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Farm Power and Agricultural Machinery Technologies

Adaptation and Evaluation of Two Row Tractor Drawn Potato Planter

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Abstract

Potato plays an important role in improving food security and cash income of smallholder potato growers in Ethiopia. Planting has been accomplished by traditional methods to planting the potato tubers on the field, which is a labor intensive, time consuming and low yield of potato per hectare. To overcome this problem, a tractor drawn automatic row planter was developed. The performances of the potato planter were evaluated in the laboratory and farm level to study the effect of planter forward speed and hopper filling level on various dependent parameters like missing index, multiple index, precision index and quality of feed index. Accordingly, the mean spacing index value ranged between 30.39 cm to 37 cm with increase in forward speeds. The multiple indexes and miss index ranged from 9.65% to 12.35% and 12.35 % to 22.70% respectively. A larger value of missing index at higher speeds can be attributed to higher cup velocity which gives little time to the seeds to fill up in the cups. Quality of feed index was ranged from 66.25% to 76% and the value of precision index was obtained in the range of 14.63 to 19.45%. The mean value of theoretical field capacity, effective field capacity and field efficiency of the machine were 0.180 ha/hr, 0.15 ha/hr and 82.13 % at 1.5 km/hr forward speed respectively. The average depth of seed placement was found 7.04 cm. The study revealed that speed of operation significantly affected mean seed spacing, multiple indexes, missing index, precision index and quality of feed index. Finally, it is concluded that, although the planter's performance is satisfactory, but, it needs further modifications at the seed metering mechanism so as to minimize the production cost the machine and seed damage.

Keywords: *Potato Planter, Development, Speed, Hopper filling, Field capacity, Field efficiency*

Introduction

Agriculture contributes significantly in Ethiopian economy. Ethiopian's economic progress of a nation is very important for the development of its citizen and Ethiopia being the country with increasing of population dependent on agriculture for livelihood can only prosper, if agriculture is sustainable. Farm equipment are used in farming operations to increase productivity of land and reducing labour requirement with timeliness in operations, for efficient use of inputs. Besides producing cereal, pulse and other crops, vegetable crops also play an important role in the self-food security.

Potato is an important cash crop, which can be cultivated in wide range of soils and weather conditions. It is the fourth most important staple food items in the world (Hakan Kibar, 2012). It provides high nutrition and an adaptive species for climate change. Potatoes use less water for nutritional output than all other major food sources and can be grown across Africa (Vita and IPF, 2014). Potato plays an important role in improving food security and cash income of smallholder potato growers in Ethiopia. Planting has been accomplished by traditional methods to planting the potato tubers on the field, which is a labor intensive, time consuming and low yield of potato per hectare.

Planting is the process of placing seeds in the soil to have good germination. It is one of the most important cultural practices associated with crop production. An exercise which should result in plant stands at the desired density that emerges quickly and uniformly. A good seed planting gives the correct amount of seed per unit area, correct depth at which seed is placed in the soil and correct spacing between row-to-row and plant-to-plant. This is a key factor for efficient harvesting in a mechanized establishment. Uniform seed distribution within the soil results in better germination and emergence increased yield by minimizing competition between plants for available resources such as light, water, and nutrients. A number of factors affect seed distribution in soil such as the seed metering system, seed delivery tube, furrow opener design, physical attributes of seed, and soil conditions (Karayel *et al.*, 2008).

In Ethiopian farmers are inspired in potato cultivation because of high demand in market and its comparatively high price. Looking to present situation of the potato in Ethiopia, it is noticed that the level of productivity is very low. The production of potato can be enhanced by adopting different measures such as increasing area under cultivation, use of improved high yielding verities, supplementing with nutrient requirements, adopting appropriate plant protection measures and efficient machinery for its cultivation.

Regarding the benefit of potato to human being for consumption and as well for self-food security, there is need to increase the planting rate of potato in the country which is necessary to produce more potato, and will only be achieved by employ farm mechanization. The Manual method of planting seed, normally result to low placement of seed, spacing efficiencies and severe ache for the farmer that reduces the magnitude of farmland to be planted. So, the use of planter which is essential to make more food is beyond the capacity of small-scale farmers. It is very important to develop a planter with low cost that will decrease the hard labour to farmers, enable them to maximise their farm size. Therefore, this study was aimed and initiated with the objective of adaptation and evaluation of two row automatic mini tractor drawn potato planter.

Materials and Methods

This chapter deals with the technique and procedure of development of mini tractor operated two row potato planters with design aspects of various components and constructional details and methodology of testing the potato planter in the laboratory as well as in the field. The materials used to develop the planter and equipment used to test the row planter has been discussed under respective title.

Description of the machine

The developed automatic potato row planter was designed as a three-point hitch mounting type machine consisting of major components of frame, seed hopper, metering device, shafts, power transmission wheel, chain and sprockets, seed tubes, furrow openers and cover. The details of each component are given below:

Frame

The main frame was made with a mild steel rectangular tubular section of dimensions 50 mm x 50 mm x 5 mm. It supports all other components of the planter. A three point hitch assembly is used to hitch the planter with the tractor. The frame and other component parts of the planter were made using appropriate bolts and nuts.

Seed hopper

The seed hopper was designed considering the bulk density and angle of repose of potato seed as 650 kg/m^3 and 35.5° respectively (Sagni Bedassa, 2019). The capacity of the hopper was determined considering following factors.

Row to Row distance: 60 cm
Plant to plant spacing: 30 cm
Seed rate (assumed): 2300 kg/ha

The volume of the hopper was determined on the basis of average bulk density (650kg/m^3) of the potato seeds (Olaoye and Bolufawi, 2001)

$$V = \frac{S_R}{n \times BD} \qquad 1$$

Where: - S_R = seeding rate (kg/ha)

n = number of refilling per hectare

B_D = bulk density of the seeds (kg/ m3)

$$V = \frac{2300}{35 \times 650} = 0.1m^3$$

The Length of the hopper was taken as length of the frame and on the basis of length, volume; angle of repose the hopper has trapezoidal shape vertically having 350 mm and 200 mm rectangular width at top and bottom respectively and 1200 mm length. The height of the hopper is 400 mm.

Power transmission

The power is transmitted from the ground wheel shaft to a shaft fitted above the main frame by a chain and sprocket with speed ratio 1:2. The driven shaft is supported by the main frame with necessary support arms. The drive is transmitted from the shaft to the potato metering cup of driven shaft through chain and sprocket.

Ground wheel

The ground wheel diameter was selected on the basis of ground clearance that is available below the seed box. Since the ground wheel was more concerned for supporting the planter and its movement along with the planter and for power transmission, main focus was given on the width of the wheel, so as to prevent its sink age into the soil. A sheet of 80mm width and 3mm thickness was selected and 60cm wheel diameter was used. The ground wheel was fitted to the mainframe with shaft and supporting frameworks.

Metering mechanism

The seed metering mechanism of the potato planter is a cup type vertical drive. As the tractor moved forward the seed-metering device was rotated by a chain-sprocket arrangement through drive wheels. Seed to seed spacing is regulated by the rate of rotation of the seed-metering sprocket. The metering sprocket rotation i.e. the seed spacing of potato was maintained by the planter drive wheel diameter and the size of sprockets attached to the planter drive wheel and shaft of the seed-metering sprocket. The number of cups was determined by the following equation (Momin, 2006).

$$S_P = \frac{\pi \mathrm{DT_2}}{\mathrm{nT_1}} \qquad 2$$

Where: - Sp = Seed to seed spacing of potato in the field (0.3 m)

D = Diameter of the planter drive wheel (0.6 m)

T_1 = Number of teeth of the sprocket attached to the planter drive wheel axle (15)

T_2 = Number of teeth of the sprocket attached to the seed metering axle (30)

n = Number of cups

From equation 2, $n = \frac{\pi \times 0.6 \times 30}{0.3 \times 15} = \frac{56.55}{4.5} = 12.57 \approx 13 cups$

Furrow opener

After a study of various available furrow openers, it was decided on the basis of the soil type that a shovel type furrow opener would be most suitable for tilled soil to form a furrow of sufficient width to facilitate proper placement of potato seeds. A shoe type furrow opener was attached to the main frame below the seed hopper at a distance of 60 cm. The shank was made from a 12 mm thick flat bar. The wing was made from 4 mm thick mild steel sheet metal. The wings were welded to the shank of mild steel that was fixed to the frame of the planter so that furrows are opened and potato seeds are dropped at the bottom of furrow. The depth of seed placement can be varied by adjusting the height of furrow opener shank upwards or downwards.

Ridger

The ridger is used for covering the dropped seeds. The soil lifted and thrown by the wings of the ridgers and cover the dropped potato seeds at the rear. The ridges wing could be adjustable based on required ridge width.

Seed delivery chute

The metered seed has to be transported to furrow bottom. Chute sizes of 90 cm length and 15 cm diameter were provided from the bottom of the seed metering unit.

Working principle of potato planter

For operating the potato planter in the field, three point linkage of planter was attached to the tractor with the help of pin. Seed hopper filled with good quality of potato seeds and as the planter moves forward, the chain and cup assembly starts moving through the seed hopper in which seeds are stored. As the chain moves up it carries seeds in the cup, which are located at same distance from each other. As the chain moves further up the cup gets inverted inside a chute which drops the seed to the ground. At the same time the furrow opener opens a furrow in which the seeds are planted. As the planter moves further, the ridger attachment then covers the seeds and makes a ridge.

Performance Evaluation of Potato Planter

In order to evaluate the performance of the potato planter, it is essential to check it with respect to seed rate, mechanical damage, seed distribution, seed placement, power requirement, field efficiency and fuel consumption. It was evaluated for above mentioned parameter by performing the following tests in the laboratory as well as in the field.

Laboratory test

Before conducting the performance evaluation of the planter in the field, laboratory tests were carried out for obtaining the correct seed rate.

Calibration of planter

The performance of the fabricated tractor drawn potato planter was tested in the laboratory. The calibration is done to get a predetermined seed rate of the planter. The following procedure was followed for calibration of the planter.

I. Area covered in 20 revolution of ground wheel was determined.

II. The planter was jacked up so that the ground wheel runs freely. A mark was made on the drive wheel and at some convenient place on the body of planter so as to count the revolution of the drive wheel easily.

III. The seeds were filled in the hopper and containers were placed under the furrow openers.

IV. The ground wheel was rotated manually at an average speed of tractor i.e. 1.5 km/h.

V. The quantity of seeds dropped from furrow openers for 20 revolutions were collected and weighed.

VI. Calculate the seeds dropped in kg ha^{-1}.

Mechanical seed damage test

The mechanical damage test was conducted to find out percentage of damage of seeds that takes place during actual operation. From the metered seeds the damaged seeds were weighed separately and percentage damage was calculated as follows:

$$\text{Damage percentage} = \frac{\text{Weight of damaged seed}}{\text{Total weight of seeds collected}} X\,100 \qquad 3$$

Performance evaluation of the planter

The performance indices of a planter namely multiple index, miss index, quality of feed index and precision along with mean and standard deviation keeping theoretical spacing as base was calculated from the measured spacing between dropped seeds as follows (Kachman and Smith, 1995), (Al-Gaadi, 2011).

Mean seed spacing

Mean seed spacing (S) is the mean of total number of spacing measured.

$$S = \sum_{i=1}^{N} \frac{X_i}{N} \quad (4)$$

Where, N = total number of spacing measured

Xi = distance between consecutive seeds

Miss index

Miss index is an indicator of how often the seed skips the desired spacing. The planter was operated in the field and the distances between two consecutive seeds were measured in a span of 50 m. It is the percentage of spacing greater than 1.5 times the theoretical spacing.

$$I_{Miss} = \frac{n_1}{N} X\, 100 \quad (5)$$

Where, n_1 = Number of spacing in the region > 1.5 theoretical seed spacing

N = Total number of observations

Multiple index

The multiple index is an indicator of more than one seed dropped within a desired spacing. It is the percentage of spacing that are less than or equal to half of the theoretical spacing in mm.

$$I_{Mult} = \frac{n_2}{N} X\, 100 \quad (6)$$

Where, n_2 = Number of spacing in the region ≤ 0.5 theoretical seed spacing

N = Total number of observations

Quality of feed index

The quality of feed index is the measured of how often the spacing was close to the theoretical spacing. It is the percentage of spacing that are more than half but not more than 1.5 times the theoretical spacing. The quality of feed index is mathematically expressed as follows:

$$I_{qfi} = 100 - \left(I_{Miss} + I_{Mult}\right) \quad (7)$$

Where, Imiss = Miss index

Imult = Multiple index

Precision index

Precision in spacing (Ip) is a measure of the variability (coefficient of variation) in spacing, between seeds after accounting variability due to both multiples and misses.

$$I_P = \frac{S_d}{S} X\,100 \quad 8$$

Where, S = Theoretical seed spacing

Sd = Standard deviation of the spacing more than half but not more than 1.5 times the set spacing S

Field performance test of the planter

The developed prototype of potato planter was tested for field performance. The test was conducted at farmer's field. The test plot was prepared by local ardu plough to obtain a fine seedbed for potato planting. The TY – 254B tractor (25 hp) was used for field test. The tractor operator and three persons were employed for data collection. The following parameters were observed during the field test.

Seed spacing

During the field trial the seed to seed spacing was measured in the field at five different locations randomly with measuring tape.

Row to row spacing

While conducting the field test of the planter the spacing between two adjacent rows was measured at five randomly selected locations with the measuring steel tape and average was determined to represent row to row spacing.

Height and width of ridge

Height and width of the ridge was measured with the help of meter scale at three randomly selected places in each plot.

Wheel slippage

The wheel slippage of tractor was measured by marking the sides of rare tyre lugs and the distance the tractor moves forward at every 10 revolutions under no load condition and the same revolution with load on same surface was measured and expressed mathematically as:

$$\text{Wheel Slippage} = \frac{M_2 - M_1}{M_2} X\,100 \quad 9$$

Where: M_2 = Distance covered at 10 revolutions of the tractor drive wheel at no load (m)

M_1 = Distance covered at 10 revolution of tractor drive wheel with load (m).

Fuel consumption

The fuel consumption was determined by refill method. The fuel tank of tractor was filled up to its top, before the start of planting operation. After completing the planting operation the fuel tank was refilled up to its top by a measuring cylinder. The volume of fuel used was taken into account as fuel consumed for a particular time period.

Theoretical field capacity

Theoretical field capacity was measured by considering the width of operation and travel speed of the tractor. The theoretical field capacity was expressed in ha h^{-1} and computed by the following formula;

$$\text{Theoretical field capacity (ha / h)} = \frac{W \times S}{10} \qquad 10$$

Where, W = Width of planter, m

S = Speed of operation, Km/h

Effective field capacity

The effective field capacity is the actual rate of coverage including the time lost in filling the hopper and turning at the end of the rows. However in calculating the effective field capacity (ha hr^{-1}), the time consumed for effective work and the time losses for other activities such as turning, refilling of seeds were recorded.

$$\text{Effective field capacity (ha / h)} = \frac{\text{Area of Plot (ha)}}{\text{Time taken (h)}} \qquad 11$$

Field efficiency

Field efficiency is the ratio of the effective field capacity to the theoretical field capacity as follows:-

$$\text{Field efficiency} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100 \qquad 12$$

Cost of Operation

The cost of operation of the potato planter in terms of Birr/ha and Birr/hr was determined considering fixed cost and variable cost with the help of straight line method. The straight line method assumes equal reduction in the value of machine every year. An economic life of 10 years and annual use of tractor and planter was considered as 850 and 300hr respectively. The detail calculation of cost of operation of planter is given in appendix table B and C.

Seed germination test in field

The planter was operated in the field and after the week of planting potato, germinated seeds were measured in a span of 5 m. The number of germinated seeds was measured in span of 5 m and the percentage of seed germinated was computed.

Experimental design and data analysis

Experimental treatments were set up in Randomized Complete Block Design (RCBD) with three replications used in the study. The analysis of variance (ANOVA) and mean table for different parameters were tabulated and the level of significance was reported.

Result and Discussions

A tractor drawn two row automatic potato planter prototype was fabricated. The performance of the machine was evaluated in the laboratory as well as in the field. The data were analyzed and results are discussed in this chapter.

Laboratory Performance of Potato Planter

The fabricated two row mini-tractor operated automatic potato planter was tested in the laboratory to evaluate its performance. The results are discussed in the following sections.

Calibration of planter

The ground wheel was rotated for 20 revolutions and metered seeds were collected from all the two furrow openers and seed rate was calculated and the results are given in table 1. The recommended potato seed rate per hectare is 2200 - 2500 kg, as per the package of practices. Hence, the developed potato planter was calibrated was achieved 2313 kg ha^{-1}.

Table 1. Calibration results planter

S. No	Description	Value
1	Number of furrow openers	2
2	Spacing between the furrow openers, m	0.6
3	Diameter of ground wheel, m	0.6
4	Number of revolutions	20
5	Area covered in 20 revolution (m^2)	45.12
6	Potato seeds collected, kg	10.41
7	Mean seed rate (kg/ha)	2313

The effects of different speed and hoper filling level on seed rate are presented in Table 2. It was observed that the seed rate was decreased with increase in speed due to reduction in exposure time of cups to seeds. While there was an increase in seed rate with increasing hoper filling level due to opportunity of cups to pick up a seed.

Table 2. Seed rate and mechanical damage at different speed and hoper filling

Variables		Seed rate (kg/ha) (Mean)	Mechanical damage (%) (Mean)
Speed(km/h)	Hoper filling level		
1.5	Halve (HF1)	2344	0.82
2.0		2308	0.87
2.5		2256	0.92
1.5	Three fourth (HF2)	2349	0.83
2.0		2314	0.90
2.5		2286	0.97
1.5	Full (HF3)	2357	0.86
2.0		2320	0.95
2.5		2290	0.98

Mechanical seed damage

The seed were collected randomly during calibration and observed for damaged seeds from a two kg seed lot, the percentage of seed damaged were calculated. The effects of forward speed and hoper filling level on mechanical seed damage are presented in Table 2. It is clear that as the speed increase the mechanical seed damage increase in all hoper filling level of potato seeds. The mechanical seed damage was higher due to higher rotational speed of the metering roller at higher speed. At high rotational speed the cup strike the seeds with greater impact resulting in mechanical damage.

Performance evaluation of potato planter

The planter was tested in a ploughed field for 50 m strip length. The field testing of the planter was conducted for different combinations of forward speeds and hoper filling level. The forward speeds of 1.5 km hr^{-1}, 2 km hr^{-1} and 2.5 km hr^{-1} and hopper filling level of half, three fourth and full were selected to obtain the recommended seed spacing of 30 cm. The field performance observations on seed spacing, missing index, multiple index, Quality of feed index and Precision index were computed and presented in table 3.

Fig. 1. Measurement of Seed Spacing

Table 3. Effect of forward speed and hopper filling level on performance of the planter

Sl. No.	Experiment runs	Mean Seed spacing, cm	Miss index, %	Multiple index, %	Quality of feed index,%	Precision index, %
1	S_1HF_1	31.10	12.35	11.65	76.00	14.63
2	S_2HF_1	33.30	18.07	10.90	71.05	17.41
3	S_3HF_1	36.65	21.50	10.90	67.60	18.63
4	S_1HF_2	30.51	15.35	11.40	73.25	15.81
5	S_2HF_2	33.05	15.65	12.35	72.00	16.68
6	S_3HF_2	36.55	22.70	11.05	66.25	19.45
7	S_1HF_3	30.39	12.70	14.65	72.65	16.15
8	S_2HF_3	33.90	16.70	10.75	72.55	16.43
9	S_3HF_3	37.00	21.00	9.65	69.35	18.53

Effect of forward speed and hopper filling level on mean seed spacing

The effect of forward speed and hopper filling level on seed spacing is presented in Table 3. From figure.2, it is observed that the mean spacing between consecutive seeds increased, with increasing in planter forward speed. The mean seed spacing for lowest planter forward speed

(S1) was in the range of 30.39 cm to 31.10 cm and for (S2) it ranged from 33.05 to 33.90 cm. However, for (S3) it ranged from 36.55 to 37 cm for all hopper filling levels as presented in Table 3.

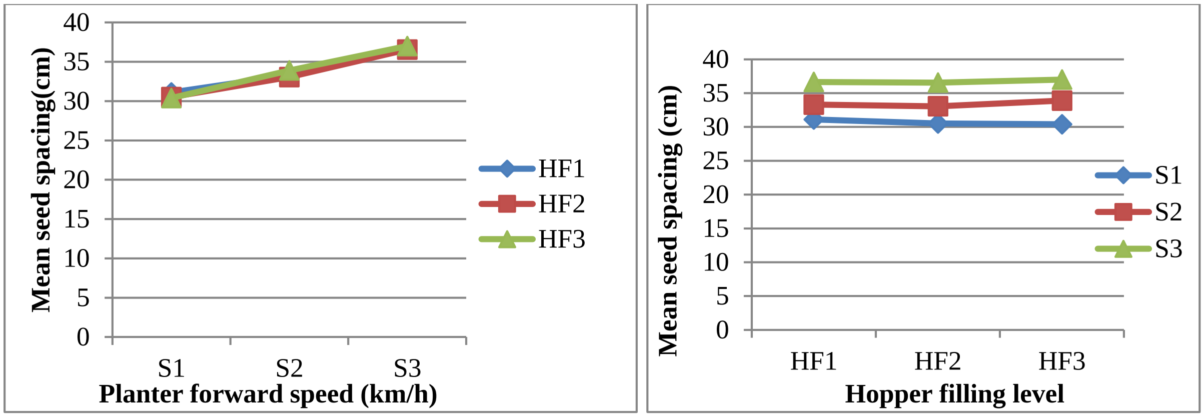

Fig. 2 Effect of planter forward speed and hopper filling level on mean seed spacing

Appendix Table A1 show the results of statically analysis on the effects of forward speed and hopper fill level on mean seed spacing. Mean seed spacing was significant for various planter forward speeds ($p < 0.05$). However, mean seed spacing was not significantly affected by hopper filling level and interaction of planter forward speed and hoper filling level ($p > 0.05$). As the planter forward speed increases there was significant increase in mean seed spacing. A similar trend was observed for potato planters as reported by Gaadi and Marey (2011).

Effect of planter forward speed and hopper filling level on seed missing index

The effect of forward speed and hopper filling level on seed missing index is given in Table 4. The missing index ranged from 12.35 % to 22.70 % for different combinations of forward speeds and hopper filling level. The highest missing index 22.70 % was observed for highest forward speed (S3) of 2.5 km/h and the lowest missing index of 12.35 % was obtained at a forward speed (S1) of 1.5 km/h. Figure 3 shows the effect of forward speed and hopper filling level on miss index. However, the effect was dominantly due to variation in forward speed than hoper filling level. Increasing in forward speed of operation from 1.5 km/h to 2.5 km/h resulted an increase in percentage of seed missing index. Momin *et al*. (2006) evaluated semi-automatic potato planter and reports that the missing index of 10 and 13% for operation speed of 1.8 and 2km/hr. Al-Gaadi (2011) also reported that the performance of an auto feed cup-belt potato planter under different operating conditions with different tuber shapes for whole and cut tubers. The highest missing index of 16.42% at 3 km h^{-1} travels speed. Appendix Table A2 show the results of statically analysis on the effects of forward speed and hopper fill level on missing index. The analysis of variance (ANOVA) showed that the planter forward speed and interaction of forward speed and hopper filling level shows significant effect ($p < 0.05$) on seed missing index.

Table 4. Effect of planter forward speed and hopper filling level on miss index (MISI)

Parameter		Source of variation			Measure of differences	
	Forward Speed level	V_1	V_2	V_3	LSD (5%)	SE(M)
MI (%)		13.47^{a}	16.80^{b}	21.73^{c}	0.714	0.240
	Hoper loading level	H_{25}	H_{50}	H_{75}		
		17.30^{ab}	17.90^{a}	16.80^{b}	0.714	0.240
		Interaction(V*H)			1.237	0.416
	Forward speed level	H_{25}	H_{50}	H_{75}		
	V_1	12.35^{a}	15.35^{b}	12.70^{c}		
	V_2	18.05^{d}	15.65^{b}	16.70^{be}		
	V_3	21.50^{f}	22.70^{f}	21.00^{g}		

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

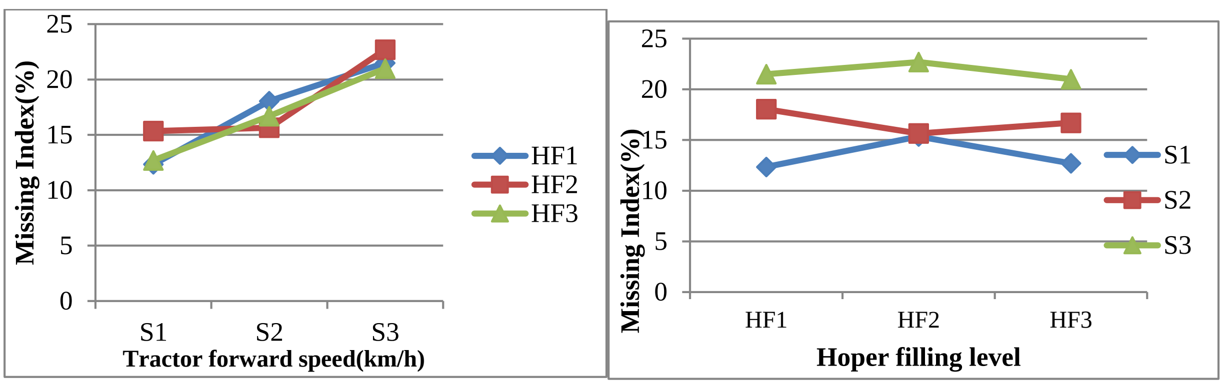

Fig. 3. Effect of planter forward speed and hopper filling level on missing index

Effect of forward speed and hopper filling level on multiple index

The effect of forward speed and hopper filling level on multiple indexes is presented in Table 5. The multiple index ranged from 9.65 % to 12.35 % for all levels of forward speeds and hopper filling level. The maximum multiple index was observed, for lowest level of forward speed and medium level of hopper filling. However, the lowest multiple index, 9.65% was for maximum level of forward speed (S_3) and maximum level of hopper filling (HF_3). Fig 4 shows the effect of forward speed and hopper filling level of multiple index. The multiple index decreases as planter forward speed increases for all levels of hopper filling. Misener (1979) evaluated the cup and picked type potato planters and reports that the average multiple index per 30.5 m of row length ranged from 6.2% to 33.6% for the cup type and from 6.8%) to 29.0% for the pick type planter over various forward speeds. Appendix Table A3 show the results of statically analysis on the effects of forward speed and hopper fill level on multiple index. The analysis of variance (ANOVA) revealed that the planter forward speed and the interaction between planter forward speeds with hopper filling level ($p < 0.05$) had significant effect on the multiple indexes.

Table 5. Effect of planter forward speed and hopper filling level on multiple index (MULI)

Parameter		Source of variation			Measure of differences	
	Forward Speed level	V_1	V_2	V_3	LSD (5%)	SE(M)
MULI (%)		12.57^a	11.33^b	10.53^c	0.726	0.244
	Hoper loading level	H_{25}	H_{50}	H_{75}		
		11.15^a	11.60^a	11.68^a	0.726	0.244
		Interaction(V*H)				
	Forward speed level	H_{25}	H_{50}	H_{75}		
	V_1	11.65^a	11.40^a	14.65^b	1.257	0.416
	V_2	10.90^a	12.35^a	10.75^c		
	V_3	10.90^a	11.05^{ab}	9.65^{ac}		

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

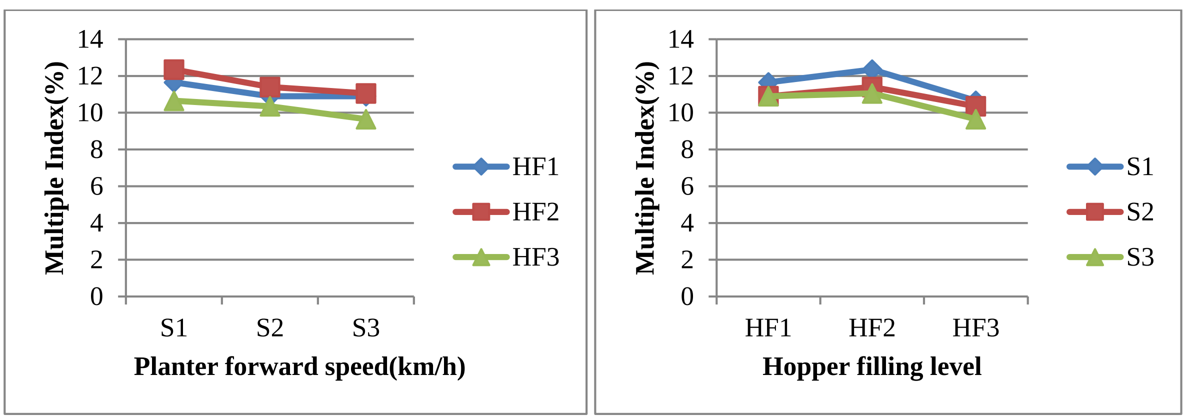

Fig. 4. Effect of planter forward speed and hopper filling level on multiple index

Effect of forward speed and hopper filling level on quality of feed index

The results pertaining to quality of feed index is given in Table 6. From the table 6, it is clearly observed that, the quality of feed index ranged from 66.25 % to 76 %. The highest quality of feed index (76 %) was observed for the lowest level of planter forward speed (S1) and one fourth level of hopper filling (HF1) whereas lowest quality of feed index, 66.25 % was observed for the parameter combination of highest forward speed (S3) and half level of hopper filling (HF2). The quality of feed index decreased from 76 % to 66.25 % with increasing in forward speed as shown in Fig. 5. Similar result was observed for potato planter with high quality of feed index at lower forward speed reported by Gaadi and Marey, (2011). Appendix Table A4 show the results of statically analysis on the effects of forward speed and hopper fill level on quality of feed index. The analysis of variance (ANOVA) revealed that the planter forward speed and the interaction between planter forward speed and hopper filling level had significant effect on quality of feed index at ($p < 0.05$) probability.

