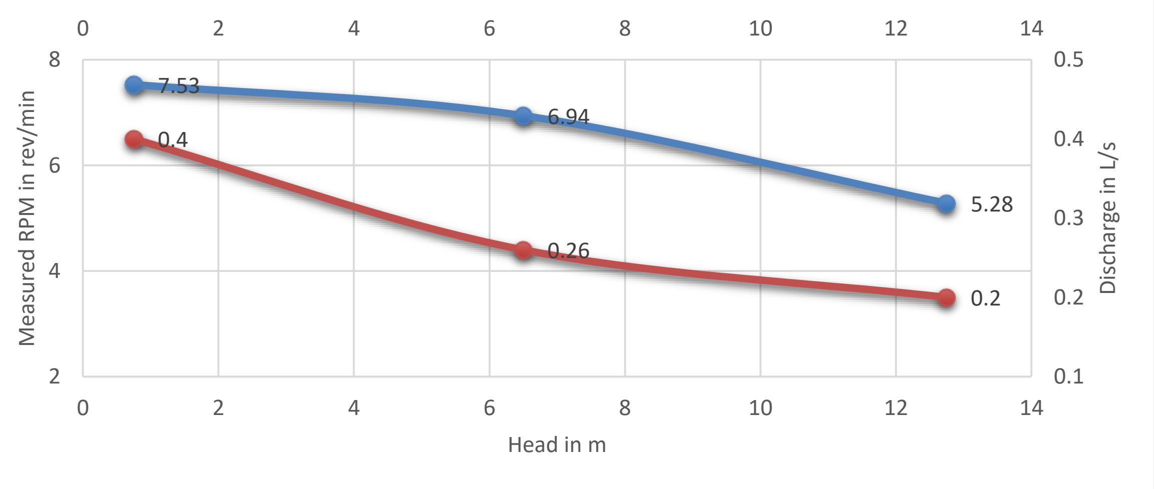

Fig. 4 Discharge, Measured Revolution versus Head in meter

As (Dubey, 2016), the discharge of pump at different heads was seen that as the head increases the discharge decreases.

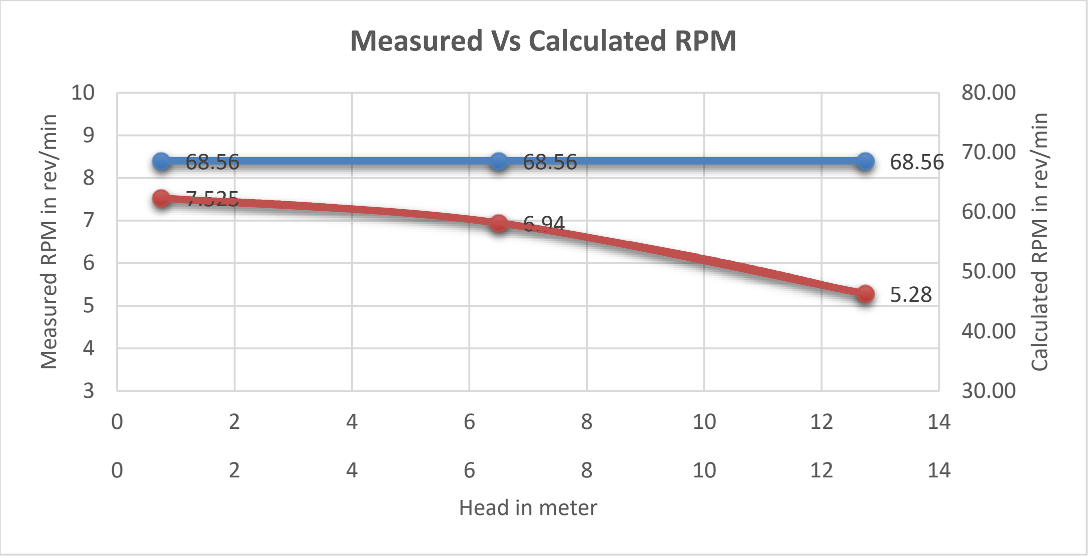

Fig.5 Calculated Discharge, Measured Revolution versus Head in meter

As (Mishra and Verma, 2016) the spiral tube water wheel pump has the potential to pump water for agriculture and domestic purpose as it extract water above 50 ft head .Spiral tube water wheel pump is direct replacement of small standard piston pump and just as efficient at pumping a set volume per day.

As shown in fig. 6 the efficiency of the spiral water pump increases as head increases, this is because the amount of water delivered or discharged is changing with respect to the head. The rate decreasing of discharge is less than the rate increasing of head.

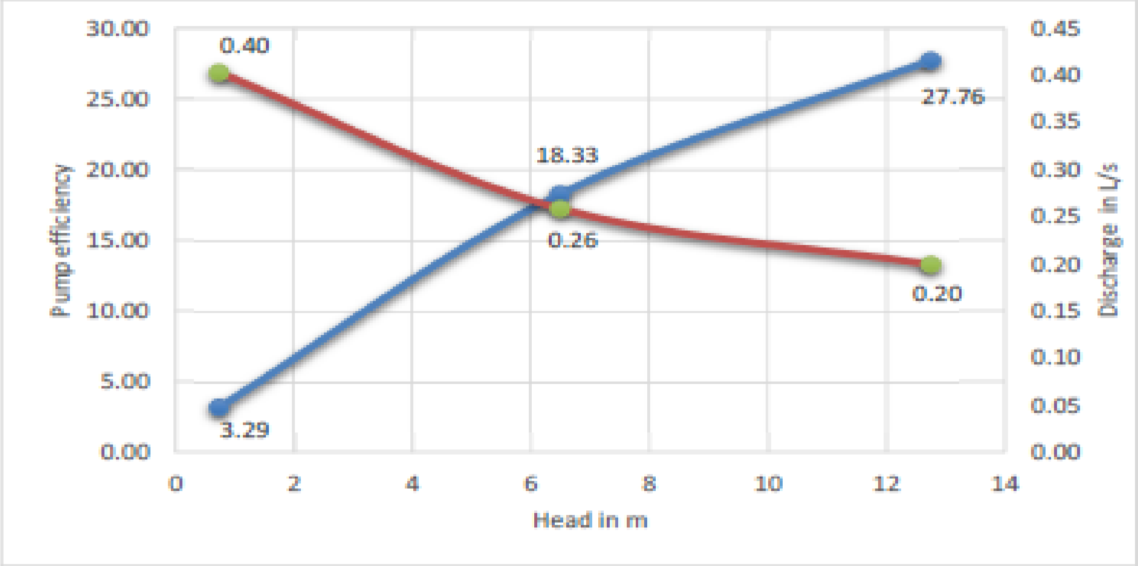

Fig. 6 Discharge, Pump efficiency versus Head in meter

In the study of (Patilet al., 2013), the hand operated experimental setup is designed and constructed to analyze the performance of the spiral coil pump under different parameters. The parameters considered are submerged ratios, rotational speed, layers of coils. For setup of 0.8 m wheel diameter with seven numbers of coils, the maximum head obtained is in between 4.3 m to 5 m with maximum discharge 1200 lit/hr. for single layer and 2280 lit/hr. for double layer of the coil with efficiency range 20% to 74%.

Conclusion and Recommendation

The experiment was tasted at Seka and karsa wereda of Jimma Zone on Gibe and Bulbul River respectively. Using multi-layer coil pump, water inlet from the upper layer gives higher discharge, higher static head and better pump performance (head and discharge). Increasing hose diameter leads to better coil pump performance. The pump was proven to be capable of delivering over 12 L/min of water under pressure heads of up to 12-m.

The pump works without electricity or fuel (powered by the river) hence, it can use in the rural areas for agricultural applications, made from local materials and easily maintained by the residents. For the coil pump to be truly sustainable over time (applicable) for demonstration, special care must be taken in fabricating the rotating joint, depend on the site including floating structure is better.

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Evaluation and Demonstration of Micro Tube Drip Irrigation Technology in Edo Kontola Adami Tulu Jido Kombolcha District

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Abstract

Drip irrigation is widely recognized as one of the most efficient methods of watering crops. A field study was conducted on a sandy loam soil at Adami Tulu Ido Kontola area, to demonstrate micro drip irrigation on tomato and hot pepper yield during the dry seasons.Therefore, the aim of this study was; demonstration and awareness creation on drip irrigation technology backyard production at household level.Two crops tomato and pepper were used for the purpose as test crop. The demonstration were replicated at four farmer's plot of land at two location I and II. Some parameters of tomato and hot pepper and water use efficiency were used to evaluate and demonstrate micro tube drip irrigation systems. The overall effect showed that drip irrigation system performed better in both of the crops. The overall biometric parameters and yield of tomato under micro tube drip irrigation system similar at both location except no of cluster per plant (NCP) and no of fruit per plant (NFP) were 12.54, 37.54 and 8.85, 26.46 at location I and II respectively. The marketable yield and total yield of tomato shows that a yield difference in each location due management and awareness of farmers that the highest marketable yield observed in location I which were 41.71Qt/ha and 71.71Qt/ha on which a better management of farmers give to the crop and at location II was recorded around 28.14 Qt/ha and 54.57Qt/ha respectively. Hot pepper performs differently in both locations in total yield, 85Qt/ha and 54Qt/ha in location I and II. Overall, hot pepper used less amount of water compared with tomato but higher yield were obtained in tomato yields in both farmers demonstration sites. Finally this technology should be popularized and Future study could require in different crop and area for more water productivity and crop production.

Keyword: drip irrigation, backyard, water management, crop, waer amount and yield

Introduction

Sustaining productivity and constantly increasing total production remain a major challenge to the agricultural sector. Irrigation has a vital role to play in Ethiopia to ensure food security and remains a high priority consideration in development strategy and prevention of future famines.

Agricultural water management will be the key to maintain food security and income generation for the rural poor. In irrigated agriculture, about half of the water is consumed in evaporation and transpiration from plants and moist soil surfaces. In areas where water is scarce, there is a need to use all the available water (and increase that amount where

possible by means of water transfer, water desalination, sewage treatment, reuse of drainage water, storage etc.) at maximum efficiency; that means decreasing conveyance and application losses to the minimum feasible levels, and irrigating where and when the beneficial effects of irrigation on the yield will be as high as possible (FAO, 2002b).
All the above improvements of surface irrigation may not be enough, and due to the limited volumes of water harvested and stored compared with crop water requirements, it is economically necessary to get even more from the water: this may be done in many cases by adopting efficient irrigation methods, which can apply the scarce water more accurately; i.e. at the right time and place, - and minimizing losses through leaking conveyance canals, surface run off or deep percolation. Improved benefits of such systems can be derived by using efficient water application methods such as drip irrigation (Ngigi et al., 2000). The water collected then, can be used much more efficiently for supplemental irrigation for much larger areas, or for longer seasons.

Drip irrigation is introduced primarily to save water and increase the water use efficiency in agriculture. Studies carried out across different countries including Ethiopia have confirmed that drip irrigation plays a paramount role in increasing yield and water use efficiency of crops. it has the potential to use scarce water resources more efficiently to produce crops as water can be delivered precisely to the root zones rather than irrigating the entire field surface as with other methods (Tagar *et al*., 2012).
The experience from many countries show that farmers who switch from furrow system to drip systems can cut their water use by 30 to 60% and crop yields often increase at the same time because plants are effectively ‘spoon fed’ the optimal amount of water when they need it (Sijali, 2001). The use of such drip irrigation system permits reduction of water loss up to 50% and can increase the yield per unit of land by up to 100% compared with surface irrigation systems (Cowater, 2003).

Small-scale drip irrigation systems, which operate with pressure head of 0.5-15m, can be further simplified to fit the special low-capital circumstances of the less developed countries. The development of low-head emitters, which are technically easy to understand and need simple filtration, has reduced much of the initial capital investment necessary and making drip irrigation systems affordable to smallholder farmers. For smallholder farmers that drip irrigation provide means of economical biomass production per unit of water and increasing cropping intensity by growing a crop during the dry season (Sijali, 2001).

drip irrigation is clearly going to be considered as one of the alternatives in the planning of irrigation in the developing world. In these countries, the drip irrigation methods that will be preferred are those that are “userfriendly” to the small farmers, full proof, easy to learn, simple in operation andmaintenance, flexible to fit fields of different sizes and shapes, a variety of crops and many uncommon situations, and easy to repair, and relatively inexpensive to install. There is growing interest in the technique and the rapid expansion in drip irrigation recently has been associated with large investments in commercial farms (Hillel, 1997). This scenario is now changing and many efforts are being made around the world to develop low cost,simple drip irrigation systems to the small holder, which are being used in some parts ofAfrica.

Therefore, the reaserch were proposed with the objective to evaluate and demonstrate drip irrigation system at the farmer's circumstances and efficiently utilize the scarce water resources and maximize crop yield and quality at smallholder farmers conditions

Material and Methods

The study was carried out in Adami Tulu JidoKombolcha (ATJK) in Edo Kontolaarea. Before start of experimental activities group discussions were conducted with purposively selected section of irrigation water user (IWU), women representatives, DA, woreda expert, KA leaders and some individuals.

One PAs and 2 farmers from PA was selected based on willingness to accept the technology, irrigation accessibility, interest to participate on training and accessibility of site for monitoring and evaluation. Training&field visit were prepared. Some of the most important soil chemical and physical properties of the selected field were determined.

A low pressure drip irrigation systems were tested for its performance under tomato and hot pepper under farmer's condition. The system was installed on well prepared fields of $50m^2$ area to grow tomato and hot pepper. The water container should be raised 0.5 to 1.5 m above ground level depending on cultivable plot area to create sufficient pressure. Low cost and appropriate hand water lifting device washer pump were used to fill the water container. Climatic data were collected from the nearby agro-meteorological observatory and crop water requirement for the selected crops were worked out using FAO CropWat 8.

The selected variety seed were sowed on nursery field.The seedling wasthen transplant on well prepared experimental plots. Other agronomic and crop protection practice were adopted uniformly as per recommendation for tomato and hot pepper production.

Training

Training was conducted both in the beginning (introductory) and at the mid on drip irrigation importance in dry areas, installation and application utilizationof water. Moreover, field days were organized at the site where more than 50 surrounding farmers attended and became aware on micro drip irrigationas well as its benefit with limited amount of available water in the area with its water utilization and importance of the system option of getting additional income and also provided their feedback on the drip irrigation methods.

***Farmers and DAs participation**:* As discussed earlier two farmers were involved in the activity. With the idea of implementing of micro drip irrigation technologies in the off season in where dry spells of the year in their back yards using ground water as water sources by sharing common understanding with in farmers, discussion and training was held with participant farmers and DAs. In one the sites, where the drip irrigation technologies was conducted in the compound of water shortage area high value crops were planted with drip irrigation and demonstrated to the farmers and member FRG farmers which provided easy mechanism for awareness creation. The participant farmers, in general, played the role of information sharing to other farmers, providing feedback on the structures, recording and provided information and took an active part all the way from installation of drip to the harvested crop.

Data management and analysis

The data were handled and documented appropriately. Agronomic, yield and social data (farmers‟ perception) were collected. The collected data were analyzed by using simple descriptive (MS-Excels).

Result and Discussion

Results from field trials demonstrate that low cost drip systems easily pay for themselves in one growing season, and stimulate shifts to more intensive agricultural practices by small farmers.Micro tube drip irrigation technologies were demonstrated to the farmers in Adami Tulu districts of Edo Kontola kebeles in order to utilize the limited amount of water available in dry seasons using ground water as a source of water on where farmers have in their back yards by planting high value crops in their homestead.

Amount of water applied through micro tube drip irrigation system

Tomato exhibits indeterminate growth habit with simultaneous vegetative and reproductive growth. The life span of tomato crop the crop grown under normal season ranges between 4 to 5 months.On an average of three years, 115 irrigations as dripwere applied to tomato crop. Amount of water used per plant per irrigation ranging from 2- 4 litres and water used per plant per day ranging from 0.96-2.2 litres in drip irrigation. Total amount of water used in drip irrigation were 2500 m^3 to 2580 m^3 on an average of three years,on the two demonstrated farmers trial were applied to the crop.

In drip irrigation system, water is applied drop by drop only to the root zone of the plants. Thus, a large amount of water away from root zone could be saved. The results of present investigation also revealed improved marketable yield and fruit quality in case of tomato through drip irrigation. Water saving using drip irrigation on crops can be as much as 80% when compared to other irrigation techniques (Bogle and Hartz, 1986). Raina et al. (1998) reported that drip irrigation besides giving a saving of 32% water resulted in 49.5% higher yield as compared to surface irrigation. Proper management of tomatoes under drip system can be able to repay itself in a short period.

Hot pepper completes its life cycle within 3 to 4 months. It was irrigated 105 times in drip irrigation. As regards amount of water used per plant per irrigation, water used per plant per day and total amount of water used hot pepper, a similar trend was observed to those of tomato. Amount of water used per plant per irrigation ranging from 1.85- 3.5 litres and water used per plant per day ranging from 0.75-1.55 litres in drip irrigation. Total amount of water used in drip irrigation were 2000 m^3 to 2050 m^3 on an average of three years,on the two demonstrated farmers trial was applied to the crop.

Table1. Average amount of water used

Crop	**Irrigation systems**	**No of irrigation**	**Water used per plant per irrigation (litres)**	**Water used per plant per day (litres)**	**Total amount of water used (m^3)**
Tomato	Drip	115	2-4	0.96-2.2	2500-2800
Hot pepper	Drip	105	1.85- 3.5	0.75-1.55	2000-2050

Yield and Yield Parameters of Tomato under Drip Irrigation Method

The overall biometric parameters and yield of tomato under micro tube drip irrigation system under farmers condition of vegetable production showed that a better yield performance. The average values of plant height recorded at location I and location II were 61cm and 65cm respectively the result is the same in line with Jiregna, T. D., 2013, Chernet, S., et al, 2013, and Meseret, D. R., et al, 2012, reported that plant height ranges between (57.74-68.04 cm), (4-97 cm) and (40.2 to 107 cm) respectively. The primary branch (PB) and secondary branch (SB) which were recorded in the two locations around 2.69 and 2.68 and also the average value of secondary branch (SB) at the two demonstration sites were recoreded 4.46 and 4.77 at location I and location II the result gained the same with Jiregna, T. D., 2013, reported that number of branch ranges between 4.72 and 9.3.

Table 2. Biometric component of tomato

Locations	**Parameters**				
	Ph (m)	PB(#)	SB (#)	NCP (#)	NFC (#)
Location I	0.61	2.69	4.46	12.54	3
Locations II	0.65	2.68	4.77	8.85	3

***Ph**=Plant Height, **PB**=Primary Branch, **SB**=Secondary Branch, **NCP**=Number of Cluster per Plant, **NFC**=Number of Fruit per Cluster

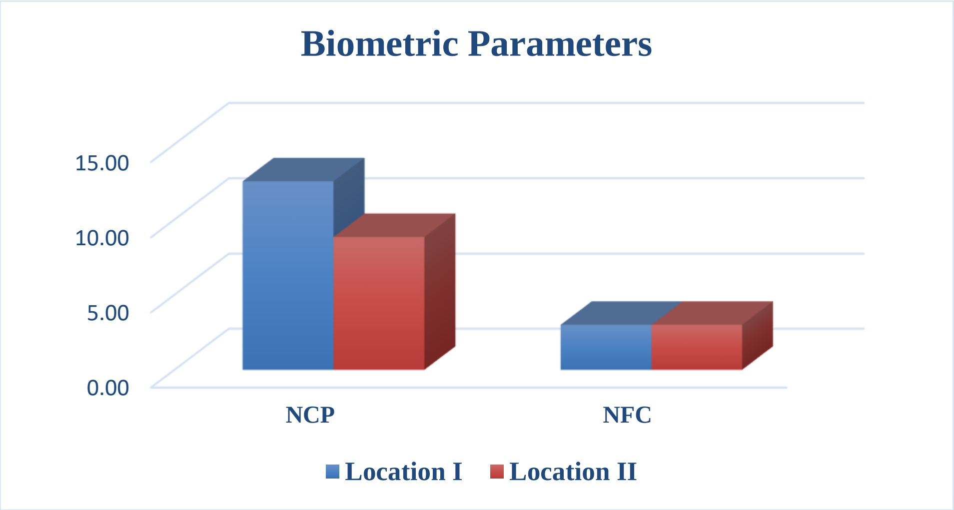

Figure 1. Graph of Agronomic parameter of tomatoin both demonstration sites

The average values of number of cluster per plant (NCP) recorded at location I and location II were 12.54 and 8.85 respectively; this is similar in the range of in line with finding of Satyendra K., et al., 2013. The number of cluster per plant (5.91 to 15.05). The number fruit per cluster (NFC) of tomato at demonstration sites recorded at both locations were 3.

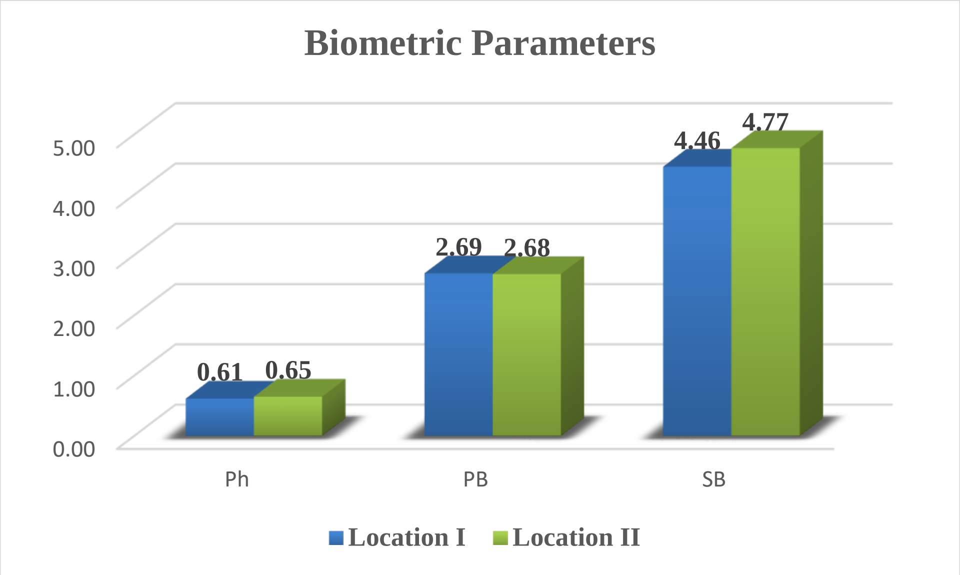

Figure 2. Graph of plant height, primary and secondary branch

Yield and yield parameter of Tomato

The average values of yield parameter of number of fruit per plant (NFP) recorded at location I and Location II of demonstration sites were 37.54 and 26.46 respectively the result gained supported by Jiregna, T. D., 2013, reported that number of fruit per plant ranges between 8.10 and 36.12.

Table 3. Yield and yield parameter of tomato

Locations	Parameters		
	NFP (#)	MY(Qt/ha)	TY (Qt/ha)
Location I	37.54	41.71	71.71
Locations II	26.46	28.14	54.57

***NFP**=Number of Fruit per Plant, **MY**=Marketable Yield, **TY**=Total Yield

The marketable yield of tomato at demonstration sites shows that a yield difference in each location due management and awareness of farmers that the highest marketable yield observed in location I which were 41.71Qt/ha on which a better management of farmers give to the crop and at location II was recorded around 28.14Qt/ha.

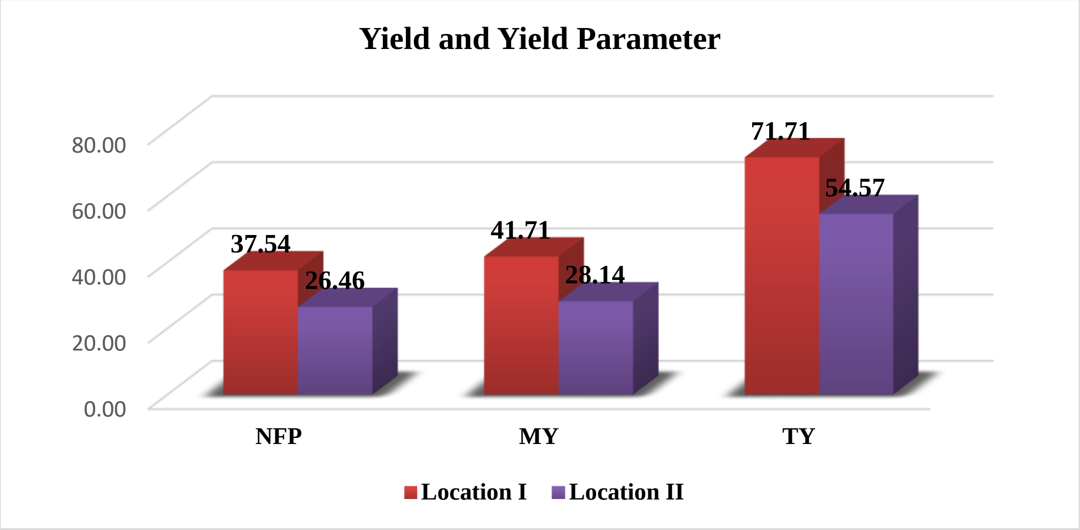

Figure 3. Graph of Number Fruit per Plant, Markeatable and Total Yield of tomato at each location

Yield and Yield Parameters of hot pepper under Drip Irrigation Method

The overall yield performance of hot pepper under farmer’s conditions on the demonstrated drip irrigation were well performed.The no of fruit per plant of hot pepper at demonstration sites recorded that in average 20.45 and a n average plant height of 63.94cm as well as the average value of fruit weight per plant 113.72gm were recorded.

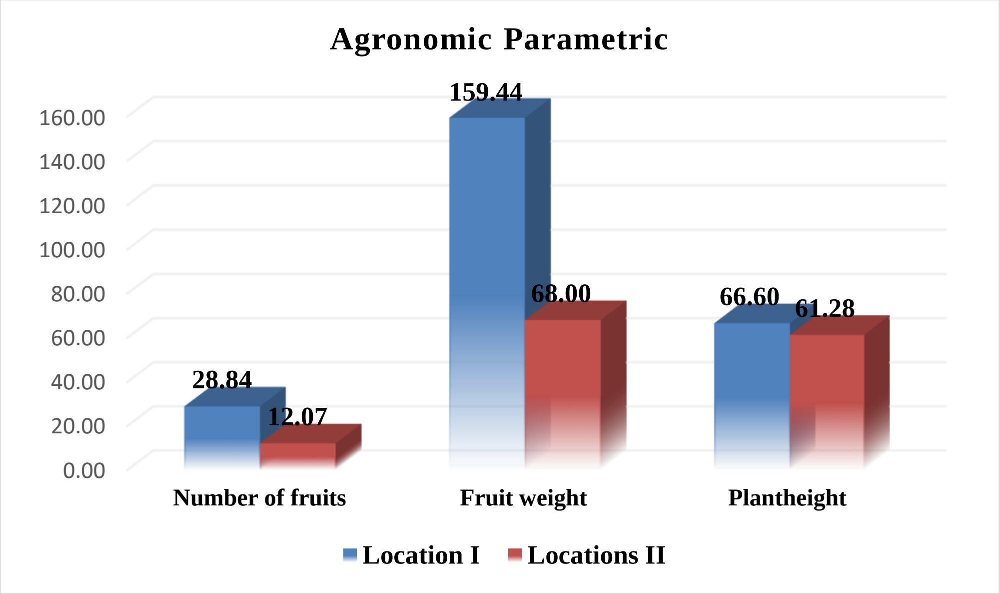

Figure 4. Graph of Number of fruits, fruit weight and Plant height of pepper per location

The average total yield of hot pepper recorded in the demonstration were 69.5 ton/ha this result in line with the yield obtained in the range but not much when compared to national average i.e. the yields recorded were 64.20 and 54.50 q/ha, respectively (CSA, 2006, 2007). The overall the highest total yield of hot pepper under better management were gained around 85ton/ha the result gained supported by the result of (Takele, 2009) on hot pepper variety (mareco fana variety) performance under drip irrigation using different irrigation water application levels were 85.7.

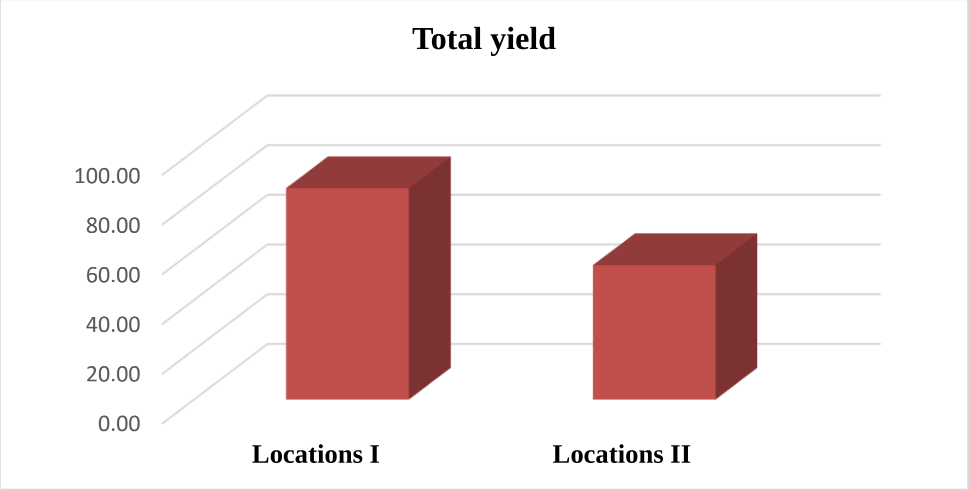

Figure 5. Graph of total yield of hot pepper at each location

Farmers' perception on drip irrigation technology

All FREG members and also non FRG farmers, development agents, experts and researchers were closely evaluate the performances of the drip irrigation technologies under tomato and hot pepper based on their own criteria. The most important criteria used in evaluating the system, were water saving, cost, operation simplicity, labor, maintenance, water source, and yield obtained were used as evaluation criteria by FREGs in study area on the basis of their knowledge and irrigation practices used in the area. Based on those criteria, the FREGs evaluation showed that, the technology was preferred by farmers due to its better water saving methods operation simplicity, labor, maintenance, homestead vegetable production than their traditional irrigation practice for the crops. Moreover total yield of both crops obtained higher as compared to locally produced crop variety.

Table 4. Farmer's perception on drip irrigation technologies

Evaluation criteria	**Locations**	**Numbers of farmers participated**	**Frequencies of farmers accept the technology**	**Acceptance of technology (%)**
Water saving	I	50	47	94
	II	50	46	92
Cost	I	50	40	80
	II	50	42	84
Operation and simplicity	I	50	45	90
	II	50	45	90
Labor	I	50	43	86
	II	50	40	80
Maintenance	I	50	36	72
	II	50	33	66
Water source and pumping	I	50	40	80
	II	50	41	82
Yield	I	50	48	96
	II	50	47	94

NB: I and II represents for locations of demonstration sites

Conclusion and Recommendation

In general It was further observed that much higher amount of water will be used by the crops if farmers sown under furrow system as compared to those sown under drip system. In drip irrigation system, water is applied drop by drop only to the root zone of the plants. Thus, a large amount of water away from root zone could be saved. Overall, hot pepper used less amount of water under drip irrigation systems compared with tomato but higher yield were obtained in tomato yields in both farmers demonstration sites

Drip irrigation saved water as compared to furrow irrigation since only small area around plantswas irrigated; application of water was very slow that improved water penetration, reduced weed growth. It may be concluded that two crops consumed much less amount of water under drip irrigation.This suggested that drip irrigation system has a greater scope for the production of off-season vegetables grown under homestead production especially in water scarce areas.

Novel irrigation technologies need to be tested under local environments and particular agricultural production systems. Thus, the main challenge confronting both rain fed and irrigated agriculture is to improve sustainable water use for agriculture. Drip irrigation increased fruit yield of tomato and improve the consumption of less water.

Therefore, as recommendation it will be suggested that the farmers in the study area who have limited amount of water in their ponds, ground water, washer pump and hand dug wells in their backyards or homestead production of vegetables ought to adopt drip irrigation method instead of traditional surface irrigation methods.

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Participatory Evaluation of Improved Irrigation Water Management Technologies in Dugda District, Central Rift Valley, Ethiopia

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Abstract

It is a wide-ranging practice using every drop of water for crop production through suitable irrigation practices. The objective of this study was to evaluate and demonstrate improved irrigation water management for onion production under farmers' condition. The activity was carried out for two consecutive years (2018 and2019) in Dugda district at Bekele Girisa and Shubi Gamo kebeles on three farmer's field. Two irrigation practices; improved furrow irrigation method (measured water application) and farmers' practice (traditional water application) were used. Improved furrow irrigation method gave better yield advantage ranging in between 17.52-58.73% at three demonstration sites as compared to that of farmer's practices. The improved irrigation method also showed better increment on yield components of bulb weight, bulb size and bulb diameter. Irrigation water use efficiency of improved irrigation practice was also found in the range of 4.9-6.6kg/m^3. The amount of water saved by using the improved irrigation method at each location also was found that 47.4%, 45.4% and 43.6% more water saved than farmer's practices at each locations and this would be sufficient to irrigate 0.77 to 0.90 hectare of additional area of onion crop leading to better economic returns as compared to that of farmer's practices.

Key Words: water management, irrigation water measurement, water saved and yield

Introduction

Irrigated agriculture plays a major role in the livelihoods of nations all over the world. In Ethiopia, although irrigation has been long practiced at different farm levels, there is no efficient and well-managed irrigation water practice (Dessalegn, 1999). The reason could be little efforts made to investigate the irrigated land management and water use in the country. Even some research results have indicated that sometimes no difference is observed between rain fed and small scale irrigation user smallholders in their food security status (Pedén*et al*., 2002).

In Ethiopia, very few irrigation water management technologies have been developed through research. In Adami Tulu research center, irrigation scheduling for crop such as tomato, onion and green pepper have been done on-station. But, these technologies are demonstrated toend-users so that get the chance to adopt them. Lack of organized technology/information dissemination mechanisms is one of the limiting factors. The other one is lack of focus on adoption of the technologies. It is usually understood as a work of development agents (DA), but much cannot be expected from that end. So in Ethiopia context, the research side should play much role in this regard. Hence, an on-farm demonstration and evaluation of improved irrigation water management technologies is about taking out of relevant and efficient irrigation methods to the farmers so as to improve the irrigated agriculture sector.

From experiences and field observation, it is believed that farmers are applying excess or less amount of irrigation water without considering crop need. On the other side ‘improved’ irrigation water management practice means the knowledge of applying the right amount at the right time (i.e. ‘when’ and ‘how much’ to apply).

Irrigation and water harvesting research team of Adami Tulu research center has recommended proper irrigation scheduling of tomato, onion and green pepper based on climate-crop-soil relationships forAdamitulu and similar agro-ecological areas. Therefore, this research study wasintended to evaluate and demonstrate these proper irrigation scheduling technologies under farmer’s circumstance.

Materials and Methods

The evaluation and demonstration were conducted during irrigation season (December-April) of 2018 and 2019,on three farmers’ fields at different locations around Dugda district (two farmers at BekeleGirisa and one farmer at ShubiGamokebeles). Bombay Redonion varietywas selected as test crop due to farmers’ preference and its wide use and area coverage at both kebeles.The demonstration activities were carried out with three farmers around Dugda district on eight plots. Data on soil, climate and crops were used to determine when and how much to irrigate for onion crop planted on the demonstration plots. Three inches Parshall flume was used to measure the amount of water diverted in to farmers and demonstration plots.

Depths of water application for plots were determined based on effective root zones of the selectedcrops and monthly average evapo-transpiration (mm/day) of the area throughout growing stages. For the first two months, 30cm root depth was considered for the crop. After two months, 45cm root depthwas considered for onion crop (Allen *et al*., 1998).

Before starting the activities, irrigation and extension researcher of Adami Tulu research center visits different farmer managed irrigation practices. Group discussions about the objective of the activity with member of Farmers-Research-Extension-Groups (FERGs), development agent (DAs) and farmers’ representative of the area were taken. Training was given for farmers and DAs on improved irrigation water management technologies. Then two test sites and two willing farmers were selected. Farmers’ selections were carried out based on availability of land, access to irrigation water, individual interest and acceptance of the farmer by the society. Supporting guidelines on how to determine appropriate irrigation schedulingand how to measure the amount of water passing through the Parshall flume were prepared and distributed for farmers.

Hosting farmers were trained and assigned to measure the amount of water to be applied at each irrigation event for both experimental and farmers practice plots. During the study period several farmers were invited to observe the activities and on-farm training/technical explanations were given.

For the demonstration plots during the initial and the last phases, 11.4 and 17.7 mm of water at four days intervals were applied for onion, respectively. The amount of water applied by farmers to their fields were measured and recorded. Application and measurement of water for the demonstration and farmers' plots were started just after transplanting both crops.

Determination of Crop Water Requirement

Determination of onion crop water requirement throughout the growing season was determined based on FAO guidelines by identifying all the required data (Table 1)..

Table 1: parameters of CWR determination

Crop type	Total growing days	Parameters	Growing stages			
			Initial	development	Mid-season	Late season
Onion	120	Kc	0.4	0.7	0.95	0.85
		days	25	30	45	20
		Ky	0.45		0.8	0.3
		p	0.25			
		At harvest	0.75	Total Ky	1.1	
		Root depth	0.3	0.45		

Yield advantage

The relative yield advantage were determined by using the following equation

$$\textbf{Yield advantage (\%)} = \frac{\text{Yield of improved irrigation-Yield of farmers practice}}{\text{Yield of farmers practice}} \text{ X100}$$

Regular follow up

The activity was regularly visited by a team composed of researchers from Adami Tulu Agricultural Research Center, experts from district agriculture office as well as DAs at each sites.

Data collected

In order to compare the two irrigation practices (improved irrigation management and farmers practice), data on the volume of water being applied during total growing period and at each irrigation event were recorded. And the performances of the crops during their growing season together with their total yields were collected. Yield (marketable, unmarketable, bulb length and bulb diameter) data of onion were collected from the two middle central row of furrows net areas of (0.75m*5m) $3.75m^2$from each of hosting farmers.

Data managements and analysis

The data were handled with care and documented appropriately. Frequent monitoring and evaluation technique were employed to control reliability of the data. The data collected during the field studies were analyzed and compared using simple descriptive statistics.

Results and Discussion

The total numbers of irrigation during the growing period of onion on the three demonstration plots were 22 times for four months. Both improved and traditional practices were irrigated at the same time, their differences were on the depths of water applied at each irrigation events. All the three farmers were applying water at different dates with the improved practices because of their planting dates varies.

Regarding water application, it was observed that farmers were diverting excess water to their plots without considering crop water requirement and moisture holding capacity of the soil. So, it is common to see water stagnating between furrows for several days. On the other hand, furrows in the improved or demonstration plots were free of any excess water.

Water requirements of Onion

Estimation of the water requirement of a crop is one of the basic needs for crop planning on the farm. Results of crop water requirement (ETc) were determined based on climate conditions of the area by determining the reference evapotranspiration (ETo) and multiplying with crop coefficient (Kc) of the onion crop (table 2).

Table 2: Crop water requirement and potential evapotranspiration

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	7.59	8.07	7.95	7.48	7.21	7.26	5.66	5.36	5.50	6.97	7.76	7.49
No. of days	31	28	31	30	31	30	31	31	30	31	30	31
ETo (mm/month)	235.3	226.0	246.5	224.4	223.5	217.8	175.5	166	165	216	232.8	232
Kc (crop coefficient)	0.4	0.7	0.95	0.85								
Crop water requirement (mm/day)	3.04	5.65	7.55	6.36	6.13							
Crop water requirement (mm/month)	94.1	158.2	234.2	201.9	201.1							
Irrigation requirement (mm/day)	5.1	9.4	12.5	11.22	10.82							
Irrigation requirement (mm/month)	156.8	263.7	390.2	336.6	335.2							

Water applied

Amount of irrigation water applied were measured throughout the developmental stages of crop growing to each of the specific sites of farmers plot and also the farmers practice was also measured (Table 3).

Table 3 Number of irrigation and amount of irrigation water applied for onion crop

Location	Practices	Plot area m^2	Number of irrigation	Irrigation depth (mm)	Total amount of water applied(mm)
F1$_{BG}$	Measured	15	22	20.36	448

	Farmers practice	15	22	38.73	852
$F2_{BG}$	Measured	15	22	20.36	448
	Farmers practice	15	22	37.27	820
$F1_{SG}$	Measured	15	21	20.38	428
	Farmers practice	15	21	37.86	795

*$F1_{BG=}$Farmer 1 at BekeleGirisa, $F2_{BG=}$Farmer 2 at BekeleGirisa, $F1_{SG}$= Farmer1 at ShubiGamo

As indicated in the above table the depth of water applied by traditional (farmers practices) is more than the improved irrigation application on each of the three farmers plots that the farmers were applied 90.18%, 83.04% and 77.46% more irrigation water, respectively at the three sites.

Effect of improved irrigation water management on crop yield

Bulb length and bulb diameter

Data in Table (4) show that the bulb weight (gm) and diameter (cm) improved methods of irrigation were affected onion crop at the three sites of study. Improved water management method showed that a better bulb which was observed with bulb diameter and bulb size with corresponding increased values of 3.36 to 6.72% and 2.78 to 12.1%, respectively over that of the farmer's irrigation system. The bulb diameter and length character exhibited the same trend with corresponding Increment of improved irrigation values reached an average of from (0.1-0.16cm) and (0.1-0.39cm) over farmers which traditionally used of irrigation respectively.

Table 4 average marketable and unmarketable onion yields and bulb weight, diameter and length obtained from traditional and improved activities.

Location (PA)	Farmers	Practices	Bulb weight (gm/plant)	Bulb length (cm/plant)	Bulb diameter cm/plant	Unmarketable yield (ton/ha)	Marketable yield (ton/ha)
BekeleGirisa	Farmer 1	Improved	59.20	2.68	3.70	2.35	28.83
		Farmers practice	58.50	2.54	3.60	3.82	24.53
	Farmer 2	Improved	64.78	3.08	3.79	1.74	29.47
		Farmers practice	55.16	2.98	3.56	1.77	18.57
ShubiGamo	Farmer 1	Improved	56.63	2.54	3.41	1.95	21.77
		Farmers practice	55.32	2.38	3.02	2.06	18.40

Bulb weight

As shown in table 4 the mean weight bulb Improved water management method yielded 1.20 to 17.44% more bulb weight per plant as compared to farmers practice. The value of bulb weight were increased on average from (0.7 - 9.62gm) of improved irrigation over farmer’s practices.

Yield

As indicated in Table 4, the average yield gained in applying or usage of proper application of water in amount and time or improved irrigation greater than that of farmers used to apply the irrigation water by their method. Those the yield obtained in range of 217.67 Qt/ha to 294.71 Qt/ha with the proper application in amount of irrigation water and in time of the crop needs (improved irrigation) maximum with that of the range of 184.00 Qt/ha to 245.33 Qt/ha observed in farmers practices that traditionally by applying the irrigation water to their field without knowing the amount of water the onion crop requires on which the farmers used excess water to their fields. The excess amount may cause water logging i.e poor aeration to the roots and soil. Hence over irrigation leads to reduced growth which may result in yield reduction.

Water Use Efficiency

The results showed that by using better water management technologies of improved irrigation by proper application of water (amount and time) to the crop resulted in highest water productivity values (i.e., more than 100% increment over the traditional practice) (Table 5).

Table 5: Water Use Efficiency of improved and traditional irrigation at each location

Location	**Practices**	**Applied water (m^3/ha)**	**Yield (kg/ha)**	**Water use efficiency (kg/m^3)**
$F1_{BG}$	Measured	*4480*	28832	6.4
	Farmers practice	*8520*	24533	2.9
$F2_{BG}$	Measured	*4480*	29471	6.6
	Farmers practice	*8200*	18567	2.3
$F1_{SG}$	Measured	*4480*	21767	4.9
	Farmers practice	*7950*	18400	2.3

*$F1_{BG=}$ Farmer 1 at BekeleGirisa, $F2_{BG=}$ Farmer 2 at BekeleGirisa, $F1_{SG}$=Farmer1 at ShubiGamo

Yield increment and water saved

Applying proper amount of irrigation water according to crop water requirement and better management and utilization of irrigation water leads to higher yield advantages than that of traditionally farmers’ practices that apply irrigation water to their field. Hence, as shown in Table 6 improved irrigation gave a yield difference ranging in between 34 to 109Qt/ha over farmers practices.

Table 6: Yield increment and water saved from improved irrigation management

Location	Irrigation	Increase in yield	Amount of water saved

	Practices	(Qt/ha)	%	(mm)	%
$F1_{BG}$	Measured	43	17.53	404	47.42
	Farmers practice	0	0	0	0
$F2_{BG}$	Measured	109	58.73	372	45.37
	Farmers practice	0	0	0	0
$F1_{SG}$	Measured	34	18.30	347	43.65
	Farmers practice	0	0	0	0

*$F1_{BG=}$Farmer 1 at BekeleGirisa, $F2_{BG=}$Farmer 2 at BekeleGirisa, $F1_{SG}$=Farmer1 at ShubiGamo

Improved irrigation water applications on onion bulb yield (Table 6) the result indicated that proper water application to furrow method of irrigation under better management and utilization of irrigation water resulted in higher yield advantage of 17.53% to 58.73% as compared to farmers’ methods of irrigation water application practices. Similarly, irrigation water amounts that were applied under two methods of application showed significant difference between them; improve irrigation method saved 43.6 to 47.42% water than farmers’ practices. Those farmers were applied 347 to 404 mm excess water which was above the crop water requirement leading to yield loss.

Perceptions of farmers on improved irrigation

All FREG members and neighboring farmers, development agents, experts and researchers were closely evaluate the performances of the improved irrigation water management and farmers practice based on their own criteria.

Conclusion and Recommendation

In this study, improved irrigation water management technologies was found to be best performing and gave better onion yield and water use efficiency for the study area. The relative yield advantage obtained was in between 17.52 to 58.73% over farmer’s practices at three sites.

The value of water productivity decreased as the amount of irrigation amount increased. Irrigation water use efficiency generally tends to increase with a decline in irrigation amount (Howell 2006). Water productivity can be increased by increasing yield per unit land area. In addition, water management strategies and practices should be considered in order to produce more crops with less water.

The results from demonstration have shown that there is potential of increasing the productivity of irrigation water at farmer levels. Evaluations and regular visits of the demonstration activities showed that farmers’ perception were changed towards proper irrigation water management. Measuring of irrigation water to be applied in to the field should be based on the soil, crop and climate data, so availability of this information is very important.

To achieve better control and management of water in onion production, the irrigation schedule should be based on the crop requirement for water. Onion water requirement is influenced by crop variety, soil type, and soil moisture regime, physiological and environmental factors. In order to maximize onion yield and its quality and to use the irrigation water efficiently, it is recommended to give proper amount and in time of onion crop needs and also awareness creation at farmer's level on irrigation water management and utilization should be given.

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Effect of deficit irrigation at different growth stages on seed yield, yield components and water productivity of onion (Allium cepa L.), in Oda Bultum districts, West Hararghe

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Abstract

The aim of this study was to evaluate the effects of different irrigation level on seed yield, yield components and water productivity of onion (Allium cepa L.). The experiment was carried out on two farmer's field on Midhagdu small scale irrigation at Oda Bultum district, West Hararghe zone during 2018/19. The experiment was laid out in a randomized complete block design with three replications of five irrigation levels (i.e.100, 90, 80, 70 and 60%) in combination of four growth stages (vegetative, bolting, flowering and seed formation stages) with non deficit at all growth stages as control. The combined result of deficit furrow irrigation techniques indicated that there were significance (*$p<0.05$*) *difference between the seed yield and water productivity while there was no significance* (*$p<0.05$*) *on other growth parameters. The highest mean of yield and returns were gained from 20% deficit at vegetative stage with cost benefit ratio of nine which shown the principle of onion yields were higher with less water stress and reduced with increase in water stress. Thus, the findings summarized that using deficit irrigation of 20% were economically profitable and saves water than no deficit at all growth stage at study area and in similar irrigation available agro ecology.*

Key words: *onion, water productivity, seed yield*

Introduction

Onion (*Allium cepa* L.) is commonly cultivated in all countries of tropical Africa including Ethiopia (Grubben and Denton, 2004). Onion is important in the daily Ethiopian diet and all the plant parts are edible, although the bulbs are widely used as a seasoning or a vegetable in various dishes. It is one of the most economically important horticultural crops in the country. The area under onion is increasing from time to time mainly due to its high profitability per unit area, ease of production and increases in small scale irrigation practices. It is produced both under rain-fed in the "Meher" season and under irrigation during off-season that constitutes much of the area under onion production (Nigussie *et. al.*, 2015). During 2006, the rainy season about 16, 578.72 ha of lands were planted and more than 0.17 million tons of bulbs were obtained with an average yield of 10.6 tons/ha (CSA, 2006).

Onion suitably grows in between 500-2400 mean above sea level. But, the best growing altitude so far known in Ethiopia is between 700-1800 m.a.s.l. Besides altitude which has an indirect bearing on climate, onion production is affected by temperature, rainfall and soil. It is suitably grown under mild seasons without extremes of heat, cold or moderate rainfall. Optimum temperature of 18.3-23.90°C day and 10-12°C of night temp are ideal for onion bulb production. But lower temperature is preferred for seed stalk development. Onion requires deep alluvial and friable or sandy loam soil with a pH limit of 6.0 - 8.0 (Olani and Fikre, 2010). Onion does not tolerate badly drained soil and also it is moderately sensitive to soil salinity (Nigussie, *et al.*, 2015). Onion is the second most produced and important vegetable crop next to potato in eastern part of Ethiopia (Bezabih and Hadera, 2007). The major crops cultivated using irrigation in the study area (Western Hararghe zone) were high value crops, about 43.2% cultivated both hot pepper and tomato followed by combination of onion, cabbage, red root and tomato by 19.9% and 13% cultivate both onion and tomato as well the left others cultivate different horticultural crops (Ayala *et.al.*, 2018).

Onion is cultivated both under rain fed and irrigated condition in Western Hararghe zone particularly in Gemechis, Guba Qoricha, Anchar, Habro, Oda Bultum and Daro Labu districts. In Gemechis district, for instance, A. *cepa* L. was produced in total land area of 218.94 and 431.64 hectares during the main (Meher) and short (Belg) rainy seasons, respectively and the average bulb yield obtained was 6.5 tons per ha which is far less than both from the national and world average yield of 10.6 and 13.4 tons per ha, respectively (FAO, 2006). This may be due to the vegetable seed (including onion) supply and distribution system is generally weak in Ethiopia. There is limited access of improved varieties, seed source and quality as well as price (Tabor and Yusuf, 2012 cited in Amsalu *et al*., 2014). The bulk of existing cultivated vegetable seeds are imported, often-that are not adapted to the local agro-climate (Amsalu *et al*., 2014). Similar problem related to seed supply system of vegetables is reported in Eastern part of Ethiopia (Bezabih and Hadera, 2007) where less quality seeds of onion imported from other areas (central rift valley for example) and from abroad through different marketing channels.

As survey done by (Ayala *et.al.*, 2018) shown several constraints responsible for low onion yield were water shortage for irrigation, lack improved seed varieties recommended for the area, diseases outbreak, pest, drought and low price were among major problems of irrigation practices on the study area. Among these listed constraints, availability of irrigation water that resulted from absence of adequate surface (rivers, lakes, streams) and ground water resources, low rainfall amount which is characterized by having high spatial and temporal variability (i.e., within and inter-annual variability) in the area is the major one which has to be addressed through its efficient utilization of available water.

Thus, there is need to introduce irrigation scheduling based on developmental stage or deficit irrigation; which is the technique of applying water on a timely and accurate basis to the crop, and is the key to conserving water and improving irrigation performance and sustainability of irrigated agriculture in the intended areas. Water availability and cultural practices may influence not only the interrelationships between onion seed yield and its components but also its quality. Several works have been conducted on onion bulb production through efficient and water saving practices like application of deficit irrigation at different developmental stage but a little information is available on identifying its effects for onion seeds production in Ethiopia in general and the study area in particular. It is reported that yield and quality of onion seed are greatly affected by soil moisture content during various growth and development stages (Dilip *et al.,* 2014). It is important to find out the most critical growth stage(s) of onion for quality seed production. Therefore, the present study was undertaken to evaluate the effect of deficit irrigation at different growth stages on seed yield, yield components and water productivity of onion for optimum production.

Materials and Methods

Description of study area

The study was conducted in Oda Bultum district of West Hararghe zone. The district is located at longitude and latitude of 08^{0}54’318’’ N and 040^0 02’10’’E at 404 km east of Addis Ababa, capital city of Ethiopia. The annual rain fall is 900 mm-1100 mm). It has a mean maximum and mean minimum temperature of 28°C and 25°C; respectively. The district is characterized reddish sandy loam in color.

Experimental Design and Treatments

The study was conducted at Oda Bultum district, West Hararghe zone. Starting from October 2018 the activity was conducted on two farmer’s field on Midhagdu small scale irrigation. Onion variety *“Bombay red”* was used as test crop. Bulb to seed method of seed production was selected for this study. The experiment was laid out in a randomized complete block design with three replications of five irrigation levels (i.e.100% ETc- no water deficit, 90% ETc-10% water deficit, 80% ETc-20% water deficit, 70% ETc-30% water deficit and 60% ETc-40% water deficit) in combination of four growth stages; vegetative (VS), bolting (BS), flowering (FS) and seed formation stages (SFS) in different combinations giving a total of twenty one treatments. The experimental plot size of 3m x 2m was used with spacing between plots 1 m and blocks 1.5 m in order to avoid water flow among treatments. This gives a total experimental size of 12m x 62m. Bulbs were set upright and at a depth of 2.5 cm. Spacing between plants was 30 cm and between row 40cm and total plant population in one plot was about 50 plants. Measured amount of water (according to the treatments) was applied to each plot at required intervals to maintain the soil moisture content in the root zone up to field capacity. The crop was kept weed free by manual hoeing.

Table 1. Treatment arrangements

Treatments	Growth stages				Description
	Vegetative stage (VS)	Bolting stage (BS)	Flowering stage (FS)	Seed form. stage (SFS)	
T1	100%	100%	100%	100%	No water deficit at any stage

T2	90%	100%	100%	100%	10% water deficit at VS
T3	100%	90%	100%	100%	10% water deficit at BS
T4	100%	100%	90%	100%	10% water deficit at FS
T5	100%	100%	100%	90%	10% water deficit at SFS
T6	80%	100%	100%	100%	20% water deficit at VS
T7	100%	80%	100%	100%	20% water deficit at BS
T8	100%	100%	80%	100%	20% water deficit at FS
T9	100%	100%	100%	80%	20% water deficit at SFS
T10	70%	100%	100%	100%	30% water deficit at VS
T11	100%	70%	100%	100%	30% water deficit at BS
T12	100%	100%	70%	100%	30% water deficit at FS
T13	100%	100%	100%	70%	30% water deficit at SFS
T14	60%	100%	100%	100%	40% water deficit at VS
T15	100%	60%	100%	100%	40% water deficit at BS
T16	100%	100%	60%	100%	40% water deficit at FS
T17	100%	100%	100%	60%	40% water deficit at SFS
T18	90%	90%	90%	90%	10% water deficit at all stages
T19	80%	80%	80%	80%	20% water deficit at all stages
T20	70%	70%	70%	70%	30% water deficit at all stages
T21	60%	60%	60%	60%	40% water deficit at all stages

Estimation of Irrigation Water

The irrigation water was applied to bring the soil moisture content at the root zone to field capacity taking into account the effective root zone depth. Before each irrigation times, soil moisture was determined by Gravimetric method. Measured amount of water was applied to all treatments. The effective root zone of onion is considered to vary from 30-40 cm depending on the growth stage. The depth of water was determined using the following equation (eq-1):

$$d = \sum_{i}^{n} \frac{M_{fci-M_{bi}}}{100} BixDi \qquad Eq - 1$$

Where;

d = net amount of water to be applied during an irrigation, mm

Mfci = field capacity moisture content in the ith layer of the soil, percent

Mbi =moisture content before irrigation in the ith layer of the soil, per cent

Ai = bulk density of the soil in the ith layer

Di = depth of the ith soil layer, mm, within the root zone, and

n = number of soil layers in the root zone D.

Determination of Effective Rainfall

Effective rainfallis determined using USDA method and is deducted from gross irrigation to supply the remaining irrigation requirement (Eq. 2 & 3).

$P_{effective} = P_{total}$ (125-0.2 × P_{total})/125 for $P_{total} < 250$ mm Eq-2

$P_{effective} = 125 + 0.1 \times P_{total}$)for $P_{total} > 250$ mm Eq-3

Where: $P_{effective}$ = Effective rainfall, mm

P_{total} = Total rainfall, mm

Irrigation interval,

I (days) =d_{net} (mm)/ET_{crop}(mm/day) Eq-4

Where, ET_{crop}(mm/day) is peak evapo-transpiration demand of the crop

Data collection

Soil physical properties such as field capacity**,** permanent wilting point, bulk density**,** soil texture were taken once before commencing the treatment; soil moisture content every 7 days (may adjusted based on Equ-4 above) after commencing the treatments taken at a depth of 20 cm and 40 cm.

Soil chemical properties such as PH, CEC, organic carbon, available P & K, total N were determined from composite soil samples taken at two layers 0-20cm/20-40 cm before treatment application and at harvest analyzed with standard laboratory procedures.

Growth parameters and yield components: five plants from middle of each plot were selected randomly at harvest for collection of data on growth, yield components and yield such as plant height(cm), Number of flower stalk/plant, Length of scape (cm), Diameter of scape (cm), Diameter of Umbel (cm), Seed yield per plant (g) and Seed yield (Kg/ha).

Irrigation schedule and water productivity: amount of irrigation water used for each treatment (mm), time of application (interval), Water productivity (kg/m^3) were taken.

Economic data: all necessary data were taken to determine cost to benefit ratio that help to separate the most economical treatment to be used for further demonstration and scale up.

Soil sampling and Analysis

Composite soil samples were collected from three locations of the experimental field at soil depth of 0-40 cm for soil Physico-chemical property analysis. Undisturbed soil samples were collected for bulk density determination using core sampler of volume 98.125 cm^3 for every 20 cm soil depth up to 40 cm.

Soil Moisture Determination

Composite soil samples were taken at 4-7 days interval at depth of 0-40 cm for soil moisture analysis using gravimetric method in order to schedule irrigation. The collected soil samples were placed in an oven dry at a temperature of 105^0C and dried for 24 hrs. Its gravimetric water content was then determined using the expression (Cuenca, 1989).

$$\theta dw = \frac{(Wws-Wds)}{Wds} x100 \ldots \ldots\ldots\ldots\ldots\ldots 3$$

Where; Wws= weight of wet soil (g) θdw = water content expressed on weight basis in (%), Wds = weight of dry soil (g)

Determination of soil physical characteristics

Soil texture: The hydrometric method was used for the particle size analysis of the bulk soil samples corresponding to each depth ranges. The textural class of the soil was determined using USDA textural triangle following the procedures indicated by Day (1965).

Bulk density: For the determination of bulk density, undisturbed soil samples were collected and oven dried for 24 hours at a temperature of 105^0C to remove the soil moisture to get the dry weight of the soil. It was then computed using the following equation as stated by Michael (1978).

$$\rho b = \frac{\mathrm{Wd}}{Vs} \ldots\ldots\ldots\ldots\ldots 1$$

Where: ρb is the bulk density of the soil in g/cm^3, Wd is the weight of oven dry soil in gram and Vs is the volume of the same soil sample in cm^3 (core volume).

Field capacity and permanent wilting point

The Field capacity (FC) and permanent wilting point (PWP) were determined using pressure plate and pressure membrane apparatus, respectively. Soil samples were saturated for one day (24 hours) and a pressure of 1/3 bar and 15 bar were exerted, respectively for FC and PWP, until no water droplets detected.

Determination of soil chemical characteristics

The soil pH was determined by measuring soil solution of 1:2.5 ratios (soil to water) with a pH meter using combination glass electrode as described by Jackson (1958). The percentage of organic carbon (OC) was determined following the wet digestion method as described by Walkley and Black (1934). OM content was then determined by multiplying OC by 1.724 (Nelson and Sommers, 1996). Electrical conductivity of the irrigation water and the soil was determined using electrical conductivity meter (EC meter).

Depth and Discharge Measurement

The total amount of water required was diverted to the furrow with calibrated parshal flume having appropriate opening diameter of three inch (3") with a length of 2 m and its appropriate head ranges from 3-33 cm. Water flow to each furrow was controlled by the difference in depth between the water level in the feeder canal and free water level at the outlet at the furrow head. It was calculated as suggested by Michael, (1997):

$$\mathrm{Q} = 0.1771\mathrm{h}^{1.55} \ldots . 2$$

Where; Q = discharge from parshall flume (l/s)

h = effective head of Parshall flume causing flow (cm)

The time required to deliver the desired depth of water into each furrow was calculated using the equation recommended by Israelsen (1980).

$$\mathrm{t} = \frac{dxwxl}{qx60} \ldots\ldots\ldots\ldots 3$$

Where; d= gross depth of water applied(cm) t= application time (hr) l= furrow length in (m), w= furrow spacing in, (m) q= flow rate (discharge)(l/s)

Flow Time Measurement

First, the amount of water required for each treatment was calculated, then parshall flume calibrated at different head using stopwatch during each irrigation water application in order to assess the treatment effects. Data on water volume and length of irrigation time was taken during all irrigation events from discharge of the parshall flume. For each treatment, the water productivity, WP (kg/m^3) was calculated using the following formula as described by Michael (1997)

$$\mathrm{Wp(kg/m3)} = \frac{seed\ yield(kg)}{amount\ of\ water\ used(\mathrm{m3})} \ldots\ldots\ldots.\ 2$$

Data analysis

The means of the above parameters was subjected to analysis of variance (ANOVA) using Gen-stat version 16th computer software. Mean comparison done by using least significant difference test at 5% probability level.

Result and Discussion

Physico-chemical properties of soils of the experimental site

The bulk density, water content of field capacity (FC) and permanent wilting point (PWP) values is presented in Table 2. The average bulk density values were 1.24g/cm^3 and 1.18g/cm^3 for 0 - 40 cm on the first and second location during 2019 respectively, on Midhagdu PA (Table 2). The soil moisture content at field capacity of the soil ranged from 39.6% to 40.1% on 40 cm depth on different location. The permanent wilting point values obtained varied between 28 % and 29.5 % on location basis. Based on these parameters irrigation was applied on depth basis at all locations by measuring amount of water using parshall flume.

Table 2. Bulk densities, field capacity and permanent wilting point of the soil

Depth (cm)	Bulk Density (g/cm^3)	FC(%)	PWP(%)	Texture	Site
0-40cm	1.24	40.1	28	Sandy loam	Midhagdu 1
0-40 cm	1.18	39.6	29.5	Silt loam	Midhagdu 2

Soil chemical properties

Soil pH's of the area were 7.51 and 7.52 which found to be optimum for onion production. Both of them were classified under slightly alkaline category. The electrical conductivity of the soil (ECe) was 1.7 and 0.87 mmhos/cm, respectively at 25^{0}c. Since, the EC of both areas were less than 2 mmhos/cm it's classified under non-saline soil. The total nitrogen N (%) 0.27 on first location is categorized as high while on the second location 0.18 is classified as medium. The exchangeable sodium measures the amount of soil exchange capacity occupied by sodium and expressed as a percentage which is 0.02% for this area is very low on both locations. An ESP>15% indicates that soil sodium will probably limit permeability (Scianna *et.al.*, 2007).

location	**Depth (cm)**	**EC(mmhos/cm)**	**pH**	**TN (%)**	**P(mg/kg)**	**K(mg/kg)**	**% OC**	**CEC(meq/100g)**	**Na(meq/100g)**
Midhagd 1	0-40	1.7	7.51	0.27	92.4	491	0.59	25.1	0.9
Midhagd 2	0-40	0.87	7.52	0.18	49.6	371.5	0.48	33.5	0.9

Effect of deficit irrigation on growth parameters and yield of onion Seed at Oda Bultum district

Plant height

The analysis of variance result shows that different irrigation water levels had significant effect on growth parameters of plant height at both locations (see Table 3 and 4). The tallest plant height was recorded on 40% deficit at vegetative stages (77.27 cm) while the shortest was recorded on 40% deficit throughout growth stage (65.2 cm) on the first location and on the second location no deficit at all stage recorded tallest by (73 cm) while shortest was recorded on 30% deficit at bolting stage. However, when we see the combined mean of two locations plant height the tallest was recorded on 20% Bs and 10% Fs while the shortest was recorded on 40% throughout all growth stage. The result agrees with (Bhagyawant *et.al*, 2015) 40% water deficits all through the crop season, plant height were reduced. The shortest plant height was due to water stress when the crop needs more water. Also, the result obtained agrees with the finding of (Dirirsa.G, 2017) who reported reduced plant height of onion due to water deficit at vegetative and bulb formation stages. The increasing of plant height with adequate soil moisture application is related to water in maintaining the turgid pressure of the plant cells which is the main reason for the growth (Enchalew *et.al.*, 2016). In the other side the shortening of plant height under less soil moisture stress may be associated due to the closure of stomata to conserve soil moisture evaporation, this leads to reduce uptake of CO_2 and nutrient. Therefore, photosynthesis and other biochemical reactions are hindered, eventually affecting plant growth.

Number of tiller per plant

The number of tiller per plant is important growth parameters contributing to seed yield. As number of effective tiller per plant increase, the yield increase. If the number of tiller per plant is not effective the yield decrease. The application of different irrigation water levels showed that higher number of tiller per plant were recorded 10% deficit at bolting stage, 40% deficit bolting stage, 10% deficit throughout all growth stage and lower number of tiller per plant were recorded on 40% deficit throughout growth stage, 20% deficit at bolting and flowering stage and 30% deficit at bolting stage on both locations (Table 3 and 4).

Number of flower stalk per plant

Number of flower stalk per plant is summation of number tillers forming flower including mother stalk. This is important parameters affected seed yield positively, if it effectively bears a seed. As shown from Table 3 and 4 the highest number of flower stalk per plant was found from treatments of 10% on all growth stage except 10% thr on first location and on 30% throughout growth stage and on all other growth stage except 30% Vs on the second location.

Length and diameter of Scape

There was no significance difference between irrigation water regimes on length and diameter of scape. The highest length of scape was found on 20% Bs, 10%Fs and no deficit at all growth stage while the lowest was found on 40% Fs and 30% Vs(Table 5). This shows length of scape reduced with increase water stress. While highest diameter of scape was found on 20% thr and 40% Vs and the lowest was found on 20% Vs and 20% Sf. The combined mean of length of scape and diameter of scape ranges from 64.27 cm to 69.12 cm and 2.32 cm to 2.72 cm respectively.

Diameter of Umbel

The diameter of umbel is important growth parameters contributing to seed yield. The irrigation water regimes had no significant difference at ($p<0.05$) on umbel diameter, which was ranged from 5.5 to 6.25 cm with mean of 5.8 cm (Table 5). This ranges similar with studies of (kumar *et.al,* 2014). The highest combined mean of diameter of umbels were recorded from no deficit at growth stage (100%) and 20% Bs with similar values of 6.25 cm while the lowest was obtained from 20% Fs with values of 5.55 cm (Table 5).

Seed yield per plant (g) and seed yield (kg/ha)

The analysis of variance result shows that there were significant yield difference at ($P<0.05$) between deficit irrigation on seed yield (kg/ha). There is significant difference between treatments of deficit irrigation 30%Sf and 40% thr on first location and 20%Sf and Nd on second location (Table 3 and 4). As observed from Table 3 and 4, the highest yield obtained from 30%Sf (778 kg/ha) and 20% Sf (943.6kg/ha) while the lowest yield obtained from 40% deficit throughout growth stage (490.7kg/ha) and no deficit at all stage (100%) by (541.8kg/ha) on Midhagdu 1 and Midhagdu 2 respectively (Table 3 and 4). As shown from this result high water stress and high amount of water application affects the seed yield. There is significance difference between treatment 30% deficit applied at seed formation stage (30%sf) and 40% deficit applied throughout growth stage (40% thr) as well as between 20% deficit applied at Seed formation stage (20%Sf) and no water deficit at all stage (100%). As observed from the Table 3 and 4 onion seed yield is affected at 10%Vs, 40% thr and Nd at both locations.

The average seed yield per plant ranged from 6.9 to 9.4 g with an average of 8.2 g. The highest seed yield per plant (9.4 g) and (9.2 g) were obtained from 20%Vs and 20% Sf respectively. While the lowest seed yield per plants were found on no deficit irrigation at all stages and 40% throughout all growth stage with values of 6.95 g and 7 g respectively. From the results it is clear that flowering stage of onion seed production may be considered critical. However, the role played by each of the yield contributing factors is actually the result of complex interactions with all the others and, as such, is difficult to interpret (Kumar *et.al.*, 2014).

Analysis of ANOVA shows that there is no significance difference between the growth parameters and yield components when we see both locations means compared together (Table 5). The highest mean of yield from two locations were recorded on 20% Vs, 20%Fs, 20%Sf and 10% Sf while the lowest mean yield was recorded from Nd, 40% thr and 40% Sf. This shows that the optimum seed yield were obtained on 20% on all growth stages except on bolting stage only, while high water stress and no deficit throughout growth stages affects yield of onion negatively on Oda Bultum district. Thus, the onion yields are higher with less water stress and reduced with increase in water stress except on no deficit at all growth stage. This result agreed with Bhagyawant *et.al* (2015) which reported the 20% deficit irrigation did not reduce the onion yield significantly.