Table 6. Effect of planter forward speed and hopper filling level on quality of feed index (QFI)

Parameter		Source of variation			Measure of differences	
	Forward Speed level	V_1	V_2	V_3	LSD (5%)	SE(M)
QFI (%)		73.97[a]	71.87[b]	67.73[c]	0.913	0.307
	Hoper loading level	H_{25}	H_{50}	H_{75}		
		71.55[a]	70.50[b]	71.52[a]	0.913	0.307
		Interaction(V*H)				
	Forward speed level	H_{25}	H_{50}	H_{75}		
	V_3	76.00[a]	73.25[b]	72.65[b]		
	V_5	71.05[b]	72.00[b]	72.55[b]	1.581	0.532
	V_7	67.60[c]	66.25[c]	69.35[d]		

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

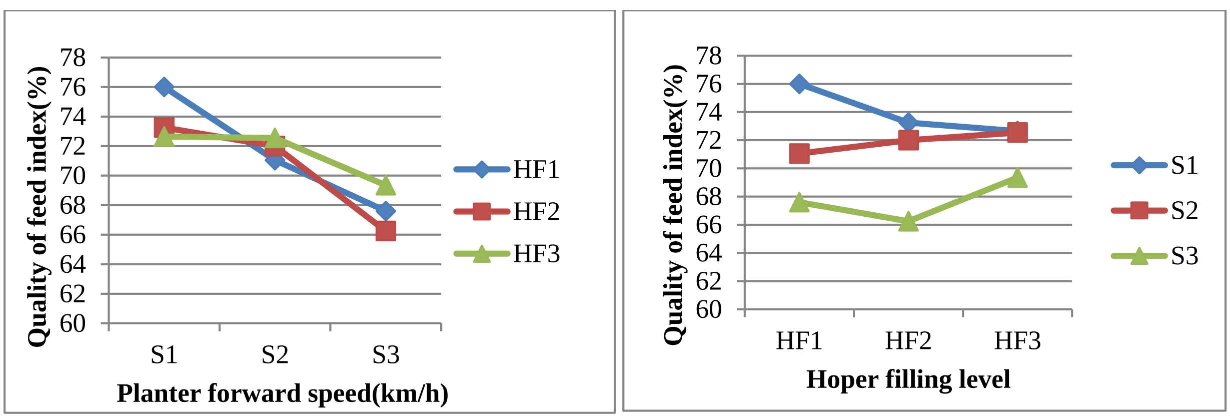

Fig. 5. Effect of planter forward speed and hopper filling level on quality of feed index

Effect of forward speed and hopper filling level on precision index of

The effect of forward speed and hopper filling level on precision spacing index of planter performance is given in Table 7. The lowest precision index (14.63 %) was obtained at lower forward speed. However, the maximum precision spacing index 19.45 % was observed at highest level of forward speed. The effect of forward speed and hopper filling level on precision index is shown in Fig. 6. At the highest level of forward speed and maximum hopper filling level resulted in maximum precision spacing index. Lower values for the precision index indicate better performance compared to higher values of precision index (Kachman and Smith, 1995). Appendix Table A5 show the results of statically analysis on the effects of forward speed and hopper fill level on precision index. The analysis of variance (ANOVA) showed that forward speed of the planter on precision index was significant at probability ($p < 0.05$). However, the hopper filling level and the interaction between forward speed and hopper filling level had no significant effect on precision index at ($p > 0.05$).

Table 7. Effect of planter forward speed and hopper filling level on precision index (PI)

Parameter		Source of variation			Measure of differences	
	Forward Speed level	V_1	V_2	V_3	LSD (5%)	SE(M)
PI (%)		15.53[a]	16.84[b]	18.87[c]	0.587	0.198
	Hoper loading level	H_{25}	H_{50}	H_{75}		
		16.89[a]	17.31[a]	17.04[a]	0.587	0.198
		Interaction(V*H)				
	Forward speed level	H_{25}	H_{50}	H_{75}		
	V_1	14.63[a]	15.81[b]	16.15[b]		
	V_2	17.41[b]	16.68[b]	16.43[b]	1.017	0.342
	V_3	18.63[c]	19.45[c]	18.53[c]		

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

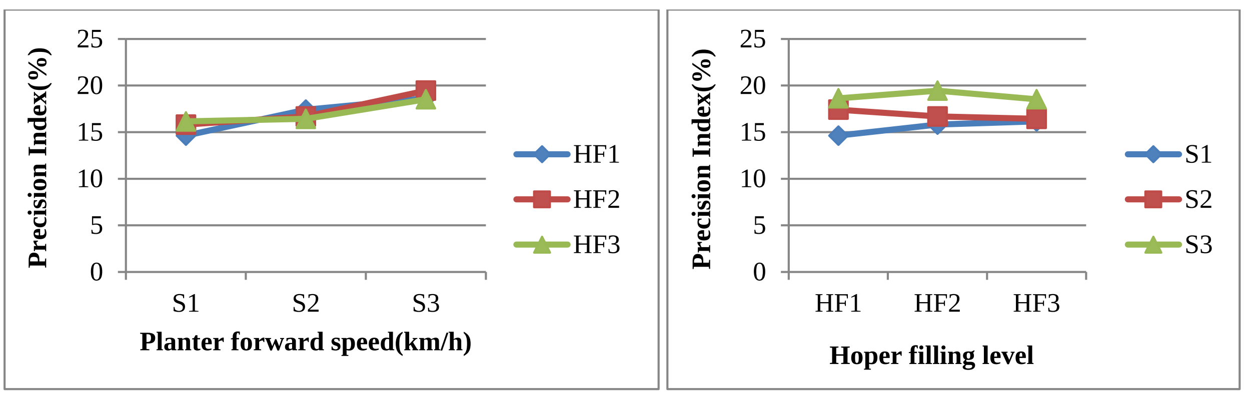

Fig. 6. Effect of planter forward speed and hopper filling level on precision index

Field Performance of Potato Planter

Depth of seed placement

The average depth of seed was 7.04 cm and it did not vary between the furrow openers, which indicated that the placement in the furrow openers were uniform. According to Ram (1975) the depth at which the seed must be planted to enable to get contact with a sufficient moist layer in order to ensure germination is generally 5 to 10 cm. The depth obtained by the planter was therefore within the desirable limit.


Fig. 7. Measurement of seed placement depth

Height and width of ridge

The measurement of height and width of the ridges made by the planter is presented in Table 4. The height of ridge was 20 to 24 cm and average distance was 21.98 cm. The bottom width of ridge was varying from 44 to 45.5 cm and average width was 44.6 cm and it did not vary between the ridges, which indicate the ridges are uniform.

Table 4. Height and Width of Ridge

S/No.	Height of Ridge (cm)	Bottom width of Ridge (cm)	Top width of Ridge (cm)
1	22	44.5	14
2	20.8	45	14.8
3	24	45.5	15.2
4	23.7	44.8	15.5
5	20	44.2	14.8
6	21.4	44	14.7
Avg.	21.98	44.6	14.83

Fuel consumption

The fuel consumption was measured by the procedure as described in the section 3.2.7.5. The planter was operated in an area of 0.06 ha at operation speed of 1.5 km/hr. The time and fuel consumption for the test area was measured by refilling methods. The fuel consumption obtained was 1.22 *lt/hr*. Momin *et al*. (2006) evaluated semi-automatic potato planter and reports that the fuel consumption of 1.5 lt/hr at operation speed of 1.5 km/hr.

Theoretical field capacity, Effective field capacity and Field efficiency

The data regarding on the theoretical field capacity, effective field capacity field efficiency are presented in Table 5. The mean theoretical field capacity, effective field capacity and efficiency of the potato planter were 0.18 ha h^{-1}, 0.15 h^{-1} and 82.13% at a forward speed of 1.5 km h^{-1}.

Momin *et al*. (2006) evaluated semi-automatic potato planter and reports that the theoretical field capacity, effective field capacity and field efficiency of 0.27km/hr, 0.18ha/hr and 66.67 % respectively at operation speed of 1.5 km/hr. Asheesh M. et al., (2017) also develop and evaluated automatic potato planter and reports that the effective field capacity and field efficiency of 0.09ha/hr and 60.7 % respectively at operation speed of 2 km/hr.

Table 5. Theoretical field capacity, Effective field capacity and Field **efficiency**

Plot no.	**Speed (km/h)**	**Total time required (Sec)**	**Theoretical field capacity (ha/h)**	**Effective Field Capacity (ha/h)**	**Field Efficiency (%)**
1	1.5	213.85	0.180	0.1480	82.22
2	1.5	214.72	0.180	0.1476	82.00
3	1.5	214.12	0.180	0.1479	82.17
Avg.	1.5	214.23	0.180	0.1478	82.13

Note: - Size of plot = 20 × 4.4m and Width of Planter = 1.2 m

Seed germination test in field

The mean seed germination percentage was 83.75% at a speed of 1.5 km/h. The result raveled that the developed tractor worked functionally and satisfactory.

Fig. 8. Field observation seed germination

Summary and Conclusions

Summary

A prototype of two row automatic potato planter drawn by mini tractor was developed. The planter consists of seed metering mechanism, seed tube, furrow openers, drive wheel, power transmission and ridger. The performance of the tractor operated potato planter was tested in the laboratory and field respectively. The developed potato planter was field tested with three different forward speeds and three hopper filling level. Seed spacing indices parameters of the planter which includes, missing index, multiple index, quality of feed index and precision in seed spacing were used to evaluate functional performance of potato planter. The mean spacing index value ranged between 30.39 cm to 37 cm with increase in forward speeds. The multiple index and miss index ranged from 9.65% to 12.35% and 12.35 % to 22.70% respectively. Missing index increases with increasing planter speed and increasing seed meter velocity. Quality of feed index was ranged from 66.25% to 76% and the value of precision index was obtained in the range of 14.63 to 19.45%.

The metered seed were observed for mechanical damage which was found less than 1 % for all speeds as well as hopper filling level. The mean field test germination count of 83.75% was obtained. Average depth of potato seed placement was observed as 7.04 cm. The dimension of ridge formed during operation was as per requirement and average values of the ridge of top width 14.83cm, average height of the ridge from bottom of furrow 21.98cm and bottom width furrow 44.6 cm were recorded. The average fuel consumption (l/ha) of the planter at speed (km/h) of 1.5 were 8.1 *l* ha^{-1}. The average theoretical field capacity (ha/h), effective field capacity (ha/h) and field efficiency (%) for the speed of operation (km/h) 1.5 were 0.180 ha/h, 0.1478 ha/h and 82.13% were obtained respectively.

Conclusion

The newly developed mini tractor drawn two row automatic potato planter was evaluated in the laboratory as well as in field for its performance. Based on the results obtained the following conclusions are drawn:- The planter can be used for planting the potato Seeds in the field at required row to row and plant to plant spacing. The minimum values of missing index 12.35%, multiple indexes 10.40%, precision index 14.63% and maximum value of quality of feed index 76.00% were observed. Average seed spacing was range from 30.39 to 37.00 cm. The average mechanical seed damage (%) was varied from 0.836 to 0.956, which was less than 1 percent as per recommendation. The depth of planting 7.04 cm of potato seeds, which is within the recommended range of the average depth of potato planting was 5 cm to 10 cm. Based on the performance evaluation results, it is concluded that the tractor drawn automatic potato planter is satisfactory and can be subjected to further modifications at the seed metering mechanism so as to minimize the production cost the machine and seed damage.

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On-Farm Evaluation of Tractor Drawn Wheat Seed Drill

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Abstract

This experiment was conducted to evaluate the performance of tractor drawn wheat seed drill machine which can sow wheat and fertilizer at predetermined depths and row spacing. The machine performances were evaluated in terms of Seed and fertilizer rate, depth of seed placement, row spacing, plant population, field capacity and field efficiency, randomized complete block design with three forward speeds, three hopper loading and three replicationswere used as experimental design. There were no visible and internal seed damaged by the machine and it shows that there was no reduction in germination percentage when compared with seed supplier recommendation. The seed and fertilizer rate was calibrated and recorded as 125 kg/ha and 150 kg/ha respectively for 20 cm row spacing. The seed drill was evaluated at speed of 3, 4, 5 km/hr and hopper loading level of H_{50}, H_{75}, *and* H_{100}. *Both operating speed and hopper loading capacity of the machine had significant effect on seed and fertilizer rate at* $p < 0.05$. *The average field capacity, field efficiency, and fuel consumption at 4km/hr speed of operation were* 0.43 *ha/hr,* 85.93*% and* 3.8 *l/hrrespectivly. 378 to 380 plants population per 1.2* m^2 *area were counted during seedling count. Depending on the results of performance evaluation, it is concluded that the developed seed drill machine can be efficiently and economically used by the majority of farmers.*

Key words: *seed drill, performance, field capacity and field efficiency*

INTRODUCTION

It has been frequently claimed by agricultural experts and researchers that Ethiopia could be food self-sufficient, if the existing factors of agricultural production are well exploited. And yet, numerous factors can affect agricultural production and productivity improvement. The increased use of modern farm inputs, modernization of farming by using improved farm implements along with introduction of modern technologies to the sector are the major ones.

Farming system in Ethiopia is categorized as small land holdings, because of more than two-thirds of the population living in rural areas with high population density. There are 111.5 million hectares of land in Ethiopia, out of that 74.5 million hectares are suitable for agriculture, and 13.6 million hectares land is now under production (CIMMYT, 2014).

In Ethiopia cereal crops are the major food crops for the majority of the country's population. As well as serve as a source of income at household level and contributes in for foreign currency earnings Wheat is one of the most important cereal crops of the world and is a staple food for one third of the world's population (Hussain MI, Shah SH, 2002).

Meher Season Post-Harvest Crop Production Survey shows that a total land area of about 12,486,270.87 hectares was covered by grain crops, from which a total volume of about 266,828,807.04 quintals of grains were obtained. Out of the total grain crop area, 79.88% (9,974,316.28 hectares) was covered by cereals. Wheat took up 13.33% (about 1,664,564.62 hectares) of the grain crop area. Cereals contributed 86.68% (about 231,287,970.83 quintals) of the grain production of which wheat made up 15.81% (42,192,572.23 quintals) (CSA, 2015/2016) and (Anbessie Debebe *et al*., 2020).

Ethiopia is the largest producer of wheat in sub-Saharan Africa. It ranks fourth after maize (Zea mays), sorghum (Sorghum bicolor) and teff in in terms of area coverage and ranks second in case of total production and productivity after maize. It covers about 1.80 million hectares annually (CSA, 2014), and 75.50% of the current total wheat production area is located in Bale, Arsi and Shewa highlands. In Ethiopia wheat productivity per hectare is less as compared to other wheat producing countries.

The low use of improved farm inputs (biological and mechanical), dependency on rainfall and traditional farming practices are the causes of its low production and productivity of the crops. Cognizant of this fact, extension system has been contributing efforts to promote production and productivity of wheat. Even though all the hard work made to make farmers adopt improved practices, unavailability of proper row seed drill machine made the implementation unsuccessful.

Uniform and timely establishment of optimum plant populations affects yield increment. Manual row planting practice is tedious and results in low seed placement, low spacing efficiencies and serious back ache for the farmers due to the longer hours required for careful hand metering of seeds which limits the size of the field that can be planted in rows (Kalay Khan, 2017).

To combat problems of optimum plant population establishment, Ethiopian Institute of Agricultural Research and regional agricultural engineering research centers (Melkassa, Jimma and Asella) had tried to develop and adapt animal drawn wheat seed drill. Other individuals including farmers had been trying to develop row planting machine to modernize wheat production in Ethiopia. Various types of animal drawn wheat row seeders were developed using different design approaches with their own advantage and limitations. Tamrat Gebiso *et al.,* (2017) evaluated and verified available prototypes for wheat seed drill and recommend suitable ones for further demonstration and pre-scaling up.

Asella Agricultural Engineering Research Center has developed animal drawn wheat seed drill, with fluted metering mechanism, capable of planting four rows in single pass having 0.12 ha/hr effective field capacity and capable of sowing 111.42 kg/ha wheat seed. Seed breakage, heavy weight and the chain miss aligned during flute exposed length adjustment was the problems observed with this wheat seed drill during field test.

Melkassa Agricultural Research Center has developed and demonstrates a six row animal drawn wheat seed drill with no fertilizer metering device. This seeder was designed to cover 1.2m width at a go having effective field capacity of 0.11 ha/hr and capable sowing 171.51 kg/ha of wheat seed.

Jimma Agricultural Engineering Research Center has developed animal drawn wheat seed drill, capable of planting four rows in one pass having 0.09 ha/hr effective field capacity and capable of sowing 49.70 kg/ha wheat seed. Minimum seed rate application which is below the recommended 125 kg/ha was the problems observed with this wheat seed drill during field test.

Even though, wheat seed drills were designed, modified, tested and evaluated continuously by different researchers at different research centers, still there is no proven wheat seed drill that can be used under farmers' conditions.

In general, the drawback observed to-date is that wheat seed drills are not able to maintain uniform seeding rate and also even seed delivery to improper design and manufacturing. In order to overcome these problems, tractor drawn wheat seed drill were developed and tested at AAERC for the purpose of masters' thesis project and had 0.36 ha/hr field capacity and capable of sowing 124.4 kg/ha and 149 kg/ha of wheat seed and fertilizer respectively at 4 km/hr with half hopper loading level. (Abulasan K, unpublished).

Therefore, this research project is re-initiated to enrich the data taken during preliminary test and to have full data that was not taken due to unavailability of budget allocation for successive planting season with the f objective to evaluate performance of developed tractor drawn wheat seed drill in the study area.

Material and Methods

Descriptions of Study Area

Design, fabrication, testing and calviration was conducted at Assella Agricultural Engineering Research Center located in the Arsi zone of Oromia Region and it has 6° 59' to 8° 49' N latitude and longitude of 38° 41′ to 40° 44' E and an elevation of 2,430 meters above sea level.

Working principles of the machine

The operation principle of the seed drilling machine is very simple and attached to the tractor through three-point linkage. Seeding can be accomplished by just pulling the seed drilling machine in well prepared and harrowed field. Since the seed and fertilizer metering is directly attached to the ground wheel shaft, the seed and fertilizer metering flute roller rotates, seeds and fertilizer are automatically dropped into the opened furrow through the seed delivery tube outlet by means of gravity.

Performance Test and Evaluation

Before actual test was carried out in the lab or field, the machine was tested to confirm the functionalty of all the rotating parts, to check any malfunctioning parts and defects in the manufacturing.

Fig.1. Field performance evaluation of seed drill Laboratory performance testMechanical damage

The test for seed damage was conducted by rotating wheel 10 times with the seeder held (raised up) position at fully loaded seed hopper and the discharged seeds from from each seed tube were collected and observed for any external seed damage. Any visible damaged seeds during the calibration were separately weighed and the percentage seed damage was determined as (Rangapara J., 2014).

$$\% damage = \frac{W_s}{W_{ts}} x100$$

Where, W_s =weight of damaged seed; W_{ts} = Total weight of collected seeds

Uniformity of seed distribution

The test for seed uniformity was carried out to identify variation between furrows in seed metering devices. To assess uniformity of seeds droped from each seed tube, the machine was drawn by 25 hp tractor at predetermined speed of operation (3, 4, and 5 km/hr) and hopper loding capacity (half, three fourth and full) on 100m length track test. During the test run, sample bags were placed under each seed tube to collect the discharged seeds. Three observations were taken for each test run over 100m distance. The collected seeds in the bags for each seed metering device after each test run were weighed and compared.

Seed germination test

Seed germination test was conducted to check internal seed damage. To calculate the germination percentage, 100 wheat seeds discharged from seed drilling machine were sown on petri dish and counted after 10 days and percentage germination was calculated as (Rangapara J., 2014).

 

Fig. 2. Seed germination test on petridish

$$Germination(\%) = \frac{N_{sg}}{N_{sp}} x100$$

Where, N_{sp} = Number of seed planted; N_{sg} = Number of seed germinated

Field test

Field testing was carried out on a well prepared and harrowed test plot. Depending on the obtained parameters in laboratory test, the machine was operated at three different forward speeds 3, 4, and 5 km/hr and three different hopper filling capacity. Seed rate, seed uniformity, seed damage, time required (hr/ha), labor requirement, cost of planting, plant population, field efficiency, field effective capacity and uniformity of seed distribution as well as soil bulk density and moisture content of soil were determined during the field test.

Moisture content of soil

Soil samples were collected from 0 to 20 cm depth of soil surface before starting the operation to determine soil moisture content. Five soil samples were collected randomly from the test plot. The samples were placed in an oven for 24 hours at temperature of 105°C. The soil samples were weighed before and after drying. The moisture content (Db) was determined by (Rangapara J., 2014).

$$MC = \frac{M_w - M_d}{M_d} x100$$

Where, MC= moisture content, Mw= mass of wet soil sample, and Md = mass of dry soil sample

Bulk density of soil

Five soil samples were taken randomly from field plots by core sampler. The bulk density of the soil was determined from dry weight of the sample and volume of the soil sample. Bulk density of soil was calculated using the following (Rangapara J., 2014).

$$BDS(\frac{g}{cm^3}) = \frac{Md}{Vs}$$

Where, BDS= bulk density of soil; Md=mass of dry sample (g); Vs=volume of core sampler (cm^3).

Operating speed

The operating speed of the machine was determined by recording the time required for traveling 50 m distance with the help of stopwatch.

Theoretical field capacity

The coverage of the implement based on 100% of time at rated operating speed and covering 100% of its rated width is known as theoretical field capacity.

$$TFC({}^{ha}\!/_{hr}) = \frac{Width(m) * Speed({}^{Km}\!/_{hr})}{10}$$

Effective field capacity

The effective field capacity was calculated from the actual area covered by the machine, based on its total time required and its width.

Effective field capacity (ha/h) $= \frac{Actual\ Area\ covered\ (ha)}{time\ required\ to\ cover(h)}$

Field efficiency

Field Efficiency is the ratio of effective field capacity to theoretical field capacity, expressed in %.

$$FE(\%) = \frac{EFC}{TFC} x100$$

Fuel consumption

The fuel consumption was measured by top-up method. The fuel tank was filled to its full capacity before and after the test run and amount of refilling after the end of test was the fuel consumption for the test.

Draft and power requirement

Draft required was measured using spring dynamometer connected to the tractor on which the machine was mounted. Another auxiliary tractor was used to pull the machine mounted tractor when the mounted implement was engaged through the dynamometer. The auxiliary tractor pulls the implement-mounted tractor with the later in neutral gear, but with the seeder in the operating position and draft was recorded in the 50 m distance. On the similar test plot, the implement was lifted off the ground and the draft was measured again. The difference between the two readings, gives the net draft of the implementas expressed by (Rangapara J., 2014).

$$Draft(KN) = Dl - Du$$

Where;

D_l= draft of under loaded condition, D_U= draft of under unloaded condition

The tractor power consumption was determined by following formula:

$$Power(hp) = \frac{Draft(KN) x Speed(m/s)}{75}$$

Wheel slip

Wheel slip is also known as speed reduction and it occurs due to presence of soil moisture content. Wheel slippage is an important parameter which influences the machine field capacity. To determine wheel slip, a mark on the ground wheel of the machine was made to count the number of revolution of the wheel to cover 20m distance with load and without load separately. The drive wheel slip was determined by following equation (Nirala, 2011);

$$Wheelslip = \frac{A - B}{A} x100$$

Where, A = number of turns of wheel without load, B = number of turns of wheel with load

Row spacing and depth of seed placement

Row to row spacing was provided by fitting furrow openers at 20cm distant to the main frame with bolt and nuts before sowing operation. While seed drill was in operation, five random measurements of actual row to row spacing were recorded by using meter tape. The depth of seed and fertilizer placement was adjusted by raising or lowering the furrow opener at desired depth of seed and fertilizer placement, then the depth of seed and fertilizer placement were measured using a metering tape and graduated ruler. Randomly selected five readings were recorded for the six furrow openers from the test plot.

Plant population and uniformity

Plant population was determined at randomly selected spots for each experimental plot per square meter areas and by counting number of seedling emerged. Plant uniformity test was carried out by counting average number of plant in each row per meter distance and variation in between the rows was determined.

Fig.3. Plant population count

Cost of operation

Cost analysis of annual and hourly operational costs of the tractor and seed drill machine were based on capital cost of the tractor and seed drill, interest on capital, cost of repairs and spare parts, labor cost, and depreciation. The operational cost components of the seed drill prototype and 25-hp tractor were estimated in Birr (EB) according to Wen-yuan Huang *et al* (1979). An economic life of 10 years and 850 hours per year for tractor is assumed, and the seed rill is expected to be used 425 hours per year.

Fixed cost

Depreciation

Depreciation was a measure of the amount by which value of the machine decreased with the passage of the time. The annual depreciation was calculated as follows (Kepner*et al.*, 2005)

$$D = \frac{C - S}{L \, x \, H}$$

Where: - D = Depreciation per hour, C = Capital investments (Birr), S = Salvage value, 10% of capital investment (Birr), L = Life of implement in hours or years, H = Annual operational hours of the seed drill

Interest

Interest was calculated based on the average investment of the machine taking into account the value of the implement in the initial and final year. The annual interest on the investment can be calculated as follows (Kepner*et al.* (2005) :-

$$I = \left(\frac{C + S}{2}\right) \times \left(\frac{i}{H}\right)$$

Where: - I = Interest per hour, i = interest on the investment (%) per year

Variable cost

Repair and maintenance cost

The repair and maintenance cost of the machine was taken as 10% of the cost of the seed drill and tractor (Kepner*et al*., 2005 and Kamboj*et al.*, 2012).

$$RM = \frac{C \times 10\%}{H}$$

Where: RM = Repair & maintenance cost per hour, H = Annual working hours of the drill

Wages of operator

Wages was calculated based on actual wages of workers per day or hourly paid.

Total cost of tractor drawn seed drill per hour

The total cost of wheat sowing per hour of the tractor drawn seed drill was calculated from the summation of total fixed cost per hour and total variable cost per hour as follows.

Total Cost/h = Fixed Cost per hour + variable Cost per hour

Experimental Design

The experimental design was factorial with randomized complete block design having three replications. The three level of speed of operation and three level of hopper holding capacity were used as treatments each with three replications. The experimental design was laid as 3^2 with three replications and had total of 27 test runs (3x3x3 = 27).

Statistical Analysis

The data was 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 was different at 5% levels of significance was separated using least significant difference (LSD 5%) test. The least significant difference (LSD) test was performed for the mean values of actual seed and fertilizer application rate in relation to forward speed and hopper level of filling.

Results and Discussion

This study was conducted to evaluate the performance of six row wheat seed drill machine capable of sowing wheat seeds and fertilizer at predetermined rates, row spacing and depths.

Mechanical Damage Test

Table1. indicated that the mechanical damage due to metering device were observed and it was found that there was no mechanical damage to the seeds at all the selected forward speeds, due to adjustable flap curvature to avoid impact and friction between fluted roller and seeds. The same findings were reported by Pradhan and Ghoshal (2012). Furthermore, the seed germination test was carried out and seeds germination before metering and after metering of seeds were con-

ducted and internal damage of seeds were measured by sowing of 100 seeds in petri dish and found that no internal seed damage was observed, these mean that the observed 97 % germination potential was similar with that of predicted by seed supplier (Ethiopian seed Enterprise, Asalla branch).

Table 1 Data obtained from laboratory test of the seed drill machine

bservations	Speed, km/h	Seed rate obtained, kg/ha	Mechanical damage, %	Germination %
1	3	127.20	0.0	97
2	4	124.18	0.0	97
3	5	121.43	0.0	97

Seed Distribution Test

Table 2 indicated that the variations in seed distribution of wheat among the rows (metering device). It was observed that the entire samples collected for the similar speed of operation and hopper loding level was nearly similar and there was slight deviation among the sample i.e. (0.28-1.48) and coefficient of variation was in range of 0.08 - 0.35.

Table 2 Mass of fertilizer fallen from each metering device per 100 m length at different speed and hopper holding capacity.

Speed	H.filling	mass of seeds from each furrow opener per 100m length, gm						CV
		F1	F2	F3	F4	F5	F6	
3	50 %	305.30 ± 0.05	305.17 ±0.01	304.33 ± 0.38	304.97 ± 0.10	305.70 ± 0.23	305.67 ± 0.21	0.17
	75 %	303.87 ± 0.21	304.97± 0.28	304.73 ± 0.11	303.90± 0.20	304.80± 0.20	303.80 ± 0.24	0.18
	100 %	305.00 ± 0.40	305.13 ± 0.46	305.00 ± 0.40	303.70 ± 0.18	303.07 ± 0.46	302.72 ± 0.62	0.35
4	50 %	297.97 ± 0.03	298.23± 0.10	297.97 ± 0.03	298.37 ± 0.15	297.73 ± 0.13	297.93 ± 0.04	0.08
	75 %	296.10 ± 0.24	296.27 ± 0.16	296.60 ± 0.02	297.00 ± 0.16	296.70 ± 0.03	297.20 ± 0.25	0.14
	100 %	295.13 ± 0.25	296.43 ± 0.33	295.77 ± 0.03	295.87 ± 0.08	295.30 ± 0.17	295.63 ± 0.03	0.16
5	50 %	293.63 ± 0.01	292.87± 0.33	293.63 ± 0.01	293.23 ± 0.17	294.47 ± 0.38	293.83 ± 0.10	0.19
	75 %	292.20 ± 0.17	292.53 ± 0.03	292.17 ± 0.20	292.90 ± 0.14	292.23 ± 0.16	293.53 ± 0.42	0.18
	100 %	291.70± 0.17	292.23 ± 0.06	292.40 ± 0.14	292.17 ± 0.03	291.73 ± 0.16	292.33± 0.11	0.10

Effects of seed drill forward speed on seed rate

The analysis of variance (ANOVA) shows that the machine operational speed and hoper filling level had significant effect ($p < 0.05$) on wheat seed rate, where as the interaction of hoper loading level and machine forward speed had no significant effect ($p > 0.05$) on wheat seed rate. Table 3 shows the effect of forward speed, hopper filling level, and the combined effect of forward speed and level of hopper loading on wheat seed rate. Figure 4 shows the relationship between machine forward speed and seed rate.

Table 3 Effects of seed drill operating speed and hopper filling level on seed rate

Parameter	**Source of variation**				**Measure of differences**	
	Speed level				LSD (5%)	SE(M)
Seed rate (Kg/ha)	V_3	V_4		V_5	0.20	0.06
	127.20[a]	124.18[b]		121.43[c]		
	Hopper filling level					
	H_{50}	H_{75}		H_{100}	0.20	0.06
	124.70[c]	124.21[b]		123.90[a]		
	Interaction(V*H)					
	Speed level	H_{50}	H_{75}	H_{100}	0.33	0.11
	V_3	127.59[a]	127.21[b]	126.81[c]		
	V_4	124.48[d]	124.19[de]	123.85[fg]		
	V_5	122.02[h]	121.24[ij]	121.04[ik]		

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

Increasing forward speed from 3 to 5 km/hr as well as increasing hopper loading level from H_{50} (half) to H_{100} (full) had decreased the seed rates. Nonetheless, the forward speed and hopper loading level combination had no significant effect on wheat seed rates. Maximum seed rate of 127.59 kg/ha were observed at forward speed of 3 km/hr and half hopper filling level. Whereas the minimum seed rate of 121.04kg/ha were obtained at 5 km/hr and full hopper filling capacity. This clearly shows that speeds higher than 5 km/hr would results in less seed rate, in contrast speeds less than 3 km/hr would results in higher seed rate, which can result beyond the recommended 125 kg/ha of wheat seeds (informal communication with experts).

In general, it can be seen from Table 3. The level of seed and hopper filling had significant effect on seed rate but their combination had not significant effect on seed rate. Nonetheless, the effect was dominantly due to disparity in hoper filling level and speeds than their combination.

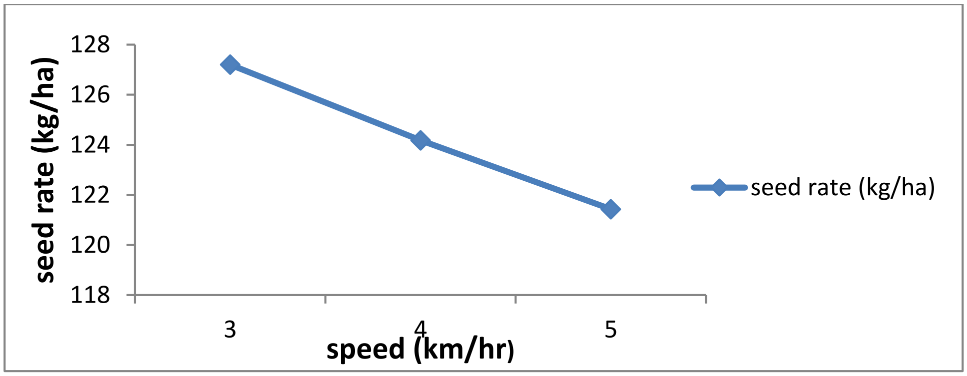

Fig. 4 Effects of seed drill forward speed on wheat seed rate

Effects of seed drill operating speed on fertilizer rate

The analysis of variance (ANOVA) revealed that the seed drill operating speed and level of hopper filling had significant effect ($p < 0.05$) on fertilizer rate, where as the combination of hoper filling level and seed drill operating speed had no significant effect ($p > 0.05$) on fertilizer application rate. Table 4 shows the effect of speed, hopper loading level, and their combined effect on fertilizer rate. Figure 5 shows the relation between seed drill operating speed and fertilizer application rate.

Table 4 Seed drill forward speed and hopper loading level Effects on fertilizer rate

Parameter	**Source of variation**				**Measure of differences**	
	Speed level				LSD (5%)	SE(M)
	V_3	V_4	V_5		0.15	0.05
	152.27^{a}	148.40^{b}	146.38^{c}			
Fertilizer rate (Kg/ha)	Hopper filling level					
	H_{50}	H_{75}	H_{100}		0.15	0.05
	149.47^{c}	148.93^{b}	148.65^{a}			
	Interaction(V*H)					
	Speed level	H_{50}	H_{75}	H_{100}	0.27	0.09
	V_3	152.60^{a}	152.17^{d}	152.05^{d}		
	V_4	149.02^{b}	148.33^{ef}	147.85^{gh}		
	V_5	146.81^{c}	146.30^{ij}	146.05^{ik}		

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

Increasing forward speed from 3 to 5 km/hr as well as increasing hopper loading level from H_{50} (half) to H_{100} (full) tends to decrease fertilizers rates. Nevertheless, their combination had no significant effect on application rates. The maximum application rate of 152.60 kg/ha was observed at 3 km/hr speed and half hopper filling level. Whereas minimum application rate of 146.05 kg/ha were observed at of 5 km/hr speed and full hopper filling level. It can be seen that speeds greater than 5 km/hr would results in less application rate, in contrast speeds less than 3 km/hr would results in higher application rate, which exceeds the recommended 150 kg/ha of NPS-fertilizer rate ((informal communication with experts).

In general, it can be seen from Table 4 the level of fertilizers particles in the hopper and forward speed had significant effect on application rate but the combined effect of speed of operation and hopper loading level had no significant effect on application rate. However, the effect was dominantly due to variation in speeds and hoper level of filling than their combination.

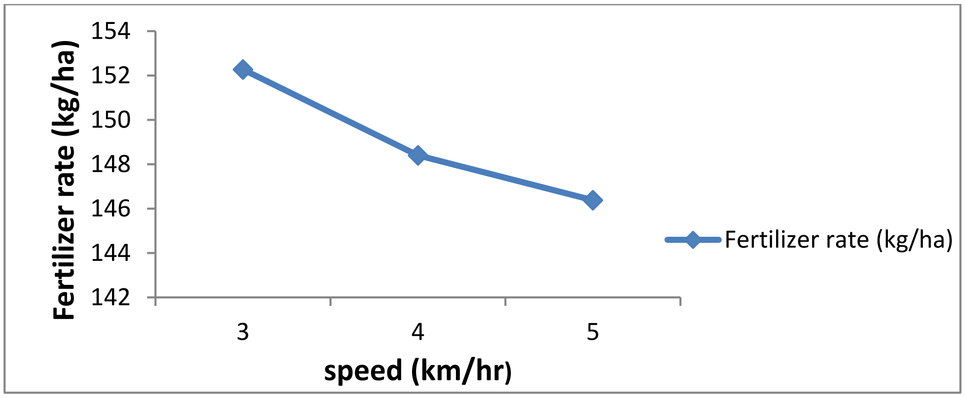

Fig. 5 Effects of seed drill speed on fertilizer rate

Moisture Content of Soil

Five soil samples were randomly taken at different places in experimental plots at 0 to 20 cm depth from the surface of soil. From table 5, the average moisture content at 20 cm depth was found 17.67 % on dry basis.

Bulk Density of Soil

The soil bulk density was measured by core cutter method with having size of core cutter having 7 cm inner diameter and 12 cm height. Five soil samples were taken at the depth level of 0 to 20cm before sowing operation. The soil samples were weighed before placing into an oven for 24 hours at 105° C and after drying the weight of sample was measured again. The average bulk density was found to be 1.40 g/cm^3 as shown in Table.5.

Table5. Soil moisture content and bulk density at the field condition (Dry basis)

Replication	Soil moisture content, %	Bulk density,g/cc
1	18.04	1.39
2	17.86	1.44
3	20.86	1.37
4	21.75	1.41
5	19.86	1.39
Mean	**19.67**	**1.40**

Operating Speed

The operational speed was conducted on the speed limit at 3 km/h, 4 km/h and 5 km/h (Table 6). The stopwatch instrument was used to measure operating speed. The optimum operational speed of tractor drawn seed drill for sowing seeds was found to be 4 km/h, which results better seed and fertilizer rate for a distance of 50m.

Theoretical and effective field capacity

As shown in the Table 6, the mean theoretical field capacity of the machine at 3, 4, 5 km/hr were 0.37, 0.50, and 0.61ha/hr, respectively. The effective field capacity the machine at speed level of 3, 4, 5 km/hr were found to be 0.33, 0.43, and 0.50 ha/hr respectively (table 6). This indicated that both effective field capacity and theoretical field capacity of the machine increased with increase in operating speed as shown in figure 3.3. In general, this indicated that the seed drill can sow a hectare of land in 2.0 to 3.03 working hours based on the forward speed.

Table6. Seed drill performance evaluation results on (10 x 50) m^2 plot

Rep.	width, m	Length of plot, m	Time to cover 50 m (s)	Time Loss (s)	Operat-ing Speed, km/h	Fuel Consumption		TFC, ha/hr	EFC, ha/hr	FE,%	Wheel slip(%)	Draft (N)
						Total,(ml)	**l/hr**					
I	1.2	50	**58**	6	3.10	46.8	2.6	0.37	0.34	90.63	2.52	
II	1.2	50	57	9	3.16	45.9	2.5	0.38	0.33	86.36	2.62	
III	1.2	50	60	7	3.00	47.6	2.6	0.36	0.32	89.55	2.61	
	Mean	**50**	**58**	**7**	**3.09**	**46.8**	**2.6**	**0.37**	**0.33**	**88.82**	**2.58**	**454.80**
I	1.2	50	42	7	4.29	51.2	3.8	0.51	0.44	85.71	3.77	
II	1.2	50	45	6	4.00	53.4	3.8	0.48	0.42	88.24	5.17	
III	1.2	50	42	8	4.29	52.6	3.8	0.51	0.43	84.00	4.88	
	Mean	**50**	**43**	**7**	**4.19**	**52.4**	**3.8**	**0.50**	**0.43**	**85.93**	**4.61**	**466.80**
I	1.2	50	37	8	4.86	56.1	4.5	0.58	0.48	82.22	4.87	
II	1.2	50	35	7	5.14	55.8	4.8	0.62	0.51	83.33	5.45	
III	1.2	50	35	9	5.14	55.2	4.5	0.62	0.49	79.55	5.84	
	Mean	50	35.67	8.00	5.05	**55.7**	**4.6**	**0.61**	**0.50**	**81.69**	**5.39**	**474.00**

Field Efficiency

The mean values of field efficiency obtained were presented in table 6. The lower field efficiency occurred at 5 km/hr was 81.69% and the higher field efficiency was obtained at 3 km/hr was 88.82%. It can be observed that from the figure 6, field efficiency was decreased as speed increases. According to the finding of Rangapara J. (2014), as the size of the field was decreased; number of passes of the machine increased too, which results in increase in time losses and gave lower values of field efficiency.

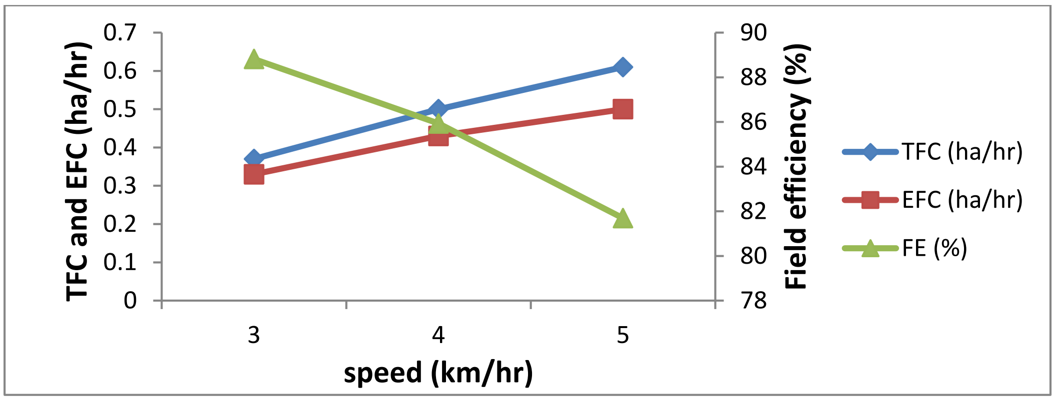

Fig. 6 Effects of forward speed on theoretical, effective field capacity and field efficiency

Fuel Consumption

The results obtained for different forward speed indicated that mean fuel consumption was increased with increase in speed (Table 6). During test run, mean fuel consumption was measured as 2.6, 3.8and 4.6 l/h at the speed of 3, 4 and 5 km/hr, respectively.

Draft and Power Requirement

Spring dynamometer was used to measure the draft required to operate the seed drill. The mean values of the net draft were measured as 454.80, 466.80 and 474.00 N at the speeds of 3, 4 and 5 km/hr, respectively (Table 6). The higher draft was measured as 474 at 5 km/hr and less 454.80 N at 3 km/hr forward speeds. Besides that, power required to operate the seed drill was determined base on operational speed and the draft required to operate the seed drill. The Power requirement was found to be 3.79, 5.2, and 6.58 Watt at 3, 4, and 5 km/hr respectively. The measured results of both draft and power requirements are indicated in Fig.7. It can be seen from the figure that both draft and power required to operate the seed drill was increased with increase in the forward speed.

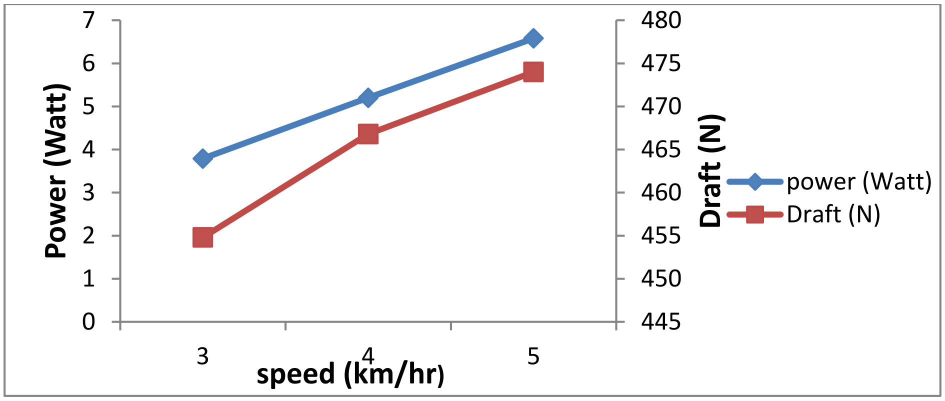

Fig. 7 Effect of speed on draft and power requirement

Wheel Slip

The wheel slippage of tractor drawn wheat seed drill was determined by using the method mentioned earlier and as shown in Table6, less wheels slip of 2.58% and higher wheel slippage of 5.39% was recorded at speed of 3 km/h and 5 km/h, respectively. It can be seen that the wheel skid was slightly increased with increase in operating speed.

Plant Populations and Uniformity

The plant stand count was conducted in the experimental plot after sowing Ogolcho wheat variety having germination potential of 97% (Ethiopian seed enterprise, Asalla branch). Number of seedling germinated per 1.2 m^2 area after fifteen days was counted and presented in table 7. The seed rate indicated that metering mechanism was properly metering the seeds without damage. However, there was some disparity of seeds emergence at the experimental field as compared to the recommended seed emergence, these variations might be due to environmental factors.

Table7. Seed germination potential obtained at field test

Replication	**Field germination count Per 1.2 m^2**		
	Expected	Counted	% Germinated
1	392	379	96.68
2	392	380	96.94
3	392	379	96.68
4	392	378	96.43
5	392	379	96.68
Average	392	379	96.68

Economical evaluation

Tractor drawn seed drill machine required only a single operator to drive tractor. The time required to plant and fertilizes a hectare of land using animal drawn planter, with one person, was 8.33 hours-ha^{-1} (Ashebir, 2015), while a single person, using the tractor drawn seed drill machine, required only 3.03 to 2.0 hours-ha^{-1} at forward speed of 3 to 5 km/hr respectively to do the similar operation. Thus, it is clearly indicated that the time required per hectare land is three times less than operating with animal drawn seed drill when tractor drawn seed drill is used at 5 km/hr.

Conclusions and Recommendations

Conclusions

From the results obtained, it can be noted that the wheat seed drill machine performance in terms of seed and fertilizer rate, depth of seed and fertilizer placement, plant population, field capacity, field efficiency, labour cost and cost of owning and operating the machine is acceptable.Thus, it can be concluded that the developed seed drill can be efficiently and economically used by the majority of Ethiopian farmers. However, the speed of operation of the seed drill should not be less than 3 km/hr and not exceed 5 km/hr in order to have optimum plant population. From this research finding, it can be concluded that 4 km/hr operating speed and half hopper filling level was the point where seed drill performs better in terms of optimum seed and fertilizer rate of application.

Recommendations

In general, the performance evaluations made shows that the machine can be used successfully on sowing operation. Though, the following issue must be addressed to make the seed drill more adaptable, popular, and usable among the farmers. Number of rows for developed tractor drawn wheat seed drill might be increased to improve field capacity and field efficiency. The seed drill may be tested for different cereal crops with replaceable metering device for further design refinements and consider using plastic rollers, instead of aluminum, as metering device and plastic seed and fertilizer hopper in the seed drill

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Adaptation and Performance Evaluation of Tractor Drawn Rigder for potato Hiller

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Abstract

This study was carried out to adapt and performance evaluation of tractor drawn rigder for potato hiller at predetermined row spacing and operating speed. The fabricated ridger consisting of a main frame, tyne, frog, mouldboard, share, and hitching system. The performances of the hiller were evaluated in terms of ridge height and width, plant damage, draft and power requirement, field capacity, field efficiency, labour cost and economics owning and operating. The experimental design used was completely randomized design (three levels of speeds of operation with three replications). The hiller was evaluated at tractor forward speed of 2, 2.5, 3 km/hr. Forward speed of the tractor had significant effect on height of ridge formed at $p < 0.05$. The average theoretical field capacity, effective field capacity, field efficiency, and fuel consumption were 0.32 ha/hr, 0.30 ha/hr, 92.57% and 1.5 l/hr respectively at speed of 2km/hr and 93.63% of weeding were observed during field test. Depending on the results of performance evaluation, it is concluded that the constructed potato ridger can be efficiently and economically used by the majority of farmers.

Key words: *performance, ridger, field capacity and field efficiency*

Introduction

Potato is one of the tuber crops grown in Ethiopia. It is grown by approximately 1 million farmers (CSA 2008/2009). Ethiopia has suitable edaphic and climatic condition for potato production. About 70% available agricultural land is located at an altitude of 1800-2500m which is suitable for potato production (FAO and Endale, G. *et al.*, 2008). It has an area coverage of 66, 745 ha and production of 784,993 tonnes in the country (FAO 2013).

Ethiopian farmer's main objective of growing potato is to ensure adequate food supply during food shortage months and as well as an important source of cash income (Gebremedhin W. *et al*., 2013.), because of its ability to provide a high yield of high-quality product per unit of input with a shorter crop cycle than major cereal crops like maize (Adane H., *et al*., 2010). Potato has been considered as a strategic crop by the Ethiopian government aiming to enhancing food security and economic benefits to the country (EIA 2012). It is among the major vegetable export products (EEI 2015).

Arsi is one of the potential potato growing areas in Southern parts of Ethiopia. Despite the potential of potato production in the zone, there are several constraints which are drastically affect to the low production and productivity of potato crop by small holder farmers. Way of hilling soil is one of the problem seen during potato plantation time as it is one of the most important tasks must be done when growing potatoes. Hilling is the mechanism of creating a mound around the base of the potato plant. Traditionally potatoes are hilled in the production cycle between emergence and closure of the canopy. Hilling can be accomplished with disks, sweep shovels, or similar tools that lift soil and deposit it on the top of the row.

The importance of hillings is improving weed control improve drainage, minimization of greening of tubers and rising of soil temperatures. Hilling or earthing up carried out twice or thrice during the crop season, accompanied by weeding and side dressing the crop with fertilizers, under irrigated conditions, whereas in rainfed conditions, weeding, earthing up, and mulching are carried out simultaneously. Usually, earthing up is done during 45–60 days after planting (DAP), 90–105 DAP and 120–135 DAP. This intercultural operation helps to form and enlarge finger rhizomes and also ensures adequate aeration to roots. Also protects rhizome from the attack by scale insects and check weed growth (Panigrahi et al., 1987). Flat bed, followed by earthening up and proper management of each of these factors was found to be the best practice to maximize quality and quantity of tuber yield (Ajai et al., 2002).

In potato production areas of the country hilling potato crop performed by the traditional method by either manual method by the help of a slatted short handle hoe, an axe, cutlasses spade and some other local tools or by a pair of Oxen drawn maresha. Traditional method of hilling adopted in potato cultivation is slow, time consuming, tedious, inefficient and involve drudgery, hence increases, the cost of production. In order to overcome this problem, it is essential to adapt and modify the existing tractor drawn ridger to potato hiller and evaluating its performance for small scale farmer.

The tractor mounted Ridger imported by Kaleb services farmer's House Company was used for furrow making and has single ridger per row. In order to utilize and address the demand of farmers involved in potato production, double row ridger is ecential for potato hilling and weeding purpose must be adapted, modified and evaluated for the better earthening up process of potato hilling. Therefore, this research project is aimed to construct proper tractor drawn ridger for potato hilling with the objectives to adapt Tractor drawn Rigder for potato Hiller and evaluate the performance of the adapted tractor drawn potato hiller.

Materials and Methods

Descriptions of Study Area

The design, fabrication, testing and evaluation was carried out at Assella Agricultural Engineering Research Center located in the Arsi zone of Oromia Region and it has 6° 59’ to 8° 49’ N latitude and longitude of 38° 41′ to 40° 44’ E and an elevation of 2,430 meters above sea level.

Description of the Hiller

The materials available in local markate were used for the construction of different parts of the tractor drawn potato hiller. The main parts of adapted tractor drawn hiller are; main frame, three point hitch system, Tyne, Share and Frog.

Fig.1. developed prototype of potato hiller

Main frame

Frame is the skeletal structure of the ridger on which all other components are mounted. The two design factors considered in the determination of the material required for the frame was the weight and strength. In this case, mild steel square hollow section of 60 mm x 60 mm and 5 mm thickness were used to give the required strength.

Tyne

It is made from mild steel flat iron having 730mm x 60mm x 20mm thickness dimensions so as to withstand the load encountered in actual field condition during the hilling operation. Three tynes were fixed on the main frame of the ridger using bolt and nuts with provisions to adjust the width and depth by moving the tyne in both horizontally and vertically respectively.

The upper end of the tyne was welded to MS sheet metal having 100 x 100 mm x 6mm thickness. MS sheet metal were provided with hole of 16 mm diameter and 80 mm center to center distance and so that the tyne were attached to main frame with bolt and nut through these holes.

Share

It is the part which penetrates the soil and makes cut below the surface. The share of hiller was made as a slip type which was made of MS sheet metal of 6 mm thickness. The share was provided a shape at the end such that it makes an angle of 30° with the horizontal.

Frog

The frog is made from mild steel sheet metal having 4 mm thickness. Both share and mouldboard were bolted to the frog and connected to upper part of landside. During the ridging operation, draught force 'D' acts at the angle of the shovel which cause a bending stress (σ) due to resistance of the soil at the bended side initiating twisting of the rod.

For calculation purpose soil resistance K_o was assumed to be horizontal and acts in the axis of symmetry of shovel and it was assumed to be 0.25 kg/cm^2 for heavy soil.

Table 2. 1 Specific Soil Resistances up to a Depth of 15 cm

S.No.	Soil type	Specific resistance, kg/cm^2
1	Light soil	about 0.12 kg/cm^2
2	Medium soil	about 0.15 kg/cm^2
3	Heavy soil	about 0.20 kg/cm^2
4	Very heavy soil	about 0.25 kg/cm^2

Source: Dubey, 2003

The draft force applied to the tip of share was determined using the following equation (Kurtz et al. 1984).

$$D = K_o * n * w * d \qquad (1)$$

$$D = \left[0.25\ x3\ x\left(\frac{2+6}{2}\right)x11\right]x9.81$$

$$D = 323.73N$$

Hence factor of safety was assumed to be 3. Thus, total draught exerted on the shovel was calculated as follows.

$$D = 323.73x3$$

$$D = 971.2N$$

The draft force applied on each opener was determined as follows.

$$D = \frac{971.2N}{3}$$

$$D = 323.73N$$

Where: D = draft force, N, Ko = specific soil resistance, W= width of opener, cm; d=depth of opener, cm; n=number of furrow openers.

Hence, square hollow pipe M.S furrow openers of 730mm x 60mm x 20 mm thickness size was quite safe and the size was available in the market.

Hitching system design

Potato hiller was connected or hitched to a tractor through three point linkage provided at the rear end of tractor, which is hydraulically controlled. The geometry dimensions for mast height, lower hitch point span, mast and linch pin hole distance were determined according to (ASAE S217.12 DEC01 (ISO/DIS 730: 2007).

Performance Test and Evaluation

Field performance tests were carried out to obtain actual data on overall implement's performance and working capacity in the field. The field trials of tractor drawn potato hiller were conducted at Tiyo districts of Arsi Zone. Plant height, moisture content of the soil, soil bulk density, ridging width, ridge height speed of operation, total area of hilling, total operating time and plant damaged/injured were observations recorded at the field.

Fig.2. Field performance evaluation

Moisture content of the soil

Samples of the soil were collected at 25 cm depth of soil surface before hilling operations for bulk density and soil moisture content determination. Five soil samples were collected randomly from the exprimental plot. Then, the soil samples were kept in oven for 24 hours at temperature of 105°C and weighed before and after drying. The moisture content (Db) was determined by (Rangapara J., 2014).

$$Mc = \frac{Ww - Wd}{Wd} \quad (2)$$

Where: Mc = Moisture content of soil, % db, Ww = Weight of wet soil, and Wd = Weight of oven dry soil.

Bulk density of soil

Bulk density of the soil is the oven dry mass per unit volume of the soil. It was measured by using core sampler by taking different soil samples randomly from each test plots. The bulk density was calculated by using following formula.

$$\delta = \frac{M}{V} \quad (3)$$

Where, δ = bulk density of soil, g/cm^3, M = oven dry mass of soil, g; and V = volume of core sampler, cm^3.