Table 3: Growth parameters and yield of onion on Midhagdu scheme 1 field during 2018/19

Trt	**Plant ht(cm)**	**Tiller/plt**	**No. flower stalk/plt**	**Lnth of scape(cm)**	**Dia. of scape/mm**	**dia. of umbel/cm**	**seed yld/ plant (g)**	**Total yld (kg/ha)**
10%Bs	76.20	12.47	12.33	71.93	3.18	6.3	7.0	586.4
10%Fs	74.00	11.20	10.40	70.07	3.47	6.1	7.9	662.4
10%Sf	69.13	11.13	10.53	65.40	3.65	6.2	7.8	649.8
10%thr	71.47	10.13	8.60b	67.93	3.39	6.0	7.1	595.8
10%Vs	70.00	10.73	10.33	66.00	3.78	6.0	7.6	637.2
20%Sf	73.47	11.00	10.67	69.33	3.17	5.5	7.1	588.4
20%thr	77.53	11.80	11.20	71.27	3.77	6.3	8.8	734.4
20%Bs	75.33	11.00	10.93	71.60	3.79	6.2	6.8	565.3
20%Fs	71.33	9.40b	9.13b	64.00	3.68	5.7	8.1	675.4
20%Vs	67.87b	9.13b	8.53b	64.47	3.12	5.8	8.5	708.7
30%Bs	75.47	7.73b	7.27b	70.87	3.97	5.8	8.0	665.1
30%Fs	71.47	9.93	9.73	67.60	3.44	6.0	9.3	777.2
30%Sf	68.20b	10.20	9.73	64.27	3.87	6.1	9.3	778.7
30%thr	74.80	9.93	9.53	70.80	3.62	6.3	8.6	718.1
30%Vs	70.87	10.53	10.27	66.87	3.35	5.7	8.0	663.2
40% thr	65.20b	12.33	11.87	64.80	3.64	6.0	5.9	490.7
40% Vs	75.27	10.93	10.47	73.00	3.87	6.1	8.4	697.2
40%Bs	75.67	11.6	11.20	71.40	3.23	6.2	6.9	574.8
40%Fs	69.27	9.93	9.47	66.00	3.37	5.7	7.1	591.6
40%Sf	67.60b	10.67	9.53	63.80	3.23	6.0	6.6	550.4
Nd	73.53	9.6	9.80	69.30	3.66	6.5	7.4	618.6
LSD(0.05)	8.93**	3.05**	3.06**	9.73(ns)	2.00(ns)	0.93**	**4.1(ns)**	**246.7****
CV	7.5	17.6	18.4	8.7	37.8	9.4	**5.6**	**23.2**

SF= seed formation stage, VS= vegetative stage, BS= bolting stage, Thr= equal at all stage, FS= flowering stage, Nd= no deficit at all stages

Table 4: Growth parameters of onion on Midhagdu scheme 2 field during 2018/19

Trt	**Plant ht(cm)**	**Tiller/plt**	**No. flower stalk /plt**	**Lnth of scape(cm)**	**Dia. of scape(mm)**	**dia. of umbel (cm)**	**seed yld/plant(g)**	**Total yld (kg/ha)**
10%Bs	68.01	10.13	9.33	63.57	1.54	5.64	9.4	782.4
10%Fs	72.13a	9.27	8.33	67.88	1.49	5.54	8.1	677.9
10%Sf	67.60	8.87	7.60	63.86	1.52	5.70	10.2	848.1
10%thr	70.20	11.47	10.80	65.87	1.65	6.10	8.4	701.4
10%Vs	68.00	9.40	8.20	64.30	1.57	5.86	6.9	577.7
20%Sf	69.13	9.60	8.73	65.60	1.48	5.97	11.3	943.6
20% thr	69.27	8.60	7.80	65.63	1.67	5.50	7.2	597.1
20%Bs	70.90	9.33	8.80	66.63	1.63	6.29	8.4	696.3
20%Fs	65.00b	8.33	8.00	61.07	1.54	5.40	10.1	843.7
20%Vs	66.07b	9.67	9.13	62.08	1.52	5.72	10.2	849.3
30%Bs	64.87b	10.07	8.53	61.48	1.44	5.41	9.9	821.5
30%Fs	70.07	11.00	10.20	66.27	1.72	5.82	7.2	602.9
30%Sf	70.87	11.07	10.20	66.87	1.54	5.76	7.9	661.4
30%thr	68.33	11.33	10.53	64.47	1.56	5.75	7.7	638.9
30%Vs	66.97b	9.73	8.73	63.00	1.66	5.92	9.2	770.6
40% thr	69.47	8.33	7.73	66.07	1.54	5.83	8.1	676.7

40% Vs	68.13	9.33	8.40	63.53	1.57	5.64	9.1	754.8
40%Bs	68.57	9.67	9.07	63.97	1.51	5.76	10.7	891
40%Fs	66.87b	9.93	9.27	62.53	1.84	5.67	11.0	918.9
40%Sf	70.87	10.93	10.67	66.87	1.58	5.86	7.8	645.9
Nd	73.67a	9.00	8.73	68.93	1.59	6.00	6.5	541.8
LSD(0.05)	**6.43****	**3.15(ns)**	**3.4(ns)**	**6.57****	**0.33***	**0.64***	**7.4(ns)**	**372.3****
Cv(%)	**5.70**	**19.60**	**22.90**	**6.10**	**12.80**	**6.70**	**8.9**	**30.7**

SF= seed formation stage, VS= vegetative stage, BS= bolting stage, Thr= equal at all stage, FS= flowering stage, Nd= no deficit at all stages

Table5. The combined mean of growth parameters and yield of two locations

Trt	**Plant ht(cm)**	**Tiller/plt**	**No. flower stalk/plt**	**Lnth of scape(cm)**	**Dia. of scape/cm**	**dia. of umbel/cm**	**seed yld/ plant(g)**	**Total yld (kg/ha)**
10%Bs	72.11	11.30	10.83	67.75	2.36	5.97	8.20	684.40
10%Fs	73.07	10.24	9.37	68.98	2.48	5.82	8.00	670.15
10%Sf	68.37	10.00	9.07	64.63	2.59	5.95	9.00	748.95
10%thr	70.84	10.80	9.70	66.90	2.52	6.05	7.75	648.60
10%Vs	69.00	10.07	9.27	65.15	2.68	5.93	7.25	607.45
20% Sf	71.30	10.30	9.70	67.47	2.33	5.74	9.20	766.00
20%thr	72.40	10.20	9.50	68.45	2.72	5.90	8.00	665.75
20%Bs	73.12	10.17	9.87	69.12	2.71	6.25	7.60	630.80
20%Fs	68.17	8.87	8.57	62.54	2.61	5.55	9.10	759.55
20%Vs	66.97	9.40	8.83	63.28	2.32	5.76	9.35	779.00
30%Bs	70.17	8.90	7.90	66.18	2.71	5.61	8.95	743.30
30%Fs	70.77	10.47	9.97	66.94	2.58	5.91	8.25	690.05
30%Sf	69.54	10.64	9.97	65.57	2.71	5.93	8.60	720.05
30%thr	71.57	10.63	10.03	67.64	2.59	6.03	8.15	678.50
30%Vs	68.92	10.13	9.50	64.94	2.51	5.81	8.60	716.90
40% thr	67.34	10.33	9.80	65.44	2.59	5.92	7.00	583.70
40% Vs	72.70	10.13	9.44	68.27	2.72	5.87	8.75	726.00
40%Bs	72.12	10.64	10.14	67.69	2.37	5.98	8.80	732.90
40%Fs	68.07	9.93	9.37	64.27	2.61	5.69	9.05	755.25
40%Sf	69.24	10.80	10.10	65.34	2.41	5.93	7.20	598.15
Nd	73.60	9.30	9.27	69.12	2.63	6.25	6.95	580.20
Lsd (0.05%)	**7.68 (ns)**	**3.10 (ns)**	**3.23 (ns)**	**8.10(ns)**	**1.16(ns)**	**0.78(ns)**	**5.75(ns)**	**309.50**
Cv (%)	**6.60**	**18.60**	**20.60**	**7.40**	**25.30**	**8.00**	**7.25**	**26.95**

SF= seed formation stage, VS= vegetative stage, BS= bolting stage, Thr= equal at all stage, FS= flowering stage, Nd= no deficit at all stages

Effect of Deficit irrigation on water productivity

The seasonal water used (mm), total irrigation water applied (m^3/ha) and water productivity are explained on Table 6 and 7 below. The total seasonal water used ranges from 187.53 mm/season to 312.63 mm/season from 40% deficit throughout all growth stage and no deficit at all growth stage respectively on the first location (Table 6). The highest water productivity was found on 30% and 20% deficit at all growth stage with values of 0.328

kg/m^3 and 0.294 kg/m^3 respectively while the lowest was found 10% deficit at bolting stage and no deficit at all growth stage with values of 0.193 and 0.198 kg/m^3 respectively (Table 6). The water productivity ranges from 0.193 kg/m^3 to 0.406kg/m^3 on both locations. The highest water productivity was found on 20% deficit seed formation stage and 40% deficit throughout all growth stage with values of 0.359 and 0.406 kg/m^3. The highest yield of seed also found on 20% deficit seed formation stage (Table 7). When we see the mean of water productivity on both locations the highest water productivity was found from 30% thr (0.33kg/m^3) and 40% thr (0.33kg/m^3) while the lowest found from no deficit at all growth stage (0.2kg/m3). This shows the increase in the water stress the higher water productivity found (Table 8).The result agrees with (Ayana, 2019) the water productivity increased with decreasing water supply.

Table 6.Total water used and water productivity on the Midhagdu scheme 1 field

Trt	Total seasonal water used(mm)	Total irrigation water applied(m^3/ha)	Onion Seed yield(kg/ha)	Water productivity(kg/m^3)
10%Bs	303.63	3036.30	586.4	0.193
10%Fs	305.16	3051.60	662.4	0.217
10%Sf	303.60	3036.00	649.8	0.214
10%thr	281.32	2813.20	595.8	0.212
10%Vs	306.83	3068.30	637.2	0.208
20% Sf	294.53	2945.30	588.4	0.200
20%thr	250.05	2500.50	734.4	0.294
20%Bs	294.63	2946.30	565.3	0.192
20%Fs	297.75	2977.50	675.4	0.227
20%Vs	301.03	3010.30	708.7	0.235
30%Bs	285.63	2856.30	665.1	0.233
30%Fs	290.33	2903.30	777.2	0.268
30%Sf	285.47	2854.70	778.7	0.273
30%thr	218.77	2187.70	718.1	0.328
30%Vs	295.23	2952.30	663.2	0.225
40% thr	187.53	1875.30	490.7	0.262
40% Vs	289.43	2894.30	697.2	0.241
40%Bs	276.63	2766.30	574.8	0.208
40%Fs	282.93	2829.30	591.6	0.209
40%Sf	276.43	2764.30	550.4	0.199
Nd	312.63	3126.30	618.6	0.198
LSD(0.05)			**246.7****	**0.16(ns)**
Cv (%)			**23.2**	**29.9**

SF= seed formation stage, VS= vegetative stage, BS= bolting stage, Thr= equal at all stage, FS= flowering stage, Nd= no deficit at all stages

Table 7.Water Productivity of Midhagdu scheme 2 location

Trt	Total seasonal water used(mm)	Total irrigation water applied(m^3/ha)	Onion Seed yield(kg/ha)	Water productivity(kg/m^3)
10%Bs	270.17	2701.7	782.4	0.290

10%Fs	270.33	2703.3	677.9	0.251
10%Sf	270.02	2700.2	848.1	0.314
10%thr	249.69	2496.9	701.4	0.281
10%Vs	271.67	2716.7	577.7	0.213
20%Sf	262.61	2626.1	943.6	0.359
20% thr	221.95	2219.5	597.1	0.269
20%Bs	262.83	2628.3	696.3	0.265
20%Fs	263.17	2631.7	843.7	0.321
20%Vs	265.83	2658.3	849.3	0.319
30%Bs	255.50	2555.0	821.5	0.322
30%Fs	256.00	2560.0	602.9	0.236
30%Sf	255.20	2552.0	661.4	0.259
30%thr	194.20	1942.0	638.9	0.329
30%Vs	260.00	2600.0	770.6	0.296
40% thr	166.47	1664.7	676.7	0.406
40% Vs	254.17	2541.7	754.8	0.297
40%Bs	248.17	2481.7	891	0.359
40%Fs	248.83	2488.3	918.9	0.369
40%Sf	247.80	2478.0	645.9	0.261
Nd	277.50	2775.0	541.8	0.195
LSD(0.05)			372.3**	0.09*
Cv (%)			30.7	22.1

SF= seed formation stage, VS= vegetative stage, BS= bolting stage, Thr= equal at all stage, FS= flowering stage, Nd= no deficit at all stages

Table 8.Comined mean of seasonal water used, onion yield and water productivity

Trt	Total seasonal water used(mm)	Total irrigation water applied (m^3/ha)	Onion Seed yield(kg/ha)	Water productivity(kg/m^3)
10%Bs	286.90	2869.00	684.40	0.24
10%Fs	287.75	2877.45	670.15	0.23
10%Sf	286.81	2868.10	748.95	0.26
10%thr	265.51	2655.05	648.60	0.25
10%Vs	289.25	2892.50	607.45	0.21
20% Sf	278.57	2785.70	766.00	0.28
20%thr	236.00	2360.00	665.75	0.28
20%Bs	278.73	2787.30	630.80	0.23
20%Fs	280.46	2804.60	759.55	0.27
20%Vs	283.43	2834.30	779.00	0.28
30%Bs	270.57	2705.65	743.30	0.28
30%Fs	273.17	2731.65	690.05	0.25
30%Sf	270.34	2703.35	720.05	0.27
30%thr	206.49	2064.85	678.50	0.33
30%Vs	277.62	2776.15	716.90	0.26
40% thr	177.00	1770.00	583.70	0.33
40% Vs	271.80	2718.00	726.00	0.27
40%Bs	262.40	2624.00	732.90	0.28

40%Fs	265.88	2658.80	755.25	0.29
40%Sf	262.12	2621.15	598.15	0.23
Nd	295.07	2950.65	580.20	0.20
LSD(5%)			309.50	0.12*
Cv (%)			26.95	26

Cost Benefit Analysis

The result shows that highest yield and returns were gained from 20% Vs, 20% Fs and 20% Sf. 20% Vs gave a net income of 291,700 Birr/ha (Two hundred thousand and seven hundred birr) and highest cost benefit ratio of 14.7. Thus, the findings summarized that using deficit irrigation of 20% were economically profitable and saves water than no deficit at all growth stage at study area.

Table 9.Partial budget analysis

	Inputs used										
Trt	Land rent	Land prep. and seed sowing	Fertilizer (Birr /ha)	Labour (Birr /ha)	Pesticid (birr/ha)	Yield (kg/ha)	Water price (m^3/birr	Total cost(Etb / ha)	Total ReturCost (ETB /ha)	Net income (Birr)	B/C
10%Bs	12000	5600	1600	415	300	1368.8	11476.0	31,391.0	273,760.0	242,369.00	7.7
10%Fs	12000	5600	1600	417.8	300	1340.3	11509.8	31,427.6	268060.0	236,632.40	7.5
10%Sf	12000	5600	1600	411	300	1497.9	11472.4	31,383.4	299580.0	268,196.60	8.5
10%thr	12000	5600	1600	397.8	300	1297.2	10620.2	30,518.0	259440.0	228,922.00	7.5
10%Vs	12000	5600	1600	412.6	300	1214.9	11570.0	31,482.6	242980.0	211,497.40	6.7
20% Sf	12000	5600	1600	371.4	300	1532.0	11142.8	31,014.2	306400.0	275,385.80	8.9
20%thr	12000	5600	1600	353.6	300	1331.5	9440.0	29,293.6	266300.0	237,006.40	8.1
20%Bs	12000	5600	1600	390.8	300	1261.6	11149.2	31,040.0	252320.0	221,280.00	7.1
20%Fs	12000	5600	1600	381.4	300	1519.1	11218.4	31,099.8	303820.0	272,720.20	8.8
20%Vs	12000	5600	1600	400.0	300	1558.0	11337.2	31,237.2	311600.0	280,362.80	9.0
30%Bs	12000	5600	1600	354.4	300	1486.6	10822.6	30,677.0	297320.0	266,643.00	8.7
30%Fs	12000	5600	1600	351.8	300	1380.1	10926.6	30,778.4	276020.0	245,241.60	8.0
30%Sf	12000	5600	1600	348.6	300	1440.1	10813.4	30,662.0	288020.0	257,358.00	8.4
30%thr	12000	5600	1600	309.4	300	1357.0	8259.4	28,068.8	271400.0	243,331.20	8.7
30%Vs	12000	5600	1600	357.8	300	1433.8	11104.6	30,962.4	286760.0	255,797.60	8.3
40% thr	12000	5600	1600	262.5	300	1167.4	7080.0	26,842.5	233480.0	206,637.50	7.7
40% Vs	12000	5600	1600	339.7	300	1452.0	10872.0	30,711.7	290400.0	259,688.30	8.5
40%Bs	12000	5600	1600	335.8	300	1465.8	10496.0	30,331.8	293160.0	262,828.20	8.7

40%Fs	12000	5600	1600	330.6	300	1510.5	10635.2	30,465.8	302100.0	271,634.20	8.9
40%Sf	12000	5600	1600	330	300	1196.3	10484.6	30,314.6	239260.0	208,945.40	6.9

Conclusion and Recommendation

In western Hararghe, where this study was done is affected by constraints of water scarcity, less irrigation availability, lack of improved seed of onion and low rain fall. So, this study on deficit irrigation improves water productivity, irrigation management and onion seed production resulting in water saving by maintaining soil moisture content below optimum level throughout growth season. The onion seed yields and field water productivity are higher with less water stress and reduced with increase in water stress. From this study, it is recommended that 20% deficit irrigation shows the highest onion seed yield. As well as the findings summarized that using deficit irrigation of 20% were economically profitable and saves more water than no deficit at all growth stage at study area and in similar irrigation available agro ecology.

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Evaluation of Deficit Irrigation Effect on Water Use Efficiency and Yield Response for Onion and Potato at Ketar scheme

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Abstract

In the context of improving water productivity, there is a growing interest in deficit irrigation practice whereby water supply is reduced below maximum levels and mild stress is allowed with minimal effects on yield. The study was implemented during the dry season for three years from December 2017 to May 2019 to study the effect of deficit or three water levels (100, 75 and 50 % CWR) on application efficacy, storage efficiency, distribution uniformity and irrigation water use efficiency of the potato and onion. From the result the average of application efficiency (Ea), storage efficiency (Es) and distribution uniformity (DU) of the three water levels (100%, 75% and 50%) were 60.97%, 70.27%, 75.4%, 55.45% ,62.68%, 88.68%, 88.24%, 87.61% and 89.89% for potato and 60.06%, 70.81%, 85.81%, 65.03%, 60.24%, 66.02%, 88.49%, 87.89% and 86.24% for onion respectively. The highest Ky of 0.98 and 0.85 was attained at 50% CWR for potato and onion respectively and the lowest was 100% CWR for both crops. This show the highest yield reduction was registered under 50% CWR. The application efficiency, storage efficiency, distribution uniformity and yield response of 75% CWR is slightly low from full irrigation water level. So it is recommended to use 75% CWR for both crops in saving water as it has low yield reduction in from water reduced and to implement deficit irrigation on farm participatory training should be given for application of right amount of water.

Key Words: *Deficit, potato, onion, efficiency and yield response*

Introduction

Food production and water use are inextricably linked. Water has always been the main factor limiting crop production in much of the world where rainfall is insufficient to meet crop demand. With the ever increasing competition for finite water resources worldwide and the steadily rising demand for agricultural commodities, the call to improve the efficiency and productivity of water use for crop production, to ensure future food security and address the uncertainties associated with climate change, has never been more urgent (FAO.2012).

The pressure on agriculture is increasing due to population growth thereby creating a need to improve agricultural production and productivity. Water has been identified as one of the scarcest inputs, which can severely restrict agricultural production and productivity unless it is carefully conserved and managed. There is a growing recognition that increases in food production will largely have to originate from improved productivity per unit water and soil (FAO, 2005, NRMD, 2011)

The increase in water demand has resulted in new methods of saving water worldwide with about 70% of water being used in agriculture globally; water saving techniques has to be practiced. Irrigation technologies and irrigation scheduling may be adopted for more effective and rational uses of limited supplies of water. Deficit irrigation is one of the methods designed to ensure the optimal use of allocated water. It maximizes water use efficiency for better yields per unit of irrigation water applied through by exposing the crops to a certain level of water stress either during a particular period or throughout the growing season (Shreedhar R. *et al.*, 2015).

At present and more so in the future, irrigated agriculture will take place under water scarcity. Insufficient water supply for irrigation will be the norm rather than the exception, and irrigation management will shift from emphasizing production per unit area towards maximizing the production per unit of water consumed, the water productivity. To cope with scarce supplies, deficit irrigation, defined as the application of water below full crop-water requirements (evapotranspiration), is an important tool to achieve the goal of reducing irrigation water use. While deficit irrigation is widely practiced over millions of hectares for a number of reasons from inadequate network design to excessive irrigation expansion relative to catchment supplies it has not received sufficient attention in research.

In order to ensure successful deficit irrigation, it is necessary to consider the water retention capacity of the soil. In sandy soils plants may undergo water stress quickly under deficit irrigation, whereas plants in deep soils of fine texture may have ample time to adjust to low soil water matric pressure, and may remain unaffected by low soil water content. Therefore, success with deficit irrigation is more probable in finely textured soils (FAO, 2002).

Deficit irrigation has been suggested as an alternative strategy for making better use of irrigation water. Deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield. In this method, the crop is exposed to a certain level of water deficit either during a particular period or throughout the whole growing season (English and Raja, 1996).

Deficit irrigation has been practiced in different parts of the world (Bekele, 2007). Deficit irrigation is a strategy which allows a crop to sustain some degree of water deficit in order to reduce irrigation costs and potentially increase revenues. English and Raja (1996) described three deficit irrigation case studies in which the reductions in irrigation costs were greater than the reductions in revenue due to reduced yields. Deficit irrigation can lead, in principle, to increased profits where water costs are high or where water supplies are limited. In these case studies, crop value was associated closely with yield, and crop grade and marketability were not germane.

The main objective of deficit irrigation is to increase the water use efficacy of a crop by eliminating irrigations that have little impact on yield. The resulting yield reduction may be small compared with the benefits gained through diverting the saved water to irrigate other crops for which water would normally be insufficient under traditional irrigation practices (FAO, 2002). Therefor to overcome irrigation water shortage and increase water use efficiency this study was initiated with the objectives of determining water use efficiency and yield response of potato and onion at selected water levels under furrow irrigation.

Materials and Methods

Description of the Study Area

The study was conducted on Ketar medium scale irrigation scheme situated in Tiyo woreda of Arsi zone Oromia Regional State of Ethiopia during dry season (December 2017 to May 2019).The district is located at longitude and latitude of 7^{0} 46' 30" - 7^{0} 54' 0" N and 38^{0} 55' 30"-39^{0} 4' 30" E. The scheme was designed to irrigate around 430 ha of land, has discharge of 800 litir/s and was recommended as it can irrigate 795 ha if canal is lined (reduction of conveyance loss) and reduced over irrigation (deep percolation and tail water runoff loss) (Dinka, 2017).

The climate of the area is generally warm and temperate. The average annual temperature is 13.8°C at an average 15.1 °C, April is the hottest month of the year at an average 12.7 °C December is the coldest month of the year. The rainfall here is 1118 mm. Precipitation is the lowest in December, with an average of 12 mm. In July, the precipitation reaches its peak, with an average of 187 mm. The woreda has an altitude of 2430m above sea level (a.s.l) (Yazachew and Kasahun, 2011).

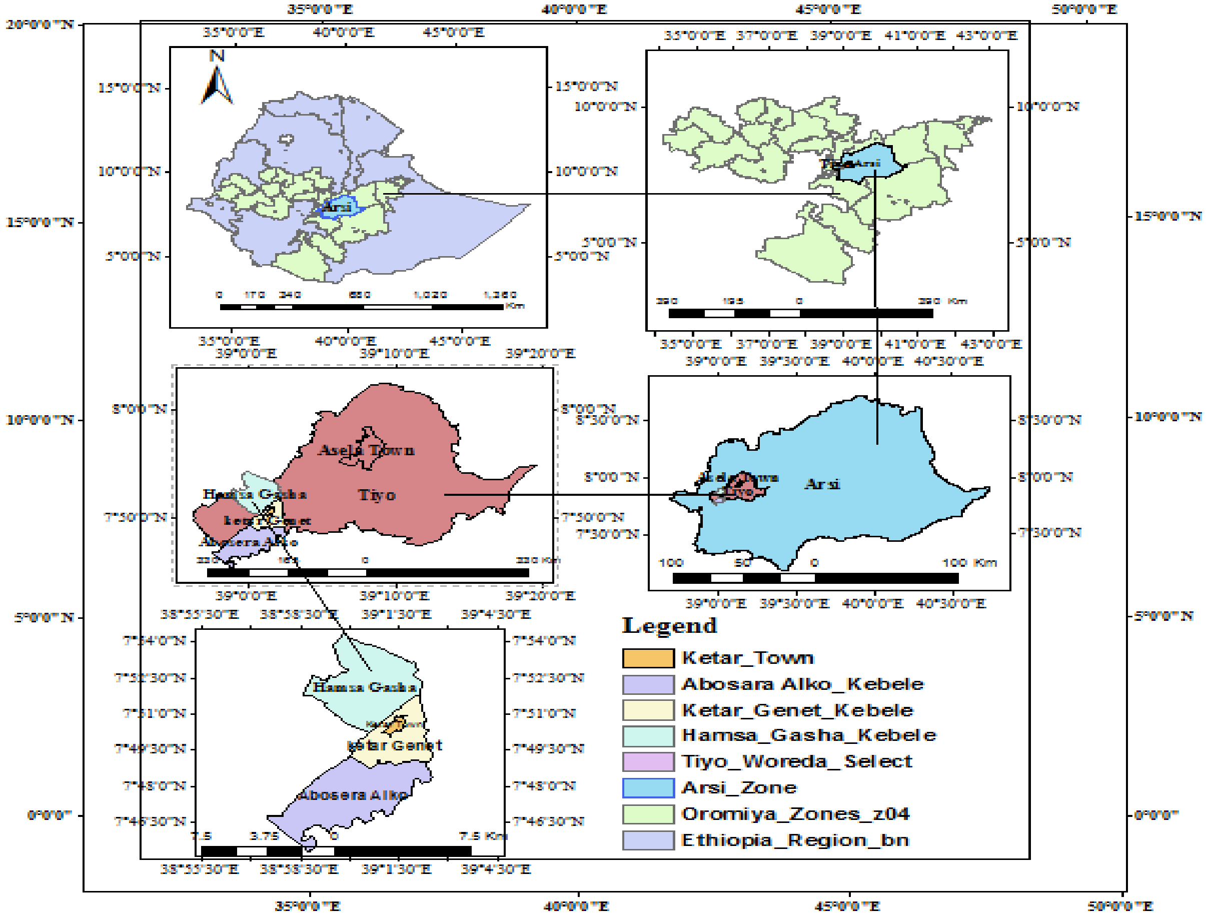

Figure 1- Map of study area

Experimental Design and Treatments

The crops used for this experiment were potato and onion. For each crop experiment was done individually and the experiment was arranged in Randomized Complete Block Design (RCBD) with three replications. The treatments considered for the experiments were three irrigation water levels which are 100% CWR, 75% CWR and 50% CWR. of the irrigation requirement. The experiment was conducted on individual plot size of 5 m x 5 m (25 m^2) with 9 number of such plot for each crops. The spacing between the blocks and plots were kept as 2 m and 1.5 m respectively.

Data Collection

Soil data collection

To determine the soil texture, organic matter content, pH and EC, disturbed soil samples and for bulk density, moisture content at field capacity (FC) and permanent wilting point (PWP) undisturbed soil samples were collected by core sampler and auger from two depths 0-30cm and 30-60cm at three points diagonally of the experimental site and were taken to laboratory for analysis.

For textural analysis of the soil hydrometer method was used for analyzing particle size distribution and USDA textural triangle was used to identify the textural class. The organic matter content of the soil was determined by titration method. The soil was oxidized under standardized condition with potassium dichromate in sulphuric acid to determine the carbon content. The status of organic matter content was obtained by multiplying carbon content with 1.724 (Walkley and Blank, 1934).

The soil bulk density was analyzed after oven drying the samples for 24 hours at 105°C and weighed for calculating dry density as given by Michael, (2008)

$$\rho_b = \frac{M_s}{V_t} \tag{1}$$

Where: ρ_b = soil bulk density (gm/cm^3)

M_s=mass of dry soil (gm) and

V_t =total volume of soil in the core sampler (cm^3)

Soil pH was determined by using water suspension with soil to water ratio 1:2.5 by PH meter. EC was determined by method of water suspension with soil to water ratio 1:2.5 by electro conductivity meter.

The soil moisture content at field capacity (FC) and permanent wilting point (PWP) was determined after soil samples were saturated for one day (24 hrs) using the pressure plate apparatus. Field capacity was determined by exerting a pressure of 0.33 bars and permanent wilting point was determined by exerting a pressure of 15 bars until no change in moisture will be observed. The FC and PWP values were further used to determine total available water (TAW). To undertake the test of parameter three soil samples from each plot. Once FC and PWP determined TAW was determined as stated Allen *et al*., (1998).

$$TAW = \frac{(FC - PWP)}{100} * BD * D \tag{2}$$

Where: TAW = total available water (mm)

FC = field capacity (% by weight)

PWP = permanent wilting point (% by weight)
D = depth of root zone (mm)
BD = specific density of soil

For maximum crop production, the irrigation schedule was fixed based on readily available soil water (RAW). The RAW was the amount of water that crops can extract from the root zone without experiencing any water stress. The RAW was computed from the expression:

$$RAW = TAW * MAD \tag{3}$$

Where: RAW is readily available water and MAD is management allowable depletion normally varies from 0.3 to 0.7 depending on soil type.

Climatic data

Necessary parameters, like minimum and maximum temperature, relative humidity, wind speed and daily sunshine hour 20 years of the study area were collected from National Meteorological Agency to determine mean daily reference evapotranspiration (ETo).

Crop Water Requirement and Irrigation Water Requirement

CROPWAT version-8 was used and climatic data were fed to calculate the reference evapotranspiration (ET_o) of the study area.

$$ET_c = ET_o \text{ x } K_c \tag{4}$$

Where: ET_c = crop evapotranspiration (mm/day)
ET_o = reference crop evapotranspiration (mm/day)
K_c = crop coefficient

Net-irrigation requirement for the crop was determined according to cropping pattern. Total irrigation water requirement for the crop was calculated using net-irrigation requirement of the crop, irrigated areas and irrigation efficiency.

Irrigation interval was calculated as;

$$I = \frac{d_{net}}{ET_c} \tag{5}$$

Where, I = irrigation interval (days)
D_{net}=net-depth of irrigation (mm)
ET_c=daily crop evapotranspiration (mm/day)

The depth of irrigation application is the depth of water that can be stored within the root-zone between the fields capacity and allowable level of the soil water depleted for a given crop, soil and climate. It is equal to the readily available soil water over the irrigate zone (James, 1998). The moisture deficit (d) in the effective root-zone is found out by determining contents at the field capacity and bulk densities of each layers of the soil (Mishra and Ahmed, 1990).

$$d = \sum_{i=1}^{n} \frac{(FC_i - PWP_i)}{100} * \gamma_i * D_i * P \tag{6}$$

Where: FC_i= field capacity of the irrigation water layer on oven dry weight basis (%)
PWP_i=actual moisture content of the water layer on oven dry weight basis (%)
γ_i =apparent specific gravity of the soil of irrigation layer

D_i=depth of the irrigation layer (mm)
P= depletion fraction (%)
n= number of layers in the root zone

Soil moisture measurement

For soil moisture determines gravimetric method was used. For this soil before and after irrigation were collected from two soil depths (0-30 cm and 30-60 cm) of the field. The samples were taken at 30 cm depth interval within the effective root zone, which was considered to be 60 cm for potato and 40cm for onion. The moisture status of the soil profile for each field was measured before and after each irrigation event. The samples were collected using manually driven soil auger. The soil sampler was placed in the air tight container and weighed prior to placing in an oven dry at 105 °C. The sample was left in the oven for 24 hrs, although a constant dry weight (less than 0.1% change during an hour) is usually achieved prior to this (Walker, 2003). The oven dried soil samples with container and cover was weighed again. After the soil moisture sampler collected and oven dried, the moisture was calculated as a percentage of dry weight of the soil sample (W) as

$$W = \frac{M_t - M_s}{M_s} * 100 = \frac{M_w}{M_s} \% * 100 \qquad (7)$$

Where: W=weight of soil sample (gm)
M_t=weight of fresh sample (gm)
M_s=weight of over dried sample (gm)
M_w=weight of moisture (gm)

To convert these soil moisture measurements into volumes of water, the volumetric moisture content (θ) was calculated as

$$\theta = \frac{\rho_b * W}{\rho_w} \qquad (8)$$

Where: θ=volumetric moisture content (%)
ρ_b = Soil bulk density (gm/cm^3)
W= moisture content on dry weight basis (%)
ρ_w = unit weight of water (1gm/cm^3)

Discharge measurements at field

The flow of water into the experimental flow was measured using 3" (3 inch) size parshall flume to be installed at its entrance. Discharge measurement was taken at 2/3A (two-third of length of converging section). Then the flow depth observed on the flume was converted to the corresponding discharge using equation (9) for 3" size parshall flume. Then the total volume of water applied (V_a) was calculated using equation (10) as stated (James, 1988) and the total depth of applied water was calculated based on the representative plot.

$$Q = C_f (KH)^{n_f}$$

For 3’’ parshall flume, $Q = 0.1771H^{1.550}$ (9)

$$V_a = Q * \Delta t \qquad (10)$$

Where: Q= discharge through the flume (l/s)
C_f= discharge coefficient from rated tables
K = unit constant (K= 3.28 for H in m)
n_f =flow exponent from the tables
V_a = total volume of water applied (m^3)
Δt =flow time to the field

Determination of Irrigation efficiency

Application efficiency

It is expressed as:

$$E_a = \frac{V_s}{V_f} * 100 \tag{11}$$

Where: E_a =Water application efficiency (%)
V_s =Volume of irrigation water stored in the root zone (m^3/s or ha-m)
V_f = Volume of irrigation water delivered to farm or field (m^3/s or ha-m)

Volume of irrigation water stored in the root zone was determined by calculating available water in the root zone in either volume bases or weight bases by determining soil moisture content before and two days after irrigation by gravimetric or oven dry method for the selected plots. Volume of irrigation water delivered to plot was taken from discharge which was measured at field channel (flow which reaches the command area of the selected plot) by parshall flume.

Distribution uniformity

The distribution uniformity is more commonly used to characterize the irrigation water distribution over the field in surface irrigation systems, but it also can be applied to micro and sprinkler irrigation systems. The low-quarter distribution uniformity (D_u) is defined as the average depth infiltrated in the low one-quarter of the field divided by the average depth infiltrated over entire field. It is expressed as:

$$D_u = \frac{D_{lq}}{D_{av}} * 100 \tag{12}$$

Where: D_u=Distribution Uniformity (%)
D_{lq}=Average depth of water infiltrated in the low one-quarter of the field (m)
D_{av}= Average depth of water infiltrated over the field (m)

For computing average depth of water infiltrated over the field, moisture content of the field was measured before and after irrigation and their difference and mean of their difference was calculated. For computing average depth of water infiltrated in the low one-quarter of the field, moisture content of the field was measured before and after irrigation and their difference was calculated for the least four from descending order and then mean of their difference was computed. From D_{av} and D_{lq} distribution uniformity (Du) was computed for the three plots (by dividing mean of difference of overall sample for mean of difference of least quarter)

Water storage efficiency

Soil water storage efficiency (E_S) is defined as the ratio of the volume of water stored in root to volume of water required filling the root zone to near field capacity and is expressed as

$$E_s = \frac{V_s}{V_{fc} - V_a} * 100 \qquad (13)$$

Where: E_s= Soil water storage efficiency (%)

V_s= Volume of water stored in the soil root zones from an irrigation event (m^3/s)

V_{fc}= Volume of water at field capacity in the crop root zone (m^3/s or ha-m)

V_a =Volume of water in soil root zone prior to irrigation event (m^3/s or ha-m)

Water productivity

The water utilization by crop is generally described in terms of water use efficiency (kg/ha, kg/m3 or q/ha) (Michael, 1997). Water use efficiency (WUE) and irrigation water use efficiency (IWUE) are determined by dividing the yield to seasonal ET and total seasonal irrigation water (IW) applied (Tanner and Sinclair, 1983).

$$WUE = \frac{Y_a}{ET_c} \qquad (14)$$

Where: WUE = water use efficiency (kg/m^3)

Y_a = is actual yield (kg/m^2)

ET_c = seasonal crop evapotranspiration (m^3/m^2)

$$IWUE = \frac{Y_a}{IW} \qquad (15)$$

Where, IWUE- irrigation water use efficiency (kg/m^3)

Ya - actual yield (kg/m^2)

IW - irrigation water applied (m^3/m^2)

Yield response factor of crops to deficit water

When water supply does not meet the crop water requirements, the ETc will decrease. Under this condition, water stress will develop in the plant, which will adversely affect crop growth and, ultimately, crop yield. To predict the reduction in crop yield when crop stress was caused by a shortage of soil water:

$$1 - \frac{Y_a}{Y_m} = K_y \left[1 - \frac{ET_a}{ET_m}\right] \qquad (16)$$

Where; Ya = actual yield (kg ha-1); Ym = maximum yield (kg ha-1); ETa = actual evapotranspiration (mm); ETm = maximum evapotranspiration (mm), and Ky = yield response factor.