Plant height

The plant height of potato crop during hilling operation in potato field was randomly measured by the help of measuring tape and replicate five times.

Speed of operation

Speed of operation of tractor drawn hilling implement was measured by recording the time required to cover 20m distance. Speed was calculated by using the following formula.

$$Speed(km/hr) = \frac{3.6\, x\, distance\ travelled(m)}{Time\,(s)} \tag{4}$$

Theoretical field capacity

It is the rate of field coverage that was obtained if implements performing its function 100 % of the time at the rated speed and always covering 100 % of its rated width.

$$TFC = \frac{W \times S}{10} \tag{5}$$

Where: TFC = Theoretical Field Capacity, ha/h; S = Speed of Operation, km/h; and W = Theoretical width of implement, m.

Effective field capacity

It is the actual average rate of coverage by the implement. The total time required to complete the operation were recorded and effective field capacity was calculated as follows.

$$EFC = \frac{A}{T} \tag{6}$$

Where: EFC = Effective field capacity, ha/h; A = Actual area covered, ha; and T = Total time required to cover the area, h.

Field efficiency

It is the ratio of theoretical and effective field capacity and calculated by using the following formula.

$$\text{Field Efficiency} = \frac{\text{EFC}}{\text{TFC}}\, x100 \tag{7}$$

Draft and power measurement

Draft was measured using a spring dynamometer attached to the tractor on which the implement was mounted. Another auxiliary tractor was used to pull the implement mounted tractor through the dynamometer.The auxiliary tractor pulls the implement-mounted tractor with the later in neutral gear and the implement in the operating position. Draft was recorded in the 20 m distance. On the same field, the implement was lifted off the ground and the draft was recorded. The difference between the two readings, gives the draft of the implement as expressed by (Rangapara J., 2014).

$$Draft(KN) = Dl - Du \quad (8)$$

Where: D_l= draft of under loaded condition, D_U= draft of under unloaded condition
The tractor power consumption was also determined by following formula:

$$power(W) = Draft(N)\, x\, speed(\frac{m}{s}) \quad (9)$$

Fuel consumption

The fuel consumption was measured by graduated cylinder by refilling method that filling a fuel tank to its full capacity before test run and then, by refilling a known volume of fuel to the fuel tank and the volume of fuel refilled was taken as fuel consumed per plot.

Weeding Efficiency

It was determined by the weed count method at 5m length of row were measured by marking the field and the number of weeds and stubbles enclosed within the range of marked length were counted before starting the test and on the same row it was counted after the test run. Randomly five observations were taken within the test plot.

The weeding efficiency was calculated as follows

$$\text{Weeding efficiency}(\%) = \frac{W_1 - W_2}{W_1} x 100 \quad (10)$$

Where,
W1 = Number of weeds per 5m row length counted before ridging; and
W2 = Number of weeds per 5m row length counted after ridging.

Measurements of height and width of ridging

Height and width of ridging were measured by setting the level that controls the lifting mechanism at a level corresponding to the required depth of cut and driven at a predetermined forward speeds fo2, 2.5 and 3 km/hr. The depths of cut (height of ridge) were measured with a measuring tape, from the bottom of the furrow to the surface level of the soil at randomly selected points and three observations were recorded at each speed of operation.

Plant Damaged

During hilling operation plant damaged/injured in selected row were counted and three observations were taken at different forward speed of operation and the percentage of plant damage was calculated.

Cost estimation

Estimation of annual and hourly operational costs of the Tractor and fabricated hiller were depending on capital cost of the tractor and the implement, interest on capital, cost of repairs and spare parts, labor cost, and depreciation. The operational cost components of the hiller prototype and 25-hp tractor were estimated in Birr (EB) according to Wen-yuan Huang *et al* (1979). An economic life of 10 years and 260 hours per year for tractor is assumed, and the implement is expected to be used 260 hours per year.

Fixed Cost

Depreciation

It was a measure of the amount by which value of the implement decreased with the passage of the time. The annual depreciation was calculated according to Kepner *et .al. (*2005) as follows:-

$$D_P = \frac{PP - SV}{LxH}, (EB/h) \qquad (11)$$

Interest

Interest was determined on the average investment of the machine taking into account the value of the implement in the initial and final year. These are usually calculated on yearly basis. The annual interest on the investment was calculated according to Kepner *et al.* (2005) as follow:-

$$I = \left(\frac{PP + SV}{2}\right) \times \left(\frac{I\%}{H}\right) \text{ },(EB/h) \quad (12)$$

Insurance & taxes (IT)

The annual insurance and taxes on the investment was calculated according to Kepner*et al.* (2005) as follow:-

$$IT = 1\% \, of \, PP \quad (13)$$

Housing

$$\text{Housing} = 1\% \text{ of PP} \quad (14)$$

$$Total\ fixed\,\text{cost} = D_p + I + IT + Housing \quad (15)$$

Variable cost

Repair and maintenance cost

The repair and maintenance cost of the implement and tractor was taken as 10% of the cost of the purchasing price (Kepner*et al.*, 2005 and Kamboj*et al.*, 2012).

$$RM = 10\% \text{ of } PP \quad (16)$$

Wages of operator

Wages was determined based on actual wages of workers per day or hourly paid.

Total cost of potato ridging per hour

The total cost of potato ridging per hour was calculated from the summation of total fixed cost per hour and total variable cost per hour as follows.
Total Cost/h = Fixed Cost per hour + variable Cost per hour

Where: Purchase price (Pp): 123,000 EB, Salvage value (SV): 10%, Interest rate: 10 %, Repair and maintenance (RM): 10% , Insurance & taxes (IT): 1% of PP, Housing: 1 % of PP, Fuel consumption: 3.46 lit/hour , FC = 23.06 EB per lit Lubrication cost (L.C): 140 EB per lit, Lubrication consumption: 25% of fuel ,Labor cost (LaC): 200 EB per day and Dp = Depreciation

Experimental Design

The experimental design was factorial with complete randomized design with three replications. The three levels of forward speed of tractor (2 km/hr, 2.5 km/hr and 3 km/hr) were used as treatments with three replications. The experimental design was laid as 3^1 with three replications and had total of 9 test runs (3x3 = 9).

Data Analyzing

The collected 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 height of ridge and plant damage in relation to forward speed and hiller's working capacity.

Results and Discussion

Moisture content of the soil

Five soil samples were collected randomly at 0-25 cm depth of soil surface before hilling operations by using core sampler. As shown in the table1, the mean moisture content at 25 cm depth was found 19.67 % on dry basis.

Bulk Density of Soil

Bulk density of the soil is the dry mass per unit volume of the soil. It was measured by core cutter method before starting hilling operation. Soil samples were taken randomly from exprimental plot by using core cutterhaving 7 cm inner diameter and 12 cm height. Five soil samples were taken at the depth of 0 to 25 cm before hilling operation. The soil samples were weighed before placing into an oven for 24 hours at 105^{o} C and after drying the weight of sample was measured again. The average bulk density was found to be 1.39 g/cm^3 as shown in Table 1.

Table1. Soil moisture content and bulk density at the field condition (Dry basis)

Replication	Soil moisture content, %	Bulk density,g/cc
1.	18.04	1.39
2.	17.86	1.44
3.	20.86	1.37
4.	21.75	1.37
5.	19.86	1.38
Mean	19.67	1.39

__Speed of operation__

Operation speed of tractor drawn hilling implement was measured by recording the time required to cover 20m distance. The operation speed was recorded on the speed range at 2 km/h, 2.5 km/h and 3 km/h as shown in the table 2. The stopwatch was used to record the time of operation. The optimum operational speed of tractor drawn potato hiller for hilling operation was found to be 2 km/h, which results better ridging height.

Table2. Ridger performance evaluation results on (10 x 50) m^2 plot

S/no	Parameter	Mean values at different speed level		
		2 km/hr	**2.5 km/hr**	**3 km/hr**
1	Ridge height, (cm)	21.33	17.33	13.33
2	Ridge width, (cm)	41.5	48.6	51.2
3	Plant damage (%)	5.77	7.69	10.00
4	Effective field capacity (ha/hr)	0.30	0.36	0.41
5	Theoretical field capacity, (ha/hr)	0.32	*0.39*	0.46
6	Field efficacy, (%)	92.57	*91.06*	88.37
7	Weeding efficiency, (%)	93.63	93.63	93.63
9	Draft requirement (N)	560	617.67	660.50
10	Power requirement (Hp)	0.42	0.57	0.74
11	Fuel consumption (lit/hr)	2.5	3.1	3.8
12	Man-hr, (hr/ha)	3.33	2.78	2.44
13	Cost of operation, (Birr/hr)	259.64	259.64	259.64
14	Cost of operation, (Birr/ha)	864.60	721.80	633.52

__Field Capacity and Efficiency of Potato Hiller__

The average theoretical field capacity of the hiller at 2, 2.5, 3 km/hr were 0.32, 0.39, and 0.46 ha/hr, respectively. Where as, the effective field capacity at forward speed level of 2, 2.5, 3 km/hr were observed as 0.30, 0.36, and 0.41ha/hr respectively (table 2). This indicated that both theoretical field capacity and effective field capacity of the implement increased with increase in operational speed as shown in figure 3. Generally, the implement can hill or ridge a hectare of land in range of 2.44 to 3.33 working hours based on the forward speed of tractor.

The mean values of field efficiency were shown in table 2. The lowest field efficiency recorded at 3 km/hr forward speed was 88.37% and the higher field efficiency was obtained at a speed of 2 km/hr was 92.57%. Figure 3reveals that, field efficiency decreased as speed increases. Ran-gapara J. (2014) suggested that as the size of the field was decreased; number of passes of the implement increased too, which results in increase in time losses and gave lower values of field efficiency. The main reason for the decrease in field efficiency by increasing operational speed was due to the less theoretical time consumed in comparison with the other test plots.

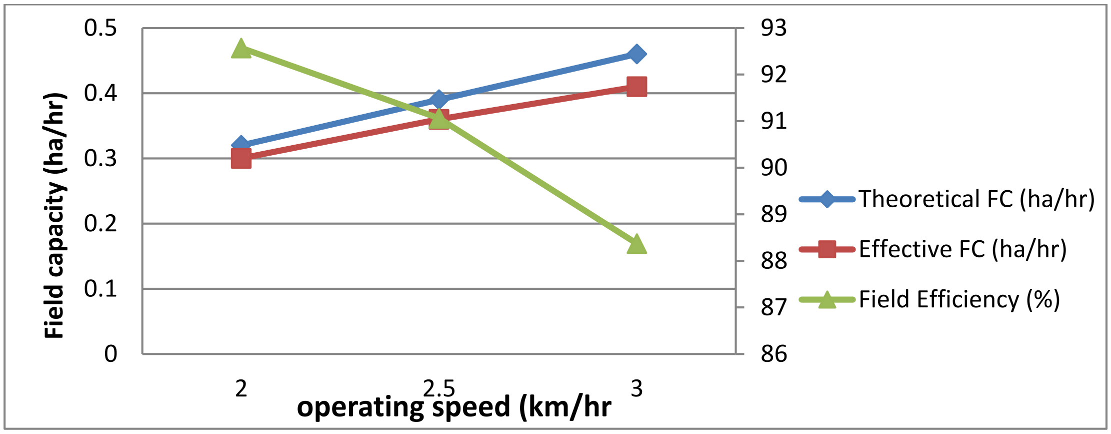

Fig.3. Effects of tractor linear speed on theoretical, effective field capacity and field efficiency

Draft and power measurement

The draft required to operate the potato ridger was measured using spring dynamometer. The mean values of the draft were measured as 560N, 617.67N and 660.50N at the speeds of 2, 2.5 and 3 km/hr, respectively as shown in the table 2. The higher draft was measured as 170.50 at 3 km/hr and the lower 140 N at 2 km/hr forward speeds. Besides that, power required to operate the implement was determined based on the forward speed and the required draft to operate the implement. The power required was found to be 0.42, 0.57 and 0.74 hp at 2, 2.5, and 3 km/hr respectively. The observed pattern of both draft and power requirements are shown in Fig.4. It can be seen from the figure that both draft and power required to operate the implement was increased with increase in the operational speed.

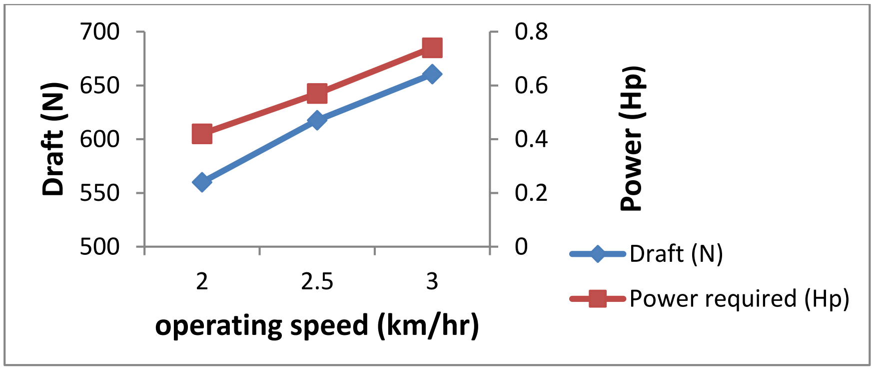

Fig.4. Effects of tractor linear speed on draft and power

Fuel consumption

The results obtained for forward speed indicated that mean fuel consumption was increased with increase in operating speed as depicted on the fig.5. Mean fuel consumption was recorded as 2.5, 3.1 and 3.8 l/h at the operating speed of 2, 2.5 and 3 km/hr, respectively. Almost similar (3.83 l/hr) finding was reported by Raghavendra et al. (2013).

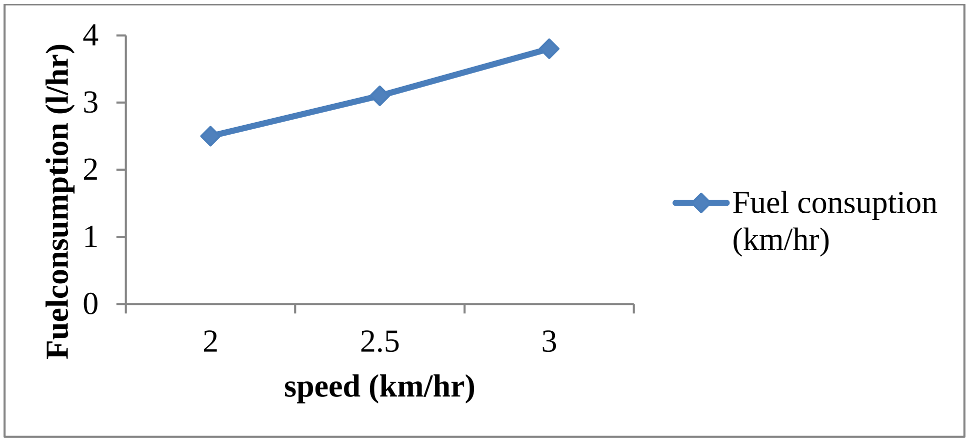

Fig.5. Effects of tractor linear speed on fuel consumption

Effects of operating speed on height and width of potato hilling

The average ridge height and width of ridge were found to be 21.33 cm and 41.5 cm respectively at operating speed of 2 km/hr as shown in Table 2 which was nearly similar with the findings of Makki and Sulieman (2008).

The analysis of variance (ANOVA) in table 3, shows that the implement forward speed level had significant effect ($p < 0.05$) on ridge height as shown in figure 6. The height of soil ridge was tend to decrease as the forward speed increases, whereas, width of soil ridge was increased with increase in speed. These indicated that, as the speed increases, the volume of soil disturbed and lifted for hilling deformed to flat tip shape rather than making cone shape and in this case, the width of hilled soil increases whereas, height of soil ridge decreases as the speed increase and vice versa.

Table 3 Effects of operating speed level on height of ridging

Parameter	Source of variation		Measure of differences	
	Speed level	Height of ridge	LSD (5%)	SE(M)
	V_2	21.33[a]	1.998	0.577
	$V_{2.5}$	17.33[b]		
Height of ridge (cm)	V_3	13.33[c]		

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

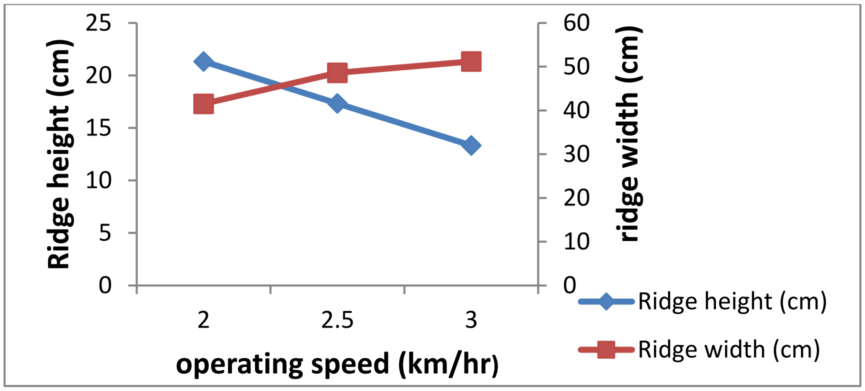

Fig.6. Effects of tractor linear speed on height and width of potato hilling

Weeding Efficiency

Beside soil ridging or hilling operation, weeding operation is also done by tractor drawn potato ridger and as indicated in the table 2, the weeding efficiency was determined by considering the number of weed before and after weeding operation. The average value of weeding efficiency for potato hiller was found to be 93.63%.

Plant Damaged

The percentage of plant damage during ridging operation at different operating speed was shown in table 2. The average percentage of the plant damage as 5.77, 7.69 and 10 was obtained 2, 2.5 and 3 km/hr respectively. It can be seen from the table 2; plant damaged was increased with increase in the operational speed. The plant damage may also occur due to narrow spacing between the root areas that disturbed by the implement during operation and based on the experience of operator.

Cost Estimation

Potato ridging or hilling cost by tractor drawn ridger for potato hilling was determined in view of fixed and variable costs. The production cost of tractor drawn ridger for potato hilling was determined by calculating the cost of different parts and its construction cost was 1,248.13 birr. The fixed cost for ridger per hour (80.86 birr) and variable cost (178.78 birr) were found from the calculation. Annual operation of the ridger was considered as 260 hour based on 33 actual days annually for potato hilling operation with 8 working hours (informal communication with experts). Annually coverage area was determined by multiplication of the effective field capacity and annual hours of operation.

Conclusion and Recommendation

Conclusion

A double-row tractor drawn ridger for potato hiller has been fabricated and tested. The production of the implement was made from available material in the local market that makes it an adaptable and affordable technology for farmers who participate on production of root and tuber crops in Ethiopia. The operation speed had significant effect ($p < 0.05$) on height of the ridge. Increasing speed of operation from 2 to 3 km/hr decreases the height of ridge, whereas, width of hilled soil increased. This clearly shows that operating speeds higher than 3 km/hr would results in less soil ridge height and greater width of soil ridge. Therefore, it can be concluded that, optimum ridge height of 21.33 cm and 41.5 cm ridge width can be hilled at 2 km/hr of operational speed.

The mean theoretical field capacity of the implement at 2, 2.5, 3 km/hr were 0.32, 0.39, and 0.46 ha/hr, respectively. As well as effective field capacity at the same speed level of 2, 2.5, 3 km/hr were found to be 0.30, 0.36, and 0.41 ha/hr respectively. This indicated that both theoretical field capacity and effective field capacity of the implement increased with increase in speed. Generally, this shows that the implement can hill the soil on a hectare of land of 2.44 to 3.33 working hours based on the forward speed. The lower field efficiency occurred at 3 km/hr speed was 88.37% and the maximum field efficiency observed at a speed of 2.5 km/hr was 92.57%.It can be seen that, field efficiency was decreased as speed increases. From results obtained, it can be concluded that the fabricated ridger implement can be efficiently, effectively and economically used by the majority of farmers.

Recommendations

The performance test the implement shows that the implement can be performing hilling operation well on farms. Nonetheless, the following issue must be addressed to make the implement more popular, adaptable and usable among the farmers.

Further research is essential to establish the effect of different soil type and moisture contents on the performance of the ridger for potato hiller and comparative performance evaluation is necessary to establish the economic and technical performance of the ridger and other soil engaging implements

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Irrigation, Drainage and Water Harvesting Engineering Technologies

On-Farm Evaluation of Manual Well Driller for Shallow Ground Water in Western Oromia, Ethiopia

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Abstract

Manual drilling is an art and science of extracting groundwater using human means/power. Machine-drilled wells are often very expensive and not affordable by large parts of the population in developing countries. Hand dug wells often collapse if not properly lined. So the aim of this study was on-farm evaluation of manual well driller for wise utilization of ground water at Dedo, Jimma, Dedo and Omo Nadda of Jimma Zone. The Driller was capable of drilling up to the hard impervious sub surface. In this study the driller was drill up to 24 m depth. The maximum human power required were 6 in number. The depth of drilled and time taken at different sites Dedo, Jimma, Omo Nadda I and Omo Nadda II were (2.83 hr, 9.5 m) , (11 hr, 24 m) , (7.3 hr, 12.2 m) and (2.6 hr,10.12 m) respectively. The Drilling capacity is of driller as dawn ward depth increases the time taken and human power required increases. There is direct relationship between the time and depth of the drilling on the specific site. As recommendation, special care must be taken in fabricating the cutting tip due to the occurrence of impervious layer. From field observation it is better to upgrade the manual driller to engine or motor powered because the operators' feedback indicated that driller become difficult as the depth increase.

Key words: *Dawn ward depth, Driller, well, working water*

INTRODUCTION

The introduction of manual well drilling in Ethiopia was initially aimed at the promotion of irrigation at household level, but more recently the technology has been applied to development of domestic water supplies as well. In practice, people use the manually drilled wells for various purposes, be it drinking, irrigation or watering of livestock, depending on their needs. Approximately 83 percent of Ethiopia's population of 82.8 million lives in rural areas and 52 percent of the rural population live in poverty (IFAD). Improving small holder farmers' agricultural productivity and access to water can increase their incomes, improve food security, and provide water for livestock and domestic needs. One solution for reliable and affordable access to shallow groundwater resources is manually-drilled wells. Once a well is drilled and farmers are able to access water, farmers have a variety of pump options (e.g. treadle pumps, motorized pumps) available to lift water from the well; a variety of water storage technologies; and a variety of water applications methods (e.g. drip or sprinkler) available to apply water to crops. While manual well drilling is prevalent and highly developed in many Asian countries, it is not widely available in Ethiopia.

Single cropping is the norm in Ethiopia, and double-cropping is practiced along rivers. Women play an important role in agricultural production, which is predominantly subsistence, rain fed agriculture. The potential irrigable area is 3.7 to 4.3 million hectares (Mha), but the actual irrigated area is approximately 7-10% of this potential (AgWater, 2010).

Increasing female and male farmers' access to groundwater can contribute to increased incomes, improved food security and improved access to water for livestock and domestic needs. In many contexts, private sector manual well drilling is a reliable and affordable means to access shallow groundwater, but it is not widely available in Ethiopia.

Manual drilling is an innovative low-cost technique for groundwater development where human labor is used for drilling the hole.

Machine-drilled wells are often very expensive and not affordable by large parts of the population in developing countries. Another alternative is to drill 'shallow' water wells (up to about 35 meter depth) by hand, so reducing the price of a well by a factor 4 -10 compared to a machine-drilled borehole. This cost reduction not only enables NGOs and Governments to construct more water wells, but also opens the door to villagers, farmers, schools and small communities to have a well-constructed independently through the private sector (Arjen van der Wal, 2010).

Manual drilling is an art and science of extracting groundwater using human means/power. It is a process that aims at creating a hole in the ground up to the water table with a good yield. It is also referred to as hand drilling. Hand drilling is also known as manual drilling; human powered drilling, and is sometimes referred to simply as low cost drilling. As the names suggest, hand drilling technologies primarily utilize human energy. Unlike hand digging, which requires a person to be physically below ground to dig the well (in Ethiopia is commonly 1.2 m in diameter, with the use of concrete rings and sometimes masonry linings), hand drilling enables the operators to remain above the ground and drill a narrow diameter borehole (50-200mm). Drilled depths depend on the technology and the soil formation, but can reach to 50 m and sometimes more.

In many countries manual drilling teams experience problems with site selection, loss of working water, soil determination, logging, well installation, well development, water quality and well yield (flow rate of the well). These problems may occur when the drilling process is not completely understood. The maximum depth of manually drilled well by iDE in Ethiopia is 47 meters. Since January 2009 iDE has drilled more than 500 wells in Oromia, SNNPRS and Amhara regions almost all are for irrigation purpose and the pumps installed are rope and washer pumps and other iDE designed low cost pumps.

Hand dug wells are lower in cost and very useful in formations with a low permeability due to their capacity to store water which seeps in through well walls overnight. However, the total yield/day may be low, and water quality may be poor because the water comes from an open source allowing pollutants to enter easily. Hand dug wells also often collapse if not properly lined. A hand dug well lined with concrete rings, preventing it from collapsing, has a high yield, but the price will be significantly high. So it is recommended to use manual driller to drill well. In addition to this, well drilling technologies problems or demand was raised by ADPLAC as a major problem of the area. For this, this study was conducted to evaluate the performance of manual well driller for wise utilization of ground water under farmer's condition.

Material and Method

Materials

Materials used were; GI drill pipes, different size pipe diameter, wrenches, Angle iron, container and working water.

Method

Study Area

The study was conducted in Jimma, Dedo and Omo-Nadda in Jimma zone of Oromia Regional State of Ethiopia.

Soil of the Study Area

The area is characterized by gentle, flat and undulating topography with the altitude ranging from 1650 – 2200 m.a.s.l. According to Van Ranst et al., (2011), the major reference soil groups in the Gilgel Gibe catchment are Nitisols, Acrisols, Ferralsols, Vertisols and Planosols. The middle and high altitude soils are less rich in nutrients due to the fact that they have been under human land use for long (SLMP, 2009).

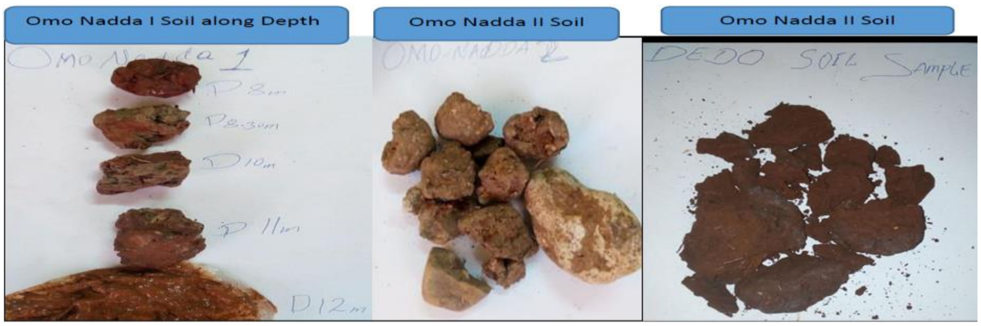

Fig 1:- Soil type at study site

Descriptions of the Driller

The driller has different components Valve, cutting tip, drilling pipe, handle, support and seat.

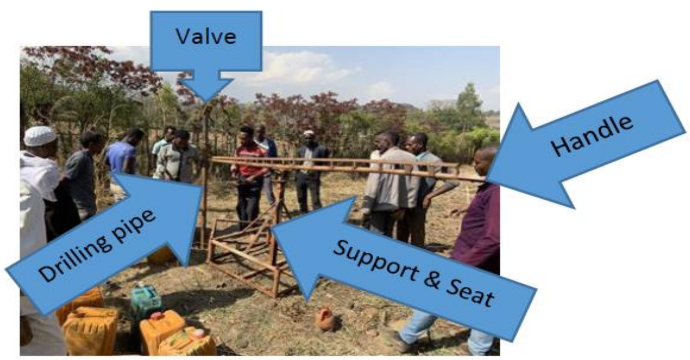

Fig 2:- Part of the drilling

Drilling site selection

Sites were selected from Jimma zone. Before the drilling of a new well starts, a good drilling sites were selected. In most cases the villagers or owner of the new well was point out a location which was suitable for them as users. From all districts five sites were selected based some criteria like ground water table.

Actions Taken Into consideration

The sludging technique (which consists of 1.5", 3.5" and 5.5" diameter drilling bits, and 1.5" GI drill pipes of 24 meters long, pipe wrenches and other small tools) were used. The drillers were experience in drilling from 1.5" to 5.5" diameter wells and the time it takes were measured to complete the well depending on the depth and type of formation.