Statistical analysis

The results were analyzed by descriptive statistically using Microsoft excel and compared averages result of parameters.

Result and Discussion

Physico-Chemical Properties of Soil

Table 1 below shows the physico-chemical property of the study area. From this soil pH values were found in range of 5.34-6.03 and have average of 5.49. This indicates moderate acidic soil. Electrical conductivity (EC) of the stations was in range of 0.10-0.32 mmhos/cm at room temperature (25°C). Average organic matter contents (OM) of the experimental site were 3.58. Soil texture class of study area was clay loam. The average values of pH, Electrical conductivity and organic matter were 5.49, 0.16 and 3.58 respectively. According to Classes of salinity and EC (1 dS/m = 1 mmhos/cm; as adapted from USDA (1998), soil which has electrical conductivity 0<2 mmhos.cm is non-saline soil.

Table 1:- Soil pH, EC, OMC and texture determination of experimental site

Sample No	P^H	EC (mmhos /cm at 25ºC)	OC %	OM	Soil texture			
					Sand %	Silt %	Clay %	Class
1	5.47	0.1	1.97	3.4	30	32	38	CL
2	5.34	0.24	2.04	3.52	26	36	38	CL
3	6.03	0.21	2.19	3.77	25	37	38	CL
4	5.39	0.32	1.98	3.41	34	24	42	C
5	5.29	0.12	1.94	3.34	29	35	36	CL
6	5.57	0.11	2.15	3.71	30	36	34	CL
7	5.34	0.13	2.23	3.84	32	35	33	CL
8	5.51	0.11	2.13	3.67	36	30	34	CL
9	5.47	0.14	2.09	3.6	34	22	44	C
Average	5.49	0.16	2.08	3.58	31	32	37	CL

CL=Clay loam C= Caly

Irrigation Water Requirement

Table 2 show the average seasonal irrigation water applied for potato crop. For the three water levels (100, 75 and 50 % CWR) the average of seasonal irrigation water applied per plot was 16.55, 12.41 and 8.27 m^3 respectively. From this the average of seasonal irrigation water need per hectare of potato crop for the three water levels (100, 75 and 50 % CWR) were 6620, 4963.6 and 3309.2 m^3 respectively. The water saved per hectare using two water level which are (75 and 50% CWR) were 1656.4 and 3310.8 m^3 reference to 100% CWR. From this result, using deficit more water was saved to expand commend area of scheme.

Table 2:- Average Seasonal water application of water on potato experimental plot

Irrigation Day	Gr. Irr (mm)	Gross Irrigation depth (m)	Plot Area (m^2)	Average Volume of SWA ($m^{3)}$ (100%CWR)	75%CWR)	(50%CWR)
1	37.3	0.04	25	0.93	0.70	0.47
2	22.1	0.02	25	0.55	0.41	0.28
3	27.3	0.03	25	0.68	0.51	0.34
4	37.3	0.04	25	0.93	0.70	0.47
5	40.1	0.04	25	1.00	0.75	0.50
6	53	0.05	25	1.33	0.99	0.66
7	46.7	0.05	25	1.17	0.88	0.58
8	47	0.05	25	1.18	0.88	0.59
9	53.3	0.05	25	1.33	1.00	0.67
10	53.5	0.05	25	1.34	1.00	0.67
11	51.1	0.05	25	1.28	0.96	0.64
12	56.2	0.06	25	1.41	1.05	0.70
13	64.4	0.06	25	1.61	1.21	0.81
14	72.5	0.07	25	1.81	1.36	0.91
15	0	0	25	0.00	0.00	0.00
Total				16.55	12.41	8.28

CWR = Crop water requirement SWA=Sessional water applied

The average of seasonal irrigation water applied for onion crop was illustrated under table 3 for the three water levels (100, 75 and 50 % CWR). From this table the average of seasonal irrigation water applied per plot were 14.93, 11.20 and 7.47m^3 and seasonal irrigation water need per hectare of onion crop for the three water levels (100, 75 and 50 % CWR) were 5972, 4480 and 2988 m^3 respectively. The water saved per hectare using two water level which are (75 and 50% CWR) were 1492 and 2984 m^3 reference to 100% CWR. From this result, using deficit more water was saved to expand commend area of scheme.

Table 3:- Average seasonal water application of water on onion experimental plot

Irrigation day	Gross Irign Depth (m)	Plot Area (m^2)	Volume (m^3) 100%CWR	75%CWR	50%CWR
1	0.05	25	1.32	0.99	0.66
2	0.03	25	0.77	0.58	0.39
3	0.03	25	0.87	0.65	0.44
4	0.04	25	0.97	0.73	0.49
5	0.05	25	1.25	0.93	0.62
6	0.06	25	1.39	1.04	0.70
7	0.06	25	1.51	1.13	0.76
8	0.06	25	1.50	1.13	0.75
9	0.06	25	1.61	1.21	0.81
10	0.06	25	1.51	1.13	0.75
11	0.09	25	2.24	1.68	1.12

12	0.00	25	0.00	0.00	0.00
Total			14.93	11.20	7.47

Application Efficiency (E_a)

Table 4 shows the application efficiency of the experimental site were calculated using depth of water stored to crop root zone divided by depth of water applied to field. The average of application efficiency of the three water levels for potato and onion were 60.97%, 70.27%, 75.4% and 60.06%, 70.81% and 85.81% respectively. The water application efficiency of the two water levels (75% and 50%) was greater than the full irrigation (100%) even though the amount of water application was lower. This is due to properly used water and applied to field without more loss. The three application efficiency of the potato crop and two water levels (100% and 75%) were fall in the interval of recommendation for surface irrigation 50-80% as stated by Lesley (2002). But the average application efficiency of water level of 50% of onion crop was greater than 80% which are better than recommendation.

Table 4:- Average of application efficiency of selected crops

Applied water level	Application efficiency	
	Potato	Onion
100	60.97	60.06
75	70.27	70.81
50	75.4	85.64

Water Storage Efficiency (E_s)

According to Michael (2008), the importance of determining storage efficiency is that, when water supplies are limited or when excessive time is required to secure adequate penetration of water into the soil. Table 5 shows water storage efficiency of study experimental sites for potato and onion crops. The average storage efficiency of potato were 55.45%,62.68% and 88.68% and for onion were 65.03%,60.24% and 66.02% respectively for the 100%,75% and 50% of irrigation water level. Water stored efficiency was found as less than 100% due to the water applied was lost in form of deep percolation and runoff.

Table 5:- Average of water storage efficiency of selected crops

Applied water level	Storage efficiency	
	Potato	Onion
100	55.45	65.03
75	62.84	60.24
50	88.68	66.02

Distribution Uniformity (DU)

From Table 6 DU of the three irrigation water level (100%, 75% and 50%) were 88.24%, 87.61% and 89.89% for potato and 88.49%, 87.89% and 86.24% for onion respectively. According to Irmak *et al.,* (2011) DU less than 60% low and DU greater than 75%

recommended. So the DU of the three irrigation schemes was greater than 75% so it is under recommended percentage for the three water levels.

Table 6:- Average Distribution uniformity

Applied water level	Distribution Uniformity (DU)	
	Potato	Onion
100	88.24	88.49
75	87.61	87.89
50	89.89	86.24

*Irrigation water use efficiency (*IWUE)

From table 7 the average of irrigation water use efficiency calculated were the highest at 50% water level for the two crops and the lowest were calculated at 100%CWR water levels. The 75% water level is the medium of the two water levels.

Table 7:- Average of irrigation water use efficiency

Applied water level	Average IWUE	
	Potato	Onion
100	1.76	2.26
75	1.82	2.93
50	2.38	4.22

IWUE = Irrigation water use efficiency

Yield Response

Yield response factor of potato crops to deficit water was described under table 8. From this table average Ky value rage were 0 - 0.98 and the highest Ky of 0.98 was attained at 50% CWR and the lowest was 100% CWR. This show the highest yield reduction was registered under 50% CWR. The deficit by 25% or 75% CWR is no more yield reduction therefor it is recommended.

Table 8:- Yield response factor of potato crop to deficit irrigation water

Water level (%)	Ya	ETa	Ya/Ym	ETa/ETm	1-(Y_a/Y_m)	1-(ET_a/ET_m)	Ky= {(1-(Y_a/Y_m)/ (1-ET_a/ET_m))}
100	22093.2	3.76	0.97	1	0.03	0	-
75	22800	2.82	1.00	0.75	0.00	0.25	0.00
50	12060	1.88	0.53	0.5	0.47	0.5	0.94
50	11760	1.88	0.52	0.5	0.48	0.5	0.97
100	16800	3.76	0.74	1	0.26	0	-
75	21576	2.82	0.95	0.75	0.05	0.25	0.21
75	16080	2.82	0.71	0.75	0.29	0.25	1.18
50	10984	1.88	0.48	0.5	0.52	0.5	1.04
100	22712	3.76	1.00	1	0.00	0	-

Ya = actual yield (kg ha-1); Ym = maximum yield (kg ha-1); ETa = actual evapotranspiration (mm); ETm = maximum evapotranspiration (mm), and Ky = yield response factor.

Table 9 show yield response factor of crops to deficit water was described. From this table average Ky value rage were 0 - 0.85 and the highest Ky of 0.85 was attained at 50% CWR and the lowest was 100% CWR. This show the highest yield reduction was registered under 50% CWR. The deficit by 25% or 75% CWR is no more yield reduction therefor it is recommended.

Table 9:- Yield response factor of onion crop to deficit irrigation water

Water level (%)	Ya(kg/ha)	ETa	Ya/Ym	ETa/ETm	1-(Y_a/Y_m)	1-(ET_a/ET_m)	Ky= {(1-(Y_a/Y_m)/ (1-ET_a/ET_m))}
100	12200	662	0.80	1	0.20	0	-
75	13000	496.5	0.86	0.75	0.14	0.25	0.58
50	8520	331	0.56	0.5	0.44	0.5	0.88
50	8400	331	0.55	0.5	0.45	0.5	0.89
100	15200	662	1.00	1	0.00	0	-
75	13120	496.5	0.86	0.75	0.14	0.25	0.55
75	13400	496.5	0.88	0.75	0.12	0.25	0.47
50	9240	331	0.61	0.5	0.39	0.5	0.78
100	13200	662	0.87	1	0.13	0	-

Conclusion and Recommendation

Conclusion

In this study, an attempt was made to evaluate deficit irrigation deficit or three water levels (100, 75 and 50 % CWR) using application efficacy, storage efficiency, distribution uniformity and irrigation water use efficiency of the potato and onion crops. Laboratory result of soil data shows that texture class of soil in study area was clay loam. The average values of pH, Electrical conductivity and organic matter were 5.49, 0.16 and 3.58 respectively.

For the three water levels (100, 75 and 50 % CWR) the average of seasonal irrigation water applied per plot and per hectare of potato crop were 16.55, 12.41 and 8.27 m^3 and 6620, 4963.6 and 3309.2 m^3 respectively. For onion were 14.93, 11.20 and 7.47m^3 and 5972, 4480 and 2988 m^3 respectively. The water saved per hectare using two water level which are (75 and 50% CWR) were 1656.4 and 3310.8 m^3 for potato and 1492 and 2984 m^3 for onion reference to 100% CWR respectively.

The average of application efficiency (Ea), storage efficiency (Es) and distribution uniformity (DU) of the three water levels (100%, 75% and 50%) were 60.97%, 70.27%, 75.4%, 55.45% ,62.68%, 88.68%, 88.24%, 87.61% and 89.89% for potato and 60.06%, 70.81%, 85.81%, 65.03%, 60.24%, 66.02%, 88.49%, 87.89% and 86.24% for onion respectively. The irrigation water use efficiency calculated was the highest at 50% water level for the two crops and the lowest were calculated at 100%CWR water levels.

The highest Ky of 0.98 and 0.85 was attained at 50% CWR for potato and onion respectively and the lowest was 100% CWR for both crops. This show the highest yield reduction was registered under 50% CWR. The deficit by 25% or 75% CWR is no more yield reduction therefor it is recommended.

Recommendation

It is highly recommended to use 75% CWR for both crops in saving water as it has low yield reduction in from water reduced. Before implementing a deficit irrigation program, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season. To implement deficit irrigation on farm participatory training should be given for application of right amount of water. As this water saving technology (deficit irrigation) is best for water stress areas it is strongly recommended to conduct further research works for other schemes particularly at highland areas as it has less evapotranspiration than that of lowlands.

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Effect of deficit irrigation on yield and water productivity of tomato crop under drip irrigation system using rain water harvesting at fedis on station

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Abstract

Improving productivity of irrigation water is becoming a critical issue in arid and semi-arid areas of Ethiopia. The objective of the study was to evaluate the effect of deficit irrigation on yield and water productivity of tomato under drip irrigation system. An experiment was conducted at fedis agricultural research center in 2017 and 2019 cropping season. Four treatments replicated three times in RCBD. In the study, irrigation treatment which receives full application of irrigation water (100% ETc) was considered as control treatment and 85% ETc, 75% ETc and 65% ETc were deficit irrigation treatment with three replication arranged in RCBD. The study revealed that both maximum CWUE and maximum IWUE was obtained by T_3 *(75% application of irrigation water) while the lowest value of CWUE and IWUE was respectively obtained from* T_4 *(65% application of irrigation water) in two consecutive years. Even though maximum total tomato yield was obtained by control treatment (full irrigation) it is not advisable for arid and semi-arid areas since full water application which leads to lower CBR (cost benefit ratio) gained relative water applied to deficit treatment. The study further reveals, yield response factor was gradually increased as deficit irrigation level increased. The minimum and maximum yield response factor was obtained at 75% ETc and 65% ETc, respectively. Generally,* T_3 *(75% ETc application of irrigation water) was the most economically attractive treatment with lower cost of production and optimum net benefit and with optimum tomato yield than the other application level.*

Key words: *Drip system, deficit irrigation, water productivities, yield parameters*

Introduction

Agriculture is one of the main consumers of fresh water resources in the world. It is consuming more than two thirds of total withdrawals (Gan *et al*. 2013) In many parts of the world, irrigation water has been over-exploited and over-used (Chai *et al*. 2014), and freshwater shortage is becoming critical in the arid and semiarid areas of the world. About 70% of total consumptive water uses are consumed in irrigation (Huffaker and Hamilton, 2007).

In Ethiopia, irrigation development is increasingly implemented more than ever to supplement the rain-fed agriculture. It aims to increase agricultural productivity and diversify the production of food and raw materials for agro-industry as well as to ensure the agriculture to play a pivot for driving the economic development of the country (Mekonen, 2011). Moreover, Ethiopia has planned to irrigate over 5 Mha with existing water resources, to contribute around ETB 140 billion per annum to the economy and to ensure food security for up to six million households i.e. about 30 million direct beneficiaries (Seleshi *et. al*., 2010).

Research and development of water saving agriculture is a challenging task today to make agriculture and industries sustainable in term of water consumption. Although Satisfying crop water requirements can maximize production from the land unit, it does not necessarily maximize the return per unit volume of water (Oweis *et al,* 2000). Therefore, there is a need to achieve maximum production per unit water applied. Advanced irrigation methods and water management practices coupled with proper irrigation scheduling can help achieve high crop yields with minimum water applications.

Under traditional system of irrigation, water availability is not considered. However, rising demand for water calls for changes in the management of irrigation and scheduling to improve crop water use efficiency thus saving the scarcely available water for agriculture. Three methods are however available for enhancing vegetable production in a country. Allocating more area, developing and adopting new technologies and utilizing the available resources more efficiently (Bakhsh *et al.,* 2007). It is unsustainable to allocate more area to vegetable production due increasing pressure on land as a result of increasing population. Deficit Irrigation (DI) being a new irrigation technology that utilizes water resources efficiently is a suitable option. In DI the crops are subjected to a certain degree of water stress during specific growth stages or throughout the whole growing season, without significant reduction in yields compared with the benefits gained through diverting the saved water to irrigate other crops (Kipkorir *et al*., 2001).

Deficit irrigation is the application of less water than is required for potential ET and maximum yield, resulting in conservation of limited irrigation water (Musick, *et al.,* 1994). Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains by maximizing yield per unit of water. Deficit irrigation as characterized by English (1990) has the fundamental goal to increase water use efficiency (WUE). Fereres and Soriano (2006) recently reviewed deficit irrigation and concluded that the level of irrigation supply should be 60 - 100% of full evapotranspiration (ET) needs in most cases to improve water productivity. Studies have shown that deficit irrigation significantly increased grain yield, ET and WUE as compared to rain fed winter wheat (Oweis, *et al.;* 2000).

The scarcity of irrigation water in arid and semi-arid areas of Ethiopia was the common problem for crop production. Most districts of eastern Hararghe were living under this complex situation. Since deficit irrigation system is applicable in such situation to save this scarce resource, its effect should be evaluated for this area.

When water supplies are limiting, the farmer's goal should be to maximize net income per unit water used rather than per land unit. Recently, emphasis has been placed on the concept of water productivity (WP), defined here either as the yield or net income per unit of water used in ET (Kijne *et al.,* 2003). Reduction in irrigation water used will result in reduced costs of irrigation water, pumping costs and total cost of crop production (English, 2002).

The water saved can then be used to irrigate additional land thereby increasing total farm profit (English and Raja, 1996; Fereres and Soriano, 2007). Although reduction in yield is expected when plants are subjected to limited irrigation water, the resulting yield reduction will be small when compared to the benefits gained. Therefore, this study was aimed to evaluate the effect of deficit irrigation on yield and water productivity of tomato under drip irrigation system by using roof top rain water.

Materials and Methods

Experimental site description

The experiment was conducted at Fedis woreda at bokko kebele on Fedis research station during dry or off season for two years. The station was located at 09^0 07' 51.6" North latitude, 042^0 04' 24.3" East longitude and Altitude of 1715 m a.s.l. The site receives mean annual rainfall of 827.59 mm, which is erratic and uneven distribution the mean min. and max. Temperature of the area is 9.28 ^{0} C and 28.4 ^{0} C respectively.

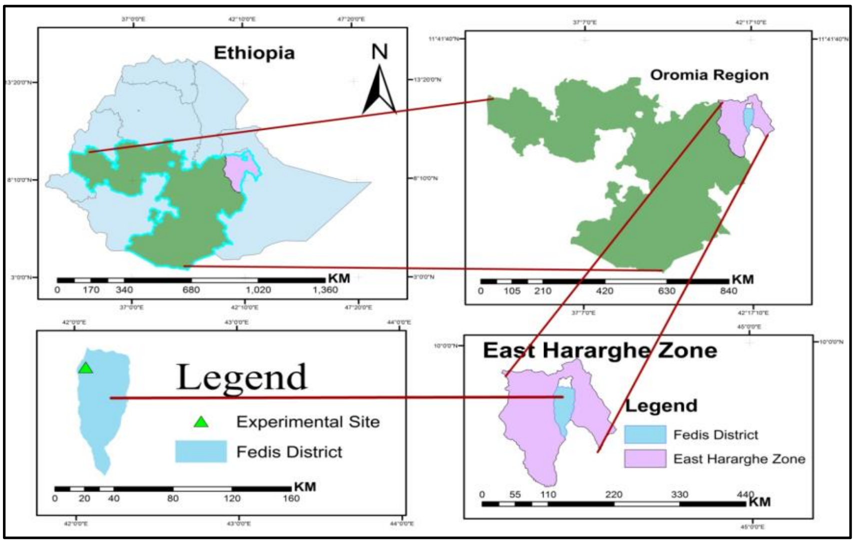

Fig 1. Map of study area

Experimental design and treatment

The experiment was laid out in RCBD consisting of four treatments with three replications. Treatments were; no deficit/ full irrigation and three deficits at two plant growth stage i.e. three irrigation water application levels at crop development and late stage as described in Table below. The experimental field was divided into 12 plots and each plot had 2.1m by 2.7 m size. Distance between plots was 1m and distance between blocks was 1.5 m. The row spacing of tomato was 70 cm which was equal with drip lateral line with plant spacing of 30 cm. Transplanting was under taken at height of 12-15 cm. the recommended fertilizers of 200 kg ha^{-1} of P_2O_5 and 100 kg ha^{-1} of NPS were applied at crop establishment during frits cultivation and at development stage. Tomato Seeds (*Melka shola* variety) was sown in a nursery on well prepared seed bed size of 1m x 5 m.

Table 1. Combination experimental treatments

Treatment	Description
T_1	FI (100% ETc) throughout growing stage
T_2	DI (85% ETc) at development and late stage
T_3	DI (75% ETc) at development and late stage
T_4	DI (65% ETc) at development and late stage

Where: FI –is full irrigation, DI –is deficit irrigation and (ETc) - Crop evapotranspiration

Data to be collected

Soil Texture

The particle size distribution in the soil profile was done using the hydrometric method following the procedures outlined in Staney and Yerima (1992). Disturbed soil samples from the 3 locations on the experimental field were collected from three depths 0-20 cm, 20-40 cm and 40-60 cm at three points along the diagonal of the experimental field with the help of soil auger and composite sample was prepared. Based on the percentage of sand, silt and clay distribution the textural triangle diagram was used to determine the textural class of the soil.

Infiltration rate of soil

Infiltration rate was measured using double ring infiltrometer (FAO, 1989). The measurement was done at three sites randomly selected within experimental plot.

Determining of FC, PWP moisture content and bulk density

Field capacity (FC) and permanent wilting point (PWP) moisture content of soil samples of the study area were determined using 6 undisturbed soil samples collected by using auger from the soil pit at the depth interval of 0-20 cm, 20-40 cm and 40-60 cm from the 3 sites in the field. Soil samples were saturated for one day and a pressure of 1/3 bar (field capacity) and 15 bars (for permanent wilting point) were exerted until no more change in volume or of sample was observed at HU School of Water Resource and Environmental Engineering Laboratory. After getting FC and PWP, water availability to crops from this soil was calculated. The total available water (TAW) for the plant use in root zone was computed as the difference in moisture content between field capacity (FC) and permanent wilting point (PWP) as follows (Allen *et al.*,1998).

$$TAW = 10\sum_{i=1}^{n} (\theta_{FC} - \theta_{PWP}) * \rho_b * Z_i \qquad 1$$

where: TAW is total available water (mm), θ_{FC} is field capacity moisture content on mass basis (%) in 0-20 cm, 20-40 cm and 40-60 cm cm layer of the soil, θ_{PWP} is permanent wilting point moisture content on mass basis (%) in 0-20 cm, 20-40 cm and 40-60 cm layer of the soil, ρ_b is bulk density dimensionless and Z_r is depth of soil layer within the root zone (m).

$$RAW = TAW * MAD \qquad 2$$

Where: RAW is readily available water and MAD is management allowable depletion normally varies from 0.3 to 0.7 depending on soil type.

Gravimetric method was used to determine the soil moisture. For determination of moisture content on mass basis, the soil samples were weighed and then placed in an oven at 105^0C for 24 hours. After drying, the soil was weighed again. The soil moisture content on mass basis (θ_w) was estimated in percent using following expression:

$$\theta_w = \frac{(w_w - w_d)*100}{w_d} \qquad 3$$

where: θ_w is soil water content in (%); W_w is weight of moist soil in gram; W_d is weight of oven dry soil in gram (FAO, 1989).

$$\theta_v = \theta_w * \frac{\rho_b}{\rho_w} \qquad 4$$

Where: θ_v is volumetric water content (cm^3); ρ_b is bulk density ($g\ cm^{-3}$)

Soil bulk density was determined by three undisturbed soil samples to be taken diagonally from 3 points at depths of 0-20 cm, 20-40 cm and 40-60 cm using core cylinder. The soil samples were oven dried for 24 hours at a temperature of 105^0C to remove the soil moisture and to get the dry weight of the soil. The dry density of soil is estimated by using the following formula (Jury *et al.*, 1991).

$$\rho_b = \frac{W_s}{V_s} \qquad 5$$

Where: ρ_b is bulk density ($g\ cm^{-3}$), W_s is dry weight of the soil (g) and V_c is total volume of the core sampler (cm^3).

Reference crop evapotranspiration

Monthly reference crop evapotranspiration (ETo) for each year of climatic record was calculated based on the modified FAO Penman Mentieth equation (Allen *et al.*, 1998) using FAO CROPWAT 8 software. The input data include location, latitude, altitude and longitude of meteorological station, monthly average daily values of maximum and minimum air temperatures (^0C), air humidity, sunshine hour and wind speed at 2 m height. The input data were collected from Fedis Meteorological Station.

Crop water requirement

The crop water requirement (ETc) was determined for cabbage crop of the study area over the growing season for the average year based on the established procedure given by Allen *et al.* (1998).

Net and gross irrigation water requirement

Water needed per irrigation was determined as net depth of irrigation water that is required consumptively for crop production. It is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity. Thus it was the difference between the field capacity and the soil moisture content in the root zone before starting irrigation. This is obtained by the relation given below;

$$I_n = \frac{(\theta_{fc} - \theta_i)\rho_b * Dr}{100} \qquad 6$$

where: I_n is the net amount of water to be applied during irrigation (cm), θ_{fc} is the moisture content at field capacity in the root zone by volume (%), θ_i is field moisture content before irrigation in the root zone by volume (%), D_r is the depth of the root zone (cm) and bulk density of the soil in the root zone (g cm^{-3}).

The gross depth of irrigation water (I_g) equals the net irrigation depth (I_n) divided by the application efficiency (E_a). The following equation was used to compute gross irrigation water requirement.

$$I_g = \frac{I_n}{E_a} \qquad 7$$

where: Ig is the gross irrigation depth in mm and E_a is the application efficiency of drip irrigation 90%,

Determination of water application time and drip layout

The amount of water trickles out of the emitters was measured using measuring gauge and time of application was intensively monitored using stopwatch during each irrigation. The duration of time for the emitters to deliver the desired depth was calculated using the following relationship (Phocaides, 2000) as cited by Mandefro and Kokobe, (2015)).

$$t = \frac{0.8\,\pi\,D\,r^2}{360q} \qquad 8$$

where: D = depth of water applied (cm); t = application time (hour); q = emitters discharge rate (1 sec^{-1}), r = radius of effective wetted area (m)

Wetted diameter was measured by exposing a vertical plane passing through the point of application by taking three samples from all points of application. Wetted area of each emitter was calculated as:

$$A = \frac{\pi\,D^2}{4} \qquad 9$$

where; A = Wetted area covered by each emitter (m^2) D= Average wetted diameter covered by each emitter (m

Irrigation system design, field layout and water application method

Irrigation water was obtained from rooftop rain water harvested during rainy season for the experiment which was then stored in concrete lined reservoir/tank near the experimental plots. Three concrete reservoirs were constructed at appropriate place around the houses for collecting rainwater. Each reservoir was designed to have a storage capacity of 25 m^3, and yielding a total of 75 m^3.

The required amount of irrigation water was applied by drip irrigation system from temporary water storing tank. The water in ground reservoir was fetched into elevated temporary water storing tank. This water was distribution on above ground thank placed at a height of 1.30 m at appropriate pressure head to supply required amount of water for each plot. The main line receives water directly from the water storing tank and distributed each laterals.

Drip system consisted of water storing tank, main lines; sub main lines, lateral lines, emitters and regular filter. The sub main line was connected to the mainline. The drip lateral lines in each plot received equal amount of irrigation water from the sub main line. The spacing between each emitter was 40 cm and between lateral was 70 cm which match with the intra- and inter-row spacing of the test crop.

Water Use Efficiency

The productivity of total applied water (PAW) is defined as crop yield per unit volume of water supply to the crops, Molden (1997), and is estimated by dividing crop yield, estimated from crop production functions by total applied water. The irrigation water amounts were compared for field water use efficiency (FWUE) and crop water use efficiency (CWUE). Field water use efficiency is the grain yield produced per amount of irrigation water applied

.

$$\mathrm{CWUE}=\frac{\text{Grain yield (kg)}}{\text{Crop water requirement (m}^3)} \qquad 10$$

$$\mathrm{FWUE}=\frac{\text{Total grain yield produced (kg)}}{\text{Total amount of water applied (m}^3)} \qquad 11$$

Yield Response Factor

The yield response factor (Ky) of tomato which relates relative yield decrease to relative ET deficit under this study was estimated using the following equation which is formulated by Doorenbos and Kassam (1979). It describes the relationship between the relative yield decreases produced by relative evapotranspiration deficit in a given irrigation scheduling protocol. The formulation relates four parameters (Y_a, Y_m, ET_a and ET_m) to a fifth: K_y, the yield response factor as:

$$1-\frac{Y_a}{Y_m}=K_y\left[1-\frac{ET_a}{ET_m}\right] \qquad 12$$

where: Ya = actual yield (kg ha^{-1}), ET_m= maximum evapotranspiration (mm), Y_m = maximum yield (kg ha^{-1}), K_Y = yield response factor and ET_a = actual evapotranspiration (mm),

Partial budget analysis

Economic water productivity analysis was begun by considering the general relationship between the crop water use and crop yield per haare of land at the different deficit irrigation application levels using the partial budget analysis. Net income (NI) in Birr ha^{-1}, generated from tomato crop, was computed by subtracting the total cost (TC) in Birr ha^{-1} from the total return (TR) in Birr ha^{-1} obtained from tomato sale as:

$$\mathrm{NI}=\mathrm{TR}-\mathrm{TVC} \qquad 13$$

TC is the sum of FC and VC. Fixed costs (FC) are those that do not vary between irrigation treatments, i.e. tomato seeds, fertilizer, pesticides, land rent and farm implements. Variable costs, on the other hand, are those that do vary between irrigation treatments, i.e. irrigation water and labor. The amount of water to be saved (SW) per ha of land from irrigation deficit was computed by subtracting deficit water application levels from the irrigation treatment that used the highest irrigation water level, i.e. 100% ETc. The extra irrigable land area (A) in ha which was served by the saved irrigation water was determined by dividing the total saved water per ha of land (SW) in m^3 by the irrigation water use for a ha of land (IWU) in m^3 ha^{-1} as **(**Horton, 1982): The net income from saved water (NI_{sw}) in Birr that was obtained from irrigating extra land of area (A) in ha was expressed as:

$$\mathrm{NI_{sw}} = \Delta\mathrm{NI} \times \mathrm{A} \tag{14}$$

Methods of data analysis

All measured variables were subjected to Genstat 15th edition software for analysis of variance. When the treatment effects were found significant, the mean difference was tested using least significant difference at 5% level of probability.

Result and Discussion

Soil physical property of experimental site

The soil physical properties of experimental site were presented in Table 2. The analysis of particle size distribution indicated that the soil texture at depths of 0-40 cm was sandy loam, but at lower depth (40-60 cm) it was found sandy clay loam. Thus, according to the USDA soil textural classification, the particle size distribution of experimental site revealed that the soil textural class was sandy clay loam. The average soil bulk density of 0-60 cm soil depth was 1.54 g cm^{-3}. The bulk density of soil, generally, showed a moderately decreasing trend with depth from 0-20 cm to 20-40 cm and, then increase in bulk density (1.61 g cm^3) was observed at depth of 40-60 cm as from the table below. Generally, bulk density of experimental site was found between the ranges of 1.50 -1.61 g cm^3, this shows at lower depth compacted or there may be hard pan.

Field capacity (FC), permanent wilting point (PWP) are also presented in Table 2. The top soil (0-20 cm) had relatively lower available moisture content as compared to the subsoil. Average value of available soil moisture content through a soil depth (0 - 60 cm) were observed as 24.0 % and 14.9 % in volume present field capacity (FC) and PWP respectively.

Table 2: Soil physical properties of experimental area

depth (cm)	Particle size distribution			Textural class	PWP in (vol %)	FC in (vol %)	B_d (g cm^{-3})	Infiltration rate (mm hr^{-1})
	Sand%	Silt%	Clay %					
0-20	69	11	20	SL	13.8	22.4	1.51	21
20-40	68	12	20	SL	13.86	22.5	1.50	
40-60	66	12	22	SCL	14.9	24.0	1.61	
Average	**67.67**	**11.67**	**20.66**	**SCL**	**14.18**	**23.1**	**1.54**	

where: SL: sandy loam SCL: sandy clay loam PWP is permanent wilting point, FC is field capacity and B_d is bulk density

Average/representative value of TAW 33.30 % (in volume base was obtained by considering the average of the upper 0 - 60 cm soil depth. The infiltration rate of experimental site used in determination of CWR was determined by double ring infiltrometer which was 21mm hr^{-1}.

Reference Evapotranspiration and Crop Water Requirement

Reference evapotranspiration

Analysis of monthly reference evapotranspiration (ETo) calculated from historical records of 10-year data of Fedis Meteorological Station estimated by CROPWAT software for study area. The mean reference evapotranspiration was occurred 4.4 mm day^{-1}, minimum and maximum had no negligible difference as shown (Table 3). The crop water requirement (ETc) of tomato was calculated using crop coefficient approach on the basis of meeting the evapotranspiration rate of a disease free crop growing in large field under optimal soil conditions including sufficient water and fertility and achieving full production potential under the given growing environment.

Table 3: Depth of net and gross irrigation water applied to each treatment in two growth season (mm)

2017 Growing Season																
Growth Stage	Initial stage			Development			`Mid stage				Late stage			CWR mm	I_{net} (mm)	I_{gross} (mm)
	Months (February (F) up to June (J))															
Irrigation month by decade	01-F	10-F	20-F	01-M	10-M	20-M	01-A	10-A	20-A	01-M	10-M	20-M	01-J			
ETo (mm/day)	4.6	4.6	4.6	4.4	4.4	4.4	4.2	4.2	4.2	3.9	3.9	3.9	3.7			
Kc-cofficient	0.6	0.6	0.6	0.7	0.9	1.0	1.2	1.2	1.2	1.1	1.1	0.9	0.8			
ETc (mm/decade)	27.3	27.3	21.7	29.8	37.6	49.8	49.3	48.4	47.3	45.8	41.2	40.0	31.6	497.3		
T_1 (100 % ETc) /control	27.3	27.3	21.7	29.8	37.6	49.8	49.3	48.4	47.3	45.8	41.2	40.0	31.6	**497.3**	**448.0**	**497.8**
T_2 (D by 85% at D_{VS} & L_S	27.3	27.3	21.7	25.3	32.0	42.3	49.3	48.4	47.3	38.9	35.0	34.0	26.9	**455.7**	**414.8**	**460.9**
T_3 (D by 75% at D_{VS} & L_S	27.3	27.3	21.7	22.4	28.2	37.4	49.3	48.4	47.3	34.4	30.9	30.0	23.7	**428.2**	**392.3**	**435.9**
T_4 (D by 65% at D_{VS} & L_S	27.3	27.3	21.7	19.4	24.4	32.4	49.3	48.4	47.3	29.8	26.8	26.0	20.5	**400.6**	**369.7**	**410.8**
2019 Growing Season (second season)																
Irrigation month by decade	01-F	10-F	20-F	01-Mr	10-M	20-M	01-A	10-A	20-A	01-M	10-M	20-M	01-J			
ETo (mm/day)	4.5	4.5	4.5	4.6	4.6	4.6	4.4	4.4	4.4	4.2	4.2	4.2	3.9			
Kc-cofficient	0.6	0.6	0.6	0.8	0.9	1.1	1.2	1.2	1.2	1.2	1.1	1.0	0.9			
ETc (mm/decade)	26.0	27.0	31.4	35.6	43.0	39.4	52.0	51.5	55.8	49.8	46.2	40.1	34.2	531.9		
T_1 (100 % ETc) control	26.0	27.0	31.4	35.6	43.0	39.4	52.0	51.5	55.8	49.8	46.2	40.1	34.2	**531.9**	**500.4**	**556.0**
T_2 (D by 85% at D_{VS} & L_S	26.0	27.0	26.7	30.3	36.6	33.5	52.0	51.5	55.8	49.8	39.3	34.1	29.1	**491.5**	**432.1**	**480.1**
T_3 (D by 75% at D_{VS} & L_S	26.0	27.0	23.6	26.7	32.3	29.6	52.0	51.5	55.8	49.8	34.7	30.1	25.7	**464.5**	**412.5**	**458.3**
T_4 (D by 65% at D_{VS} & L_S	26.0	27.0	20.4	23.1	28.0	25.6	52.0	51.5	55.8	49.8	30.0	26.1	22.2	**437.5**	**392.9**	**436.6**

T- Treatment D- Deficit D_{VS}- development stage, L_S- late stage

Crop water requirement of tomato

For seasonal crop water requirement of tomato, the average of long term meteorological data of study area was used as input for the CROPWAT 8.0 model and the reference evapotranspiration of the study area was computed and the result was presented table below. Seasonal crop water requirement of tomato determined based on the seasonal water application depth from after establishment transplanted was done. Thereafter applied water was vary based on deficit application level of each treatment as preplanned. In first year of cropping season, maximum amount of net irrigation (448.0mm) was consumed by control treatment (application of 100% ETc). Irrigation water required of other treatments (T_2, T_3 and T_4) were deduced from control according to their percentage of deficit levels during both crop growth stage (development and late stage). Similarly, for second year cropping season, maximum amount of net irrigation (500.4 mm) was consumed by full application treatment (application of 100% ETc) in the same manner for other treatments water extraction was made accordingly. Gross water applied for the crop was determined by dividing net irrigation water requirement with standard application efficiency as described (Equation 7).

Effects of Deficit Irrigation on Growth Parameters of tomato

Plant height: The result shows that tomato plant height was highly influenced by different deficit application level of irrigation water ($P < 0.001$). The highest plant height 46.17cm was recorded by control treatment (T_1). But statistically there was no significance difference between T_2 and T_3. The minimum plant height 34.33 cm was recorded by treatment T_4 and which was significantly different from all other treatments. This result is in agreement with Aman, 2013. According to his finding that plant height of the tomato variety was significantly ($p<0.01$) affected by variations in level of water application treatments of (100% ETc) which received the optimum amount of irrigation water had the highest average plant height while stressed treatment by 40% or deficit throughout growing period gave the lowest average plant height. This study revealed that plant height increased with more water application levels. This result agrees with Mandefro and Kokobe, (2015) reported that lettuce plant height increased significantly with increasing irrigation water applied. Similarly, Yazgan *et al.* (2008) reported that irrigation water levels had significant effects on lettuce height and the highest plant height values from full irrigation levels.

Number of branch per plant: Result from the analysis of variance showed that there was significance difference between treatments in case of number of branch per plant ($p<0.001$). Number of branch was affected by decreasing application of irrigation water. Full application of irrigation water (100% ETc) produces high number of branch per plant (7.83). Small amount of branch was obtained by the small application of irrigation water (65% ETc) which was (3.50). Statistically there was no significance difference between T_2 and T_3. Moreover, results show that irrigation application level has significant effect on vegetative growth. This indicated that as irrigation application level decreased from non-deficit (T_1) to high deficit level (T_4) the number of branch was also decreased.

Fruit number per plant : The ANOVA showed that there was highly significantly ($p<0.001$) difference between treatments in case number of fruit per plant. The highest mean number of fruit per plant was produced by full (100% ETc) through growth and the lowest was recorded by 65% ETc water application level at development and late stage. But statistically there was no significance difference between T_2 and T_3 in case of number of fruit per plant. Generally, finding conformed that irrigation application level had significant effect on producing much amount of fruit. This indicated that holding high amount fruit decrease as irrigation application level decreased from non-deficit (T_1) to high deficit level (T_4). This fining confirmed with (Aman, 2013) reported that treatment that received 100%, ETc or no stressed possessed the highest average number of fruits per plant, whereas the most stressed 40% water reduced treatment through resulted in smallest number of tomato fruit.

Table 4. Combined effect deficit irrigation on growth parameters of tomato in two consecutive years.

Treatment	**PH**	**NB**	**NFPP**	**MY (ton ha^{-1})**	**TY (ton ha^{-1})**
T_1	46.20^{a}	7.80^{a}	24.00^{a}	25.18^{a}	26.32^{a}
T_2	41.30^{b}	6.30^{b}	16.70^{b}	23.81^{ab}	24.96^{ab}
T_3	40.80^{b}	5.70^{b}	16.20^{b}	23.60^{b}	24.71^{b}
T_4	34.30^{c}	3.50^{c}	9.30^{c}	17.36^{c}	19.12^{c}
CV (%)	3.30	12.10	6.60	5.50	4.90
L.S.D	1.636**	0.854**	1.315**	1.50	1.42*

BN- number of branch per plant, PH- plant height and NFPP- number of fruit per plant, TY- total yield LSD: Least significance difference, CV: Coefficient of variation. Note: means followed by the same are not significant different.

Effect of Deficit Irrigation on Yield and Yield Components of Tomato

Total tomato yield: The two years combined ANOVA revealed that total tomato yield was significantly ($p<0.05$) influenced by deficit irrigation level of both pre stage. Maximum total yield (26.32-ton ha^{-1}) was obtained by non-deficit treatment (T_1) whereas, the lowest yield of 19.12-ton ha^{-1} was produced by lowest water application level during two consecutive cropping season. However, treatment T_1 and T_2 were significantly different. Total tomato yield decreased with increasing deficit irrigation level. The yield obtained by application of 75% ETc was statistically similar with 85% ETc application. From this finding optimum tomato yield was gained at 75% ETc application level hence the best deficit irrigation and appropriate than each treatment.

Marketable yield of tomato: ANOVA for marketable yield of tomato indicated that there was significant ($P < 0.05$) effect because of different levels of deficit irrigation treatments. The highest marketable tomato yield of 25.18-ton ha^{-1} was obtained from the control treatment (T_1)

and the lowest value of 17.36-ton ha^{-1} was obtained from high deficit treatment (T_4). The yield obtained by application of 75% ETc was statistically similar with 85% ETc application. In contrary, there was significant difference between treatments which received minimum amounts of irrigation water T_4 and the other treatments. In general, the results indicated that marketable bulb yield of tomato decreased as deficit irrigation level increase from optimum irrigation (100% ETc) to low application level (65% ETc). Kloss *et al.* (2012) reported improving water productivity is closely related to the irrigation practice of regulated deficit irrigation and has a direct effect on yield that is, if the amount of water applied decreases intentionally the crop yield will decrease.

Effect of deficit irrigation on yield response factor

The yield response factor (K_y) obtained from the deficit treatments T_2, T_3 and T_4 were 0.57, 0.56 and 1.76 respectively in 2017 cropping season. For 2019 cropping season, the yield response factor (k_y) obtained from the deficit treatments T_2, T_3 and T_4 were 0.43, 0.41 and 1.24 respectively. The study reveals that lower yield response factor was obtained by deficit level of 75% of ETc treatment (T_3) in which statistically similar yield was obtained with that of the T_2 while the higher yield response factor was obtained by T_4 in two consecutive years.

Table 5. Effect of deficit irrigation on yield response factor (K_y) of tomato.

		CWR of 2017 Cropping season		
Treatment	I_{net} (mm)	I_{gross}(mm)	TY (ton ha^{-1})	K_y
T_1	448.00	497.80	25.61	0
T_2	414.84	460.93	24.33	0.57
T_3	392.27	435.86	24.14	0.56
T_4	369.70	410.78	18.01	1.76
		CWR of 2019 Cropping season		
Treatment	I_{net} (mm)	I_{gross}(mm)	TY (ton ha^{-1})	K_y
T_1	500.4	556.00	27.03	0
T_2	432.05	480.05	25.59	0.43
T_3	412.47	458.30	25.22	0.41
T_4	392.94	436.60	20.23	1.24

Note: I_{net} is net irrigation, I_{gross}- gross irrigation, TY is total tomato yield and k_y is yield response factor.

Different studies revealed that yield response factor varies for different crop type and deficit condition. Since the obtained K_y<1, the crop is more tolerant to water deficit, and recovers partially from deficit, exhibiting less than proportional reductions in yield with reduced water use. When $K_y > 1$, the crop response is very sensitive to water deficit with proportional larger yield reductions; $K_y < 1$, the crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use; $K_y = 1$, the yield reduction is directly proportional to reduced water use (Doorenbos and Kassam, 1979). However, yield response factors have been found to be dependent on locations. Generally, the study showed that based on the obtained yield reduction factors (K_y) T_2 and T_3 were best application level for the study area. The application of 65 % of ETc (T_4) produce higher yield response factor which implies that the crop response was very sensitive to water deficit with proportional larger yield reduction.

Effect of deficit irrigation on water productivity

The result on CWUE and IWUE show that there was significance difference between different deficit irrigation levels. Both Maximum CWUE (14.86 kg m^{-3}) and maximum IWUE (13.37 kg m^{-3}) was obtained by T_3 (75% application of irrigation water) while the lowest value 12.54 and 11.24 kg m^{-3} of CWUE and IWUE was respectively obtained from T_4. T_2 and T_1 produce 13.95 kg $m^{-3}$and 13.37 kg m^{-3} of IWUE kg m^{-3} and 15.55 kg m^{-3} and 14.86 kg m^{-3} respectively. Statistically there was no significance difference between T_2 and T_3 in case of IWUE. ANOVA show that water application of 75% ETc produce maximum water productivity by saving 25% of irrigation water which can irrigate additional area. Even though maximum yield is produced by T_1 CWP was lowest due to maximum consumption of irrigation water. From this study application level of 75% ETc taken as the best application level for tomato production under drip irrigation system.

Table 6. Effect of deficit irrigation on water productivity of tomato in two consecutive years

Treatments	**IWUE (kg m^{-3})**	**CWUE (kg m^{-3})**
T_1	13.37^{b}	14.86^{b}
T_2	13.95^{ab}	15.55^{a}
T_3	14.35^{a}	15.99^{a}
T_4	11.24^{c}	12.54^{c}
CV (%)	3.90	3.70
L.S.D	0.626	0.663

CWUE- Crop water use efficiency; IWUE Field/ irrigation water use efficiency LSD: Least significance difference, CV: Coefficient of variation. Note: means followed by the same are not significant different

Effect of deficit irrigation on water saved and yield reduction

The result shows that yield reduction was relatively increase as amount of irrigation water application was decrease. The amount of irrigation water saved which irrigate another additional area was increase as decreasing application level. The saved irrigation water from T_2, T_3 and T_4, were 8.21%, 13.24% and 18.27% respectively for 2017 cropping season. For 2019 cropping season saved irrigation water from T_2, T_3 and T_4, were 12.33%, 16.24% and 20.15% respectively. The additional area which can be irrigated by saved water by T_2, T_3 and T_4, were 0.08, 0.15, and 0.22 ha respectively in the first season (Table 7). For the second season the additional area which can be irrigated by saved water by T_2, T_3 and T_4, were 0.14, 0.19, and 0.25 ha respectively. Even though there was relative yield reduction there was the additional yield gain due to irrigating additional area by saved water from deficit irrigation level as in table below. The result showed that the minimum yield reduction factor (K_y) was produced by T_3 (application of 75% ETc) of irrigation water.

Table 7. Relative yield reduction of tomato and water saving with respect deficit water application levels

2017- Cropping season							
Treatment	WU	TY	WS	WS	YD	AIBSW	Y
T_1	1826.33	24.12	0.00	0.00	0.00	0.00	0.00
T_2	1676.43	23.46	8.21	149.90	2.76	0.08	1.876
T_3	1584.56	23.18	13.24	241.77	3.92	0.15	3.47
T_4	1492.69	16.61	18.27	333.64	31.14	0.22	3.65
2019 - Cropping season							
Treatment	WU	TY	WS	WS	YD	AIBSW	Y_{gsw}
T_1	2039.86	26.13	0.00	0.00	0.00	0.00	0.00
T_2	1788.40	24.48	12.33	251.46	6.31	0.14	3.43
T_3	1708.56	24.03	16.24	331.30	8.03	0.19	4.57
T_4	1628.73	18.51	20.15	411.13	29.16	0.25	4.63

Note: WU-water use in (m^3 ha^{-1}), TY-total yield in (ton ha^{-1}), WS-water saved in (m^3ha^{-1}), YD or I yield decrease/increase in (%), AIBSW-area to be irrigated by saved water, Y_{gsw} is yield gained in from saved water (ton ha^{-1})

Partial budget analysis

Partial budget analysis of irrigation treatments has shown that there was increasing trend of net income (NI) for increase in water application level. It is clear that water saving at high application level is very low, though control treatment (T_1) has the highest NI in two consecutive years. This is because unit price of irrigation water at farms level in the area pay for irrigation water was very low. As a result, the direct impact of water saving generated NI was very low for a ha are of land per season.

Table 8. Benefit cost ratio per hectare of tomato production

				2017 Cropping season				
Treatment	**WU**	**AMY**	**TR**	**TVC**	**TFC**	**TC**	**NI**	**BCR**
T_1	1826.33	21709.8	217098	22829.13	25000	47829.13	169268.88	3.54
T_2	1676.43	21110.4	211104	20955.38	25000	45955.38	165148.63	3.59
T_3	1584.56	20857.1	208571	19807.00	25000	44807.00	163764.40	3.65
T_4	1492.69	14947.1	149471	18658.63	25000	43658.63	105812.28	2.42
				2019- Cropping Season				
	WU	**AMY**	**TR**	**TVC**	**TFC**	**TC**	**NI**	**B/C**
T_1	2039.86	23516.1	235161	25498.23	25000	50498.23	184662.77	3.66
T_2	1788.4	22031.7	220317	22354.98	25000	47354.977	172962.32	3.65
T_3	1708.56	21629.6	216296	21357.06	25000	46357.06	169939.04	3.67
T_4	1628.73	16656.1	166561	20359.14	25000	45359.14	121202.06	2.67

WU-water use in (m^3 ha^{-1}) ; MY is marketable yield (kg ha^{-1}) TR is Total return Birr ha^{-1}, TVC is Total variable cost in birr ha^{-1}; TVC is Total fixed cost in birr ha^{-1} TVC is Total cost birr ha^{-1} and NI is Net income birr per hectare; BCR is Benefit cost ratio

The highest variable cost of 22829.13 ETB was acquired for control treatments T_1 and the lowest variable cost of ETB was acquired for treatment, receiving 65% ETc T_4 in 2017 cropping season.

For 2019 highest variable cost of 25498.23 ETB was acquired for control treatments T1 and the lowest variable cost of 18658.63 ETB was acquired for treatment, receiving 65% ETc T_4 (Table 8).

Benefit cost ratio (BCR) of each treatment was computed as the ratio of NI earned to the TC expended. Accordingly, maximum BCR were obtained by T_3 means that treatment which receives application level of 75% ETc in two consecutive years. However, the lowest BCR was recorded under treatments receiving 65% ETc. The other remaining treatments of BCR were occupied in between largest and the smallest value of BCR. From this economic analysis T_3 was the most economically attractive treatment with lower cost of production and optimum net benefit. Even though maximum yield was obtained with the fulfillment of the entire crop water requirements practicing irrigation with moisture stress level can save irrigation water which increases the irrigated area, frequency of cultivation or release more water for downstream. The results in line with Ali *et al*., (2007) who reported water saved by DI can be used to irrigate more land on the same farm or in the water user's community, which, given the high opportunity cost of water, and may largely compensate for the economic loss due to yield reduction.

Conclusion and Recommendations

Conclusion

One of the irrigation management practices which could result in water saving is deficit irrigation and some modern irrigation methods, by maintaining the moisture content of the soil below the optimum level during specific growth stages of the season or throughout the growing period, it is possible to identify the periods during which water deficit would have a limited effect on crop production. Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains by maximizing yield per unit of water. Now a day the modern, high-tech and efficient micro irrigation methods (drip, bubbler, sprinkler etc.) are advocated worldwide,

Irrigation systems, such as drip irrigation supply water directly to the plants effective root zone and thereby minimize water loss to evaporation and seepage compared to surface irrigation. However, most of the drip irrigation technologies were tested or evaluate under different crops with growth stage deficit technology. Therefore, this study was aimed to evaluate the effect of deficit irrigation on yield and water productivity of tomato under drip irrigation system using rain water at Fedis Research station EHZ of Oromia Region. The experiment consisted of four treatments with three deficits at two growth stage 85%, 75% and 65% ETc, and no deficit or full irrigation 100% ETc at; two growth stages i.e. crop development and late stage; Accordingly mean seasonal net and gross irrigation depth applied was 406.2 and 451.35 mm, and 434.475 482.75 mm for first and second cropping season respectively, amount of irrigation depth for three-forth (75% ETc) and half (50% ETc) depth treatments were deduced from full (100% ETc), Parameters was evaluated by Genstat software 15th edition at 5% significance level include; growth components and physiological parameters, yield, physical and economic water productivity.

The result shows that plant height was highly significantly ($P < 0.001$) influenced by different deficit application level of irrigation water. The highest plant height 46.17 cm was recorded by control treatment (T_1) no deficit treatment whereas minimum 34.33 cm was recorded by treatment 65% ETc of crop water requirement. ANOVA showed that there was highly significance ($p<0.001$) difference between treatments in number of branch per plant. The ANOVA showed that NFPP of tomato was highly significance ($p<0.001$) influenced by per stage deficit levels. The ANOVA revealed that deficit irrigation level significantly ($p<0.05$) influences tomato yield. Maximum yield (26.32-ton ha^{-1}) was obtained by non-deficit treatment (T_1) while lowest application level of irrigation water had the lowest yield of 19.12-ton ha^{-1} in mean of two consecutive years.

The result on CWUE and IWUE show that there was significance ($P<0.05$) difference between different deficit irrigation levels. Both maximum CWUE and maximum IWUE was obtained by T3 (75% ETc) while the lowest value of CWUE and IWUE was respectively obtained from T_4 (65% application of irrigation water).

The highest mean of two years yield response factor (Ky) tomato was 1.14 observed in treatment deficit by 35% ETc (T_4) at DEV and LAT stage. This indicates Ky was calculated from yield gained in accordance to water applied. Crop response factors that are less than unity for conditions where deficits irrigation practices may seem to be acceptable and infeasible option either for the season or for a particular growth stage. Drip irrigation system is an appropriate irrigation method/technology for fruit and vegetable production and attractive at water stressed or in area with limited water. Summing up in terms of yield and physical and economic water productivity (crop and field water use efficiency) BCR and NR generated by DI with 75% ETc at D_{EV} and L_{AT} stage was superior of compared other treatment. The maximum yield reduction was observed in T_4 followed T_3 and T_2 application depths, but water saved by reverse (T_2 followed T_3 andT_4), or in increasing order. At 75% ETc application of irrigation water 17.4% of irrigation water was saved which can irrigate additional 0.17 ha of land, DI at 65% ETc higher yield loss and the Ky also above recommended at D_{EV} and L. stage or highest yield loss.

Recommendations

Based on the findings the following recommendations have been made

Farmers can practice either DI with 75% ETc as a best and first option which able to save, up to 17.4 % of the irrigation water with a modest in yield decrease 6.5%.

Deficit at selected crop growth stage can saves reasonable amount of water with modest effect on yield for an area of water scarce, especially for eastern Oromia

Introducing technology is recommended that all possible efforts would made to the farming community, by GO and NGO or other stake holder through demonstrate dissemination of this technology for further use to save the scarce irrigation water of study area. Since the use drip irrigation through rain water harvesting..

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Post-harvest and Product Processing Technologies

Adaptation and Evaluation of an Evaporative Cooling System Storing for Tomato

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Abstract

Perishable agricultural commodity requires great attention to sustain their supply on the market. Because of lack of appropraite handling andstorage, considerable amount of tomato goes waste before it reaches for consumption. During peak production due to storage, farmers are forced to sell tomato at extremely low prices. Therefore losses can also be minimized by storing them at low temperature and high relative humidity environment. Four low cost andenergy storage which employed evaporative cooling were constructed from local materials and evaluated. So, average based maximum and minimum ambient and room temperature variation at mid-day are 32.5 to 21.0 $°_{C}$ *and 30.7 to 19.3* ^{0}*c respectively whereas daily average maximum and minimum 5cm, 10cm and 7.5cm cavity evaporative cooling temperature become 26.6 to 17.2* ^{0}*c, 26.3 to 17.2* ^{0}*c and 26.2 to 17.0* ^{0}*c respectively. In addition daily average based maximum and minimum temperature variation for charcoal based evaporative cooler become 24.4 to 17.0* ^{0}*c. Cooled storage characterized with 7.5cm cavity reduced average daily temperature with ambient temperature that could be intercepted by minimum 4* ^{0}*c to maximum 5.9* ^{0}*c whereas charcoal cool chamber reduced temperature with minimum 4* ^{0}*c to maximum 8.1* ^{0}*c. Evaporative cooling chamber with 5cm, 10cm and 7.5 cm cavity depicted maximum & minimum relative humidity of 90% & 61%; 90 % & 64%; 94% & 66% respectively. Whereas maximum & minimum relative humidity of charcoal storage and ambient relative humidity become 94 % & 70 %; 70% & 40% respectively. As period of storage increased, rate of damage increased. For instance, at twenty days after storage cumulative damage in evaporative cooling characterized with 5cm, 10cm, 7.5cm cavity and charcoal cooler become 28.46%, 12.82%, 12.5% and 8.99% losses were registered respectively.*

Key word: *Storage,Tomato, Temperature, Relative Humidity and Loss*

Introduction

Tomato (*Lycopersicon esculentum*) is one the most important and extensively grown nutritional vegetable in the world. It ranks next to potato and sweet potato in respect to vegetable production and widely cultivated in tropical, sub-tropical and temperate climates (Bradesco& Asgedom, 2019; FAO, 2006). Tomato in Ethiopia is mostly cultivated employing rain-fed and irrigation system in all home gardens and in the field for its adaptability to widerange of soil and climate condition of the locality. Local areas of the country have favorable agro-ecology that is suitable for growth of various crops and vegetables.

With aim of enhancing agricultural development, the government is implementing a number of projects like small-scale irrigation scheme in supplement for rainfall harvesting. Small scale irrigation scheme is mostly implemented for off-season time in order to support on season production to ensure food security program thereby for market to improve living conditions of small holders.

As country the total area of land estimated to becovered by tomato farms in 2016/17 was 6,299 ha with anestimated yield of 283,648 tones with rain-fed and irrigation systemwith an average production of 45ton/ha (CSA,2017). From this, Oromia region contributes the lion's share of Ethiopia's total tomato production which accounts about 68% of total production with the remaining production coming from Amhara (9%), Tigray (5%) and Somali region (4%). Moreover more than 254,000 farmers are engaged in tomato farming practices (Tefera & Tefera, 2013).

Tomato production become lowers due to inadequate use of fertilizer, lack of adequate chemicals, knowledge gap in production and management techniques. At research station, average tomato yields can be as high as 40 tons/ha, 25 tons/ha at on-farm demonstration plots, while the national average yield is about 9 tons/ha (Teklewold& Mekonnen, 2012).

In Western Shewa Zone, under rain-fed and irrigated production systems vegetables such as potato, onion, cabbage and garlic are dominant vegetables produced under rain-fed conditions, occupying 72% of the total area of vegetable production whereas 74% of irrigated vegetable land was allocated for potato, onion and tomato production (Bezabih & Victor, 2015).Despite this the contribution of vegetable both for the diet and income generation in the region is insignificant.

The reasons are very vulnerable for pests and diseases infestation, lack of attention to product quality and prevention of physical damage, lack of market structure, as well as the lack of storage and packing facilities (FAO, 2005; Bezabih & Victor, 2017). Unlike others, vegetable are highly perishable commodities which begin deterioration sooner got harvested and most are prone to handling damage till consumed. Agricultural products damage can particularly be occurred through all stage of the chain from harvest to consumption. In general speaking, handling damage is greatly underestimated because usually mishandling do not appears until sometime damage occurred. Unfortunately poor handling and storage can easily result in a total loss of products (Gutu &Abdeta, 2018).

Existing market infrastructure, poor transport and warehouse facilities do not suit the perishable nature of vegetables as a result of which the quality of vegetables such as tomato and onion deteriorates. During the peak production season, farmers are forced to sell the products at extremely low prices particularly for tomato and onion because of lack of appropriate storage structure thereby discouraging farmers from producing in the immediate subsequent season (Bezabih & Victor, 2015).Thus considerable amount of vegetables goes waste before it reaches for consumption or is sold at a thrown away prices. Due to their highly perishable in nature 30-35% of total vegetable production go waste during various steps of the post-harvest chain (FAO, 2006; Basediya & Samuel, 2013).

An average estimated loss of tomato due to postharvest loss and low moisture stress in west Shewa are 82% and 68% respectively (Bezabih & Victor, 2015). The main losses of tomato occur at different stages of handling and transportation from rural to urban market (Singh &Satapathy, 2006). Although local demand for preserves is strong & stable, producers don't draw much profit from the market. They have trouble getting rid of their tomatoes, not least because of inadequate preservation and processing units (Spore, 2009).

Postharvest losses can also be minimized by storing them at low temperature and high relative humidity environment (Hall, 1973). Low temperature handling and storage have been described as the most important physical method for post-harvest loss control (Seyoum &Woldetsadik, 2004; Vala &Saiyed, 2014). Low temperature storage system can effectively extend shelf life of vegetables by minimizing major postharvest losses through arresting metabolic breakdown and fungal deterioration (Gutu &Abdeta, 2018).

Evaporative cooling is an efficient and economical means for reducing temperature and increasing the relative humidity of an enclosure, and has been extensively tried for enhancing the shelf life of horticultural produce (Odesola & Onyebuchi, 2009; Ugwuishiwu &Liberty, 2013) which is essential for maintaining the freshness of the commodities (Dadhich,2008). It is low-cost, low-energy and environmental friendly air conditioning system that operates using induced processes of heat and mass transfer where water and air are working fluids(Camargo,2007; Jha & Chopra,2006). This evaporative cool chamber has been proved to be useful for short term, on-farm storage of vegetables in hot and dry regions and helpful to small farmers in rural areas (Dadhich, 2008;Jha & Chopra, 2006).

So far in Ethiopia evaporative cooler was studied and able to reduce the ambient temperature throughout the day from a range of 23-43C to 14.3-19.2C with an increase in relative humidity from 16-79% to 70-82.4% on average, the temperature and relative humidity differences were 10.7C and 36.7% respectively (Getinet &Seyoum,2008). Another study in Ethiopia showed that a multi-pad evaporative cooler resulted in a 5C temperature drop and 18% relative humidity increase compared to a single pad cooler. Low-cost forced ventilation evaporative coolers have been developed and tested at Haramaya University for fresh fruit and vegetables storage under arid and semi-arid conditions (Tilehun, 2010). However, this cooler was constructed entirely from angle iron and sheet metal which is so expensive and subjective to heat transfer application. Moreover, the system requires pumps and a lot of water for recirculating over system for cooling purpose.

Nevertheless Adet Agricultural Research center had constructed and employed for some fruits and vegetables. According to the test results, sweet orange and green paper was stored in evaporative cooling chamber for two month and three weeks with damage of less than 25% & 20% respectively (AgriTopia, 2003). Even though, the center constructed cooling chamber from locally available materials, the test did not included important vegetable like tomato which is recently emerging crop.

Material and Method

Location

Bako district was previously known for its major contributor of mango and sugarcane for users. However today many farmers residing in district are practicing irrigation mainly for tomatoes, onion and sugarcane cultivation. Snice the district is potential for tomato cultivation employing offseason harvesting, study was conducted in Oromia Agricultural Research Institute Bako Agricultural Engineering Research Center. The center is located in Bako Tibe District of West Shoa Zone, Oromia National Regional State, Ethiopia which is located at 260 km in the western direction from Addis Ababa on the main road to Nekemte. The altitude of the center is 1650 meters above sea level whereas latitude and longitude of study area is 9^{0}07'N and 37^{0}03'E respectively. The mean minimum and maximum air temperatures of the location becomes 25 & 32 ^{o}c respectively.Corresponding district was selected based on potentiality for tomato and betterment for continues follow up or checkup of the date-to- date performance of the product.

Materials

Conceptual design as well as sketching and design specification were committed or commenced with inclusive of material selection. Based on design materials for the constructions of evaporative cooling chamber was properly identified and selected. Accordingly locally available bricks, riverbed sand, stone, polyethylene sheet, mesh wire, bamboo, charcoal and thatch were used for construction of required size of chamber. Technical instruments like digital psychrometric units attached thermocouples& beam balance were employed during testing.

Simple practices are useful for cooling and enhancing storage system efficiency especially in developing countries where energy savings may be critical (Basediya & Samuel, 2013). Therefore appropriate cooling storage are required for on farm storage for vegetables for very remote and inaccessible areas so as to reduce losses. Low-cost, low or zero energy, environmentally friendly cool chambers that made from locally materials which utilized evaporative cooling method was paramount important structure which reduce temperature and maintains required relative humidity in the storage. This enables to ensure sustainable shelf life of tomatoes thereby to deliver to market.

Construction of the storage

Four type of evaporative cool chambers were constructed here for experimental test. Among these three of them were made from bricks, cement and sand whereas the remaining one was entirely constructed from charcoal and other local materials. After preparation of materials, construction of all evaporative cool chamber were proceeded as follow. At beginning floor of cool chamber that has 1.5m long and 0.8m width were made from brick as well as mixture of sand and cement for better basement for vegetable loaded in crate. And then double layer of walls that has 0.7m height were erectly built up. All double layer walls which are made of brick have 5cm, 7.5cm and 10 cm cavity. These cavities were prepared to be filled with wet riverbed sand during experiment. Cool chamber's top was covered with a lid made of grass and polyethylene sheet over a bamboo frame to protect tomato from sunlight and rain. For top cover case, fine mesh wire was tightly constructed or suited beneath top lid in order to protect the fruit from damage caused by rodents and others. Warm or wasted water was get rid of cavity through provided channel. Eventually, these all components get united for complete feature of appropriate evaporative cooling chamber to be ready for storage. Moreover evaporative cooling storage constructed in side house but in some case it is constructed outside house with proper shading mechanism.

Performance Evaluation

Each evaporative cool chamber has a capacity of storing one and half local standard box of tomatoes. Before storing the tomato, prerequisite data's particularly weight of tomato, volume of tomato, storage and ambient condition were collected & documented starting on loading day. Partially matured tomatoes were directly harvested from the farm and screening was made soon and separation of undamaged from damaged done earlier to storing them.

Since storage employs evaporative cooling heat trapped from warmer pad to lower, stored product shelf life would be prolonged to better without significant decomposition & deterioration. Maintaining respiration rate is so important phenomena, snice it directly influences storage performance more. Rate of respiration is mainly affected with temperature, relative humidity and surface area of containers. To proceed with test and to maintain cool chamber condition, initially all cavity had to be filled with river sand and then water was discharged over cavity every morning and evening to maintain the required temperature and humidity.

Then, healthy tomatoes was stored in all evaporative cool chamber in crates. Similar quantity of the products were kept in charcoal made storage chamber. The number and weight of products were recorded before storage and in the course of the experiment. Healthy products got replaced while shrunk or rot one get discarded. Damage of products was computed on number basis while loss was estimated in weight.

The relative humidity of the chamber would be maintained above 75% and monitored using a hygrometer. The cool chamber becomes more applicable where minimum and maximum room temperature is in between 22 to 27 ^{0}C, minimum and maximum atmospheric temperature is in between 10 to 30 ^{0}C. Products stored in the cool chamber storage were tested using the standard methods of food quality analysis as much as possible.

Storage losses are mainly caused by the processes like respiration and evaporation of water from tomato. Therefore damage and amount survived tomatoes which determine storage performance were closely observed & data were being collected every day of all chambers. After the test committed, the obtained values was plotted graphically and curve was developed. From this graph the length of shelf-life of the tomato without damage and losses and its effectiveness judged.

Result and Discussion

Temperature and relative humidity of surrounding environment and storage as well as mass of damage and number of lossess were collected and recoreded. Since these all parameters areimportant treatment that determine number day tomato get stored without inconsiderable losses occurred.

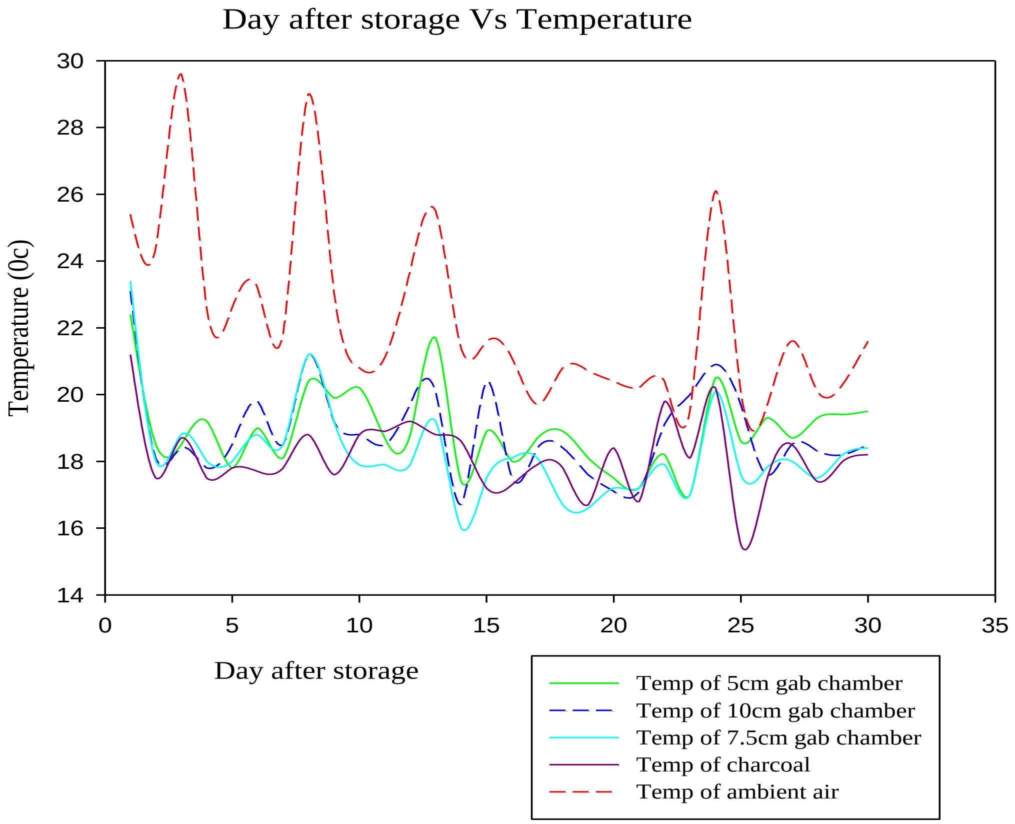

Figure 1 Temperature distribution in all evaporative cool chamber and ambient air

As it can be seen from figure 1, average based maximum and minimum ambient and room temperature variation at mid-day are 32.5 to 21.0 $^{\circ}{}_{C}$ and 30.7 to 19.3 ^{0}c respectively whereas daily average based maximum and minimum 5cm, 10cm and 7.5cm cavity evaporative cool chambers temperature become 26.6 to 17.2 ^{0}c, 26.3 to 17.2 ^{0}c and 26.2 to 17.0 ^{0}c respectively. In addition daily average based maximum and minimum temperature variation for charcoal based evaporative cooler become 24.4 to 17.0 ^{0}c. Cooled chamber characterized with 7.5cm cavity reduced average daily temperature with ambient temperature that could be intercepted by minimum 4 ^{0}c to maximum 5.9 ^{0}c whereas charcoal cool chamber reduced temperature with minimum 4 ^{0}c to maximum 8.1 ^{0}c.