During the drilling process there were a lot of different aspects which require attention to prevent things from going wrong. Besides the practical drilling skills which were executed at ground level, at the same time attention has to be paid to important processes which are happening below ground level during drilling. Dug wells may collapse during construction, particularly in clay soil areas, whereas drilling may be unable to get through stones. Abandoned dug wells can scar the landscape, whereas failed manually drilled wells are easily covered. Water that used in drilling (working water) can be flow away or worse; the borehole could collapse, burying part of the drilling equipment. And finally, once the hole has been drilled, the well casing, screen and sanitary seals should be installed at the right depth, preventing contaminated water from entering, and ensuring a sufficient yield.

Working Principle

Sludging was use water circulation to bring the cuttings up to the surface. The drill pipes were moved up and down. On the down stroke, the impact of the drill bit loosens the soil and on the up stroke, the top of the pipe was closed by valve, drawing up the water through the pipe and transporting the cuttings to the surface. On the next down stroke, the valve opens the top of the pipe and the water squirts into a pit, in front of the well. In this pit, the cuttings separate from the water and settle out, while the water over flows from the pit back into the well. The borehole stays open by water pressure. Thickeners (additives) can be added to the water in order to prevent collapse and reduce loss of working water (drill fluid). Sludging (with or without rotation) were used up to depths.

Data collected and Field tests

- Drilling Depth
- Time taken to drill
- Human power need
- Well yield or Discharge
- Soil sample at different depth per meter

Discharge

The discharge in m3/s calculated by dividing the amount of water filled to the known volume by the measured time. The discharge was calculated by

$$Q = \frac{V}{T}$$

Where: Q discharge of the pump, L/s

V = volume of water to fill the measuring drum, L

T = time required to fill the drum, s

Data management and statistical analysis

The collected data were analyzed using descriptive statistical tools.

Result and Discussion

Time taken to drill

Table 1:- Result of well driller obtained at Dedo site

Time taken (min)	Water con-sumed in lit	Human power	Dawn ward Depth from ground surface (m)
49	610	2	5
58	365	3	2
54	60	6	2.5

Table: - Result of well driller obtained at Jimma

Time taken (min)	**Dawn ward Depth from ground surface (m)**	**Watering in litter**	**Human power**
4.42	2.8	95	1
33	3.2	100	2
51	3.1	240	3
72	2.4	300	3
60	2.9	250	3
68	2.1	220	3
64	1.8	180	3
72	1.6	170	3
76	1.4	160	4
78	1.2	150	4
84	1.5	130	4

The well discharge obtained was 0.84 lit/min

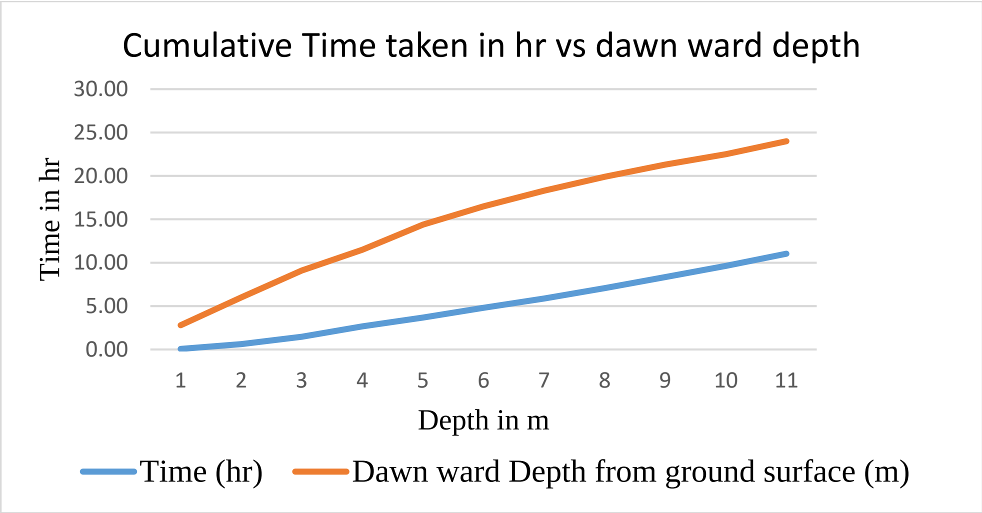

Fig 3:- Cumulative time vs dawn ward depth

As shown from the result graph there is the direct relationship between cumulative time and dawn ward depth

Table 3: Result of well driller obtained at Omo-Nadda I

Time taken (min)	Dawn ward Depth from ground surface (m)	Water in litter	Human Power
68	2.3	315	1
120	3	1050	2
106	3	1760	3
40	0.3	785	3
75	3	870	4
31	0.6	490	4

Table 4:- Result of well driller obtained at Omo Nadda II

Time taken (min)	Dawn ward Depth from ground surface (m)	Watering in liter	Human power
4.50	1.80	95	2
35.78	2.35	120	2
7.04	1.50	180	3
8.00	1.50	210	3
27.45	1.55	240	3
29.90	1.52	240	4
9.10	1.14	250	4
60.00	2.90	250	4

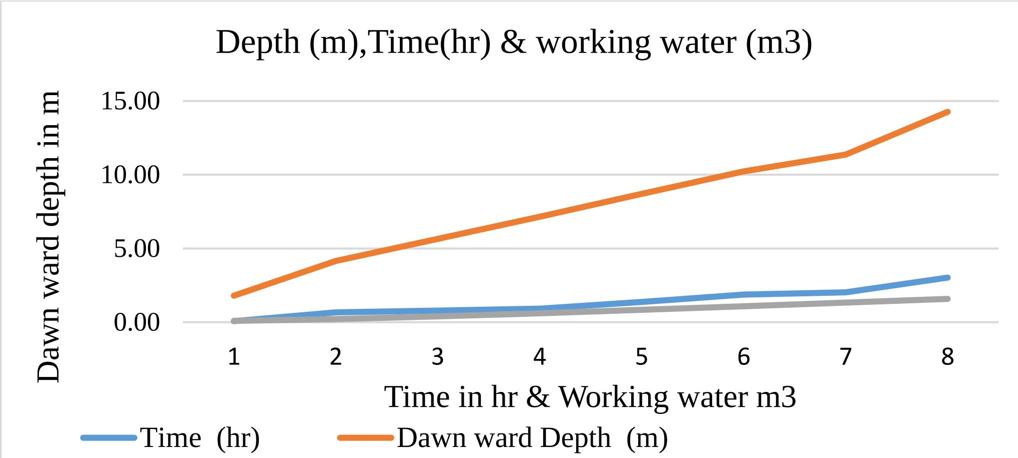

Fig 4:- Dawn ward depth in meter vs time in hour as shown from above figure the result revealed that the dawn ward drilling depth (m) increases the time taken (hr) and working water increases, this shows there is direct relationship.

Conclusion and Recommendation

On farm evaluation was done at Dedo, Jimma, Dedo and Omo Nadda of Jimma Zone. The Driller was capable of drilling up to the hard impervious sub surface. For this cause it was drilled up to 24 m depth. The maximum human power required were 6 in number. The average water used to sophisticate the soil is 0.84 lit/min. The depth of drilled and time taken at different sites Dedo, Jimma, Omo Nadda I and Omo Nadda II were (2.83 hr , 9.5 m) , (11 hr , 24 m) , (7.3 hr , 12.2 m) and (2.6 hr ,10.12 m) respectively. The Drilling capacity is of driller as dawn ward depth increases the time taken and human power required increases. There is direct relationship between the time and depth of the drilling on the specific site. As recommendation, special care must be taken in fabricating the cutting tip and during the occurrence of the impervious layer it is better to stop the drilling. The working water should be taken into consideration. From field observation it is better to upgrade the manual driller to engine or motor powered because the operator feedback that driller becomes difficult as the depth increase.

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Identification, Characterization and Mapping of Potential Irrigable areas in Ziway Micro Watershed

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Abstract

Irrigation land suitability assessment for irrigation purpose is important to utilize the land resources efficiently and mapping play an imperative role for sustainable utilization of scarce physical land resources. This study was initiated to assess and evaluate the land resources which is potentially suitable for surface irrigation in ziway micro watershed and developing suitable area map by using Geographic Information System (GIS). The evaluation of land in terms of the suitability classes was based on the method as described in FAO guideline for land evaluation. Multi-criteria decision evaluation method was used to evaluate the physical land characteristics of the study area for surface irrigation. The suitability factors that were considered for evaluation of the land for surface irrigation such as soil data was obtained from Ethio-soil, slope was derived from DEM-20 meter resolution, land use/cover was classified from satellite image of 2019 (Landsat 7 ETM+). For each of the criteria suitability map was developed. For the weighted over lay analysis as the most limiting factor slope was given (40%), land use and River proximity given equal weights (30%). After evaluating the physical land capability for surface irrigation, irrigation suitability map was developed. The weighted overlay analysis gave 70.1 and 13.3% of the study area is in the range of highly suitable to marginally suitable for surface irrigation. Thus, the overall suitability using a weighted overlay of the above factors in ArcGIS shows that potentially irrigable land suitable for surface irrigation is about 83.4% of the area. Therefore, this study will help Thus, farmers and the government should invest in those suitable areas for surface irrigation and also decision makers, investors, planners and policy-makers at the local, regional and national levels in better identification of profitable and sustainable irrigation investment.

Keywords*:* *Slope, land suitability, suitability factors, Irrigation potential, GIS*

Introduction

Agriculture is the core driver for Ethiopia's growth, development and long-term food security. About 15 to 17 percent of Government of Ethiopia's (GOE's) expenditures are committed to the sector, agriculture directly supports 85 percent of the population's livelihoods, 43 percent of gross domestic product (GDP) and over 80 percent of export value(CIA, 2009).

Ethiopia agriculture is dominated by rain-fed agriculture. However, rainfall distribution and intensity vary spatially, tending to decrease from southwest to northeast (Cheung *et al*., 2008). Rainfall also varies temporally resulting in incidents of drought every 4-5 years (Osman and Sauerborn, 2008).These rainfall patterns affect crop and livestock production and contribute to volatility in food prices, which ultimately affects overall economic development (FAO, 2005).

The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility in any country. Although Ethiopia has abundant rainfall (based on grid-based average annual rainfall and the land area, estimates that Ethiopia receives about 980 billion (~1 trillion) cubic meters (m^3) of rain a year (Seleshi, 2010)) and water resources, its agricultural system does not yet fully benefit from the technologies of water management and irrigation. The majority of rural dwellers in Ethiopia are among the poorest in the country, with limited access to agricultural technology, limited possibilities to diversify agricultural production given underdeveloped rural infrastructure, and little to no access to agricultural markets and to technological innovations. These issues, combined with increasing degradation of the natural resource base, especially in the highlands, aggravate the incidence of poverty and food insecurity in rural areas. Improved water management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity. Despite significant efforts by the Government of Ethiopia (GOE) and other stakeholders, improving agricultural water management is hampered by constraints in policy, institutions, technologies, capacity, infrastructure, and markets. Addressing these constraints is vital to achieve sustainable growth and accelerated development of the sector in Ethiopia (Growth and Transformation Plan, 2010).

According to (MoARD, 2009) report, the potential irrigable land in Ethiopia is between 3.7 and 4.3 million hectares but the area under irrigation is estimated at 7-10% of this. Of this area approximately 55% is traditional irrigation schemes, 20% is modern small-scale, and 25% is medium- and large-scale irrigated commercial farms (private and state-owned). Field assessments in small-scale irrigation projects indicate, however, that some irrigation schemes are not functional due to shortage of water, damaged structures and poor water management (AGWATER, 2010).

In Ethiopia, limited number of reports and investigations were made to assess the irrigation potential based on the physical land and water resources (Negash and Seleshi, 2004). Small scale studies conducted on soils of the country seem to be inadequate in providing basic soil information that can help to make decision on proper utilization of resources.

Appropriate management and selection of best-fit land for irrigation is a pre-requisite for wise utilization of scarce physical resource of land and water. If the land and water resources are not wisely developed and properly managed, widespread and severe environmental degradation is predictable. The concept of land sustainability implies the development and implementation of systems of land use, evaluation and management which will sustain individual and community benefits now and in the future. In Ethiopia, land resource degradation is major threat that affects the existence and livelihood of the community. The degradation of land resource, due to over exploitation and misuse along with consequent economic, social and environmental impacts has intensified the pressure on the land resource of the country (Dagnenet, 2008).

Lake Ziway, one of the important Rift Valley Lakes, is located in the Oromia Regional State about 160km south of Addis Ababa at an altitude of 1850 m.a.s.l. and has a surface area of 434 km^2 with maximum extensions of 20 km by 25 km. The Lake has a mean depth of 2.5m with some areas (especially near the islands) showing deeper gorges of up to 8m (Schroder, 1982). It has a wide watershed area of 7025km^2 (including the areas outside the watersheds of the two rivers) and two in-flowing rivers at the northern side, river Katar and river Meki, and River Bulbula connects Lake Ziway to Lake Abijata. The Lake is surrounded by a farming community, which competes the water for farming. Medium and small scale irrigation farms are foundclose to the Lake using its water or from the rivers flowing into it causing far reaching effects on the lake ecology.

Ziway is in close proximity and with a good road link to the large markets in Addis Ababa that initiated the development of commercial fishing, irrigated farming for vegetables and fast growing crops.

Irrigation is most obvious response to water scarce agricultural areas. This explains for the lots of efforts being made around the lake which has great irrigation potential. However, there is no a responsible body to ensure the sustainable use of water by protecting it from any pollution, over utilization and disturbance of the ecosystem as a whole. Currently, due to lack of institution enforcing the economic use of water, water from the lake is used as ‘open access resource’.

Future increase in food production to supply a growing population must result from new irrigation projects that should be technically and environmentally well planned. However, new potential lands, suitable for irrigation with good quality of water are scarce resources. It will contribute to local problems of soils for irrigation and providing basic information on the land and sound land management method for irrigation projects. In addition, knowledge and experience which will be gained from this study could be transferred to other similar areas of the country in order to assist the on-going irrigation projects. Therefore, this study was conducted with the aim of identification, characterization and mapping of suitable irrigable areas in Ziway micro watershed and generates the information on this watershed.

Material and Methods

Study area

Ziway micro watershed is situated in the mid rift valley, Ethiopia, which covers about 540 km^2. The watershed is located with an elevation varying from 1560 to 1800 m + MSL (mean sea level). The maximum and minimum temperature ranges between 30.2 and 12.8°C. The annual rainfall varies from 960 to 1520 mm. The major soil types identified in the study area are Eutric Leptosol, Eutric Fluvisol, Eutric Vertisols and Chromic Luvisol (FAO/UNDP, 1984). The study area is dominated by Eutric Vertisols. Majority of the land in the watershed is characterized by a gentle to flat slope (0–5%).

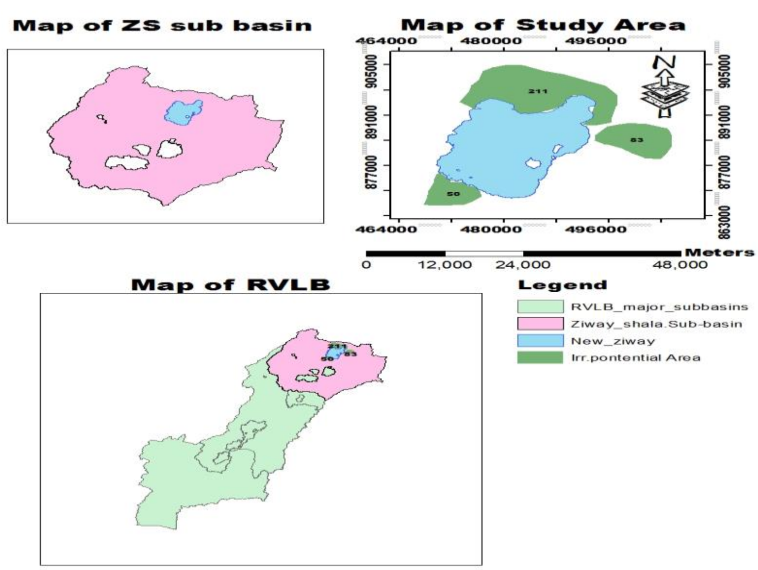

Fig.1.Study area

Selection of Criteria

Different criteria were selected for evaluating land suitability for irrigation in the study area. These criteria were selected based on extensive literature review of potential factors affecting surface irrigation in the study area.

Data sources and collection

The most important data for this study were soil data extracted from Ethio-Soil, slope derived from Ethio-DEM 30 meter resolution, Landsat 7 ETM 2019 image was used to classify land use land cover of the study area. Data for river or water source was obtained from ministry of water resource.

Data Preparation for Spatial Analysis

Slope, soil, land use and water source data were aggregated to produce suitability map for surface irrigation in watershed.

Method of data analysis

The soil suitability class's classifications were based on FAO class and soils of the study area were classified in ArcGIS 10.2. The suitability classes of the soil type classification were based on the properties and their suitability for surface irrigation. Landsat 7 ETM+ of 2019 image was used to prepare land use/ cover map of the study area through GIS software. In the process unsupervised classification was used. After classifying land use land cover, suitability classes were determined based on literature and basically FAO guideline.

Identification of potential irrigable sites

The investigation of suitable sites for surface irrigation was carried out based on slope, soil types and depth of soil, drainage suitability and distance from source to water supply. Further, the slope was classified based on FAO guidelines (FAO, 1999). The four slope suitability classes were representing highly suitable, moderately suitable, marginally suitable and not suitable for surface irrigation, respectively. The physical characteristics of the major soil types identified in the micro watershed were considered for irrigation suitability analysis.

Result and Dscussion

Land suitability for surface irrigation

Slope suitability analysis of the micro watershed

Slope is considered the main evaluation factor for surface irrigation suitability analysis because it affects water flow, the fertility of soil profile, depth of irrigation and drainage of the watershed. By using FAO guidelines (FAO, 1999), the slope map of the river basin was reclassified into five suitability classes namely: (i) highly suitable (ii) moderately suitable; (iii) marginally suitable; (iv) suitable; and (v) not suitable.

Slope of study area were identified and mapped. The slope of study area was classified into four. The 0-2% of slope is covered more area of watershed and 8-15% of slope is covered least area of watershed.

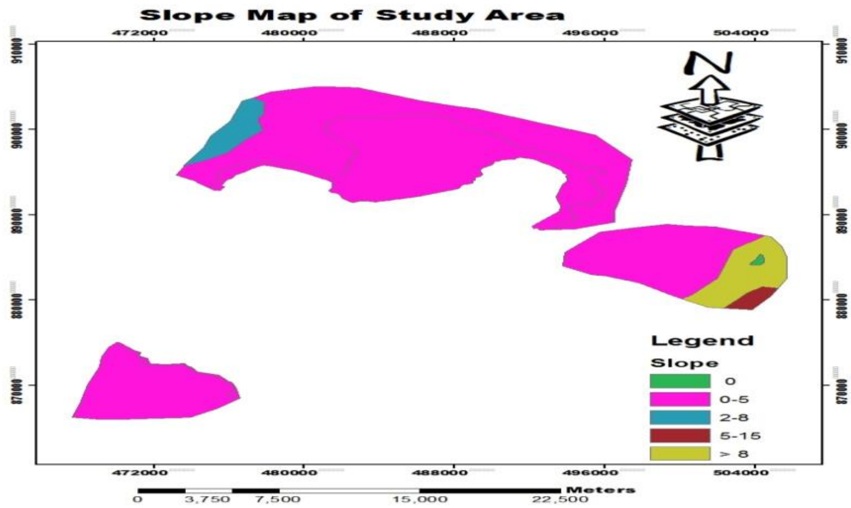

Fig.2 Slope map of the study area

According to Nethononda (2014) slopes less than approximately 8% are in general, considered suitable for irrigation development. Slope has a strong effect on the cultivation of crops. As steepness increases, use of machinery becomes limiting, and establishment and management costs increase as more erosion prevention measures become necessary (Wong, 1986).

Table 1:- Suitability classes of slope

No	Slope range	Code	Suitability classes
1	0-2	S1	Highly suitable
2	2-5	S2	Moderately
3	5-8	S3	Marginally suitable
4	8-15	N2	Not suitable

The result shows that 80.6% of the total micro watershed area is in the range of highly to moderately suitable for surface irrigation (figure 2). The remaining 15.1% of the micro watershed is classified as not suitable for surface irrigation. As indicated on this table, (highly) suitable represents slope 0-2%, (moderately suitable), represents slope 2-5%, (marginally suitable) represents slope range 5-8% and (currently not suitable) represents slope range 8-15%.

Soil type

Overall soil suitability

The overall soil suitability was estimated using the weightage of each factor (slope, soil type, depth and drainage) to obtain potential irrigable sites. The major soil groups identified in the study area were Andosols, Fluvisols, Luvisols, Nitosols and Solonetz (figure 3). From this Figure (3), it is evident that most of the part of the micro watershed soil is categorized as highly to moderately suitable (85%)

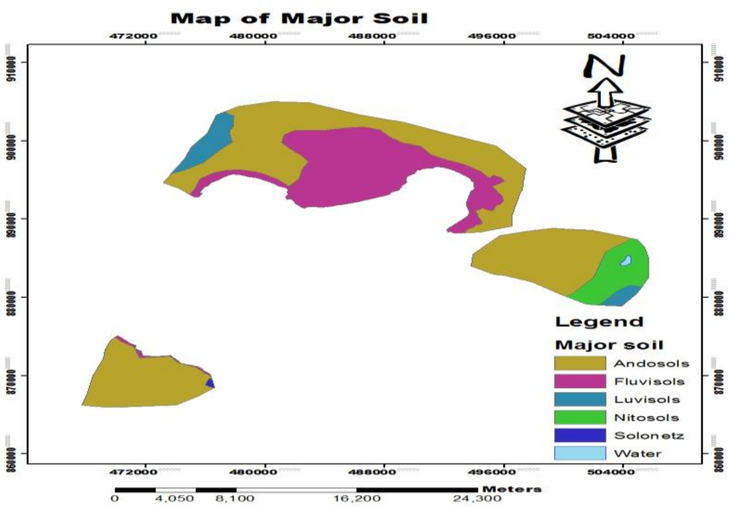

Fig.3:- Soil map of the study area

Ziway micro watershed is covered by 5 major soils. Which are Andosols, Fluvisols, Luvisols, Nitosols and Solonetz. Most part of the soils was covered by Andosols followed by Fluvisols.

Major soil of study area were identified and mapped. Soil depth was among the important physical soil parameters used to evaluate soil suitability for surface irrigation development.

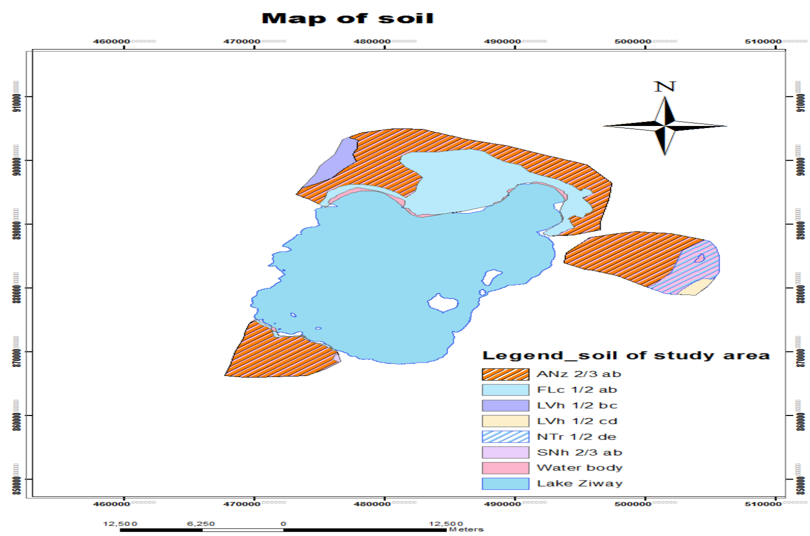

Fig.4.Soil type map of the study area

Land Use Map of the area

Land use and land cover influences irrigation practice to prepare the land for agriculture. Therefore it was taken as one input for the evaluation of land qualities of study area for irrigation. From satellite image of 2019 unsupervised classification, five LULC classes were identified namely: forestland, scrub/bush land, water body, agriculture and open area.

Major land use of study area were identified and mapped. Ziway micro watershed is covered by 5 major land useswhich are Grassland, Intensively cultivated Land, Marshland, Moderately Cultivated Land and wood land. Most part of the watershed covered by intensively cultivated followed by MCL.

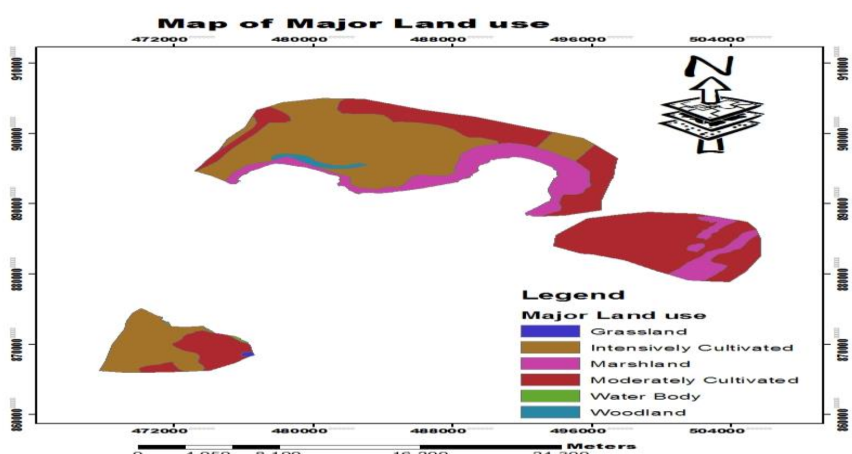

Fig.5.Land use/land covers map of the study area

As indicated in the Figure, the land use land cover classes of the study area ,agricultural land is classified as highly suitable, open areas and shrub/bush land are moderately suitable, forest land is marginally suitable and water body are not suitable for surface irrigation. The decision was made based on literature and the assumption that the agricultural lands can be used to irrigation without limitation and shrub/bush and open areas land can be used with less limitation. The forested area and water body were classified as marginally and not suitable for surface irrigation respectively.

Weighted overlay analysis

To identify potential surface irrigation area in micro watershed, a multi criteria decision making approach were used. The main physical land resources criteria were soil type, slope, land use /cover and rivers maps of watershed. Then taking slope, land use and river proximity/ distance from the river, weighted overlay analysis was done in Arc GIS10.2.

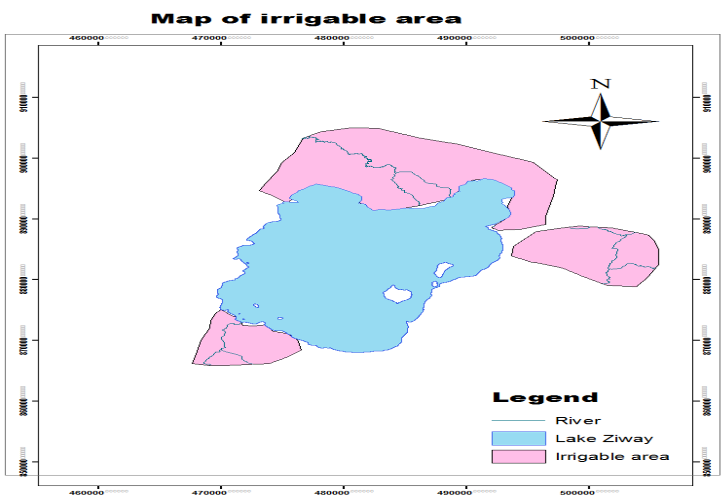

Fig.6.Irrigation suitability map of the study area

Slope was given more weight than river proximity and land use/cover as the most limiting factor for surface irrigation based on the literature. Accordingly in the weighted overlay analysis: slope 40%, river proximity 30% and land use 30% was given for suitability analysis.

Conclusion and Recommendation

The study results indicated that about 70.1 and 13.3% of the study area is in the range of highly suitable to marginally suitable for surface irrigation development based on the soil and slope of the area, respectively. The overall suitability using a weighted overlay of the above factors in ArcGIS shows that potentially irrigable land suitable for surface irrigation is about 83.4% of the area.

In order to identify the potential areas for surface irrigation soils, slope, land use and water sources were used as criteria and based on all these suitability factors areas suitable for surface irrigation were identified.

Based on the finding the following recommendations were given that the farmers in low laying areas in vicinity to different permanent ground water and rivers can practice surface irrigation and maximize their agricultural productivity.