According to Saltveint, 2005 & Irtwange, 2006respiration is mostly affected temperature, atmospheric composition, physical stress and stages of development. Ambient temperature can directly affect or influence respiration and metabolic rates. Respiration rate of agricultural product becomes higher and shelf life of stored commodities get shorter under ambient temperature ranging from 25 to 35 $^{\circ}{}_{C}$ (Basediya & Samuel, 2013). If the temperature of surrounding area goes beyond the range, deterioration of tomatoes began unless relative humidity get maintained. Thus temperature control is one of the most important factors in maintaining product quality, throughout the period between harvest and consumption (Kenneth & Wang, 2016).

Evaporation activity in cooling can lower the temperature of a container depends on wet bulb and dry bulb temperatures difference. In reality, though, while is not possible to achieve 100% of the theoretical maximum temperature drop, a substantial reduction in temperature is possible (Odesola & Onyebuchi, 2009). Therefore temperature variation have to be investigated in order to see performance of all cooling chambers.

Average values of respiratory activity of several vegetables at 0 ^{0}c and recorded that the respiratory activity increased much as temperature get increased(Burzo, 1980). He concluded that 0 to 30 ^{0}c an increased in temperature causes an exponential rise in respiration rate. According to Mangaraj & Kumar, 2009 an averaged values of respiration rate of tomato was estimated to be 10 times at 5 ^{0}c, 15 times at 10 ^{0}c, 22 time at 15 ^{0}c, 35 times at 20 ^{0}c and 43 time at 25 ^{o}c. As can be seen from this literature increasing temperature of chambers increases metabolic rate which inversely decrease shelf life of tomato. Intensive respiration activity of tomatoes was found to be varying greatly depending on variety, maturity and onset of climacteric respiration (Mangaraj & Kumar, 2009).

Effects of temperature fluctuation on quality of mushroom and matured green tomatoes was studied (Tano, 2007). They found temperature fluctuation had a major impact on composition of the package atmosphere and on product quality. Quality of the products stored under temperature fluctuation regime was severely affected as weight loss, loss of ethanol on plant tissue, and infection due to physiological damage as compared to products stored at constant temperature.

Therefore to prolong or extend shelf life of any vegetable proper storage practices which include temperature control, relative humidity and maintenance of space between products must be asserted. One way of increasing shelf life of a product can achieved by storing them at low temperature and high relative humidity conditions. These conditions are usually achieved in cold storages.

For storage losses are mainly caused by the processes like respiration, evaporation of water from the tomato, spread of diseases, changes in the chemical composition, physical properties and extreme temperature. Moreover storage life of a product varies with variety and pre-harvest conditions like quality and maturity.

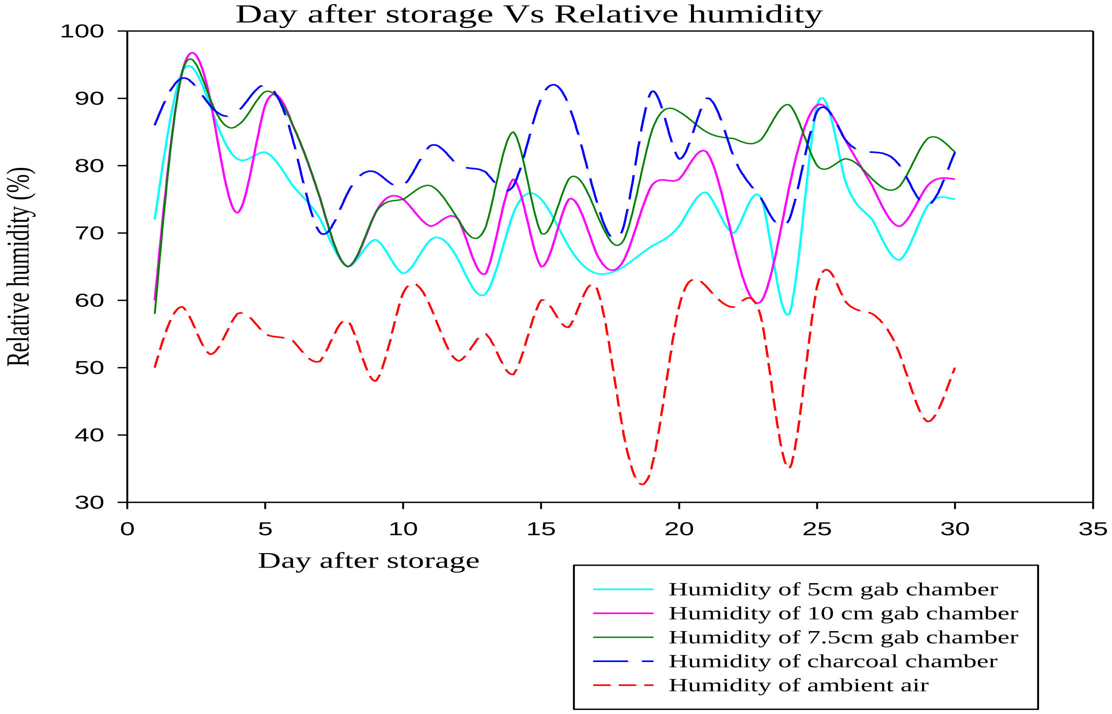

Figure 2 Relative Humidityof evaporative coolings and ambient air

Four cool chambers were tested parallel in order to investigate their cooling effectiveness of the storage. Among four, three of them were similar in feature with different cavity. Evaporative cooling chamber with 5cm, 10cm and 7.5 cm cavity depicted maximum & minimum relative humidity of 90% & 61%; 90 % & 64%; 94% & 66% respectively. Whereas maximum & minimum relative humidity of charcoal storage and ambient relative humidity become 94 % & 70 %; 70% & 40% respectively.

At high relative humidity and low temperature, according to Odesola & Onyebuchi, 2009 agricultural products maintain their weight, wilting and softening are reduced and rate of water evaporation is low and therefore cooling is low. However maintaining high humidity only around harvested produce reduces water loss, which would result in decreased returns through poor quality which mean wilting and loss of saleable weight (Basediya &Samuel, 2013).

In order to extend product shelf life, relative humidity and temperature maintained. When high relative humidity accompanied with low temperature storage achieved better shelf life. However high relative humidity and high temperate in combination favors the growth of fungi and bacteria to cause infection on stored products (Gutu & Abdeta, 2013).Cooling efficiency, temperature drop and increase in relative humidity inside the cool chamber largely depends on operating parameters. According to heat transfer application heat goes from higher to lower temperature. When water is added in cavity, the water trap heat from product stored and the storage get cooled. As soon as warm water get evaporated from tomato surface, the storage get cooled.

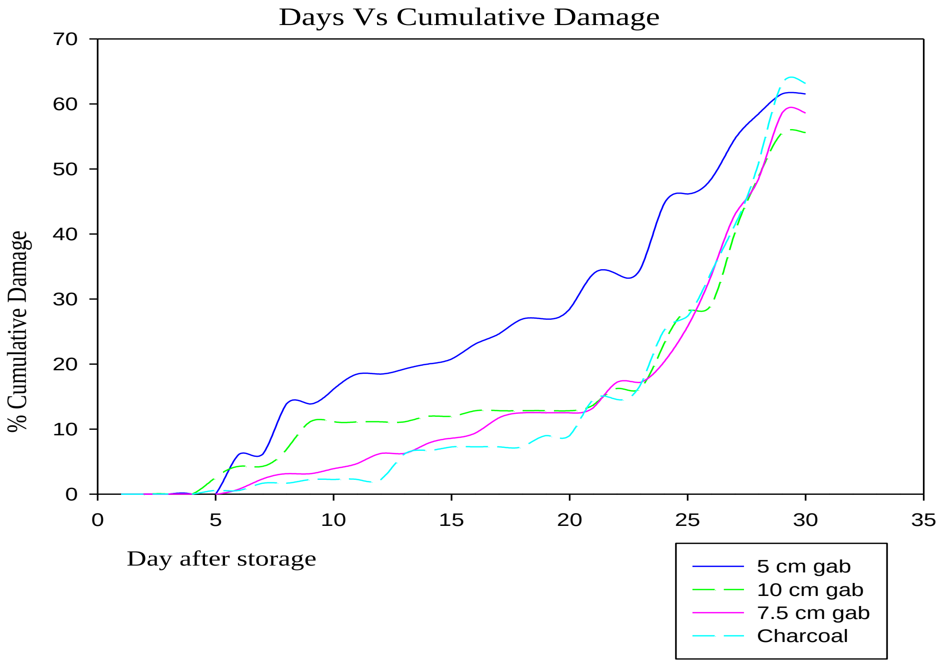

Figure3Cumulative Damage of Tomato in all evaporative coolings

As the period of storage increased, rate of decomposition and losses increased slightly different in magnitude. For instance, at twenty days after storage cumulative decomposition and loss occurred in evaporative cooling chamber characterized with 5cm, 10cm, 7.5cm cavity and charcoal cooler become 28.46%,12.82%,12.5% and 8.99% losses were registered respectively. Loss due to damage and decomposition of the tomato were mainly caused due to mechanical injury, rough handling and packing, transportation from field in to storage and respiration processes.

As water evaporates from a surface it tends to raise the humidity of the air that is closest to the water surface. If humid air remains in place, the rate of evaporation will start to slow down as humidity rises. On the other hand, if the humid air and the water surface constantly been moved away the rate of evaporation will either remain constant or increase. The greater the surface area from which water can evaporate, the greater the rate of evaporation (Odesola & Onyebuchi, 2009).

Charcoal made storage is still better in extending shelf life and minimizing losses occur in storage when compared with the remaining cooling storage. This cooler has more water holding capacity and retain better air recirculation in the system. Until twenty three days accumulative losses of tomato was not above 20% and can tolerably loss occur.

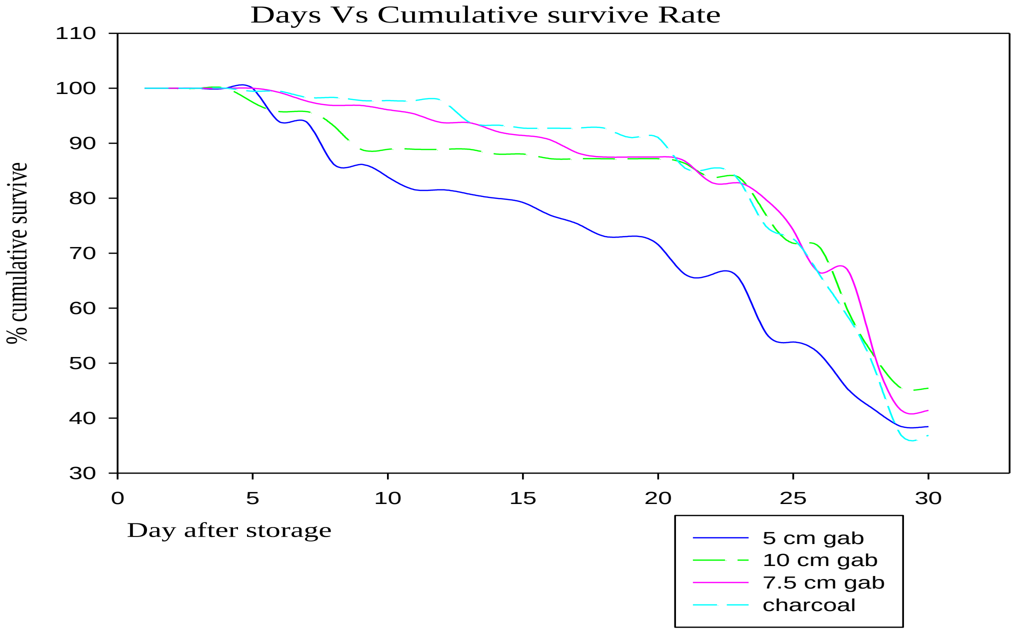

Figure4Cumulative Survived Tomato in all evaporative coolings

Surviving rate is opposite of losing of tomato, here charcoal cooling chamber is more surviving and minimizing media as compared to other storage. Surviving rate of charcoal cooling chamber above 90% until twenty days where as 7.5cm cavity able to survive above 88.35% until twenty day.

Conclusion and Recommendation

From our experimental result obtained, it is observed that several parameters are engaged to determine storage day & quality tomato. In addition to temperature and relative humidity, damage and loss have great value in order to decide shelf life of tomato. Thus, physical damages can be minimized by taking care during transportation from field to the storage and harvesting time. Losses cause due to microbial infection can be minimized by dropping evaporation rate & avoiding contact of water from product.

All evaporative coolers except 5cm cavity had prolonged shelf life of tomato for tween three days with less than 20 % losses. As day of storage increased further, cumulative losses of tomato stored in storage characterized with 7.5 cm cavity was smaller and grown slowly when compared to other storage. However, maintaining temperature and relative humidity of chambers must be done to make suitable to store with more storage day. As can be seen from few literatures and observed from our experiment, increasing temperature of chambers increases metabolic rate which inversely decrease shelf life of tomato.

Therefore evaporative cool chamber characterized with 7.5cm cavity can be recommended for storing of tomato to extend shelf life thereby to sustain availability of product over market at peak period.

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Effects of Curing on shelf life of fresh Potatoes Storage in East Hararghe Zone, Oromia

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Abstract

Potato curing is a hardening process of potato skin and, which reduces bruise; hence it is an important part of keeping quality of potatoes with minimum weight loss and storage loss. This experiment was conducted to evaluate effects of the curing on shelf life of fresh potatoes storage. The experiment has two factor replicated three times. The factors are namely; three curing period (0, 6 and 8) curing period and three potato varies (Gudane, Tulama and Shantam dhala) with three replication arranged in RCBD. The mean internal *temperature of storage ranges 12-16 ^{0}C, while the external or outside was 25-30 ^{0}C and humidity of 77-85 % inside and 40-50 % outside during storage period was recorded. The resut shows that weight loss significantly affected by curing among varieties throughout storing period with the total physiological loss of 18-24% with loss of (Gudanne < Shantama < Tulema). Accordingly both curing period have significant effect on total loss on potato varieties. The highest and lowest mean values sprouted (%) loss was observed by tulama and gudane with six day and not cured treatment respectively. Similarly the highest and lowest moisture losses (%) were recorded by gudane and tulama respectively. The result of Visual quality assessment and laboratory chemical composition analysis of stored tubers were shows that curing potato before storing produces satisfactory for each potato varieties. Generally since curing and storing of the potato tubers results shows minimal tuber weight loss and chemical composition quality via 10th to 14 week storage. Hence, curing for six days was attractive and economical, and recommend for farmers before storing the potato tubers under good storage management which was optimum to slow down fresh potato storage deterioration.*

Key words: *Potato, curing potato, storage, palatability and chemical composition*

Introduction

The potato (*Solanum tuberosum L.*) is the most important food crop in the world after wheat, rice and maize as well as ranks 4th in the world with respect to food production (Eltawil *et.al*, 2006). It is a semi-perishable commodity. Potato have important food value and cash crop in Ethiopia, especially in the high and mid altitude areas. According to CSA, 2016 of Ethiopia shown that potential production of East Hararghe zone was 194,247.72 quintal and numbers of holders 34,732.00, among potential producers worade Haramaya, Kombolcha and Dadar were most potato producing area during Meher and Balg season. Potatoes production area mainly practices by peasant farmer and both home and market supply. Though the land in the zone has high production potential both for rain fed and irrigated potato cultivation, but lack of prolonging condition with improved storages among the major factors limiting the production and productivity of farmers in all potato growing areas.

Potato storage should have adequate insulation, outside waterproofing, inside vapor proofing, ventilation, air distribution, adequate humidification, and properly designed controls for precisely maintaining the storage atmosphere. The room must be completely dark or the potato tubers must be covered. Darkness is important in preventing light from reaching the tubers and causing their skin to turn green (Herbert, 2003). Temperature, light, humidity, and air movement are the most important environmental factors affecting storability. Good storage should prevent excessive dehydration, decay, sprouting and high sugar concentrations, which result in dark colored fried products (Schaupmeyer, 1992). Appropriate and efficient post-harvest technology and marketing are critical to the entire production-consumption system of potato because of its bulkiness and perishability (FAO, 1991).

According to trials of potatoes tubers treated for two weeks by above ground pit-curing method showed only 40% total loss of tubers after 4 months of storage, compared to 100% of untreated tubers (FAO 1987). Despite precautions taken to prevent injury to the potato tuber, some damage is likely and a curing process is necessary for any wounds to heal. The healing process is facilitated by curing, which refers to putting potato tubers in a place conducive to encourage the skin to harden and heal bruises that happen during digging (Herbert, 2003). The curing process prevents rotting of harvested tubers. It should be done in a dark, dry and warm location. Potato tubers should be placed at temperature of between 15ºC and 25ºC for 4 to 15 days to cure. If the potato tubers are harvested wet, they should be drayed-off before storage.

However, there is potential production of potatoes in study districts all the product was supplying to the market during on-season and saturated the market supply which exceeding the existing demand by far. As a result, the selling price in the local market fall extremely, mostly to the extent that it cannot cover the production cost invested by farmers. So ever falling in price the farmers obliged to sell at any market value, this is due to lack of alternative means to extend its shelf life of the products toward waiting for reasonable selling price. In order to prolong the shelf life of potatoes tubers, the study was aimed to test the effect of curing condition on fresh potatoes products. The process was facilitated by dark, dry and warm location to healing wound to minimize loss, and the study was aimed to facilitate good ware storage management to control the losses due to storage relative humidity and temperature. As usually naturally ventilated air was used to regulate the inside room temperature and relative humidity. Hence the aim of this study was to evaluate effect of curing conditions on shelf life of different potato varieties and to evaluate the optimum storage period and calibrate curing factors for major potato varieties produced in the area

Materials and Methods

Description of the study area

The project was conducted on station in the compound of FARC, which is located in East Hararghe zone of Oromia National Regional State of 1885 m above sea level, eastern Ethiopia and 522 km far from Finfinne. The district is lying between 09°18’9’’N latitudes and 42°07`3’’ longitudes. Materials used during implementation were Digital weight balance, thermo-hygrometer, small water tank and other laboratory materials were collected from Haramaya University, Food chemistry laboratory.

Storage Structures

The construction site of storage was selected considering free air movement area. The basic functions of storage buildings of stored tuber were protected the commodity against weather, and provided storage temperature, air circulation, relative humidity and atmospheric condition were maintained naturally. A good ceiling was provided for insulation in order to block direct sun light and absorbed heat emitted from outside environments. Three bottom and above wall window which was covered by wire mesh to protected entrance of insect and rodent. It was opened at night to remove heat generated due to respiration and to regulate the stored tubers moisture content by carrying humidify air that come from bottom windows small tank water edible potatoes Storage was constructed from locally available material like wooden, pole and mud. The dimensions of warehouse were 1.9 m wide, 4.80 m length and 2.70 m height, and internally classified into nine shelf (9) and had classified into twenty-seven shelf (27) box. The wall of storage was covered inside and outside by mud up to 10 cm thicknesses. As figure below external and internal potato storage was attempted to describe

Sample Preparation

Removal of excess field moisture: The samples were collected from the potato producers at their edible maturity stage a few hours before curing time to avoid the possibility of moisture losses, as well as damage that might occur due to contamination of environmental factors prior to storage bruises and signs of infection were discarded from the sample before curing and storing. The stored potatoes were drayed off by natural air for removal excess moisture from the outer layer and other foreign materials were removed. As showed in figure

Curing process and storage period: Potatoes tubers of different size were obtained from each variety to undergo curing process. Curing was carried out under shade and covered by wetted grass immediately after harvest, the sample had classified as zero (0), six (6), and eight (8) days and at temperature ranges of 17-20 ^{0}C and relatives’ humidity of 74-85 %. An amount of 490 kg, for testing were prepared and applied cure with zero (0), six (6), and eight (8) days, which was referred to put potato tubers in a place conducive to encouraged the skin to harden and healed minor bruises that happen during digging. According to trials of potatoes tubers treated for two weeks by above ground pit-curing method showed only 40% total loss of tubers after 4 months of storage, compared to 100% of untreated tubers (FAO 1987).

Treatment and experimental design

The experiment was arranged in randomized complete block design (RCBD). Variety and curing periods were factors. Each treatment was replicated three times, accordingly the experiment 27 total combination of treatments which contained 18 kg sample for curing treatments. Not cured, after six (6) and eight days (8) were conducted for the experiments under constant storage managements. The treatment was prepared under two curing period and control non cured accordingly zero (0), six (6), and eight (8) days, for three different variety

Table .1 Treatments of the experiment

Treatment	**Varieties**	**Curing period in (days)**	Treatment combination**:** (Varieties with curing period)		
T_1	Gudann	0	Gudanne	with	Not cured
T_2		6	Gudanne	with	6-days cured
T_3		8	Gudanne	with	8 days cured
T_4	Shantama	0	Shantama	with	Not cured
T_5		6	Shantama	with	6-days cured
T_6		8	Shantama	with	8-days cured
T_7	Tulema	0	Tulema	with	Not cured
T_8		6	Tulema	with	6- days cured
T_9		8	Tulema	with	8- days cured

Data collected

Data were collected over a 10-14 week depending on variety and curing periods throughout storing period. Parameters include, relative humidity, temperature, carbohydrate composition, weight loss, moisture loss, and quality measurement (sensory test) were gathered as following method below. All observations were recorded as means of three replications. The data pertaining moisture contents and sprouting were statistically analyzed to determine the significant difference.

Temperature and relative humidity

The storage air temperature and relative humidity was recorded two times weekly three times in days at 4-hrs intervals during the day-time using digital electronic Thermo- hygrometer model ETHG 913 R placed inside and outside storage. The average both temperature and relatives humidity difference between the inside storage and outside was calculated by using the following relationship.

Temperature

Since the study area was not able to given the temperature (cold) that favourable for storing the product. It’s necessarily needed to maintained as much as possible by naturally ventilated method using water aeration system

$$\Delta T\ (^{\circ}C) = \frac{\mathbf{T_{out}\text{-}T_{in}}}{\boldsymbol{n}} \tag{1}$$

Where: ΔT = average residual temperature between air in the storage and ambient air
T_{in} = inside storage temperature
T_{out} = outside storage temperature
n= number of records

Relative humidity

Since the study area was not able to given the humidity (moist environment) that favourable for storing the product. It’s necessarily needed to maintained as much as possible by natural ventilated method using water aeration system

$$RH\ (\%) = \frac{R_{in} - R_{out}}{n} \tag{2}$$

Where: RH=average residual relative humidity between inside and outside of storage
R_{in} = inside storage relative
R_{out} = outside storage relative
n= number of record

Weight loss of potatoes (%)

Weight losses were taken from the sum of sprouted, rotten, color changed, and moisture loss of cured sample. The measurement was done by digital electronic balance having precision of 0.01gm, in the monthly interval and the difference between initial weight and final weight gave the total weight loss percentages.

$$W\ (\%) = \frac{Wi - Wf}{Wi} x100 \tag{3}$$

Where: W_i = initial weight
W_f=final weight
W = weight losses

Number of Potatoes sprouted

The sprouted of potato was determined by counting the number of sprouted potato at monthly intervals during the storage period. The sprouted potatoes were discarded after each count to avoid double counting.

Number of rotten potatoes (%)

The incidence of rotting was determined by counting the number of rotten potatoes were discarded after each observing to avoid double counting.

Moisture loss (%)

Moisture content has a direct economic importance and a significant influence on the shelf life of potato tubers (Sluimer, 2005). Potato tubers generally contains 63 – 80 % moisture resulting in an ambient relative humidity. On the other hand, Sluimer (2005) stated that the moisture content of potato tubers variation leads to shrinking when lost and deterioration at above internal saturation state, calculated as follows.

$$\text{Percent moisture} = \frac{\text{Loss of sample weight x}}{\text{Weight of sample}} x100 \qquad 4$$

Palatability of potatoes

The quality measurements method of stored potato was tested according to (Ma *et al.*, 2010). Within every month of stored period the stored potato tubers were cooked & tested by untrained panelists. During palatability evaluation, panelists were instructed to drink water or wash mouth after each evaluation. Sensory evaluation was done on the daytimes.

Visual quality assessment

Visual quality was examined in accordance with the sensory evaluation standards (Ma et al., 2010). Untrained panelist was scored on a scale of 9 points (1-9). In which **1.** Dislike extremely, **2.** Dislike very much, **3**. Dislike moderately, **4**. Dislike slightly, **5**. Neither like nor dislike, **6.** Like slightly, **7.** Like moderately, **8**. Like very much, **9**. Like extremely. With this regarded every one month of stored period potatoes were cooked and tested by panelist and gave score as above rating scale.

Fig. During sensory test

Chemicals composition of potatoes

The results of moisture, ash, fibre, carbohydrates, and some minerals contents were comparable to the results achieved by (Ma *et al.,* 2010), as well as by Sawicka and Michałek (2005)

Chemical combustion of stored potato was tested in laboratory throughout storing period. The potato tubers contain 35 % moisture, 25 % vitamin C, 16 % dietary fibre, 12.5 % Carbohydrates, 10 % calcium and other. The composition of potato tubers, however, varies considerably according to the class of potato, its variety of origin and the proportion of outer parts removal by particular milling process (Elias, 1972).

Methods of data analysis

All measured variables were subjected to Genstat 15th edition software for analysis of variance. When the treatment effects were found significant, the mean difference was tested using least significant difference at 5% level of probability.

Result and Discussion

Physiological weight loss

All the physiological losses mentioned below were depend on the storage conditions and perishability of tubers, therefore it could be limited by maintaining favorable conditions in the storage as well as hardening the skin of the tubers was observed to minimize the losses. ANOVA indicated that curing effect on Gudane, Shantama and Tulema variety was significance difference among treatment, of moisture losses, sprouted, colour change, but non significance for rotten and colour change ($P< 0.05$).

Table 2. Analyzed data of potato weight loss

Variety	**Treatment**	**Sprouted (kg)**	**Color change (kg)**	**Rotten (kg)**	**Moisture loss (kg)**
Gudane	Not cured	4.83^{ab}	0.91^{ab}	0.2^{a}	1.83^{a}
	Six days cured	2.00^{e}	0.65^{abc}	0.2867^{a}	0.58^{c}
	Eight days cured	3.52^{bcd}	1.04^{a}	0.126^{7a}	1.86^{a}
Shantama	Not cured	5.00^{ab}	0.55^{bc}	0.1167^{a}	1.76^{ab}
	Six days cured	2.01^{de}	0.4533^{c}	0.1967^{a}	0.56^{c}
	Eight days cured	4.33^{ab}	0.3667^{c}	0.1933^{a}	1.73^{ab}
Tulama	Not cured	5.40^{a}	0.46^{c}	0.1567^{a}	1.03^{bc}
	Six days cured	2.50^{de}	0.6633^{abc}	0.1333^{a}	0.63^{c}
	Eight days cured	3.00^{cde}	0.4767^{c}	0.1^{a}	1.49^{ab}
	CV (%)	24.20	37.70	28.90	34.30
	L.S.D (%)	1.52^{*}	0.40^{NS}	0.32^{NS}	0.75^{*}

LSD: Least significance difference, CV: Coefficient of variation. Note: mean followed by the same letters are not significant different NS stand foe non significance

Losses due to sprout

ANOVA indicated that loses due to sprout significantly affected by curing period. Sprouted in potato was not seen in first part of the storage period. The highest mean values lost in gudane, shantama and tulama variety was 4.8, 5 and 5.4 respectively, this was due to untreated by curing condition as well as the lowest mean values loss was resulted as 2.0, 2.01 and 2.5 respectively, with six-day curing, this was due to medium curing condition on the treatment applied. So that for those varieties under study curing had positive impact on shelf life of potatoes at six days curing duration, beyond this level it had negative impact which speed up the rate of moisture loss.

Moisture lose

The highest mean values loss of moisture was recorded in gudane variety, 1.86 this was due to over curing. shantama and tulama variety was, 1.76 and 1.49 respectively, this was due to untreated under curing condition as and the lowest mean values loss was resulted as 0.58, 0.56 and 0.63 respectively, with six day curing this was due to medium curing condition on the treatment applied. So that for those varieties under study curing had positive impact on shelf life of potatoes at six days curing duration, beyond this level it had negative impact which speed up the rate of sprouting.

From the result curing effect had significantly ($P<0.05$) influenced tubers weight loss throughout storage period. However, it did not significant differences for some variety among treatments in storage periods. In other way, increased curing days linearly increase physiological (total weight loss) tubers. Accordingly, six days curing condition shown good performance which result of weight loss was less as compared with that of rest treatment. Total losses throughout storage period of potatoes were recorded as 18 – 24 %. Result was lower than that of reported the Losses from tuber color greening, rotten, excessive sprouting, and other causes average about 20-30%, although losses of up to 70% have been reported (Geddes and Monninkhoff, 1984).

Chemicals composition of potatoes tubers

Accordingly, the results of moisture, ash, fibre, carbohydrates, and some minerals contents were illustrated in Table 3. Fresh potatoes consist of average 60 – 83 % moisture, 45-60% carbohydrates, 0.7 - 5% protein, 3% ash. The laboratory result of chemical composition of total soluble solid (TSS), carbohydrate, proteins, fibre, ash, Moisture contents (%) and vitamin C in average result of treatment that cured after six days was falls between ranges of the in potato tubers were comparable to the results achieved by Dua *et.al*. (2013) as well as by Sawicka and Michałek (2005).

The conducted experiments revealed that the carbohydrate and vitamin C concentrations in the studied potato curing effect did shown difference with that of not cured potato which stored under the same storage condition but different curing time on each variety. within the range of permissible values for this component in potato tubers not cured shown more qualitative loss for all three varieties majorly next to that of after eight days which affect sugar contents of tubers, so that after six-day curing shown that good performance.

Table 3. Laboratory result of chemical composition for potato varieties post storage

Collected parameters	Varieties with Treatment		
	Gudane	Shantama	Tulem

Chemical composition	Not cured	After 6th day	After 8th day	Not cured	After 6th day	After 8th day	Not cured	after 6th day	After 8th day
Sample (g)	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
TSS (%)	5.0	4.5	5.0	4.0	3.0	4.5	4.0	3.0	3.0
Vitamin C	13.0	15.0	15.0	15.0	13.0	15.0	14.0	14.0	14.0
Sample (100 ml)	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
CH_2O (%)	57.7	48.3	39.7	47.7	48.3	46.0	60.2	48.7	57.6
Moisture contents (%)	34.3	44.7	54.3	35.3	42.7	43.7	33.3	43.3	34.7
Ash (%	5.0	4.7	6.0	4.7	6.7	5.3	4.9	5.7	5.0
Protein contents (%)	3.0	2.3	2.0	2.3	2.3	2.4	1.5	2.4	2.8
Fiber (%)	1.1	0.7	0.6	0.7	0.7	0.7	1.2	0.7	1.2
Potassium (g)	196.8	122.8	126.4	153.2	102.5	151.0	150.2	176.5	173.8
Iron (g)	6.0	7.2	12.1	9.6	5.5	13.8	14.7	7.0	14.9
Calcium(g)	12.0	41.3	44.7	18.9	37.8	26.4	31.5	40.1	25.2

This due to undergo optimum curing days means, it was not too long day's not too short day. Accordingly, the result had indicated that the existing differences in chemical composition of tubers were comparable with that finding.

Temperature and relative humidity

From the plotted graph between number of record versus temperature or humidity plotted the first two column shown temperature and the second column shown humidity accordingly the inside temperature of storage was varied between 12-16 ^{0}C against ambient temperature variations between 25-30^{0}C, and Relatives Humidity inside the structure was 77-85% against that of outside 40-50%. As shown from the graph the inside average temperature was much less than ambient temperature, which was regulated by cool air entrance, this indicated that keep coldness and moistness of internal storage was critical to maintained the internal storage, similarly for humidity

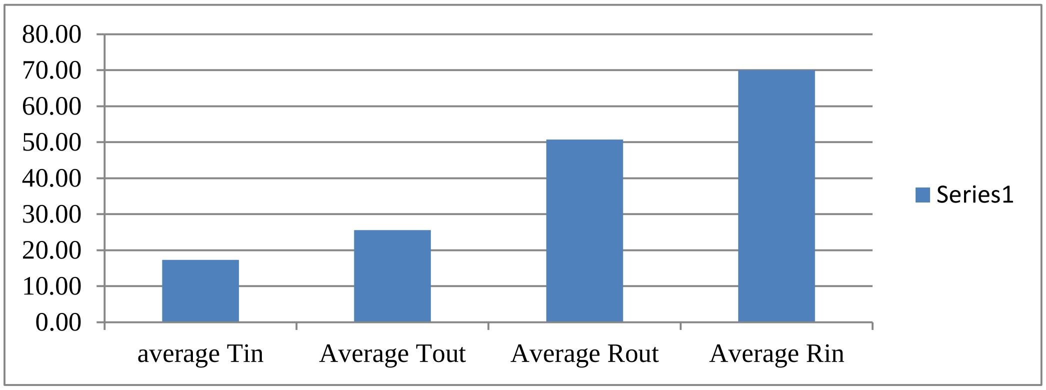

Fig 5. Temperature and humidity

Visual quality assessment

Visual quality was examined in accordance with the sensory evaluation standards (Ma *et al.,* 2010).

Table 4. Summary of average sensory result

Testing parameters	Varieties with Treatments								
	Gudane			Shantama			Tulema		
	Not cured	After 6th day	After 8th day	Not cured	After 6th day	After 8th day	Not cured	After 6th day	After 8th day
Taste	6.2	8.0	6.3	5.6	7.5	7.4	5.0	8.6	5.7
Color	6.0	7.3	7.0	4.5	6.7	5.5	4.6	7.4	5.3
Appearance	4.5	7.0	7.5	7.3	7.0	4.6	3.7	7.8	4.3
Texture	3.7	6.0	4.0	4.2	8.4	5.3	5.0	8.6	5.8
Overall acceptance	5.0	7.0	6.0	5.0	7.0	6.0	5.0	8.0	5.0

From Table 4 the sensory average result shown that for three varieties under not cured treatment had lowest value overall acceptance of scored as 5 (Neither like nor dislike), as the panelist stated that not cured treatment taste was bitter, appearance and texture of not cured was not attractive when compared with that of cured treatments. In addition, curing for six days was scored highest value of (7 and 8) like moderately and like very much respectively which was preferred than eight days curing. This revealed that for three varieties (Gudane, Shantama, and Tulema) curing condition had positive effect on six-day curing time shown good performance in case of sensory analysis.

Conclusion and Recommendation

Conclusion

The result taken from analyses of four potato varieties indicated that curing effect after six days had positive effect for major variety. The curing condition and good storage management was serve producers by preventing the spoilage of potatoes tubers which make them available at off-season in places they were harvested. Curing effect had positive impact on potato tuber storage regarding the level of the storage of fresh potato to prolong the shelf life of potato from 14 days to 10 and 14 weeks, with the total loss of 18 to 24% at the end of storage period. The result of loss was lower than trials which potato tubers treated for two weeks by above ground pit-curing method showed only 40% lost tubers after 3 months of storage. The inside storage temperature range was observed as 12-16 ^{0}C with inside Relatives humidity of 77-85%, when the outside temperature and Relatives humidity were recorded as 25-30 ^{0}C and 40-50% respectively. From the experimental result observed that moisture loss and sprouting had great importance in order to decide shelf life of stored potato. Therefore, curing was undertaken prior to storage in order to minimize the loss occurred due to moisture loss by conserving moisture and good storage management minimize loss in case of sprouting by maintaining storage atmosphere to extend shelf life of stored tubers.

Recommendation

The of curing potato tubers was prolonging shelf life of potato thereby sustainable availability of potato over the market and makes gain of additional money for farmers. In general, the structure of the storage required important care during construction totally the sun light should be blocked as much as possible from entering into the storage and time of ventilation have to be seriously applied unless there might be great losses or cause total damage on potato tubers. It would also be beneficial to select a longer period of storage and more potato variety to test potatoes to understand the chemical and physical changes which occur during prolonged storage.

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Adaptation and Performance Evaluation of Power Driven chopper

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Abstract

Maize and sorghum stalk considered among the most fodder materials in Ethiopia. Therefore the chop machine was adapted and evaluated. The research was conducted at Asella Agricultural Engineering Research Center (AAERC), Arsi Negelle and Zuway Dugda districts to evaluate the machine performance in terms of chopping efficiency, throughput capacity, cutting efficiency and fuel consumption at different speed of cutter shaft. The output of chopper was found to be remarkable achievement. The chopping efficiency was decreased from 97.28 to 92.43 % on maize stalk and 95 to 90.2 % on sorghum stalk as rpm increases from 1150 to 1850 respectively. Throughput capacity of chopper was increases from 8.13 to 12.6 kg/min on maize stalk and 10.26 to 14.5 kg/min on sorghum stalk as rpm increases from 1150 to 1850 respectively. The mean of chopping length and cutting efficiency of also 3.5 cm and 96.64 % on maize and 2.53 cm and 97.63 % on sorghum stalk respectively.

Keywords: *Throughput capacity, Cutting and chopping efficiency, Chop length*

Introduction

Livestock feed preparation is a great problem nowadays. Earlier time there is grazing area. But now the quest to increase the agricultural production in all facets, have intensified crop production by way of increasing cultivated areas thereby reducing the grazing areas. Livestock farmers especially in the sector of goats, sheep and cattle are constantly faced with problem of feed shortage during the dry season. The herd constantly relies on crop residue, but these are usually in short time.

The unavailability of sufficient feed during the dry season in the Ethiopia is a major problem in livestock production. During this period, grazing livestock lose weight and in extreme cases some deaths do occur.

Livestock production, productivity and its sustained development depend on the advancement of science and technology that will enhance production, processing, handling, storing of livestock feed. Chopping of animal feed is considered as a labour intensive processing operation in animal production system. Traditionally, animal feed, especially crop residue are chopped manually by a sickle in the farms of Ethiopia. It is a labor intensive, less efficient and time consuming operation. Traditional technology for chopping of animal feed is even more inefficient and slow as well as old in case of medium and large farms. In the other hand in Arsi zone of sorghum and maize farmer have collect the head of the crop first and release their cattle, sheep and goat on it. These animals feed the leaf only and other stalk of remain on farm and finally they burn it. Some farmers also collect the stalk together for the dry period. But due to lack of chopper and other processing machine the loss is high. AGP 2 Technology constraint survey group, ADPLAC and Sinana Agricultural Research Center (SARC) also mention the scarcity and lack of such a technology for the processing of crop residue and the need to solve the utmost problem in livestock production appear to have compelled problem to request the development of an equitable technology. In order to solve these problems adapting a chopper for crop residues, it is evident that a chopping machine incorporating an engine is the obvious solution.

So, to alleviate problems stated above it was felt appropriate to evaluate and Select engine driven chopper machine that can chop animal feed.

Material and method

Methods

Prototype was brought from FARC and evaluated. Based on result obtained, prototype was produced with modification of increasing blade number from two to four in order to increase output and maintain the acceptable chop length. Then testing both the Fedis and produced chopper the result shows as 1.4 quintal/hr and 1.9 quintal/hr respectively on FARC and produced chopper as shown in Table 1. The difference of the result was due to the number of blade. Even if, the result obtained was enough for small scale farmers but in order to address medium and large scale farmers large dairy and fattening and by comment given size upgrade was required.

Table 1. performance result of FARC and produced

Prototype	Output (kg/min)	Chop length (cm)
FARC	2.3	4.35
Produced	3.2	3.86

(a). FARC (b). Produced

Figure 1. FARC and produced chopper during testing

So based on the developed prototype of FARC and the gathered information from books and on the internet having the same concept as of forage chopper machine. And on the basis of the related data gathered and with the data of the test material that was used, the new chopper machine was fabricated at AAERC machine shop, 2018. The manufacturing of the machine was based on the following criteria: (a) Availability of the materials, (b) Simplicity and ease of machine operation and repairs, (c) Adaptability of the machine

Experimental Site Description

The experiment was conducted at Asella Agricultural Engineering Research Center (AAERC) located at 6° 59' to 8° 49' N latitudes and 38° 41' to 40° 44' E longitudes, having an elevation of 2430 meters above sea level (masl), at Arsi Negelle, which is located at longitude and latitude of 7°21′N 38°42′E with an elevation of 2043 meters above sea level and Zuway Dugda which is located at latitude and longitude of 8° N 39° E with an elevation of 1687m.

Machine description

The overall length, width and height of the machine were 148, 188 and140 cm respectively. The machine consisted of five (5) major components are as follows: (1) The feeding table (2) the cutting assembly, (3) The frame stand assembly, (4) The power transmission assembly, and (5) The material outlet. Figure 1 show the developed machine used in the experiment.

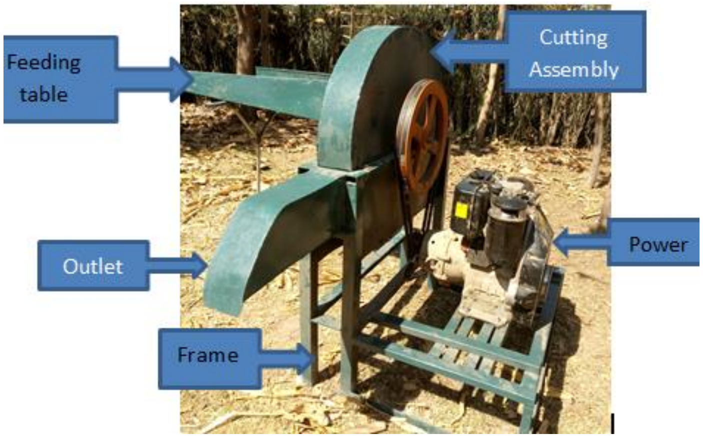

Figure 1. Chopper machine and main parts

The Feeding table

Part of the machine where in chopping material is put and prepared prior to feeding into the machine. It made up of 105 cm * 70 cm sheet metal with 1.5mm thickness.

The Cutting unit: systems intend to cut the chopping material into short lengths with reasonable consistency within a range of optional settings. This unit consists of following parts: 1. Cutter shaft: It is 30mm diameter and 31.5 cm length in size supported by two P206 bearings. This shaft carries 35cm diameter disc and 6mm thickness. This disc was used to hold cutting blade fixed with bolt and nut. 2. Cutting blade: The thickness of cutter was 4mm with the length of 40cm and 7.5 cm width. 3. Cutting unit cover: It is half circle made up of 1mm thickness sheet metal.

Base and Stand Assembly

Base and stand assembly is considered as the backbone of the machine functioned to support mainly all the parts of the machine. This is made up of steel bars and heavy duty mild steel to assure the durability of the materials.

Power Transmission Assembly

Power transmission assembly is done by mechanical operation. This is made up of diesel engine, belt and pulley. The pulley diameter was 46cm with double lines.

The outlet: An opening that permits the exit or release of materials after chopping. It made up of 1.5 mm thickness sheet metal.

Working principles

The chopper is driven by a 12 horse power diesel engine which rotates the cutting blades via a coupling joint (pulley and belt). The chopping material is introduced into the machine manually over a feeding table by the operator with a slight push of the material into the cutting unit. After chopping, the material is then blown out of the cutting unit by the help of the centrifugal force of the cutting blades through the outlet. The trajectory of the chopped materials is controlled using an adjustable flap on the discharge chute.

Preparation of Samples

Samples for experimental investigations were prepared from materials obtained after harvesting of maize and sorghum stalk. Five kilogram of samples with three replications were taken, chopped and weighed to determine the mass of chopped materials after commencing on the experiment.

Performance evaluation

The performance of the chopper was evaluated using maize and sorghum stalk. The moisture content of the forages was determined using a forced air oven. For each testing run, 5 kg of chopping material was weighed using a digital weighing scale and the length of materials was measured using measuring tape. The material was then fed into the cutting chamber of the chopper via the feeding table. The chopped materials were then collected in a sack to determine the length of the chop and weight. The time taken to chop quantity of fodder was recorded using a stop watch. A total of three test runs were made in order to obtain an average measure of the performance parameters. Then to assess the efficiency of the chopper prototype in performing the intended purpose, the following criteria was adopted.

Cutting efficiency: Cutting efficiency was calculated by measuring the stem length before cutting and the size or length of particles after cutting. (Elfatih etal, 2010). The length of materials was measured using measuring tape.

$$C_E = \frac{(L_b - L_a)}{L_b} * 100\%$$

Where: C_E = cutting efficiency (%).

L_b = Particles length before cutting, cm., L_a= Residual length after cutting, cm

Chopping efficiency

Chopping (machine) Efficiency is the ratio of the weight of the accepted output and input expressed in percent. Chopping efficiency of the machines was calculated as (Khope and Modak, 2013)

$$C_o = \frac{W_c}{W_f} * 100$$

Where, Co = Chopping efficiency
Wf = Total weight of samples fed in
Wc = Total weight of chopped out

Throughput capacity

Throughput, defined herein as the amount of forage chopped per hour when the machine is operating at optimal capacity (Harry and John, 2007). This was assessed by chopping a known amount of forage in a given time period. The quantity of forages was measured by a digital weighing balance while the time taken was measured using a stop watch.

$$C_r = \frac{W_f}{t_c} * 100$$

Where: tc = Chopping time in seconds.

Estimation of Fuel consumption

To measure the fuel consumption, first chopper machine kept on leveled surface. The fuel tank was filled up to top of the tank before the test started. After the completion of the chopping operation the engine was stopped and then the tank refilled to the original level. The quantity of fuel filled in the tank was measured using graduated measuring cylinder. The difference between amount of fuel prior to and after chopping was used to estimate fuel use efficiency.

Statistical Analysis

Data were subjected to analysis of variance following a procedure appropriate to the design of the experiment as recommended by Gomez and Gomez (1984). Analysis was made using statistix 8.0 statistical software. The treatment means that were different at 5% and 1% levels of significance were separated using LSD. Level of significance (P) for these relations was obtained by F- test based on analysis of variance.

Result and discussion

Each sample was weighted (mass before chopped) and passed to inlet into the cutting unit, coming into contact with the cutter blade. The chopped materials were collected through the outlet. The time taken to chop each sample was recorded. The collected materials were weighted as mass after chopped. Each test replicated three times. The specific chopping resistance increases with the increase of the stalks fed through the chute. The prototype was tested using maize and sorghum stalk and the results were presented in table 1.

Table1. Summarized Performance evaluation result of the prototype

Parameters	Maize stalk					Sorghum stalk				
	1150	1450	1850	CV	SEM	1150	1450	1850	CV	SEM
Cutting efficiency (%)	95.8	96.53	97.6	0.62	0.34	96.8	97.5	98.6	0.61	0.34
Chopping efficiency (%)	97.28	94.48	92.43	0.6	0.33	95	92.3	90.2	0.62	0.33
Throughput capacity (kg/min)	8.13	10.73	12..6	4.25	0.22	10.26	13	14.5	7.68	0.48
Chop length (m)	0.039	0.036	0.032	4.15	1.2	0.30	0.025	0.021	4.47	9.71
Fuel consumption (lit/qnt)	0.22					0.20				

Chop length

Mechanization of the forage chopping process is intended to reduce on farm labor demand and drudgery while improving feed intake and feed use efficiency. As shown in table 1 the mean chop length of both maize and sorghum stalk was decreased from 0.039 to 0.032 m and 0.03 to 0.021 m as RMP increased from 1150 to 1850 respectively. By adjusting the flap on outlet only it can be possible to get less chop length. Forage particle length has a critical influence on feed intake and the functionality of the rumen in dairy cattle (Bhandari et al., 2007; Yang and Beauchemin, 2009). The mean chop length produced by the prototype was within the acceptable range of between 1 to 4 cm required to maintain proper rumination and salivation (Moharrery, 2010) as sited by Kiggundu M, 2018 . When subjecting the data to Analysis of Variance there are no significant pairwise differences among the means chop length.

Cutting efficiency

Cutting efficiency was highly affected by RPM of the cutter blade shaft linearly. As can be seen in table 1 all mean of cutting efficiency of machine are significantly different from one another. Cutting efficiency was increased from 95.8 to 97.6 % and 96.8 to 98.6 % on maize and sorghum stalk respectively as RPM increased from 1150 to1850.

Chopping efficiency

Table 1 indicates that maize stalk has the higher Means of chopping efficiency which are 97.28, 94.48 and 92.43 % at 1150, 1450 and 1850 RPM respectively. Whereas means of chopping efficiency of sorghum stalk were 95, 92.3 and 90.2 % at 1150, 1450 and 1850 rpm respectively. This means that the stalk type affects significantly to the study of throughput capacity. This due to sorghum stalk was chopped in short length than of maize stalk so it may has tendency to blown away.

Throughput Capacity of machine

From the table 1, it was observed that when the machine was loaded by the test material, 1850 RMP of cutter shaft has higest the throughput capacity of 756kg/hr followed by 1450PM which is 643.8kg/hr and then 487.8 kg/hr at 1150 RPM on maize stalk. Whereas on sorghum stalk throughput capacity were 615.6, 780 and 870 kg/hr at 1150, 1450 and 1850 rpm respectively. Subjecting the data to Analysis of Variance, shows means of throughput capacity of machine on maize and sorghum stalk were highly significant at 1% level of significance. This means that the chopping machine can has a highest throughput capacity when RPM of cutting blade shaft is 1850 was used because of its fast rpm. Thus chopping time was faster. This result has similar trend with Saanoding etal, 2016.

Percent loss

Figure 3 shows the Percent Loss of the Chopper Machine when fed by 5kg of maize and sorghum stalk with three (3) different rpm with three replications. The graph reveals that the 1850 rpm has the highest mean of Percent Loss which is (7.57 %), followed by 1450rpm (5.52%), and 1150 rpm (2.72%) respectively on maize stalk and 4.97, 7.74 and 9.82% at 1150,1450 and 1850 rpm respectively.

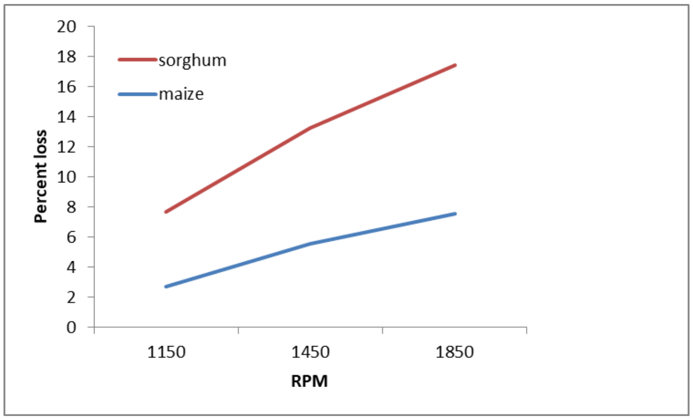

Figure 3. Effect of rpm on percent loss

Analysis of Variance, Table 3 shows significant treatment mean differences at 5% level of significance, which means that the three different rpm of cutter blade affects significantly to the study of Percent Loss. The rpm 1850 has the highest Percentage Loss because it has the fastest among the three rpm. It means that the faster the revolution per minute (rpm) the highest the Percentage of loss. The result obtained was contradicted with Saanoding A, 2016

Table 3. ANOVA table of percent loss of machine

Source	DF	SS	MS	F	P
REP	2	0.8374	0.4187		
RPM	2	35.5190	17.7595	55.07*	0.0012
Error	4	1.2900	0.3225		
Total	8	37.6465			

Fuel consumption

Fuel consumption of chopper machine was a little varies from crop to crop residue but not significant. As shown from Table 1 the average fuel consumption of machine for chopping of one quintal of maize and sorghum stalk were 0.22 and 0.2 liter respectively.

Estimation of Machine Cost

The cost of the machine includes raw material cost and production (machine and labor) cost only. Materials wastage and overhead costs are estimated from raw material and production cost.

Table 4. The summarized cost of the machine without engine

No	Parameters	Cost (ETB)
1	Raw material	4498.98
2	Materials wastage = 2.5 % 1	112.5
3	Production (machine + labor)	1023.88
4	Overhead = 5 % of 3	51.194
5	Profit = 10 % of (1+2+3+4)	568.65
6	Sell tax = 15 % of (1+2+3+4+5)	938.3
7	Selling price = (1+2+3+4+5+6)	**7193.5**

Conclusion and recommendation

Conclusion

Performance evaluations of the machines were done to determine chopping capacity, chopping efficiencies and associated losses at different speeds and constant feed rate. Three levels of cutter blade speed (1150, 1450 and 1850 rpm) were investigated to identify the optimum combination of the variables in question. The chopper was subjected to test using available material such as Maize stalk and sorghum stalk. The speed of the machine affects the length of cut and throughput capacity.

Throughput capacity increased from 487.8 to 756 kg/hr on maize stalk and 615.6 to 870 kg/hr on sorghum stalk as speed increases from 1150 to 1850rpm respectively. Whereas chop length decrease from 3 to 2.1cm on sorghum stalk and 3.9 to 3.2 with speed increasing from 1150 to 1850 pm respectively. Percent loss and throughput capacity have direct linear relation with speed whereas Chop length and chopping efficiency were vice versa. The machine was used 0.22 and 0.2 liter of diesel to chop 100 kg of maize and sorghum stalk respectively.

Recommendations

Recommendations with respect to my parameter are as follows

For future commercialization the use of higher speed is recommended.

The efficiency of the machine does not only based on the machine’s speed itself but also on the blade and shear bar clearance, so clearance and materials selection must be considered.

Since the engine sit was fixed and take wider area, made the machine large and the transportation difficult; hence an removable engine sit must be developed and Used

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Fabrication and Performance Evaluation of Small Scale Wood Gas Stove for House Hold Purpose Using Water Boiling Test Method

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Abstract

A double drum type inverted down draft gasifier was fabricated in Assela Agricultural Engineering Research Center Metal workshop. The water boiling test version 4.2.3 was used to evaluate thermal and stove characteristic performance indicators of the stoves. Performance result was compared with three stone traditional cook stove. High power and low power performance were compared and reported in this paper. During high power test wood gas stove performed better than three stone cooking method by all thermal performance indicators at tested significance level. While the traditional method numerically performed better than wood gas stove by stove character stick performance indicators though it was statically not significant. During low power test except thermal efficiency and turn down ratio where wood gas performed better than three stone cooking for all tested performance indicators were not significantly different.

Key words: *inverted down draft gasifier, wood gas stove, stove characteristics indicators*

Introduction

Wood gas is a syngas consisting of nitrogen, carbon mono oxide, hydrogen and traces of methane and other gases used as fuel. During the production process biomass or other carbon-containing materials are gasified within the oxygen-limited environment of a wood gas producer/wood gas generator. Wood gas stove is a gasification unit which converts solid biomass into wood gas or syngas through pyrolysis process. The process is preceded by pyrolysis, where the biomass is first converted to char, releasing methane and tar rich in polycyclic aromatic hydrocarbons (Wikipedia, 2019).

The development of micro-gasification is relatively new in the cooking energy sector. Many stakeholders are not yet aware of the potentials and challenges of revolutionizing the way we make fire to cook food. A gasifier cook stove powered by *wood-gas* from dry solid biomass shows great promise for making an important contribution to the goal of reducing the negative health-effects of household air pollution from cooking (Christa Roth, 2013).

There is growing concern about the negative health effects of smoke from open fires and rudimentary cook stoves operated with solid biomass or coal. In the last few decades, since indoor air pollution is understood as chronic health problem, many improved wood stoves have been developed and promoted to developing world by different organizations. Although, there is improvement in indoor air pollution problems, still there are gaps to be filled. There is an ardent quest to shift to cleaner fuels such as LPG or electricity for the sake of health. However, for billions of poorer households, this will not be a realistic scenario for years to come. We have to accept the fact that solid biomass will be the cooking fuel of choice for many of these households for the future decades. On account of their clean and efficient *combustion* of biomass, gasifiers do have the potential to bridge this gap and offer users the convenience of cooking with gas derived from the solid biomass fuels (Christa Roth, 2013).

Gas cooking is advantageous compared to direct combustion improved cook stoves (ICS) by providing cleaner burning of solid biomass (considerable reduction of soot, black carbon and indoor / outdoor air pollution), fuel efficient due to more complete combustion (less total biomass consumption), use a variety of small-sized biomass residues (no need for stick-wood or charcoal) and easy lighting allows for cooking to commence within minutes (T.B Reed and Ronal Lason, 1996).

Of the gasifiers available, an inverted (top burning) downdraft gasifier can be used for indoor cooking practice because it can be made in different sizes. The major advantage of the inverted downdraft gasifier is that the rate of gas production depends on the amount of primary air admitted to the bottom and it can be practiced indoor cooking purpose (www.free-energy).

In Ethiopia, different organization made effort to avail improved gas stoves. Of these, BAERC energy team attempt to modify this technology for Injera baking purpose and the work is underway. And the initiation of this work was adapting double cylinder inverted down draft gasifier and evaluating its performance at local condition to use in household cooking.

Materials and Methods

Materials

Materials and apparatus used for this experiment were:

- Wood Gas Stove- fabricated in AAERC work shop from different size and type mild steel materials purchased from local market
- Three stone cooking stove (TSCS)-locally prepared
- Stainless steel Cooking vessel-purchased from local market
- Timer
- Digital balance (7Kg, accuracy ±1 gram)
- Digital thermometer (accuracy ± 0.5)

- K-type thermocouple probe
- Oven
- hygrometer (air relative humidity)
- anemometer (to measure wind speed)
- Fuel wood
- Tape measure

Site Description

The test was conducted in Asella AERC with the local atmospheric conditions of ambient temperature 20-26.6oc, Air pressure 75.7Pka, Relative humidity 35% and Altitude/elevation 2430m. The test was conducted in one side opened shade where air freely flow and protected from wind blow.

Description of Stoves

The inverted down draft (double) type of Wood gas stove was fabricated by Asella AERC workshop (***figure 1***). The outer cylinder both end opened and a ring of ventilation holes drilled around the whole of the bottom edge of the cylinder and support rods are run through the drum. These rods supports perforated sheet which forms grate. The inner cylinder both ends opened forms combustion chamber. This cylinder fits inside the outer cylinder. It rests on the perforated sheet or grate which is supported by rods. This cylinder has a ring of ventilation holes drilled around the upper end of the cylinder. The third cylinder which is only slightly smaller than the outer cylinder is cut down to make a cap for the inner cylinder. The cap is not tight-fitting (1cm less than outer cylinder diameter); it effectively closes off the top of the gap between the sides of inner cylinder and the sides of the outer cylinder. The cap has riser (to increase combustion efficiency of producer gas) and circular hole cut in it, and this hole is only slightly smaller than the diameter of the inner cylinder. It is supported by the upper lip of the combustion chamber but the hole is large enough so that it does not obstruct the flow of heat up through the top of the combustion chamber. The pot seat is supported by the cap.

Fuel wood charge is lit on the top, forming a layer of charcoal, the flaming pyrolysis is below charcoal layer and the unburned fuel is at the bottom on the grate. The primary air for the pyrolysis process is entered at bottom through holes drilled at the bottom of outer cylinder and move up forming gases in the flaming pyrolysis zone as shown in the *figure 2*. The pyrolysis gas is combusted by secondary air entered from the top through clearance of top cover and holes drilled on the top of combustion chamber above the charcoal zone and part of primary air which flow through whole between inner and outer cylinders.

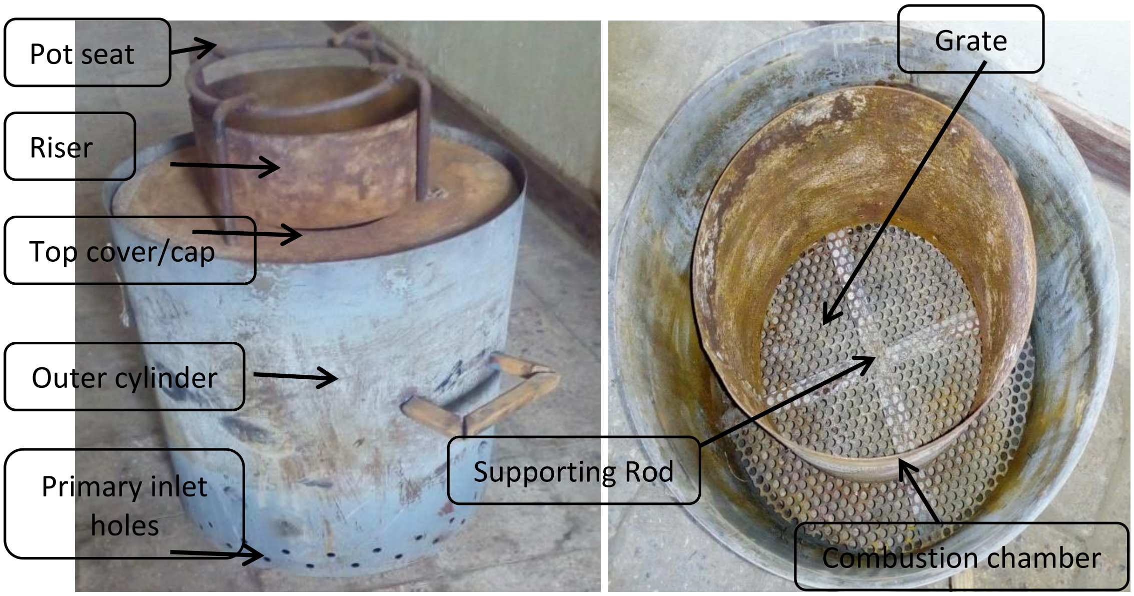

Figure 1: Photo of the fabricated stove showing different parts

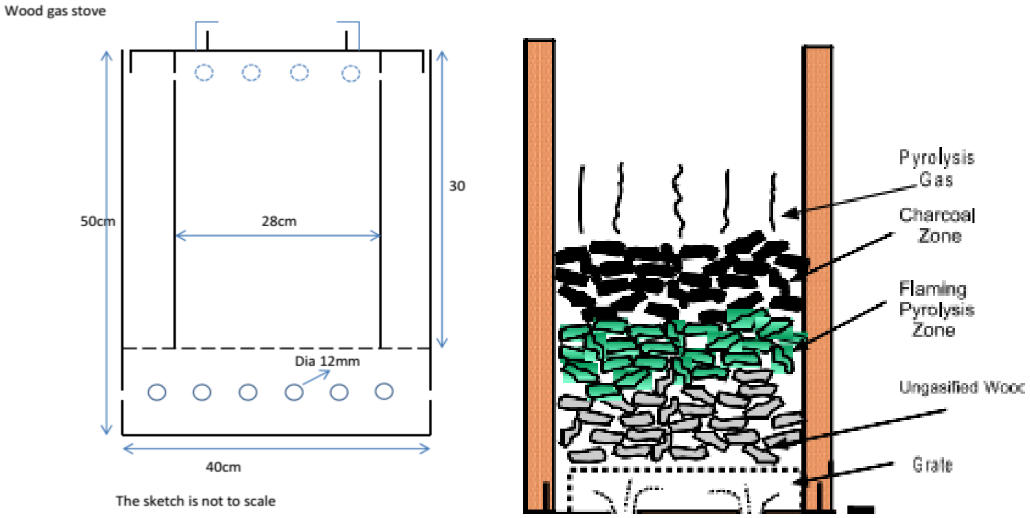

Figure 2: 2D schematic drawing (left) and Wood gas stove showing combustion process (right)

Fuel Characteristics

The wood used for the experiments was Eucalyptus (local names bargamo) obtained from the center as leftover of different activities, split and air-dried. Semi-cylindrical pieces of wood (2-4 cm in diameter and 25-30 cm in length) were used during each experiment. The moisture content (11.67%) and the calorific value of fuel wood (4090cal/gram) were determined at the end of the entire series of experiments by using oven drying method and bomb calorimeter respectively.

Performance evaluation

The Water Boiling Test (WBT) is a simplified simulation of the cooking process. It is intended to measure how efficiently a stove uses fuel to heat water in a cooking pot and the quantity of emissions produced while cooking (Roth Bails et al, 2014). It measures the quantity of fuel consumed and time required for the simulated cooking and usually employed in investigating the performance of cook stoves under different operating conditions.

The standard WBT consists of three phases that immediately follow each other. The *cold-start high-power phase*, we begun the test with the stove at room temperature and uses fuel from a pre-weighed bundle of fuel (5kg) to boil a measured quantity of water (5 Kg)in 7cm diameter stainless steel vessel. Then we replaced the boiled water with a fresh water of ambient-temperature to perform the second phase. The *hot-start high-power phase* was conducted after the first phase while stove and cooking vessel were still hot. Again, we used fuel from a pre-weighed bundle of fuel to boil measured quantity of water (5 Kg) in the vessel. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot. The *simmer phase* provides the amount of fuel required to simmer a measured amount of water at just below boiling point for 45 minutes. This step simulates the long cooking of legumes or pulses common throughout much of the world. During this phase, pre-weighed amount of fuel was used to simmer the boiled water for 45 minutes.

As it is quick method of comparing the performance of cook stoves (Roth Bails et al, 2014), we employed in evaluating the performance of the improved biomass cook stove and compared with the performance of the 3-stone traditional cook stove, which it intends to replace. For each stove, the three phases were repeated three times.

Determination of stove performance parameters

a. ***Moisture content of fuel (M):*** The moisture content of fuel wood used was determined by the weight loss of sample that was oven-dried at 100°C until the weight of the sample stabilized (Roth Bails et al, 2014). The Sample of moist fuel was taken from the fuel wood prepared for the tests and oven dried as stated above. Moisture content was calculated by equation 1 and found 11.67%.

$$M(\%) = \frac{100(W_w - W_d)}{W_d} \qquad (1)$$

Where: W_w-is weight of wet fuel sample, W_d-weight of dry fuel (after oven dried)

b. **Fuel consumed (dry base):** The amount of fuel wood used to bring water temperature from room temperature to boil (Teka.T and Ancha Venkata Ramayyaa, 2017). And it **a**ccount for two factors: (1) the energy that was needed to remove the moisture in the fuel and (2) the amount of char remaining unburned, given by:

$$\text{Mass of dry fuel} = \text{Fuel mass (wet)}*(1-M) \qquad (2)$$

c. **Burning rate**: A measure of the average unit of wood burned per unit of time during the test. Between tests, compares how consistently the user was operating the stove. Between stoves, indicates how rapidly the stove consumes fuel. And it is given by (Roth Bails et al, 2014):

$$\text{Burning rate} = \frac{\text{mass of fuel dry base}}{\text{time taken}} \tag{3}$$

d. **Firepower (F_p):** This is a ratio of the wood energy consumed by the stove per unit time. It is a useful measure of the stove's heat output, and an indicator of how consistently the operator ran the stove over multiple tests. And the firepower (Fp) is given by (Roth Bails et al, 2014):

$$\text{Fp} = \frac{\text{mass of fuel dry base} * \text{LHV}}{\text{time taken}} \tag{4}$$

Where LHV- is lower heating value of the fuel

e. **Turn-Down Ratio (TDR):** Turn-Down ratio indicates how much the user adjusted the heat between high power and low power phases. A higher value indicates a higher ratio of high power to low power, and could signal a greater range of power control in the stove (Roth Bails et al, 2014).

$$\text{TDR} = \frac{\text{cold start fuel consumed dry base} * \text{simmering time}}{\text{simmering fuel consumed dry} * \text{cold start time taken}} \tag{5}$$

f. **Thermal efficiency (η_{th})**: Thermal efficiency is a measure of the fraction of heat produced by the fuel that made it directly to the water in the pot. The remaining energy is lost to the environment. So a higher thermal efficiency indicates a greater ability to transfer the heat produced into the pot. While thermal efficiency is a well-known measure of stove performance, a better indicator may be specific consumption, especially during the low power phase of the WBT. This is because a stove that is very slow to boil may have a very good looking TE because a great deal of water was evaporated. However the fuel used per water remaining may be too high since so much water was evaporated and so much time was taken while bringing the pot to boil (Roth Bails et al, 2014). And determined using equation (M.S Islam et al, 2014).

$$\eta_{th} = \frac{4.186 * \text{mass of water boiled} * \text{change in temp} + \text{LHW} * \text{mass of Vapor}}{\text{fuel consumed dry base} * \text{LHV}} \tag{6}$$

Where LHV-lower heating value of the fuel wood and LHW-is latent heat of vaporization of water

g. **Specific fuel consumption (SFC):** This is a measure of the amount of fuel required to boil (or simmer) 1 liter of water. It is calculated by the equivalent dry fuel used minus the energy in the remaining charcoal, divided by the liters of water remaining at the end of the test. In this way, the fuel used to produce a useful liter of "food" and essentially the time taken to do so is accounted for and given by equation (Sabrina chan, 2016)).

$$\text{SFC} = \frac{\text{fuel consumed dry base}}{\text{Volume of water boiled}} \tag{7}$$

h. ***Specific Energy Consumption (SEC)***- It is a measure of the amount of energy required to boil (or simmer) 1 liter of water and given by (Roth Bails et al, 2014):

$$\text{SEC} = \text{SFC} * \text{LHV of dry fuel} \tag{8}$$

i. **Temp-Corrected Specific Fuel Consumption (*$SC^{T}c$*)** – This corrects specific consumption to account for differences in initial water temperatures. This facilitates comparison of stoves tested on different days or in different environmental conditions. The correction is a simple factor that "normalizes" the temperature change observed in test conditions to a "standard" temperature change of 75 ºC (Roth Bails et al, 2014). It is calculated in the following way:

$$SC_c^T = SC_c \cdot \frac{75}{T1_{cf} - T1_{ci}} \tag{9}$$

j. **Temp-Corrected Specific Energy Consumption (*SE^{T}_{c}*)** – Similar to the temperature corrected specific fuel consumption, this metric is a measure of the amount of fuel energy required to produce one liter (or kilo) of boiling water starting with cold stove. It is the temperature corrected specific fuel consumption multiplied by the energy content of the fuel (Roth Bails et al, 2014):

$$SE_c^T = SC_c^T \cdot \frac{LHV}{1000} \tag{10}$$

k. **The local boiling point** (**T_b**) of water is the point at which the temperature no longer rises, no matter how much heat is applied. The local boiling temperature is influenced by several factors including altitude, minor inaccuracies in the thermometer, and weather conditions. For these reasons, the local boiling temperature cannot be assumed to be 100^0 C. For a given altitude h (in meters), the boiling point of water may be estimated by the following formula (Christa Roth, 2013):

$$T_b = \left(100 - \frac{h}{300}\right)^{\circ}\text{C} \tag{11}$$

Temperature Corrected Time to Boil (Δt_c^T) – The time it took for the vessel to reach boiling temperature, corrected to reflect a temperature rise of 75 deg C from start to boil. This measure can be compared across tests and stoves to determine the "speed" of the stove at high power, often an important factor to cooks (Roth Bails et al, 2014)

$$\Delta t_c^T = \Delta t_c \cdot \frac{75}{T1_{cf} - T1_{ci}} \tag{12}$$

Where $T1_{cf}$ and $T1_{ci}$ are initial and final water temperature of the test, Δt_c-time taken to boil water.

Result and Discussion

Visual observations

Initially, the flames come out of the top of the stove, but after a few minutes, the combustion changes. The wood is slowly converted to charcoal and the gas released by this process burns with higher flame height than the wood would give as well as burning for a much greater length of time. After a while, flames no longer come out of the top of the stove, they come out of the ring of holes around the base of the outer cylinder. The heat flowing out of the bottom gets diverted around the outside of the combustion chamber, flows upwards, is caught by the cap and fed back into the combustion chamber through the ring of holes at the top of the combustion chamber. The result attained was similar with result obtained by (parashuran Nandi et al, 2016).

Performance indicator parameters determined by the above equations

Both thermal and stove characteristics indicators discussed above under determination of performance parameter part of this paper is summarized and statically discussed below.