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GIS Based Identification of Water harvesting potential Area in the Bale Low-land of South Eastern Ethiopia

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Abstract

Assessment of potential surface runoff harvesting sites is an important undertaking in a country like Ethiopia, where high spatial variability in rainfall and recurrent drought and flash floods are common. Surface rainwater harvesting (RWH) is being practiced in various areas in the country however its full potential has not yet been thoroughly explored and remains untapped. This study employs the GIS-based multi criteria decision support approach in the identification of potential sites by cost effectively integrating a number of factors in attempt to explore the full potential of surface RWH systems that takes into consideration effect of high evapotranspiration on open surfaces water bodies among other factors. The analysis, shows that of the total 500 km^2 of cathe catchment area, 29.18 % of the area has highly suitable, 40 .87% of the area has suitable ,22.49% of the total area has moderately suitable ,6.98% of the area has marginally suitable and 0.5 % of the area is not suitable for runoff water harvesting at the study area. The developed surface RWH suitability criteria were used to assess the existing water management structures in the basin. Moreover, using this GIS based approach, it was realized that the study area has a potential for runoff water. In conclusion, it was noted that providing accurate and precise spatial representation of the physiology and land use for the analysis of runoff generation potential site within the study area is an important step in developing an integrated strategy for surface rainwater harvesting plan for any catchment and the decision support system has proved to work.

Keyword: *Goro watershed, suitability criteria, Runoff, AHP, DSS and RWH*

Introduction

Water is one of the vital resources required by every living organism, yet a large percentage of the earth‘s people do not have access to an adequate and constant supply of water. In the developing world, many rural communities are located in water scarce areas, where there is uneven distribution of hydrological resources and economic and/or political barriers to pipe and distribute water from the ground or surface (UN, 2014). People in developing and under developed countries live with unsanitary conditions where their everyday survival is the main concern. They are exposed to drought; famine and death as a result of water-borne diseases come from unclean water sources and food shortage as a result of inability of land to grow crops. The problem of accessing fresh water will be more costly and difficult and it has become wider even in developed countries (Rosegrant *et al*., 2002). Climate change and a developing water resource interest for agricultural and urban development are increasing the pressure on water resources and variability of the hydrological regime. By the year 2020 between 75 and 250 million people will be exposed to highly increased water stress in Africa, in some regions of the continent, 50% of yield and agricultural production will become more severely compromised as a result of food shortage (Ammar *et al*., 2016).

Rainwater harvesting (RWH) has been distinguished and practiced in many areas as an economically practical solution for reducing water shortage, and to maximize water quality. In addition, it is seen as measure to address climate change effects on precipitation variability (Ndiritu *et al*., 2011). To overcome the problem of water shortage, it is believed that rainwater harvesting is one of the best options. Rainwater harvesting refers to the collection, storage and use of rainwater for household or agricultural purposes. The term water harvesting refers to collection and storage of natural precipitation and also other activities aimed at harvesting surface and groundwater, prevention of losses through evaporation and seepage and all other hydrological studies and engineering interventions (IFAD, 2013). Rainwater harvesting has been an alternative for rural populations, especially where a permanent water supply system is not viable (Barron, 2009).

There are numerous RWH studies that demonstrate the effectiveness to reduce users 'vulnerabilities to water supply shortage and improve their day-to-day life (Mutekwa and Kusangaya, 2006; Barron, 2009). Run-off irrigation, flood spreading, in-situ water harvesting and roof water harvesting are common RWH techniques mostly practiced in Ethiopia. Geographical Information System (GIS) and Remote Sensing (RS) are playing significant role in hydrological modeling in view of its capacity to handle enormous amount of spatial and attribute data. Some of its features, such as map overlay and analysis help to derive and aggregate hydrologic parameters from different sources like soil, land-cover and rainfall data (Ramakrishnan *et al*., 2009). In this recent years, integrated studies of RS, GIS and run-off modeling has gained significance in targeting suitable sites for water recharging/harvesting structures (Ramakrishnan *et al*., 2009). This research mainly aims at identification and prioritizing the area suitable for water harvesting by taking into consideration factors such as hydrological, physiography, environmental and socio-economic conditions. Analysts and decision-makers work at different scales of interest to deal with different types of environmental problems seeking solutions putting into their considerations the complexity of natural and human impacts that cause these problems. Remote sensing data have been attractive sources in the determination of land-cover thematic mapping, providing valuable information for delineating the extent of land-cover classes, as well as driving and analyzing hydrological data at various scales.

Today application of RS and geo-informatics for environmental assessment, natural resource conservation and geo-spatial data handling and their potential to prepare valid spatial models are in high demand. The Weighted Linear Combination (WLC) and the Boolean technique are the two major techniques used in GIS environment to select potential sites for development of projects. Common technical steps the WLC follows are: preparing layers, standardizing the suitability layers, assigning weights of relative importance to the suitability layers, combining the weights and standardizing suitability layers and obtaining an overall suitability score (Baban and Wan-Yusof, 2003; Malczewski, 2004; Ayalew and Yamagishi, 2005). This technique provides site selection of a project based on using either the or (union) or and (intersection) operations (tabor and hutchinson, 1994; chenini et al., 2010).

The area is characterized by erratic and poor distribution of rainfall over the year. The area faces frequent drought, crop failure, and lack of permanent sources of water, which brings low crops yield and sometime it completely fails due to shortage of water during the flowering or maturation stage. Hence, there is a need additional water supply for dry season drought mitigation by improving water supply options. In the rainy season that extends from June to September in which food crops are grown in thisarea, the occurrence of rainfall is unreliable. Late or early occurrence, uneven distribution, interruption and insufficiency of the rainfall are common in the area. Inadequate showers that fallduring the short raining season that extends from December to February can only support somegrass for livestock.

Rainwater harvesting is one of the best alternatives to mitigate the disaster harnessing as the water source to address the water scarcity problem. For relatively small areas, a field survey carried out by experienced people will be the best technique to select the appropriate sites and to determine the suitable methods for RWH. But, for larger areas, the application of GIS and RS could be the most relevant means (Prinz *et al.*, 1998; Kumar and Jhariya, 2016). Geospatial technology provides tools that can be used to better determine the potential of RWH to ensure sustainable development. Nevertheless, selecting sites for potential RWH is a complex process, which needs technical, physical, economic, social and environmental requirements. Such complexities demand different influential factors consideration with several decision support tools such as GIS and multi-factor analysis system. In order to fill this research gap and solve the problem, an attempt will made in this research to in order to identify potential RWH sites of the study area using GIS and RS data. Therefore the objective of this activates was to identify the watershed-based water harvesting potential area of Goro district of Bale Zone and to demonstrate water harvesting practice using small pond for drip irrigation at the study area.

Materials and Method

Description Study Area

Goro watershed is located in Bale zone of Oromia regional state, Ganale Dawa Sub- basin in Goro District with the capital located at 470 km of Addis Ababa. It lies between 6°50'0"N - 7°50'0"N" North latitude, 40°15'0"E - 40°35'0"E" East longitude with projection system UTM and datum ADINDAN. The watershed encompasses around twenty-one kebeles found in Goro Districts. The total area coverage of the watershed that obtained through watershed delineation is 500 km^2.

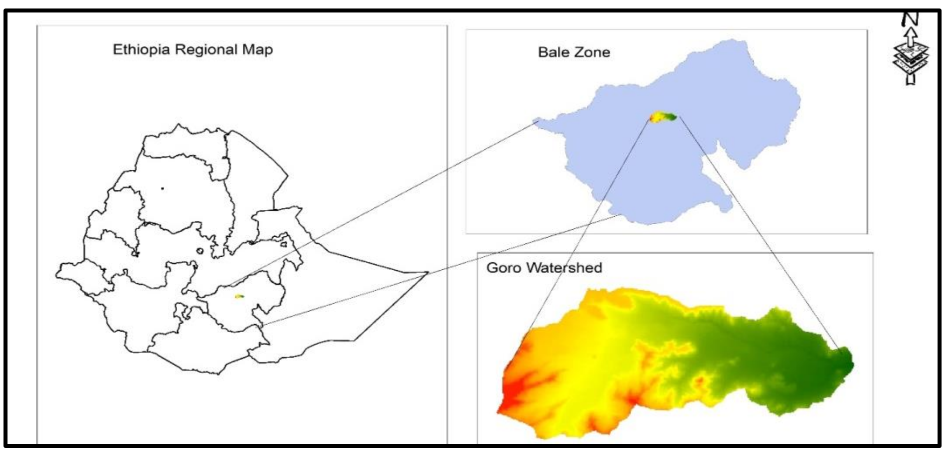

Figure1. Location map of the study area

Topography

The elevation of the watershed boundary extends from 1615 to 3219 m a.s.l. The maximum elevation of Goro watershed is located in the northeast and southeast part of the watershed and the minimum elevation of this watershed is located in the northwest part of this watershed. The study area falls in the slope ranges of (0-100 %); 60 % the area falls in the slope ranges of (0-15%), and remain area has slope greater than 15%.

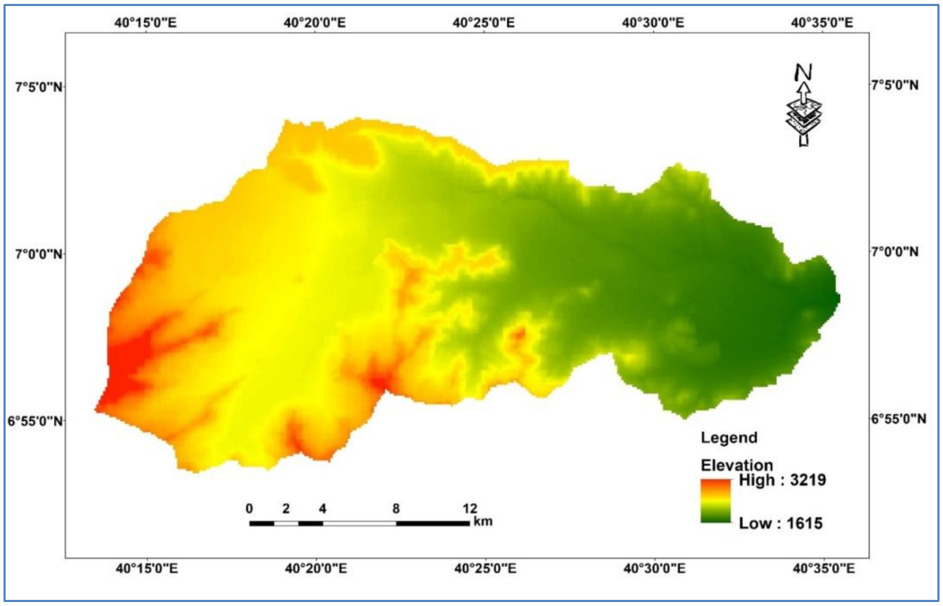

Figure2. Topographic map of Goro watershed

Data Collection

The result of this study depends on the different types of data which were collected from different sources. The data obtained to determine suitable areas for rainwater harvesting are: Digital Elevation Model (DEM), Climate data, Soil map and Satellite Imagery (Landsat 8).

Digital Elevation Model (DEM) was obtained from the United State Geological Survey (USGS) website (http://gdex.cr.usgs.gov/gdex/). The DEM has 30 m resolution. The format of data is raster data. The datum of the data is WGS-84.

Climate data were collected from the National meteorology Agency of the Ethiopia. The rainfall data is monthly from 1990 to 2021. There are 2 meteorological stations in the study area. The *soil map* of the Study area is obtained from the Earth Data Website https://earthdata.nasa.gov/. The soil map describes texture, depth and color of the soil in the study watershed.

Satellite Imagery (Landsat 8) was downloaded from USGS website on 19 of May 2021 from Website (https://earthexplorer.usgs.gov/). These data are used to describe the land use of the study area. The geo-reference of the satellite image is WGS_84 Datum project 37N.

All source maps were in vector type formats, each containing their related attribute files. These have been converted into raster datasets and then re-sampled to the same cell size (90 m) to enable the ArcGIS overlay operation. The conceptual framework is shown in Figure 3

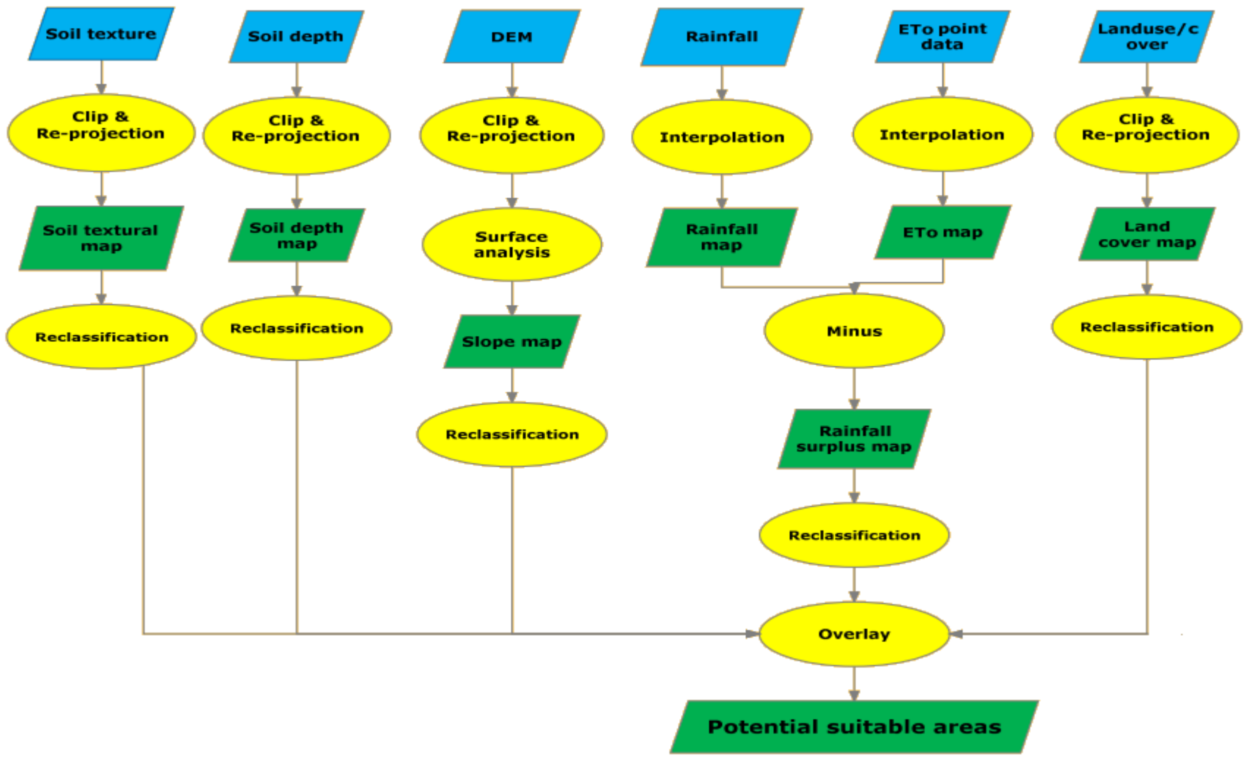

Figure 3: Flow chart for identification of potential sites.

Preparing Data and Modeling

Referring to previous studies, six criteria were chosen for determination of suitable areas for water harvesting, i.e., runoff, slope, soil depth, soil texture, land use or land cover and Rainfall (Mkiramwinyi, 2007).

Digital Elevation Model (DEM)

The hydrological parameters flow accumulation stream network and slope were derived from the Digital Elevation Model with 30 m resolution. A GIS package (ArcGIS 10.8) was used to extract the hydrological parameters. Before using the DEM to estimate any parameters, all sinks were removed in order to keep continuity of flow to the catchment outlet. Figure 2 illustrates the Digital Elevation Model after filling sinks.

Analysis of rainfall distribution from rain gauges network

The rainfall stations in the Bale zone are scattered all over the study area, which will give a suitable distribution to estimate the distributed rainfall. Rainfall point's measurements represent monthly values within the period 1990 to 2012. Interpolation was used to estimate rainfall for areas not having rainfall point measurements. Ten rainfall stations are used to interpolate the rainfall for the area. Kriging is a common method of interpolation (geostatistical interpolation technique), which is used to estimate values at unmeasured locations (Longley 2011). Optimal interpolation of kriging depends on the possibility to estimate values based on observed z values of neighboring data points, weighted according to spatial covariance values (Bohling 2005). The method is based on both the distance and the geographic orientation of known data points when estimating values in unknown areas (Vertical Mapper Guide 2009). The general formula for Kriging interpolation is:

$$A_{(So)} = \sum_{i=1}^{n} \lambda i Z\,(Si) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: Z (si) is the measured value at the i th site, λi is an unknown weight for the measured value at the ith site, n is the number of measured values and Z(so) is the predicted value.

Land Cover / Land Use

Land cover was extracted from Satellite Imagery (Landsat 8) registered 19 May 2020 with a spatial resolution of 30 meters. ArcGIS (Version 10.8) was used to derive the land cover. A different land cover/land use classes were applied through supervised classification. Combination of three bands as false color composite image with the reference map and Google map were used to define training sites. A training site is an example of an information class, such as built up, farmland, grass and forest. The training site characterization was used to create signatures for each information class. The maximum likelihood algorithm was used to classify land cover using the mean, variances and covariance data from the signature to estimate which class each pixel belongs to. Five types of land cover were found in the study area: forest, built up (settlement), water, farmland, grass with open forest and shrubs. Land cover is an important criterion when selecting suitable areas for water harvesting. On the other hand, land cover can be used to estimate the runoff depth by using the Soil Conservation Service Model (Moges 2004). The vegetation plays a significant role on the infiltration capacity of the soil. The amount of runoff lost to interception on leaves and stacks of vegetation which depends on the growth stage and the type of vegetation.

Soil map

ArcGIS 10.8 was used to geo-reference the soil map and then converted to vector data, which here 7 classes were distinguished in the study watershed.

Slope

The slope is generated from a topographic ratio, which represents the ratio of the elevation difference between two points divided by the horizontal straight distance between the two points (Winnaar 2007). The slope is derived from the Digital Elevation Model (DEM), and classifiedinto 5 slope percentage classes according to the FAO slope classification (Winnaar 2007).

Table 1: Slope classification from Winnaar 2007

No	Slope class	Slope (%)
1	Flat	< 2
2	Undulating	2 - 8
3	Rolling	8 – 15
4	Hilly	15 – 30
5	Mountainous	>30

Slope steepness is a very important factor for assigning and implementing rainwater harvesting. Mountainous areas that have high rainfall are considered as suitable areas high generate runoff (Winnaar 2007). Figure 8 illustrates the slope of the study area according to FAO. The study area has gentle slopes on the southwest part while the north and northeast have steep slopes and deep valleys.

Estimating Curve Number (CN)

Rain water harvesting is a hydrological intervention which can best be depicted through hydrological models that are able to show directions of flow, runoff and run-on area and identify locations for impounding structures. In undertaking hydrological modeling using remote sensing data in GIS environment the SCS curve runoff model is largely suitable due to its reliance on land cover parameters which can be extracted from remote sensing (Senay et al., 2004). Runoff curve number equation estimates total runoff from total rainfall and this relationship excludes time as a variable and rainfall intensity. Its stability is ensured by the fact that runoff depth (Q) is bounded between the maximum rainfall depth (P). This implies that as rainfall amount increase the actual retention (P-Q), approaches a constant value; the maximum potential retention (USDA, 2004) The runoff estimation related runoff (Q) to precipitation (P) and the curve number (CN) which is in turn related to storage (S). CN is based on the following parameters; hydrologic soil group, land use and treatment classes, hydrologic surface conditions. Equation 2 known as the runoff curve number gives the relationship between the parameters described below.

$$Q = \frac{(\mathrm{P} - \mathrm{Ia})^2}{(\mathrm{P} - \mathrm{Ia}) + \mathrm{S}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (2)$$

Where: Q = runoff depth (mm), P = rainfall (mm), S = potential maximum retention after runoff starts (mm) and Ia = initial abstraction (mm).

Initial abstraction consists mainly of interception, infiltration during early parts of the storm, and surface depression storage. Its determination is not easy due to the variability of infiltration during the early part of the storm since it depends on conditions of the watershed at the start of a storm such as the land cover, surface conditions and rainfall intensity; thus, it is assumed to be a function of the maximum potential retention (USDA, 2004). $Ia = 0.2S \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (3)$

Potential maximum retention (S) can be calculated by the Curve Number as below

$$S = \frac{25400}{\mathrm{CN}} - 254 \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (4)$$

Where: S= Potential maximum retention and CN= Curve Number

Curve Number is used to characterize the runoff properties for a certain soil and land cover/land use. The soil conservation service runoff equation uses the curve number value as input parameter. Curve Number is estimated per pixel for the study area, via the land cover map and soil map that was reclassified into Hydrologic Soil Groups and hydrologic condition (see table 2 below). Infiltration depends on the soil property which effects the relation between rainfall and runoff. The Soil Conservation Service Model divides all soils into four Hydrologic Soil Groups according to the United State Geology Survey (USGS) land use and land cover classification system (A, B, C and D) (Maidment 1993). The classification of soil to hydrologic soil group depends on infiltration rates and the soil texture composition (Melesse et al, 2002). Table 2 defines the Hydrologic Soil Groups, based on the USGS classifications system. Only classes A, B and D were found in the study area.

Table 2: Soil group and corresponding soil texture

Soil Group	Runoff Description	Soil texture
A	Low runoff potential of high infiltration rate	Sandy, loamy sand and sandy loam
B	Moderately infiltration rates leading to a moderately runoff potential	Silt loam and loam
C	High/moderate runoff potential because of slow infiltration rates	Sandy clay loam
D	High runoff potential with very low infiltration rates	Clay loam, silty clay loam, sandy clay, silty clay and clay

Hydrologic condition refers to the effect of the land cover, and represents the surface conditions in the basin in relation to infiltration and runoff (Munyao, 2010).

The land cover that is presented in figure 7 can be used together with a map of hydrologic soil group in ArcGIS to match thehydrologic soil group with the land cover.

Table 3: Runoff curve number for combination of different land cover and hydrological soil groups

Land cover	Hydrological Soil Group			
	A	B	C	D
Bare Soil	77	86	91	94
Built up	61	75	83	87
Water	100	100	100	100
Agriculture	72	81	88	91
Forest	43	65	76	82

The curve numbers were thus generated using the United State Geology Survey (USGS) land cover and Hydrologic Soil Group classification system (Maidment 1993). The curve number value for each hydrologic soil group and corresponding land cover class are presented in table 3. (Ebrahimian, 2012). A high value of the Curve Number refers to an area that has a high runoff potential and low infiltration. A low value of the Curve Number (such as 30) indicates an area that has a low runoff potential and high infiltration.

Evaluation Runoff depth

After generating the curve number map, the next step was to compute the values of the maximum potential retention (S) which indicate the initial abstraction of rainfall via vegetation and soil. By using equation 4, the value of S for each pixel was calculated. Runoff depth was then estimated by applying equation 2.

Evaluation of rainwater harvesting sites *all factors do not have the same importance for* determination of potential rainwater harvesting areas. Therefore, different weights were identified for the different factors. Site suitability for rainwater depends on the determination of the best site from a set of potential sites by analyzing all the characteristics of the candidate sites. Pair-wise comparison was used to estimate the weights of criteria, known as the Analytical Hierarchy Process (AHP). This method follows the Multi Criteria Evaluation (Drobne et al 2009). The analytical hierarchy process selects the best rainwater sites by using the Multi Criteria Evaluation module (Al-Harbi 2001).

Selection criteria of Parameters

Determination of the criteria is based on the availability of data for the study area. In this study the runoff, land cover, slope, Rainfall, soil texture and Soil depth were used. The criteria of Rainfall depth at each pixel are highly important in determining which area that has more rain water compared to other areas. Runoff depth at each pixel has been estimated by using the Soil Conservation Service (SCS) model, which is explained in the methodology part of this study. Runoff depth varies between 250 to 910 mm per year. Referring to previous studies, the depth of runoff should not be less than 300 mm per year in order to determine suitable areas for rainwater harvesting (Tsiko 2011).

Different slope class's effect runoff volume and infiltration, and therefore the rainwater harvesting are highly based on the type of slope (Munyao 2010). The amount of runoff increases with slope. Hence, slope can be used to identify the suitability of a rainwater harvesting system for a macro catchment area (Tombo 2007). Soil texture is important for rainwater harvesting because it identifies uptake infiltration rate and storage of water in the soil (Tumbo 2007). In this study three classes of soil texture are applied, fine soil, fine / medium, medium, medium / coarse, and the last one is coarse soil. These classes are based on size and spacing of soil particles, which identify the flow of water. Fine soils have high percentage of silt and clay particles, resulting in a very high-water holding capacity, while coarse soils such as sand or loamy sands have large pore spaces, and thus have a high infiltration rate. Fine and medium soils are better than coarse and medium coarse soils for rainwater harvesting. (Tumbo, 2007).

The northern part consists of undulated and mountainous regions containing grasslands, bare soils and open forests. The rainfall in the northern part of the study area is higher than in the southern part. Hence, the cultivated lands were avoided and we only focused on the undulating and mountainous areas to find suitable sites for water harvesting.

Multi attributes decision analysis

There are different methods to combine the decision criteria in the multi criteria decision analysis. In this study, a Weighted Linear Combination (WLC) is used. This weighted linear combination is employed to calculate the sum of the weighted criteria. To execute the Weighted Linear Combination method, an analytic hierarchy process is used, known as pairwise comparison. The weighted linear combination is executed in two steps within the GIS environment: firstly, the weights associated with criteria map's layers are determined Secondly; the priorities for all hierarchical levels including the level representing alternatives are combined (Drobne et al 2009). This method can be implemented by using the spatial analysis toolbars in the ArcGIS environment. The weighted linear combination is based on the following equation:

$$S = \sum Wi - Xi \ldots\ldots (5)$$

Where:S = suitable area, wi= weight of criteria i and xi is the membership value of criteria i.

Standardization of criteria weights

The criteria were calculated from different scales, and therefore it is necessary to convert the criteria to a standardized scale before applying. The standardized criteria membership values are calculated by using the minimum and maximum values as scaling points. As shown in the equation below:

$$Xi = \left[\frac{\text{Ri}-\text{Rmin}}{\text{Rmax}-\text{Rmin}}\right] * SR \ldots\ldots (6)$$

Where; Ri is the raw score of factors i, Rmin is the minimum score, Rmax is the maximum score, and SR is the range or raw score (Ronad 2006).

By using this equation, it is possible to re-organize the values of criteria from different scales to the unified scale. This fuzzy set membership function uses the range between 0 to 1 for real number scale or 0 to 255 for byte scale. The high values of the fuzzy set membership function represent very appropriate values for decision-making (Drobne et al 2009).

Selecting criteria weights

In this study, pairwise comparison, known as the Analytic Hierarchy Process (AHP), was used. This method was developed by Saaty (2008). The pairwise comparison method includes the comparison of each factor against every other factor in pairs (Ronad ,2006). The weights of criteria in Saaty's technique are computed by applying the main eigenvector of the square reciprocal matrix of pairwise comparisons between the two factors (Drobne et al.,2009). The pairwise comparison compares two criteria to determine which criterion is more important than another for a given objective. Table 5 explains the rating between two criteria on a 9-point continuous scale (Girma 2007).