***Table 1*: Calculation result summary**

Description	**Cold start**		**Hot start**		**Simmering**	
	WGS	**TSCS**	**WGS**	**TSCS**	**WGS**	**TSCS**
Phase duration (min)	17	44	13.3	40	45	45
Burn rate (g/min)	35	45	23	32	41	49
Thermal efficiency (%)	23.5	11	28.7	14	21	13.4
Specific fuel consumption (g/lit)	117	212	107	203	815	533
Specific energy consumption (KJ/lit)	1998	3543	1827	3393	14171	9261
Fire power (kw)	10.2	7.4	11.7	7.4	11.8	11.3
Turn down ratio					0.9	0.66

Where WGS-is Wood Gas Stove and TSCS is three stone cooking stoves

Table 2: Mean comparison of cold start phase for WGS and TSCS

Parameters	units	**WGS**			**TSCS**			**Significance test**		
		Mean	STD	COV	Mean	STD	COV	%mdf	t-critical	Significance at $p<0.05$
time to boil	min	17	1	0.059	44	1	0.023	61.36	27.79	**
Tcore- time to boil	min	16.79	1.29	0.077	42.31	0.96	0.023	60.31	19.52	**
fuel consumed (dry)	g	596	40.63	0.068	1119	21	0.019	46.74	9.99	**
Burning rate	g/min	35.19	4.09	0.116	25.44	0.81	0.032	27.7	2.15	ns
η (%)		23.5	0.01	0.038	10.8	0.005	0.045	54.25	11.13	**
SFC	g/liter	116.59	8.42	0.072	212	3.05	0.014	45.01	7.28	**
Temp corrected SFC	g/liter	114.97	5.54	0.048	203.9	2.93	0.014	43.61	12.056	**
Temp-corrected SEC	kJ/liter	1998.15	96.31	0.048	3543	50.94	0.014	43.6	12.06	**
Firepower	watts	10193.6	1183.8	0.116	7369	235.0	0.032	27.8	2.15	ns

From the mean comparison of cold start high power phase (table 2), the Wood Gas Stove performed significantly better than Three stone Cooking stove for most of performance indicators of stoves except for stove characteristic indicators (Burn rate and fire power) where the stoves performance was not significantly different at P<0.05.

Table 3: Mean comparison of hot start phase for WGS and TSCS

Parameters	**units**	**WGS**			**TSCS**			**Significance test**		
		Mean	STD	COV	Mean	STD	COV	%mean diff	t-critical	Significance at p<0.05
time to boil	min	13.3	1.53	0.115	40.3	0.58	0.014	66.9	10.006	**
Tcore- time to boil	min	13.2	1.86	0.141	38.8	0.56	0.014	66	7.588	**
Fuel consumed (dry)	g	535	38	0.071	190.9	298.3	1.562	48	11.085	**
Burning rate	g/min	40.5	6.38	0.157	25.6	0.80	0.031	37	2.070	ns
η	%	28.5	0.02	0.065	14	0.003	0.018	51	4.671	**
SFC	g/liter	107	7.45	0.070	203	10.53	0.052	48	9.264	**
Temp corrected SFC	g/liter	105	6.33	0.060	195.2	10.13	0.052	46	8.438	**
Temp-corrected SEC	kJ/liter	1827	110	0.060	3393	176	0.055	46	8.438	**
Firepower	watts	11742	1848	0.157	7410	232.2	0.031	37	2.070	ns

From Table 3, during hot start high power test Wood Gas Stove (WGS) performs significantly better than Three stone Cooking stove (TSCS) for most of the performance indicators except for stove characteristic (Burn rate and fire power) where stoves performances were not significantly different at P<0.05

Table 4: Mean comparisons during simmering test of the stoves

Parameters	**units**	**WGS**			**TSCS**			**Significance Test**		
		Mean	STD	COV	Mean	STD	COV	%Mean diff	t-critical	Sign. at p<0.05
Fuel consumed (dry)	g	1769.8	189.17	0.107	1749	179.9	0.103	1.15	1.527	ns
Burning rate	g/min	39.33	4.21	0.107	38.9	4	0.103	1.15	1.529	ns
η	%	20.4	0.01	0.049	13.4	0.02	0.147	34.10	3.47	**
SFC	g/liter	814.8	202.27	0.248	532.9	59.5	0.112	34.60	1.326	ns
Temp-corrected SEC	kJ/liter	14161.3	3515.4	0.248	9261	1034.6	0.112	34.60	1.326	ns
Firepower	watts	11392	1218.3	0.107	11261	1157.8	0.103	1.15	1.529	ns
Turn down ratio	--	0.895	0.042	0.047	0.659	0.068	0.104	26.36	3.598	**

From Table 4, Most of the performance indicators of the stoves were not significantly different except for thermal efficiency and Turn Down Ratio where WGS performed significantly better than TSCS at p<0.05.

Comparisons of performance parameters

Both thermal performance and stove characteristic indicators were elaborated.

i. Phase duration (min)

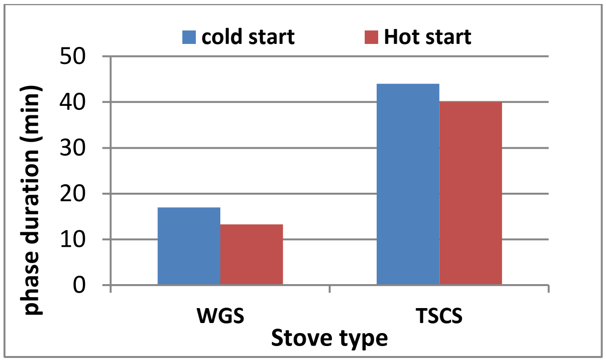

Figure 3: Phase duration comparison of WGS and TSCS

Least boiling time was recorded during high power hot start phase (13.3min and 40min) by WGS and TSCS respectively. The result obtained by the experiment was similar with (M.s Islam et al, 2014 and Sabrina khan, 2016). The boiling time reduction during high power hot start by the stoves were due to heat absorbed by stove body in this phase. Taking the mean of high power tests, the technology improved cooking time by 67.4%.

ii. Burning rate comparison

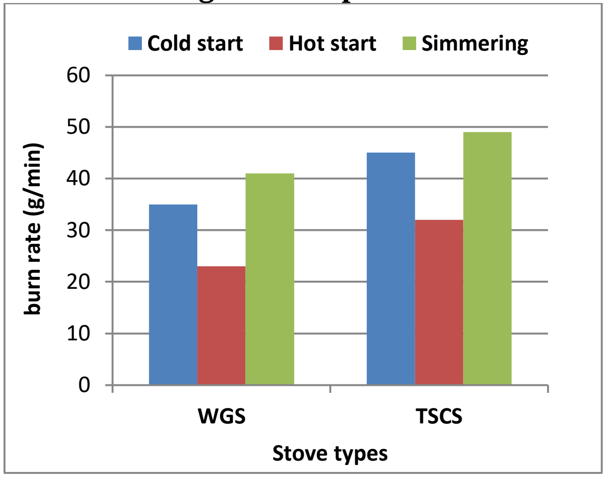

Figure 4: Burning rate comparison

Least burn rate was recorded during hot start by WGS (23g/min) and simmering test by TSCS (32g/min). Highest burn rate was recorded during simmering test by WGS (41g/min) and TSCS (49g/min). Comparing burn rate the WGS performs better than TSCS, but it was not significant at tested significance level as indicated in *Table 4*.

iii. Thermal efficiency comparison

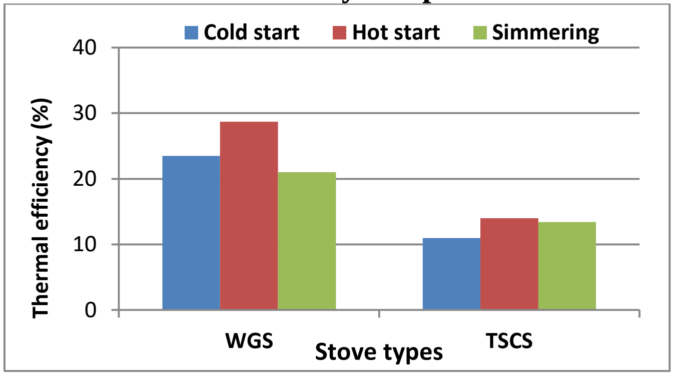

Figure 5: Shows how thermal efficiencies of the stoves compared

The highest thermal efficiency was recorded during hot start and simmering test by WGS and TSCS respectively. Least efficiency was recorded during simmering test and cold start test by WGS and TSCS respectively. The high power thermal efficiency were 26% and 12% for WGS and TSCS respectively and low power efficiency were 21% and 13.5% for WGS and TSCS respectively.

iv. Specific fuel consumption

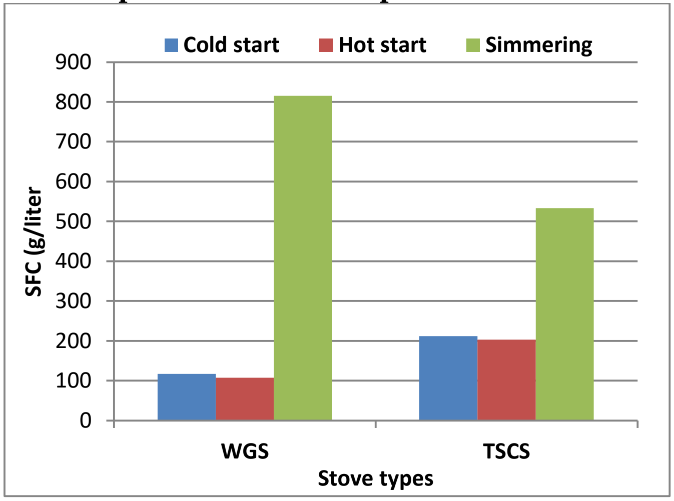

Figure 6: Shows the comparison of specific fuel consumptions

Specific fuel consumption is the measure of stove fuel consumption to boil a unit of water. Least sp. fuel consumption was recorded during hot start and cold start by WGS and TSCS respectively. As indicated, for high power test WGS recorded least SFC and low power test was recorded least SFC by TSCS. Comparing the two stoves during high power test WGS improved SFC by 46.5 while during lower power TSCS performs better than WGS.

v. Turn Down Ratio comparison

Figure 7: Compares the turn down ratio of the stoves

Comparing the mean Turn down ratio (TDR) of the stove Wood Gas Stove performed better than three stone cooking stove by 26%.

Conclusion and Recommendation

Conclusion

The Wood Gas Stove improved the thermal efficiency by 54% during high power tests and 36% in low power test when compared with Traditional cooking stove (TSCS). It can contribute to indoor air pollution reduction and afforestation in developing countries. Comparing the mean the power controllability of the tested stove WGS performs better than TSCS by 26%. The stove performed better than TSCS for all performance indicators of thermal parameters. The technology performed better than traditional stove by most of thermal performance indicators except specific fuel consumption during low power test, it is important to promote to end users.

Recommendation

- Since the technology was performed better than traditional cooking by most of thermal indicators, it was recommended to be promoted and collect end users comment for further dissemination.
- Modifying the technology to decrease thermal mass so that it could be easily used in house hold cooking condition and applying insulation on the outer cylinder.
- The evaluation was under taken on hard wood, so it was recommended to further evaluate on different feedstock available in local area

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Modification & Evaluation of Oil Drum Corncob Carbonization Technology

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Abstract

Most agricultural residues, including corncob, have low density materials and heating values, the characteristics that made them inconvenient for handling and inefficient in combustion. Therefore, converting them into a higher value energy resource is a matter of persistent issue. In this research, a corn cobs carbonization drum was made from used metal of oil container and modified to enhance its effectiveness of carbonization activity with very limited supply of atmospheric air. Accordingly, about twelve holes were drilled on the drum sides in order to follow up activity, boost carbonization process and thereby to reduce charring time. To test the modified drum, corncobs carbonizing were made and necessary data were taken.Here carbonized products were carefully removed and screened; charred and uncharred were identified, sorted out and recorded. To estimate quality and quantity of the products mass of broken & unbroken charred cobs were separated and measured. As a result, mass of charred and uncharred corn cobs were measured to be 109.3 kg and 15.7 kg respectively whereas mass of broken and unbroken charred corn cobs became 4.6kg & 104.7 kg respectively.Volume based conversion rate of modified carbonizing technology became 86.36 % whereas 56 % for the former carbonizing technology.A batch charring takes 90 to 110 minutes in improved carbonize whereas 3 to 4 hours in previous, depending on season & environment. Consecutively, modified carbonizer is performed well when compared with former. Therefore, the results of this technology can help in encouraging use of corncob as substitute to wood charcoal that could contribute in minimizing deforestation and consecutive climatic changes.

Key words: *Corn cob, Carbonization technology, Hole and Charred Cob*

Introduction

Energy is very important and cornerstone for economic and social development which brings remarkable alteration among the nation. These development lead to major changes or shift particularly in utilizing the household energy sector. High migration flows and the growth rate of urban populations mainly influenced type of fuel used and consumption pattern of energy. Energy consumption in rural areas of Africa is still low and is limited almost entirely to fuel wood (Girard, 2002). According to Madon, 2000interviewed urban women in Ethiopia, Niger and Senegal did not like to cook with wood because they found it difficult to kindle, awkward, dangerous for children, smoky and messy.

According to Samson, 2000 more than 90% of the domestic energy requirement in Ethiopia is fulfilled by wood and other products associated with them which accelerate devastation of the forest resources. The way of processing biomass fuel as source of energy is very traditional and insufficient system where it cannot hit target of satisfying energy demand. Therefore, it is easy to guess how many tones of forest get destroyed for fuel purpose to meet the energy demand in the country. Moreover magnitude of energy used implies that energy consumption status in the country is inadequate for the survival and development requirements of its population.

Even though woody biomass has important benefits, its improper usage linked to adverse environmental effects such as deforestation, degradation of land and depletion of soil fertility. Thus, these adverse conditions have significantly affect agricultural production and productivity. However huge amount of agricultural residues are available which has big potential to provide energy from both cost and pollution management perspectives. An exploitation of this residue fit well appropriate into the strategy of sustainable development and environmentally friend.

Corn cob residue in rare case is used as animal fodder and source of fuel for rural families (Legese, 2011). However, majority of agrarian community in these areas usually consider the use value of the grain whereas they paid lesser attention for postharvest by-products (CSA, 2010). Moreover farmers residing in maize belt also engaged in the act of forest destruction in an attempt to find additional financial income by supplying the urban market with fire wood and charcoal.

However, burning agricultural by-product to recover heat in the current utilization considered as inefficient and poor utilization because of the low heating value and substandard air emissions (Kang &Fan, 2012; Bhagwaro &Singaravelu, 2014). This is because; most of these residues are low density materials (Enweremadu & Ojediran, 2004; Oldeji, 2011). Apart from these, their combustion cannot be effectively controlled (Patomsok, 2007). Therefore, converting it into a higher value energy resource is a matter of pressing concern. Upgrading corncob residues to a high quality energy resource is an effective utilization of an underutilized agricultural waste.

Typically, agricultural waste conversion process includes biological and thermochemical treatments. Biological treatment focuses on an effective pretreatment process for de-constructing the impact cell wall by way of inhibitors such as acetic acid whereas thermochemical treatment is much more flexible because of the short processing time and high product yield (Liu &Wang, 2014; Yang & Jahan, 2013a;Yang & Jahan, 2013b). For high-efficiency conversion, hydrothermal carbonization is a suitable choice because the CO emissions decreases and the energy density increases during combustion of the wastes (Parshetti & Jain, 2013). Corn cob carbonization simulates the coalification process to produce char with a high energy density through the omission of the energy-intensive drying process.

In the past, Bako Agricultural Engineering Research Center had developed corncob carbonizing technology for charring of agricultural by-product. As a matter of fact raw corn cob could be converted to energy density fuel by employing a simple carbonizing technology to change it to charcoal. Here the raw cob is made to combust, in a very limited supply of atmospheric air and charring time. So far significant effort have been made in inducing the farmer to utilize corn cob carbonization technology so as to redirecting ones focus of attention to this issue and encouraging the utilization corn cob charcoal as a substitute to wood and wood charcoal. This could play great deal in climate mitigation program by minimizing forest resource continual destruction and suffering from climatic irregularities.

However, the effort made could not able to hit the target due to various drawback of the technology. The size of corn cob carbonizing drum was very small and at once, it accommodates only 150kg of raw corn cob. One batch charring takes 3 up to 4 hours depending of the season and environmental condition. This implies that charring time for one batch carbonization is too long and moreover, volumetric conversion efficiency that based on volume of corncob charcoal is 56% which still requires great attention. Therefore, this activity was initiated to solve all these problems by optimizing the size of carbonizing technology and applying holes on the drum that enhance effectiveness of carbonization activity and which return reduce charring time.

Material and Method

Material

Important materials that are required for manufacturing of corncob carbonization was identified & selected based on the design specification. According to this, sheet metals, water pipe for handling and deformed bar, five varieties of corn cobs (BH-661, BH-541, LOCAL, SHONE and LIMMU), Clay Soil, Briquettepress, Carpet,Oven, Thermometer, Bomb Calorific, Briquette Stove, Pan, Stop Watch and Digital Balance are among materials used for carbonization process. All raw corncobs utilized in this experiment were obtained from fields of farmers and local investors. These agricultural residues were mainly chosen because they are produced in large quantity in local areas and most often they were presented in widespread for local consumption and environmental pollution.

Methodology

Manufacturing of Carbonizer

After design specification was done, improvement of carbonization technology was performed and continued as below. Consequently, drum part was formed by rolling 1.5cm thickness sheet metal to 1.1m diameter. On the drum parts, twelve holes were provided in order to facilitate carbonization of raw corn cob and checkup of carbonization processes. All these holes were 16mm in diameter and suited on circumference of drum part. Exhaust chimney and coal tar box were prepared from sheet metal separately and then integrated to make one part. The carbonizer is a simple cylindrical design fabricated to provide a means of creating low oxygen environment, it was fabricated using a drum of about 120cm in height and 110cm diameter with an opening at the top for loading the corncobs feed stock. A suitable metal plate was constructed and was used as cover for the top opening of the drum during firing.

Eventually, all units were assembled to give complete corncob carbonization equipment and prepared for experimental testing. The size of the former corn cob carbonizing drum was very small and it accommodated 1.5 quintal of raw corn cob per batch whereas the modified corn cob can hold about 4 to 5 quintals raw corn cob per carbonizing activity.

Corn Cob Sample

Five varieties of raw corncobs whichare traditionally consideredas wastes were collected from private investor and known farmers. These raw corn cobs were sorted out and dried over the sun so as to reduce the moisture content of the feed stock to ensure effective carbonization. The dried corncobs were further categorized based on their distinct sizes to provide more surface or contact area for the carbonization activity. Basic density of corn cob was determined or estimated using plastic cylinder that was perfectly calibrated. The cylinder was packed with prepared samples and compacted well. Thus, the density was calculated employing this formula:

$$Density(\rho) = \frac{Mass}{Volume}$$

The higher heating value (HHV) was determined accordingto the methodology described by ABNT (Barbara & Aylson, 2012) using an adiabatic calorimeter ASTM Standard. The HHV representsthe maximum amount of energy potentially recoverablefrom a given biomass source in this case, specifically, the amount of energy in the corn cob. The determination of theraw corncob HHV is important when it is used in production of charcoal for energy purposes.

Carbonization

Corncob carbonizer was set in their working condition and then fuel material has been fed to reactor in batch to certain height of the drum. Afire ember was prepared outside the drum to be distributed over fuel material provided in carbonizer. After fuel reached required height, fire ember or glow were distributed evenly over raw fuel in order to facilitate carbonization activity per each batch. At the start of the carbonization process integrated part of exhaust chimney and lid was left open for the volatile gases to escape and collection of tar in middle cyclone. Enhancement of carbonization had been checked up throughout activity with the changing of the color of the smoke from white to none. Due to application of the holes on the drum body which speed up ignition at intended position. The drum was closed eventually after application of the last batch & change of the color of smoke has been checked up via upper lid. The lid was then closed there after; properly sealed to preventairfrom entering. The biomass material was left to carbonize for 90 to 120 minutes. When the smoke releasing ceased or after it becomes colorless, top most lid that was integrated with chimney locked down and water get jacketed.

After these all process, the carbonized product was removed over prepared carpet to further cool and safely collect charred corncob. The products were carefully with drew from reactor to further reduce damage. From this, charred product and uncharred corn cob were identified, sorted out and recorded. Weight of broken and unbroken charred corn cobs was measured to estimate the quality and quantity of the charred products. In doing so data were collected, processed and analyzed carefully employing standard data analysis tool to mark out or predict the performance of corn cob carbonization.

Briquette Preparation

The carbonized corn cob was crushed, grinded to fine particles using an electric milling machine. This fine particle was subjected to pass through 1mm standard sieve to create homogenous particles through out process. For case of binding material, natural organic binder was used or employed as binder. Here clay soil was collected and dried over oven drier until moisture content get reduced or it's mass remained constant. The dried product was crushed and sieved employing standard method and kept in sealed containers until it was used.

Briquetting and Drying

Finely pulverized char powder was added and poured into a mixing chamber and thoroughly agitated. The carbonized charred powder was mixed with binder in such a way that every particle of the carbonized material was coated with a film of the binder until thick black compound was obtained. The binder was fine clay soil and 20% clay soil concentration was applied to form briquette. Clay soil mixed carbonized corn cob were pressed in electric operating briquette machine. The machine has four molds that was fabricated of steel pipes and had mold diameter of 12 cm. The mixtures were introduced into a mold and electrically pressed to be compacted to a certain compaction rate. The briquettes were then removed from the mold and sun-dried in open air to a constant mass. In general twenty briquettes were therefore produced from five varieties binder with clay soil mixed carbonized char powder. Among these five of them were formed from raw corncob.

Briquette property

Bulk densities of the briquettes were measured immediately after ejection from the die. Then, briquettes were transferred to open air and kept forone week at room temperature to measure durability. The durability of briquettes is a measure of the ability of thebriquettes to withstand the destructive forces such as compression,impact and shear during handling and transportation. The possibleamount of fines dust generated from the briquettes due to themechanical handling and transportation can be estimated. Briquettes bulk density were calculated from the mass, diameter, and height of the briquettes.

Proximate Analysis

Proximate analysis of the briquette samples were carried out to determine percentage moisture content, percentage volatile matter content, percentage ash content and percentage content of fixed carbon. The procedure of ASTM standard was implemented and asserted in order to estimate the above stated parameters.

Energy Efficiency Test

Water boiling test procedure was applied to determine energy efficiency of raw and charred corn cob briquette. Cylindrical shaped briquette that average sample weight of 0.4 kg raw or charred corn cob briquette was applied for experimental test. As soon as briquette was ignited, cooking pot having 3L of water was placed on the briquette stove. Stop watch was used to determinate the times at which the water boiled and time required to completely evaporate water. Variation of temperature in water was monitored or measured employing thermometer and K-type thermocouple to formulate temperature profile. At end of the experiment, mass of briquette left and water get evaporated were measured. During the test, boiling and evaporatingtime, massofbriquetteused and left, burning rate and the maximum temperature achieved in the stove were estimated as recommended (Ugwu &Agbo, 2013; Ana &Fabunmi, 2016).

Result and Discussion

Carbonization of Corncob

After corncob carbonization was executed, carbonized corncob was removed over prepared carpet to further cool and safely collect charred from processed. The product was carefully withdrew from reactor to further reduce damage and screening get performed so as to separate charred and uncharred cob easily. From this, charred corncob and uncharred products were identified, sorted out and recorded. Mass of broken & unbroken charred corn cobs were separated and measured to estimate quality and quantity of the charred products. Therefore, mass of charred and uncharred corn cobs were measured to be 109.3 kg and 15.7 kg respectively.Mass of broken and unbroken charred corn cobs became 4.6kg & 104.7 kg respectively.Volume based conversion rate of modified carbonization technology became 86.36 % & whereas 56 % for the former carbonizer. One batch charring time acquired 90 to 110 minutes for improved carbonize whereas 3 to 4 hours depending on season & environment for former.

Among the several kinds of biomass resources, agricultural residues such as sawdust, rice husk, corn stover, groundnut husk become most promising choices as cooking fuels due to their availability in substantial quantities as waste annually. However, the utilization of these biomass residues in their natural form as fuel is quite challenging due to their low bulk density, low heat release and the excessive amounts of smoke they generate (Amaya & Medero,2007).

All of these characteristics make it difficult to handle, store, transport and utilize biomass residues in their raw form. One of the methods of improving the thermal value of such biomass is the application of briquetting technology (Patomsok, 2007; Suhartini & Hidayat, 2011). This involves the densification of loose biomass to produce fuel briquette which has better handling characteristics and enhanced volumetric calorific value compared to the biomass in its original state (Oladeji, 2010).

Characterization Briquette

Bulk Density of Briquette**:-**Average variationofbulk density of corn cob briquette was 494.56 to 520.01kg.m^{-3}. BH-541 & Shone hadthehighestdensity of 515.65 to 520.01 kg.m^{-3} respectively, followed by Limmu (510.35kg.m^{-3}) and BH-661 (507.45 kg.m^{-3}) & lowest densities were observed for Local variety (494.56 kg.m^{-3}). According to Kaliyan & Morey, 2009 briquetting or pelleting of corn stover or corn cobs can produce uniform productswith bulk density of 500–600 kg.m^{-3}. Whereas the whole corn cobs could behandled, transported, stored and used relatively compared tothe baled or chopped corn stover.

Corn cob briquette is so easy to transport and stored because of its higher bulk density with mean value 520.01 kg.m^{3} than corncob charcoal whose bulk densities 389.0 kg.m^{3}. The corn cob briquette is about 58 % higher in calorific value than corncob char. According to Oladeji, 2011 hiswork indicated that briquette produced from two varieties of corn cob became good biomass fuels. The corresponding maximum bulk densities of briquette produced from white and yellow corncob ranges 502-871 kg.m^{3}. The compaction ratio ranged from 2.27 to 6.50 giving an average value of 3.39 and 3.76 for briquettes produced from corncobs from white and yellow maize respectively.

However, findings show that corncob briquette has more positive attributes than agricultural residues briquette. Ingeneral, the higher thespecificgravityofbasic density of corn cobis,the greater the bulk density of its (Santos & Carneiro, 2011).

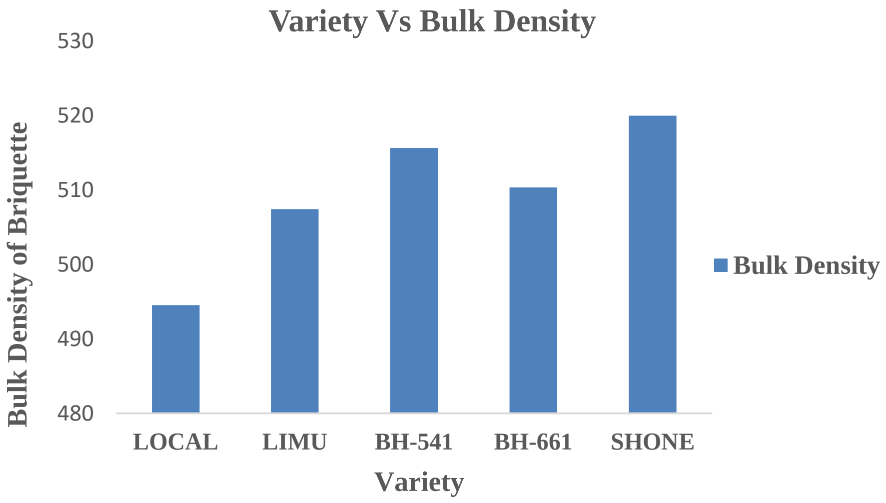

Figure 1:- *MeanBulk Density of Corn CobBriquette*

HighHeatingValue (HHV):- An average corn cob briquette high heating value HHVwere among 27.60 and 29.67MJ·kg^{-1}. Briquette of charred corn cob of SHONE showed the greatest HHV whereas BH-661, BH-541 and LIMMU were statistically similar value whose HHV become 28.58, 28.57 and 28.49 MJ·kg^{-1} respectively. LOCAL variety (27.60 MJ.kg^{-1}) showed the least performance for this property. The results are in agreement with the literature of Akintaro & Musa, 2017who found HHV valuesamong30.67to31.52MJ·kg^{-1}·

As many literature expressed, high heating value of corn cob briquette is directly related to its fixed carbon content that increases with the apparent size and physical condition of corn cob. However, this association was observed in this study with few varieties, except for SHONE, which showed the highest values for HHV and fixed carboncontent.

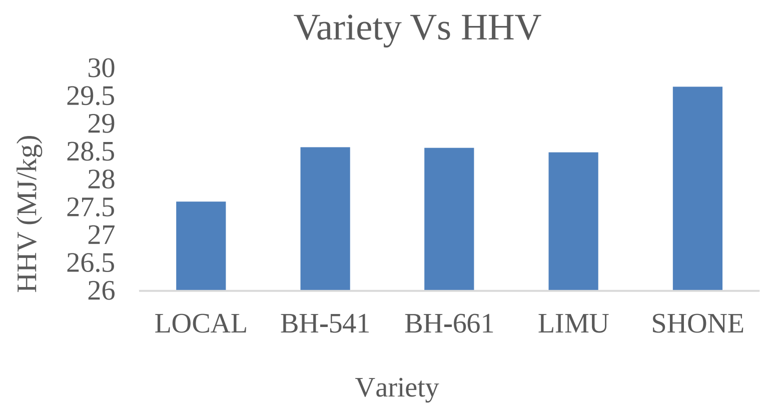

Figure 2:- Mean HHV of Corn Cob Briquette

Figure3 below showed us variation energydensity of corn cob briquetteascomparedwith raw corn cob. Energy densities of both raw and briquette corn cob were expressed with Giga Joule. Briquette made of SHONE records height energy density than other. Corn cob briquette HHVis higher than raw corn cob because most of the components that have less table bonds in the raw corn cob were broken down during carbonization. However, the compounds that have heat resilient bonds remain preserved.

From experimental test result, it can be concluded that HHV of briquette showed an average increase of 58.08%, when it is compared with HHVof raw corn cob. This is the main reason for the increase in energetic density of corn cob briquette as comparedto raw corn cob, because this is a multiplication betweend ensity and HHV. Thus, as portion of the corncob is degraded during carbonization as well as briquette density is less than thec orn cob, but briquette HHV is significantly greater, resulting in ahigher energetic density of briquette.

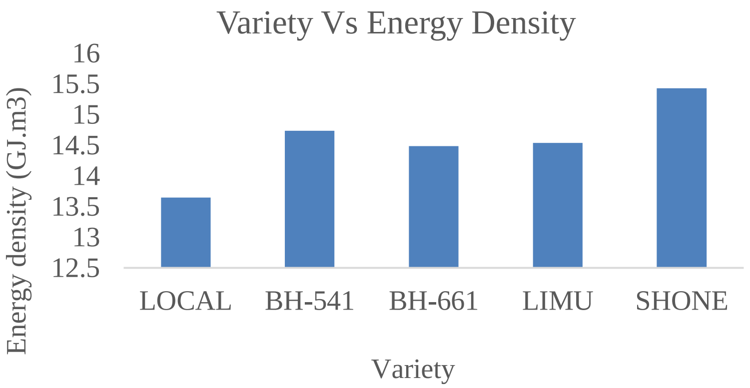

Figure 3: Mean EnergeticDensityofBriquetteand Raw Corn Cob inGJ.M^{-3}

Fixed Carbon, Volatile Matter, and Ash Contents.

Tablebe low illustrated the mean values of proximate analysis of the corn cob briquette. The analysis included fixed carbon, volatilematter andashcontents of charred corn cob involving five varieties. According to Pallavi, 2013 studied and reported that fixed carbon of carbonized briquette become more suitable for domestic application if fixed carbon content become 80.5%. The higher the fixed carbon content of a fuel, the greater the calorific value the smaller the volatile matter, the lower the ash and moisture content and the better the quality of the fuel as stated by Moore and Johnson, 1999.

However here in my experiment, average moisture content, volatile matter, ash content and fixed carbon ranged from between 7.94 to 9.86%, 15.48 to 16.86 %, 22.68 to 28.97 % and 46.50 to 52.32 % respectively for all varieties. The study insisted or encouraged farmers to utilize carbonized corncob as alternative material for energy resource. Briquettes production will be more attract and engage many human power for job creation. This will increase the sources of energy for domestic and industrial use in developing economy.

Variety	Moisture %	Volatile %	Ash %	Fixed carbon %
LOCAL	8.24	15.52	26.75	49.46
BH-541	9.58	14.46	28.86	46.53
BH-661	8.53	15.02	28.87	47.47
LIMU	8.51	13.47	26.48	51.48
SHONE	7.86	16.78	23.12	52.22

Table1:Meanvaluesofcharcoalfixedcarbon,volatilematter,and ashcontents,inpercentage

Akintaro & Musa, 2017 obtained average moisture content, volatile matter, ash content and fixed carbon of corn cob briquette ranged from between 4.43 to 7.62 %, 10.31 to 16.48 %, 3.03 to 5.06 % and 72.68 to 81.30 % respectively. Moisture content and volatile matter of this study were agreed with least difference. Whereas in case of ash content and fixed carbon quite difference occurred throughout study.

Energy Efficiency Test

Energy efficiency of corn cob briquette was evaluated employing parameters such as water boiling time, mass of biomass used, burning rate and temperature rising rate. Water boiling test was applied to determine briquettes thermal properties. At end of the experiment, results of water boiling time, burning rate and temperature distribution in water were within the ranges of 47-67min, 2.56-3.54 g/min, and 93- 94.2°C respectively. Limmu and Shone were showed lower burning rate than other that mean denser. Both of them boiled 3L of water with nearly similar time. However BH-541 boiled given water shortest time but its burning rate is higher than Limmu and Shone. They showed good material conservation for bomb bound briquettes. The results of our investigations showed that binders content increasing enhanced the thermomechanical stability and max affected negatively the energy efficiency parameters of the studied briquettes.

Variety	**Ignition time (sec)**	**Boiling Time (min)**	**Temp water (^{0}c)**	**Burning Time (g/min)**	**Specific fuel consump (g/liter)**	$\boldsymbol{\eta_{thermal}}$
BH-661	33	67	94.2	2.77	198.93	37.55
BH-541	35	47	93.2	2.87	135.90	31.97
Local	30	52	94.2	3.54	185.25	24.96
Limmu	37	52	94.1	2.64	145.23	40.73
Shone	44	54	94.2	2.56	143.76	33.76

Local boiling temp is influenced with altitude, minor error of thermometer & weather conditions. For these reasons, for a given altitude h (in meters), the boiling point of water may be estimated by the following formula:

$$T_b = \left(100 - \frac{h}{300}\right)℃$$

Therefore, maximum boiling temperature become 94.2 ^{0}c and maximum thermal efficiency recorded 40.73 % by Limmu variety whereas minimum thermal efficiency was observed with Local variety which became 24.96 %. This is because mass of raw corn cob was not heavy & internal part became very soft.

Conclusion

Corn cob carbonization technology enabled to carbonize raw corn cob of all given varieties with good mass and volume based conversion efficiency.Where corn cob were abundantly available, applying this corn cob carbonization technology assistance to redirect and encouraged utilization of corn cob charcoal as substitute to wood and wood charcoal.Carbonizing corn cob minimizes or managed coal tar and smoky that connected with health hazards associated with respiratory organ and increase energy density of corn cob.Therefore, volume based conversion rate of carbonization technology becomes 86.36 % & charring time was minimized below two hours in one batch. Moreover this play great deal in climate mitigation program by minimizing forest resource continual destruction and suffering from climatic irregularities. Among varieties, shone variety shows height performance in proximate analysis made and energy density. In addition to these, this variety was more productive in yield than other when compared with similar production land.Physical feature and size of raw corn cob of shone variety bigger than others and its strength is lower than BH-661 variety.

It can be recommended that carbonization technology minimize loss of energy occurred due to inefficient of way of processing and insufficient system to satisfy energy demand. Corn cob carbonization simulates the coalification process to produce char with a high energy density through the omission of the energy-intensive drying process. In addition encourage farmers residing in maize belt areas as source of additional financial income by supplying the urban market with charcoal of corncob.

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