Table 5: The scale of Pairwise comparison from Drobne et al 2009

Intensity of Importance	Definition
1	Equal Importance
2	Equal to Moderate Importance
3	Moderate Importance
4	Moderate to Strong Importance
5	Strong Importance
6	Strong to very strong importance
7	Very strong Importance
8	Very to extremely strong importance
9	Extreme Importance

Table 6: The Summation of values in each column

	Rainfall	LULc	Soil Texture	Slope	Soil depth	Runoff
Rainfall	1	3	7	5	3	6
LULc	0.333	1	0.25	3	3	5
Soil Texture	0.143	4	1	0.33	2	2
Slope	0.2	0.333	3.03	1	3	4
Soil depth	0.333	0.333	0.5	0.333	1	0.25
Runoff	0.167	0.2	0.5	0.25	4	1
Summation	**2.176**	**8.866**	**12.28**	**9.913**	**16**	**18.25**

Table 7: Pairwise comparison matrix for macro catchments areas

	Rainfall	LULc	Soil Texture	Slope	Soil depth	Runoff	Weight %
Rainfall	0.460	0.338	0.570	0.504	0.188	0.329	**0.398**
LULc	0.153	0.113	0.020	0.303	0.188	0.274	**0.175**
Soil Texture	0.066	0.451	0.081	0.033	0.125	0.110	**0.144**
Slope	0.092	0.038	0.247	0.101	0.188	0.219	**0.147**
Soil depth	0.153	0.038	0.041	0.034	0.063	0.014	**0.057**
Runoff	0.077	0.023	0.041	0.025	0.250	0.055	**0.078**

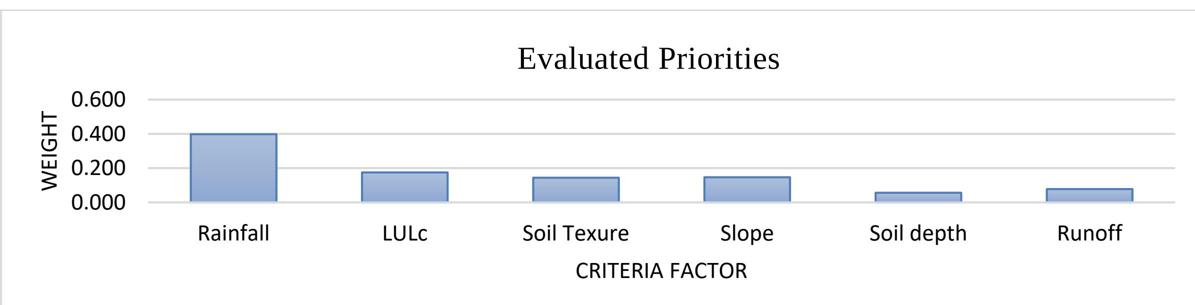

Figure 4: Evaluted criteria factor comparison

Estimating consistency of pairwise comparison

The precision of pairwise comparison is evaluated by the calculation of the Consistency Ratio (CR). The consistency ratio is used to estimate the relative weightings of each criterion. The consistency ratio is the ratio between the Consistency Index (CI) and the Random Index (RI). If the result of the consistency ratio is less than 10 % the comparison between the factors is acceptable. Otherwise, the consistency ratio allows for re-evaluation of comparisons.

$$CR = \frac{\text{CI}}{\text{RI}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (6)$$

The value of the consistency index from the above process is 0.022. The consistency ratio of this study is 2 %, which is less than 10%, so the comparison between the factors is acceptable.

Description of the farm pond and catchment

Demonstration of drip irrigation using water harvesting from ponds was under taken in the study area for demonstrating the technologies to the farmers. For interventions of water harvesting purpose farm pond was constructed on the demonstration field. The dimensions of the farm pond at bottom and top such as bottom length, bottom width, top length and top width was measured with the help of measuring tape.

Layout of typical proposed lined farm pond

Size=Top 6m*6m, bottom; 3.5m*3.5m
Shape=Trapezoidal
Side slope=1.5:1, Depth 2m
Thickness of plastic sheet: 250**µ**
Total capacity: 57.15 m^3
Effective Capacity: 51.435 m^3

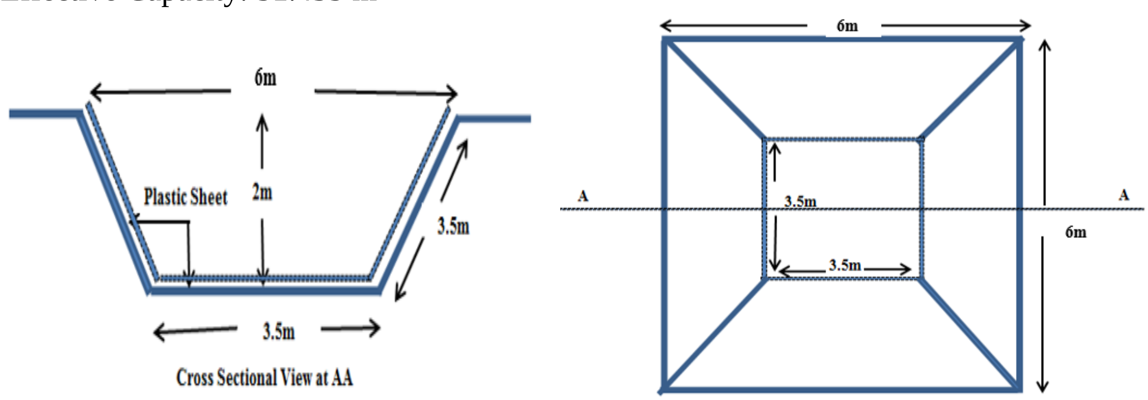

Figure 5, 6: Layout and Dimension of Farm ponds & Plan f proposed lined farm pond

- ❖ Farm ponds was constructed with farmers' local experience at Goro Districts and the use of the harvested water for production of crop, vegetable, fruits and livestock was identified in the study watershed.
- ❖ In the demonstration, researchers, DAs, farmers, technicians and other stack holders was participated and trained. After one year of the establishment, to popularize the technology based on the performance of the technology being demonstrated field days and/or workshops was organized to provide for sharing of experience to other farmers and stakeholders

Results and Discussion

Physiographic Characteristics Analysis

Land Use/ Land Cover Map

Results from data analysis, shows that the study area comprises of six major land cover/land use units which are agricultural land a large portion of 64% of the study area, followed by the mixed shrub. The built-up areas and open water bodies units cover a small portion of the study area (figure 7)

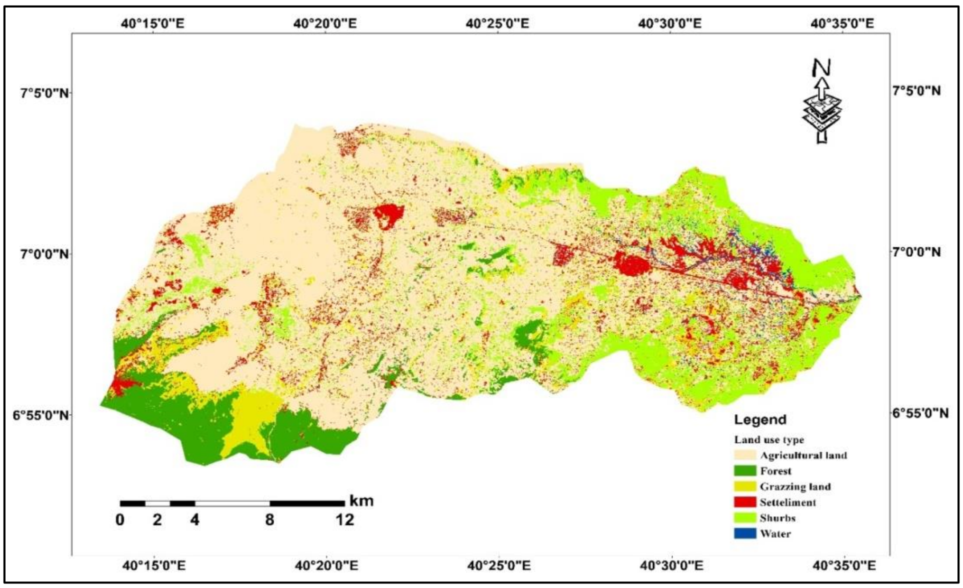

Figure7. Land use/ Land cover of the study area

Majority of the study area is cover with mixed shrub and open grass. This is very important since the vegetation cover plays a very important role on the infiltration capacity. Soil porosity is increased by the presence of this vegetation rooting system which results in increased infiltration capacity of the soil. Sparsely scattered vegetation cover causes rapid runoff on undulating slopes since the surface flow takes less time to infiltrate through the soil, whereas on bare land such as cultivated or arable fields, runoff is more compared to areas covered by vegetation (Moges, 2004).

Table 8: Land Cover Unit per Areal Coverage of the Study Area

Land use type	Area (km^2)	Area (%)
Agricultural land	319.54	63.9
Forest	39.54	7.9
Grazing land	39.62	7.9
Settlement(built-up)	33.15	6.6
Shrubs (Mixed shrubs)	65.14	13.0
Water (River and wetlands)	2.94	0.6

Slopes Density Map

The entire study area is relatively flat especially in the center part of the catchment. This is characterized by a slope percentage less than 3. The topography in the Southern part is mostly made up of undulating to generally gentle slopes. There are few areas that have hilly to steep mountainous slopes. These areas make a small percentage of the study area

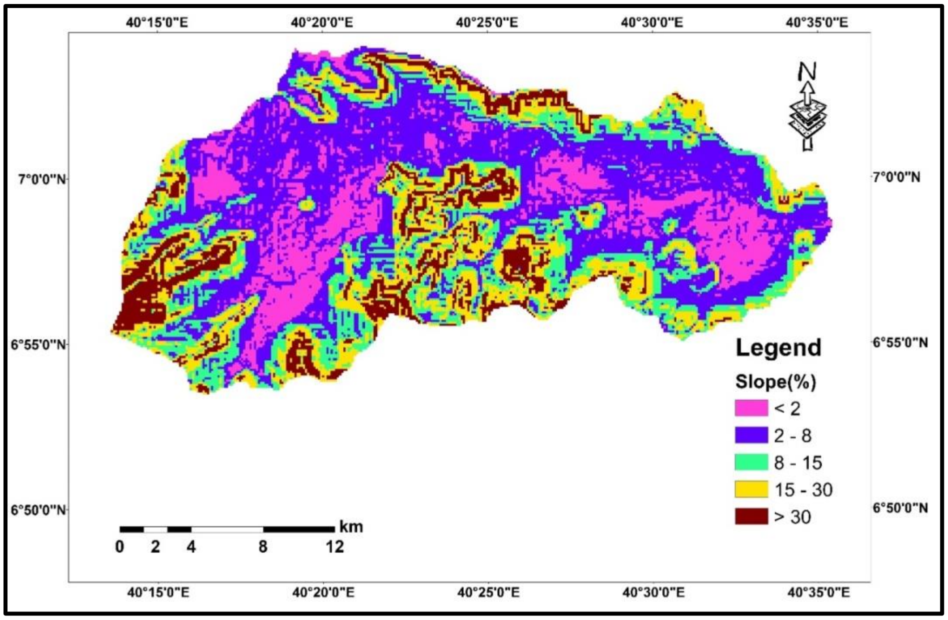

Figure 8: Slope classification map of study area

From the analysis, the study area has a flat topography with slope percentage less than 8% in majority of the areas, followed by undulating and sloping areas and few mountainous slopes of more than 30%. The slope steepness plays a crucial role in depicting areas of preferable runoff, thus steep to sloping areas have high runoff potential.

Table 9: Slope per Areal Coverage of the Study Area

No	**Slope (%)**	**Area (Km^2)**	**Area (%)**
1	< 2	76.95	15.78
2	2 – 8	188.69	38.69
3	8 – 15	84.73	17.38
4	15 – 30	86.18	17.67
5	> 30	51.10	10.48

Soil Map

Three textural classes were identified with the Clay being the dominating textural class covering 57% of the study area. There were few spots of sandy clay which only covered an area of 12 km2.

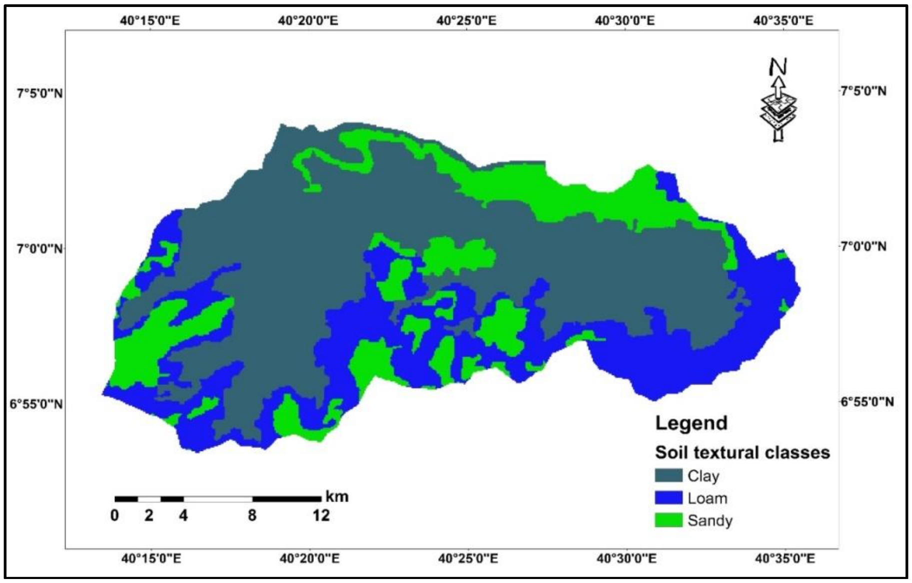

Figure 9: Soil texture in the study area

The major dominating soil in the study area is Vertisol which are developed from the Clay soil which is dominated by smectitic clay minerals that are found in a strongly seasonal climate usually exhibit 'vertic properties. The Clay soil texture covers 63% of the study area. Another soil texture type that covers most of the study area is the loamy and sandy clay loam. They cover 19 % and 15% of the study area respectively (Figure 9). The loamy soils are characterized by medium texture and are well drained. These soils are very stony and underlain by unconsolidated gravely material. They are also very shallow depth. The sandy clay loam has a bit of clay bulge in the sub soil; the soil depth is very deep to deep and is well drained.

Rainfall Distribution

The maximum amount of mean annual rainfall of the study area ranges between 1080 -1180 mm/year and the low range mean annual rainfall is between 680 -780 mm/year.

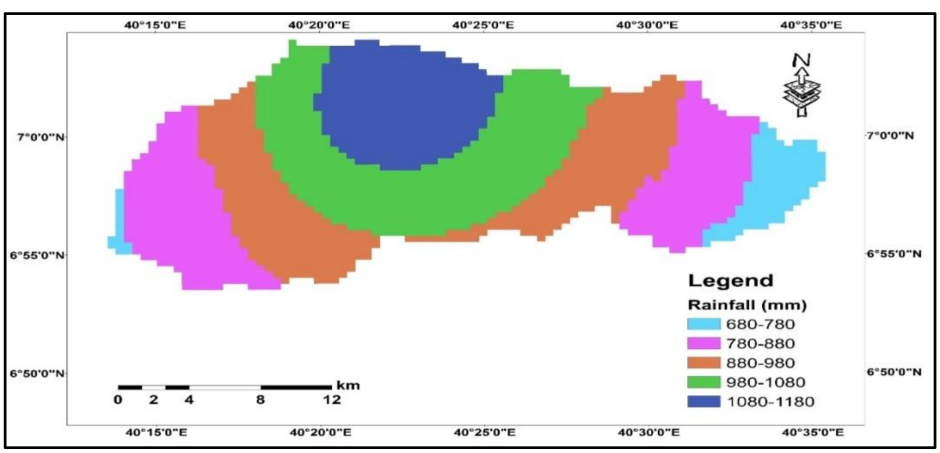

Figure 10: Spatial distribution of average yearly rainfall in the study area

Estimation of Runoff Depth Using SCS CN Model

SCS CN method has been adopted for this study, to estimate the runoff depth. Land cover /land use map and soil texture map (which was reclassified into hydrological soil group using the United States Department Agriculture classification system), were used to derive the curve numbers which were used to estimate runoff depth of the study area. The resultant Hydrological Soil Group map is shown as Figure 10. The dominant soil group appears to be group D, which is suitable for certain RWH technologies such as small dams and farm ponds.

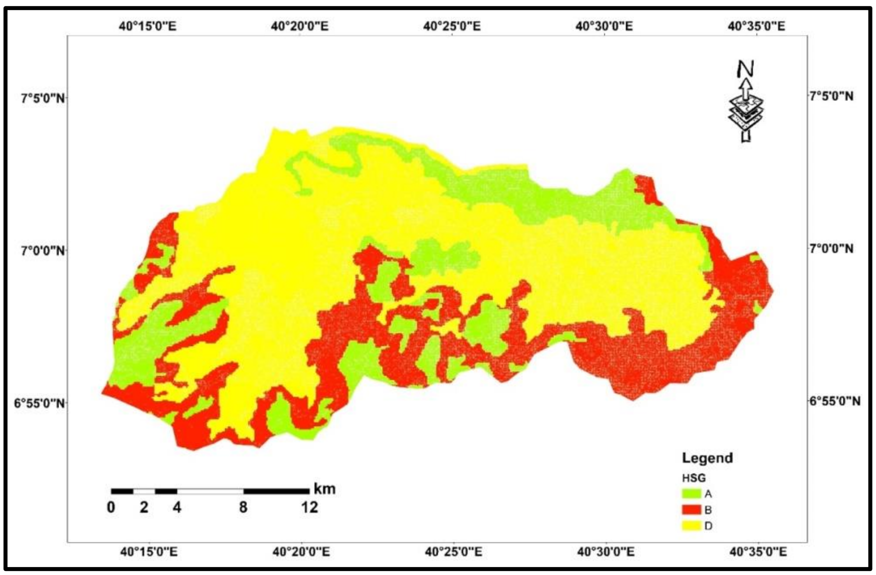

Figure 11: Hydrologic soil group in the study area

Figure 11 shows the generated CN map per pixel after possible intersection of land cover/land use map and the hydrological soil group map. This figure gives an indication of areas that have a potential to generate more runoff based on the two input factors. High CN values represent areas that have high runoff potential and low infiltration. This is due to the fact that initial abstraction and storage are minimal. There is high runoff potential in the upstream of the catchment as indicated in Figure 11, since this area is mostly covered with group D and B soils which have moderate to low infiltration rates and they are made of Clay and loamy textural classes respectively.

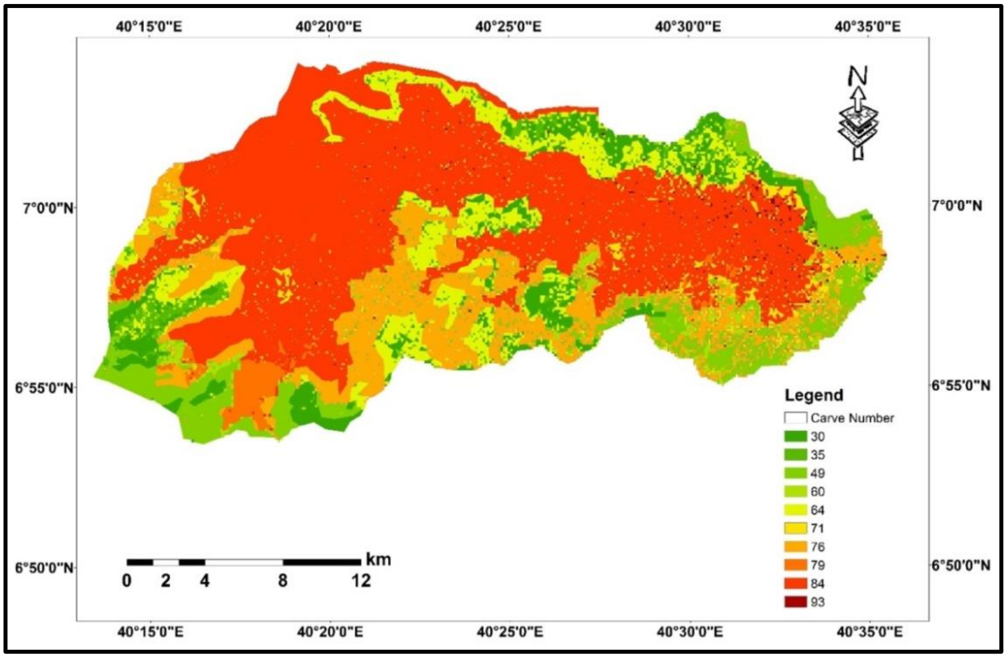

Figure 11: Curve Number of the Study Watershed

On the downstream of the catchment majority of the area is covered with group B and A soil, which has high infiltration rate and low runoff potential due to their coarse textural characteristics. The dominating soil textural class in this area is the sandy loam. However, there are some areas downstream of the study area that has high runoff potential which is represented by high CN. These are areas with group D soil and have high curve number ranges of 76-84 and the dominating land use is Agricultural land areas.

Table 10: Annual runoff depth of the land use type in the watershed

Land use type	**Runoff (mm/year)**	**Area(km^2)**	**Area (%)**
Agricultural land	580	319.5	63.9
Forest	910	39.5	7.9
Grazing land	365	39.6	7.9
Settlement	520	33.2	6.6
Shrubs	250	65.1	13.0
Water	710	2.9	0.6

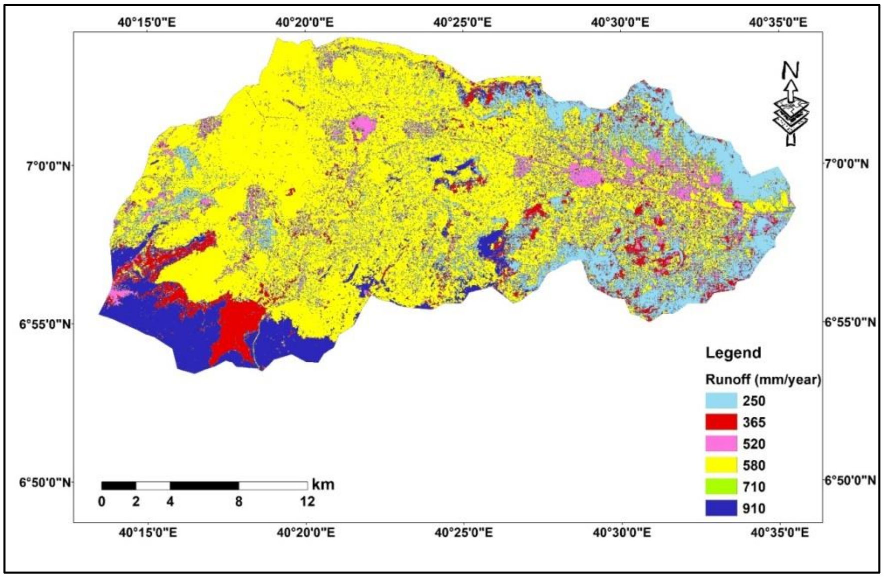

Figure 12: Runoff Depth in mm per Annum for the Study Area

Figure 12 shows the generated runoff depth expressed in mm per annum. Majority of the areas in Goro catchment have high runoff depth, these areas are covered with group D soil and are dominated by Agricultural land and forest land use.

Determination of Potential Site for Surface Rainwater Harvesting

In this study, the input layers/factors were rainfall, soil texture, soil depth, slope, runoff and land use/cover. These thematic layers were used to identify the spatial extent of potential surface rainwater harvesting site for rainwater harvesting systems and identify potential sites for different surface rainwater harvesting technologies in the Goro catchment. Since determination of the suitability of the land for potential runoff harvesting site specific and requires quantitative data and Ziadat *et al.* (2006) suggest integration of specific factors, a multi criteria analysis commonly known as Analytical Hierarchy Process which uses a pair wise comparison employed to determine which criterion is more significant than the other.

Table 11 shows different weighting factors assigned to each thematic layer for both micro and macro rainwater harvesting systems. These weights were used to identify and map suitable sites for various surface rainwater harvesting.CR for both rain water harvesting systems was calculated to evaluate if the pair wise comparison fall within the acceptable limits and the results shows that the CR for rainwater harvesting system was 2.4%.

Table 11: Different Weighting Factor for each Thematic Layer

Thematic Layer	Potential water harvesting Weight factor
Rainfall	0.398103
Land use and Land cover	0.175048
Soil texture	0.144365
Slope	0.147295
Soil depth	0.05685
Runoff	0.078339

The spatial extent of potential suitable sites in Goro catchment for rainwater harvesting has considered the following physiographic factors; runoff, slope density, soil (texture and depth), rainfall and land use which have been integrated using different assigned weights (Table 12) to produce four suitability classes. Figure 13 shows the results of this spatial extent.

Table 12: Percentage of water harvesting suitability of the study area

Water Harvesting Potential	Area(km^2)	Area (%)
Not Suitable	2.30	0.47
Marginally Suitable	33.89	6.98
Moderately Suitable	109.24	22.49
Suitable	198.55	40.87
Highly Suitable	141.76	29.18

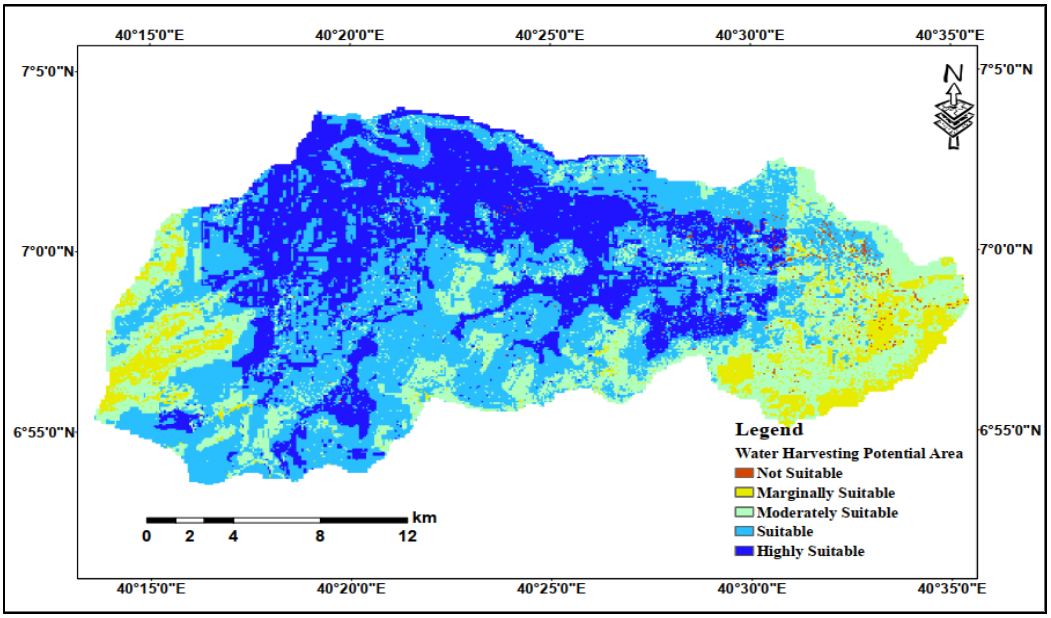

Figure 13: Potential Site for Surface Rainwater Harvesting for the Study Area

From the total study area of 500 km^2 of the Goro watershed, 29% is highly suitable, 40.89% Suitable, 22.5% moderately suitable and for surface rainwater harvesting systems. These are sites that have no limitation to sustain the intended purpose. Majority of these areas are found in locations that have relatively high runoff depth of about 580 to 710 mm/annum or more with high annual runoff coefficient, ranging between 0.78 and 0.85 and are located in high drainage density areas. Most of these suitable sites are located on undulating to sloping landscape with a slope percentage of less than 3%-15% and are surrounded by areas with higher elevation of about 1600 m.a.s.l. The soils are loamy to clay and they have vertic type soil. Areas that are classified as not suitable are found mostly in steep mountainous to hilly topography and are located far from the drainage network. This analysis corresponds to the results by Prinz *et al.* (1998) where the authors found that locations with high drainage network are ranked higher in suitability, as compared to areas with fewer networks of drainage channels. This is due to the fact that as you move away from the river there is higher potential of water losses as a result of seepage and evaporation.

The soils around this area are mostly sandy soils and this type of textural class is not suitable for location of surface farm ponds since the soil is characterized by excessively to somewhat drained and many at times are deep, so most of the harvested water will be lost through a process called percolation and hence recharging the water table. The marginally suitable sites are found in areas that area covered by loamy sand and the main dominating land use/land cover is the open grass which has a CN of ranges between 30-59 and a low runoff depth per year.

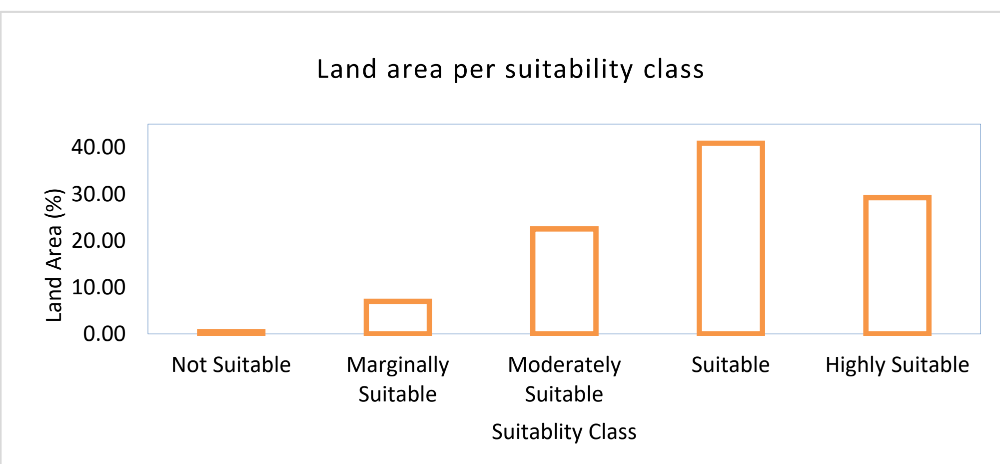

Figure 14: Percentage land area per suitability class for RWH system.

Vertisol types of soils are suitable for most macro RWH systems due to the fact that they have high water retention capacity, which is associated with low seepage and percolation. The results analysis matches with Mbilinyi *et al.* (2005) where the authors found out that farm pond were constructed on locations with Vertic soil properties. The authors further describe that, this factor is suitable, since runoff water can easily enter and leave the rainwater storage medium by gravitational force. From the results, areas with high elevation are the sites that have been analyzed to have a marginally suitable potential for RWH and occupy 6.98% of the study area (Table 12). These results correspond to the observed data in the field where few farm ponds were observed in areas of high elevation.

Validation and Testing

For testing and validating the accuracy of the identified potential surface rainwater harvesting sites in the catchment pilot test was done at highly suitable class. The intervention at the selected area was done at Nira Nagay PA of Goro district-on farm, for one year (2013) on one farmer as a demonstration. The Farm ponds was excavated at dimension of 8m*8m, with stealing basin at the inlet of the ponds for the purpose of silt trapping not let into o the pond. The pond was lined with geomembrane to reduce seepage water lose. The collected water during rainy season was stored in the Ponds (60 m^3 total capacity) for using during runoff-season for high value crop tomato (Galila variety). The plastic tank and geomembrane were found from nearby suppliers and low-cost drip set which operates with gravity installed at 1m height above the ground using barrel to supply water for tomato.

Figure 15: Constricting ponds for the surface runoff harvesting

Figure 16: Harvested water used for Irrigation by Drip irrigation

Figure 17: Demonstration of farm ponds irrigation for tomato production

Conclusions and Recommendations

Rainwater harvesting implementation may be debatable if assessment and site identification would not carry out by considering multi-criteria approaches. It is evidenced that some of the sites identified so far in different parts of Ethiopia in general and study area in particular, are failed due to improper selection of the sites. Despite of the availability of water harvesting manuals explaining about site selection, type and design, suitability analysis using geo-technologies is with far reaching importance. Currently, harvesting sites are simply selected to satisfy the quota-based distribution of woredas regardless of the guidelines given. As a result, sites are selected improperly with respect to the soil availability, design, absence of farmer's participation in planning and implementation. Effective utilization of runoff of water is important for enhancing the sustainability and acquiring rain fed related activities like farming activities, pasture availability for animal feed and others. Hence, information delivering through identification of potential sites for rainwater harvesting is important step preceeding to the actual preparation and execution. In this study, potential areas of rainwater harvesting were identified using ArcGIS10 software applications applying the multi-criteria evaluation approach to combine the effects of different environmental variables (slope, soil texture, land use, soil depth, rainfall surplus and runoff). A separate suitability analysis was done for each criteria map which produces an aggregate potential map for rainwater harvesting. Hence, large part of the study area belongs to suitable class while insignificant share is not suitable. Based on the aggregated suitability map: 29.18%, 40.87%, 22.49, and 6.98 % of the study area belongs to very high, high, moderately suitability and marginally suitable classes while the remaining 0.5% is under no suitable. The analysis gives a great advantage of optimum development for rainwater harvesting sites since it shows those areas which are conducive for the development. It also helps to direct the future development of rainwater harvesting sites thereby protecting other land uses at the same time. In general, the result of suitability analysis gives an important conception about the interactions existed among the factors. It enables to make an informed decision about the environmental conditions and thus, more sustained quality of life for the community and the surrounding ecological environment. Therefore, suitability analysis is a powerful tool for rainwater harvesting site identification and planning. Since, the application of GIS is a new and flexible technology for suitability analysis, refinement is possible when a need arises.

The results of the models revealed that there is high rainwater harvesting potential in Goro District and, if optimally harvested, the local farm water demand for crops could be achieved. The framework of this study could be adopted in research and practice to plan and manage future rainwater harvesting activities or projects in Ethiopia and other countries in the region. The study approach could be refined in future studies by including more social-ecological factors in the model.

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Evaluation of the Effect Mulching Practice under Furrow Irrigation on Growth, Yield and Water Productivity of Head Cabbage at Adami Tulu Agricultural Research Center

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Abstract

Water has been identified as one of the scarcest inputs, which can severely restrict agricultural production and productivity unless it is carefully conserved, managed and improve water use efficiency and labor without a significant tradeoff in yield. It leads to see the effect of mulching material and irrigation level were evaluated at full and half of crop water requirement. With the objective of to investigate and evaluate the effect of furrow irrigation level and mulching on water productivity, yield and yield component of head cabbage. The experiment has been under taken among the amount of water and mulching practice at Adami Tulu Agricultural Research Center of experimental site for head cabbage production. A field experiment was designed as as split plot in RCBD, replicated three times. The two factors were irrigation water level and mulching material. Irrigation was applied to furrows using Parshal flume from furrows head ditch with similar inflow rate, but the amount of application of water varies. Results obtained revealed that application of wheat straw mulch and plastic mulch significantly increased the growth and yield of cabbage. Straw mulch produced total yield of 9.68 ton/ha which was not significantly different with that obtained under White straw mulch (9.69 ton/ha). Total yield harvested from black plastic mulch were 9.33 ton/ha, which showed insignificant difference between the three mulching material. High yield of 16.60 ton/ha was recorded from full irrigation that is 100%ETc and when half of irrigation water applied the yield were 9.4ton/ha which showed significant difference between the two irrigation level. Water productivity of 4.3kg/m^3 and 3.8kg/m^3 were produced under 50%ETc and 100%ETc or full irrigation water respectively. It was found that 50%ETc irrigation level saved 50% of water as compared to full irrigation and can irrigate additional land with the amount of water saved.

Key words: *Straw Mulch, Irrigation Level, Crop Water Requirement, Water Use Efficiency*

Introduction

The pressure on agriculture is increasing due to population growth thereby creating a need to improve agricultural production and productivity. There is a growing recognition that increases in food production will largely have to originate from improved productivity per unit water and soil. To meet future food demands and growing competition for water, a more efficient use of water in irrigated agriculture will be essential. Since the beginning of civilization, man has developed technologies to increase the efficiency of food production. The use of plastic mulch in commercial vegetable production is one of these traditional techniques that have been used since 1950's. A favorable soil-water-plant relation is created by placing mulch over the soil surface. The microclimate surrounding the plant and soil is significantly affected by mulch i.e. the thermodynamic environment, the moisture, the erosion, the physical soil structure, the incidence of pests and diseases, crop growth and yield.

Vegetable crops are the eminent sources of human nutrition. These are short duration crops, which can be grown even in small spaces. Demand for fresh or canned vegetables is increasing in national and international market. Considering that the world population is estimated to increase by 65% (3.7 billion) by 2050, the demand for food will increase strain on fresh water resources (Wallace, 2000). Increase in area under production of any crop is of no use until economic yield per unit area does not increase. Commercial production of vegetable is not possible without adequate water availability throughout the growing season. Due to expected scarcity of water in future, water use efficient crops can only cope with the increasing demand. In order to maximize water use efficiency by the plant and to improve the quality of produce, the use of mulch has become an important cultural practice in many regions of the world for the commercial production of vegetable crops. Mulches can be used to conserve moisture and increase growth. The use of mulches has aided growers in increasing crop production efficiency by promoting favorable moisture and temperature conditions.

Different forms of plastic mulch are available varying from woven plastic to smooth plastic and embossed plastic films. Now-a-days 100% compostable and biodegradable mulches are also available in advanced countries and these are more environment friendly. In addition to the surface structure, the color and thickness of the mulch creates lot of variations which have an effect on the plant microclimate and in particular the soil temperature. Soil temperatures can be increased in the field by applying plastic mulches. They are inert and do not add crop nutrients to the soil by decomposition, but have been successfully used to achieve a number of effects with certain advantages over other mulches (e.g., straw mulches, clear plastic mulches).These advantages include: warming of soil for improved germination and seedling vigor, control of weeds, reduction of evaporation from the soil surface and aiding seed germination by keeping the soil surface moist.

The advent of increasing water scarcity in this century will observe less increase in irrigated land availability for food production than in the past. Novel irrigation technologies need to be tested under local environments and particularly in agricultural production systems of developing countries. While irrigation can benefit yields and enhance water use efficiency (WUE) in water limited environments, the potential for full irrigation is decreasing, with increased competition from the domestic and industrial sectors. Thus, the main challenge confronting both rain fed and irrigated agriculture is to improve WUE and sustainable water use for agriculture. Ethiopia is facing a tremendous challenge in meeting the food needs of rapidly growing population. There are small, medium and large scale irrigation systems in Ethiopia (FAO, 1995). To this end, both irrigated and dry land cropping areas will have to be developed or improved in the future. However, these tasks will not be easy, the cost of developing large scale and medium scale level irrigation is by now sky rocketing. Therefore, efficient utilization of water resources and development of small scale irrigation schemes at family level is crucial for countries like Ethiopia, which has a huge water resource: yet their population is chronically food insecure.

Traditionally, farmers in the central rift valley of Ethiopia have been using the most conventional surface irrigation system for growing crops during the dry season. However, water resources are becoming scarce resource in the area for crop production due to increasing competition for irrigation water. Efficient use of irrigation water is becoming increasingly important considering the availability of irrigation water resources and sustaining the production and productivity of growing crops in the area.

The soil moisture status in the root zone regulates plant growth and influences ET. Management practices that influence soil moisture include irrigation techniques, irrigation strategies and mulching practices. The particular irrigation technique influences the way irrigation water is applied, which influences for instance the percentage of surface wetting, which again influences ET (Raes *et al*., 2013). The particular irrigation strategy applied determines how much and when irrigation is applied. The mulching practice determines soil cover and in this way influences non-productive evaporation. Therefore this work was conducted to investigate the effects of furrow irrigation level and mulching on yield, yield component and water productivity of cabbage.

Materials and Methods

Experimental Design and Treatments

Field experiments were carried out during dry cropping season (October – April). Treatments were two water level of furrow irrigation and four mulching technique (No mulch [NM], straw mulch [SM], black plastic mulch [BPM] and white plastic mulch [WPM]). The experimental treatments were has been split plot in randomized complete block design with three replications, in which the furrow irrigation water levels were used as main plot and the four mulching technique were used as sub-plot.

Table 1. Treatment combination

Main plot (MP)	**Sub plot (SP)**			
	NM	SM	BPM	**WPM**
Full	1	2	3	
Half	5	6	7	**8**

Crop management practices

The experimental fields were divided into 24 plots and each experiment plot were had plot sizes of 5m by 5m to accommodate five furrows with spacing of 100cm and 5m length. . The plots and replications were had buffer zone of 1.0m and 4.0m between plots on none supplying and supplying canal sides, respectively to eliminated influence of lateral water movement. The experimental plots were pre-irrigated before two days to planting. Head cabbage was planted on well prepared experimental field plots. Establishment irrigation was applied before the commencement of differential irrigation. The predetermined amount of irrigation water were based on allowable soil moisture depletion for cabbage, each plot were irrigated using Parshall flume.

Irrigation management

The amount of water that can be extracted by plant roots is held in the soil in an ‘available’ form. The actual volume of water that can be obtained from the soil profile depends on the depth of the root system. Not all of the water found in the root zone was actually be taken up by roots. The total available water (TAW), stored in a unit volume of soil, is approximated by taking the difference between the water content at field capacity (FC) and at permanent wilting point (PWP). The TAW is expresses as:

$$TAW = \frac{(FC - PWP) * BD * Dz}{100}$$

Where: FC and PWP in % on weight basis, BD is the bulk density of the soil in gm cm^{-3}, and Dz is the maximum effective root zone depth in mm.

The bulk density, BD, is the mass of a soil in a unit volume for undisturbed soil condition and is expressed on dry weight basis of the soil as:

$$BD = \frac{Ms}{Vs}$$

Where: Ms is the weight of oven dry soil, and Vs is the volume of the same soil in cm^3.

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

$$RAW = p * TAW$$

Where: RAW in mm, p is in fraction for allowable/permissible soil moisture depletion for no stress, and TAW is total available water in mm**.**

Head cabbage is sensitive to water deficit. For high yield, soil water depletion should not exceed 45% of the TAW (p=45%). Irrigation was discontinued as the crop approaches maturity to allow the tops to desiccate and also to prevent a second flush of roots growth (Doorenbos and Kassam, 1979). Soil moisture was monitored gravimetrically and/or using soil moisture measuring device at 20cm soil depth increments up to 40cm soil depth (0-20, and 20-40cm) in a single replication. Permissible soil moisture depletion was taken as 100% ET requirement and all other treatments were then be adjusted accordingly to irrigate the plots. The depth of irrigation supplied at any time can be obtained from a simplified water balance equation which is expressed as:

$$In = ETc - Pe$$

Where: In is the net irrigation depth (mm), ETc is the crop water requirement (mm) and Pe is the effective rainfall (mm)

The gross irrigation requirement was obtained from the expression:

$$Ig = \frac{In}{Ea}$$

Where: Ig is the gross irrigation depth and Ea is the field application efficiency (%)

In the case of furrow irrigation, knowing the application efficiency of the furrows, the time required to deliver the desired depth of water into each furrow were calculated using the equation:

$$t = \frac{d \times w \times l}{6 \times Q}$$

Where: d= gross depth of water applied (cm),
t= application time (min),
l= furrow length in (m),
w= furrow spacing in (m), and
Q= flow rate (discharge) (l/s)

Soil moisture depletion at any soil moisture level was observed with the following expression as:

$$SMD = (FC - MC) x Dzr$$

Where: SMD = Soil moisture depletion (mm), FC = Volumetric soil moisture content at field capacity (mm), MC = Volumetric moisture content at time of irrigation (mm),
Dzr = Depth of effective root zone (mm)

Data to be collected

Soil data

Soil samples was collected from the experimental field using core samples from the soil depths of 0 - 20cm, 20 - 40cm. Soil physical properties like textural class, bulk density, and infiltration rate, OM, FC, PWP and TAW were determined.

Regular soil samples were collected from experimental plots before and after irrigation for gravimetric soil moisture determination. The gravimetric soil moisture is then determined using the expression:

$$SMC\ (\%) = \frac{(Wws - Wds)}{Wds} * 100$$

Where SMC is the soil moisture content at time of sampling (%), Wws is weight of wet soil (gm) and Wds is weight of dry soil (gm).

Crop Data

Date of planting, maturity and other relevant agronomic parameters were recorded from five randomly selected plants from three middle rows of each experimental plot and these plants were tagged for subsequent measurement. The center of each plot was harvested for yield and head trait data. The first harvest was occurred when approximately 50%of the cabbage heads reached 1 kg, while all remaining plants were harvested during a second harvest. Cabbage is harvested by cut-ting the stem at the soil surface. The heads were weighed before and after the removal of the outer wrapper leaves. Cabbage heads were classified as marketable when trimmed head weight is above 1 kg and unmarketable for head weight below 1 kg. Total cabbage yield were calculated as marketable and unmarketable trimmed heads. A total of 40 cabbage heads from furrow 20 head cabbage (5 per heads per row) per plot and 20 head cabbage (5 per heads per row) per plot was randomly selected for internal quality evaluation. Measurements of cabbage head equatorial and polar diameter, core length, and core base width were recorded. Cabbage heads were treated as a sphere for the head volume calculation and cores were treated as a cone for the volume calculation, as described by Kleinhenz and Wszelaki (2003).

Climatic data

Data on daily climate of the site were collected from the meteorological stationobservatory. The reference evapotranspiration (ETo) was computed using Penman-Monteith method, CROPWAT ver. 8.0 window based computer model from the climatic data gathered from station. The cabbage crop evapotranspiration (ETc) for each day were computed by multiplying the ETo by the crop coefficient (Kc) values obtained from FAO (1977) for each of the four stages of cabbage *viz*., initial, development, mid and late season. The KC values represented the ratio of crop evapotranspiration (ETc) and reference evaporation (ETo) rate each day. The effective rain fall were computed by the CROPWAT program from the monthly total rainfalls. The net daily crop water requirement was computed by reducing the ETc by the daily effective rainfall. The gross water requirements were computed by applying field application efficiency.

Water use efficiency

The water use efficiency was calculated by dividing harvested yield in kg per unit volume of water used. Crop water use efficiency: The crop water use efficiency is the yield harvested per ha-mm of total water used.

$$CWUE = \frac{Y}{ET_C}$$

Where: CWUE = crop water use efficiency (kg/ha-mm)
Y = yield in kg ha-1 and ET = is evapotranspiration (mm)

Field water use efficiency: Field water use efficiency is the yield harvested per ha-mm of net depth infiltrated.

$$FWUE = \frac{Y}{I_n}$$

Where: FWUE = field water use efficiency (kg/ha-mm)

Y= yield in (kg/ha) and I_n= Net irrigation is in (mm)

Data analysis

The effect of furrow irrigation under mulching on the growth and yield of head cabbage were analyzed using SAS software. The data collected were statistically analyzed following the standard procedures applicable to split plot for RCBD. When the treatment effects are found significant, LSD test was performed to assess the difference among treatments means**.**

Result and Dscussion

The experiment was conducted to determine the Yield and water use efficiency of head Cabbage influenced by different mulch practices. The analysis of variance (ANOVA) of the data on different yield components and yield of head cabbage are determined. The results have been presented and discussed, and possible interpretations have been given.

According to Ramakrishna et al. (2006) states that evaporation from the soil accounts for 25-50% of the total quantity of water used. Yield components were significantly reduced by covering material when measured at harvest. Significantly reduced head fresh weight, height and width.

Head Equatorial and Polar Diameter

The effects of mulch types/ cover material on cabbage head equatorial development were not significant different between wheat straw mulch (12.38 cm) and black plastic mulch (11.86 cm), but significantly different with white plastic mulch (10.10 cm) and bare soil (10.72 cm) (Table 1). The effects of mulch types/ cover material on cabbage polar diameter development were significant. Wheat straw mulch (11.83 cm), black plastic mulch (11.66 cm) and bare soil (10.22 cm) had significantly higher means than white plastic mulch (10.02 cm) (Table 1). White plastic mulch had significantly lower means. Cabbage head diameter in BPM and wheat straw mulch was not statistically different.

Table 1:- The effects of mulching material on Head Equatorial and Polar Diameter

Treatment	Head Equatorial	Polar Diameter
NM	10.72^{b}	10.22^{bc}
SM	12.38^{a}	11.83^{a}
BM	11.86^{ab}	11.66^{ab}
WM	10.10^{b}	10.02^{c}
LSD	1.78	1.57
CV	9.06	9.76

* *NM=No Mulch, SM= Straw Mulch, BM= Black Mulch and WM=White Mulch*

Base Width and Length

White plastic mulch had significantly higher means (11.08 cm) than black plastic mulch (10.53 cm) and straw mulch (9.87 cm) on base width. On the other hand black plastic mulch had significantly higher means (6.20 cm) than straw mulch (5.9 cm) and white plastic mulch (5.88 cm) on base length and the lowest base width were recorded on bare soil or control treatment (5.15 cm).

Table 2:- The effects of mulching material on Base Width and Base Length

Treatment	Base width	Base Length
NM	7.30^{b}	5.15^{b}
SM	9.87^{ab}	5.90^{a}
BM	10.53^{a}	6.20^{a}
WM	11.08^{a}	5.88^{ab}
LSD	2.90	0.73
CV	13.32	10.77

* *NM=No Mulch, SM= Straw Mulch, BM= Black Mulch and WM=White Mulch*

There was no significant difference in yield between the black plastic and wheat straw mulch types. The means for wheat straw were significantly higher than for black plastic mulch on base width. *Locascio et al.* reported that black plastic mulch significantly increased plant height compared to other mulch colors.

Effect of mulch type on cabbage yield (weight per cabbage head)

There is no significant variation was recorded in terms of fresh weight of unfolded leaves per plant due to the different types of mulch. Straw Mulch gave the maximum (2240g) fresh weight of unfolded leaves per plant which was statistically similar (2160g) with WPM (White Plastic Mulch) and (2070g) black plastic mulch treatment and the minimum (1383g) was found from NM (No Mulch) treatment (Table 3). The effect of mulch type was not significant ($P<0.05$) on cabbage yield (Table 3). Wheat straw and black plastic mulch had significantly higher mean weight per cabbage head and bare soil.

Table 3:- The effects of mulching material on yield of head cabbage

Treatment	WRB in gram/plot	WRA in gram/plot
NM	1383[b]	901[b]
SM	2240[a]	1453[a]
BM	2070[a]	1400[ab]
WM	2160[a]	1453[a]
LSD	713	546
CV	**25.81**	**30.72**

**WRB=Weight of outer leaves Before Removal, WRA= Weight of outer leaves After Removal, NM=No Mulch, SM= Straw Mulch, BM= Black Mulch and WM=White Mulch*

There was no significant difference in yield between the white plastic and wheat straw mulch types. The means for white plastic mulch were significantly higher than for wheat straw and black plastic mulch. Results of this study agree with findings by Chantal U. *et.al* (2017) that straw mulch and black plastic mulch have the same response on yield.

Effect of mulch type on yield of cabbage

There was no significant difference in yield between the white plastic and wheat straw mulch types, But significantly different with bare soil/control at total yield of weight after removal of the outer leaves. The highest 9.69 and 9.68 ton/ha were recorded at white plastic mulch and straw mulch, followed by 9.33 and 5.91 at black plastic mulch and bare soil respectively.

Application of wheat straw mulch and black plastic mulch significantly increased the growth and yield of cabbage than bare soil. This may have been due to the ability of mulch to retain moisture in soil and increase the plants‟ water use efficiency (Yaghi and Noum, 2013). Black plastic mulch additionally increases soil temperature and reduces weeds (Locascio et al., 2005; Gordon et al., 2010), and this promoted cabbage growth compared to bare soil.

Table 4:- The effects of mulching material on yield of head cabbage

Treatment	WRB in ton/ha	WRA in ton/ha
NM	9.22[b]	5.91[b]
SM	14.93[a]	9.68[a]
BM	13.80[ab]	9.33[ab]
WM	14.40[a]	9.69[a]
LSD	4.75	3.64
CV	25.82	30.71

WRB=Weight of outer leaves Before Removal, WRA= Weight of outer leaves After Removal, NM=No Mulch, SM= Straw Mulch, BM= Black Mulch and WM=White Mulch

Results of this study agree with findings by Decoteau *et al*. (1986) and Yang *et al*. (2015); which showed that mulching in general has a positive effect on plant height, leaf numbers and size, shoot diameter and dry matter.

Economic Analysis

The economic analysis of plastic mulching material when compared to the unmulched is highest on material cost but the bare soil and straw mulch were incurred the same amount of total cost due to straw mulch decreasese the cost of weeding when compared with bare soil.

Table 1. Economic Analysis of profitability of mulching

Parameters	**Mulching material**			
	NM	**SM**	**BPM**	**WPM**
Material cost (birr)	00.00	10000.00	42000.00	42000.00
Labor cost (birr)	25000	15000	15000	15000
Input cost cost (birr)	10000	10000	10000	10000
Average Total cost (birr)	35000	35000	67000	67000
Yield gained(kg)	59100	96800	93300	96900
Average sale price(kg/birr)	7	7	7	7
Average gross Return (birr)	413700	677600	653100	678300
Average Net return (birr)	**378700**	**642600**	**586100**	**611300**

The average net return of straw mulch treatment is greater than other mulching material and bare soil. The highest net benefit gained 642,600 birr, 611300birr and 586100birr on straw mulch, white plastic mulch and black plastic mulch respectively and the least net benefit gained 378700birr from the bare soil/unmulch of the treatment.

Conclusion and Recommendation

Use of plastic and straw mulch was beneficial in retention of soil moisture and suppression of weeds. This resulted in enhanced stem diameter development compared to the control (bare soil). Water regulates plant development by performing three basic functions; mediates environmental effects on growth and metabolism, correlates the growth of different parts of the plant, and integrates growth and metabolic activity at the cellular level. Different mulches applied in the head cabbage field had significant effect on different parameters. Results exposed that the highest head equatorial (12.38cm and 11.86cm at straw mulch and black plastic mulch, respectively), the maximum polar diameter (11.83 and 11.66cm at straw mulch and black plastic mulch, respectively), the maximum base width (11.08 and 10.53cm at white plastic mulch and black plastic mulch, respectively), the maximum base length (6.2 and 5.9cm at black plastic mulch and straw mulch, respectively), the maximum head weight before removal per plant (2240 and 2160gm at straw mulch and white plastic mulch, respectively), were recorded straw mulch treatment. Again the maximum total yield after removal of outer leaves of head (9.69 and 9.68) at plastic mulch and straw mulch). The study on "effect of mulch type on growth and yield of cabbage in the study area revealed that, Application of the black plastic and wheat straw mulch influenced positively plant growth and yield because of capacity of mulch to retain moisture for increased nutrient uptake and Black plastic and wheat straw mulches generated higher soil moisture compared to the control.

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Effect of Plastic and Organic Mulching on Soil Moisture Retention and Yield Response of Tomato under Furrow Irrigation

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Abstract

*Inadequate soil moisture during crop growing season is major factors that reduce quality produce and high-yield of tomato production at the Rift-valley of Ethiopia. For this overcome field trial was conducted to study the effect of four mulch material and two irrigation levels on soil moisture retention, water use efficiency, water productivity and yield of Gelila tomato at Tiyo worada of Golja Kebele. The treatments were 4*2 factorial combinations of mulching materials which are white plastic, black plastic, wheat straw mulch and no mulch with two water level of 100% ETc and 75% ETc. Factorial design consists of four mulching materials (white plastic, black plastic, wheat straw mulch and no mulch) as main plot and two water levels (100% ETc and 75% ETc) as sub-plot used with three replications. The interaction of irrigation level and mulching types were significantly different at ($p<0.05$) on soil moisture retention, water use efficiency, water productivity and yield. From the findings of this experiment, the highest soil moisture retention (*40.09%), *marketable (*55.17 ton/ha) *and total yield (*64.03 ton/ha) *were obtained during interaction of white plastic mulch with 100% ETc but its WUE (*12.95 kg/m^3) *was the fourth. The second was white plastic mulch with 75% ETc but WUE (16.35* kg/m^3*) and benefit cost ratio (*18.49*) were the first. The last was recorded at non-mulch. Therefore from eight treatment conducted on experiment combination of WPM * 75% ETc was recommended for the farmers and investor work on production of tomato at irrigation water shortage area.*

Key Words: *Plastic mulching, soil moisture retention, tomato, yield response*

Introduction

Tomato (Lycopersicon esculentum L.) is one of the most important edible and nutritious vegetable crops in the world. It ranks next to potato and sweet potato with respect to world vegetable production (FAO, 2006). In Ethiopia, the crop is one of the most important vegetable and commercial crops, which identified in the growth and transformation plan (GTP) as a high values. It was produced mainly in the northern and central rift valley areas (Quintin *et al*., 2013). In recent years, commercial tomato production has significantly expanded since national agricultural strategies began, favoring high value cash crops. The total area of land estimated to be covered by tomato farms in 2011/12 marketing year (MY) is 7,255 ha with an estimated yield of 81,970 MT

(11.3 MT/ha). Oromia region contributes the lion's share of Ethiopia's total tomato production (56, 279 MT or 68%) with the remaining production coming from Meki (9%), Tigray (5%) and Somali region (4%). It is estimated that more than 254, 000 farmers are engaged in tomato farming (Quintin *et al*., 2013).

Inadequate soil moisture and low soil temperature are the two major factors prohibiting quality produce and high-yield vegetable production (Vaddevolu *et al*, 2021). Mulching has become an important practice in modern field production. The use of mulches in vegetable production is undergoing a radical change away from high input, nonrenewable resources, such as plastic, to the use of high-residue organic mulches from cover crop (Kundu *et al*. 2019). Application of mulching material significantly influences on tomato plant growth, fruit yield and root zone soil temperature (Habtamu *et al*, 2016). The research reported that water directly affects the tomato yield, as it contains 94% water. For successful crop production more than 485 mm water is required during plant establishment, flowering, fruit setting and fruit development stage (FAO 1995). Sometimes, many of the farmers can't able to provide irrigation due to unavailability of irrigation facilities or even can't afford the expenses of irrigation. Under this situation mulching could be a good substitute means for irrigation to make soil moisture available.

Mulching has been reported to be increased yield by creating favorable soil temperature and moisture regimes (Habtamu *et al*., 2016,). Mulching is an effective method of manipulating crop growing environment to increase yield and improve product quality by controlling weed growth, ameliorating soil temperature, conserving soil moisture, reducing soil erosion, improving soil structure and enhancing organic matter content. Therefor to overcome irrigation water shortage and increase water use efficiency, this study was conducted with the objectives of, determining soil moisture retention, water use efficiency and yield response of Gelila tomato on two water levels and three mulching type under furrow irrigation.

Material and Methods

Study Area

The study was conducted at Arsi Zone, Tiyo worada of Katar-Genat Kebele during the off season of the rain when the crops being cultivated under irrigation.

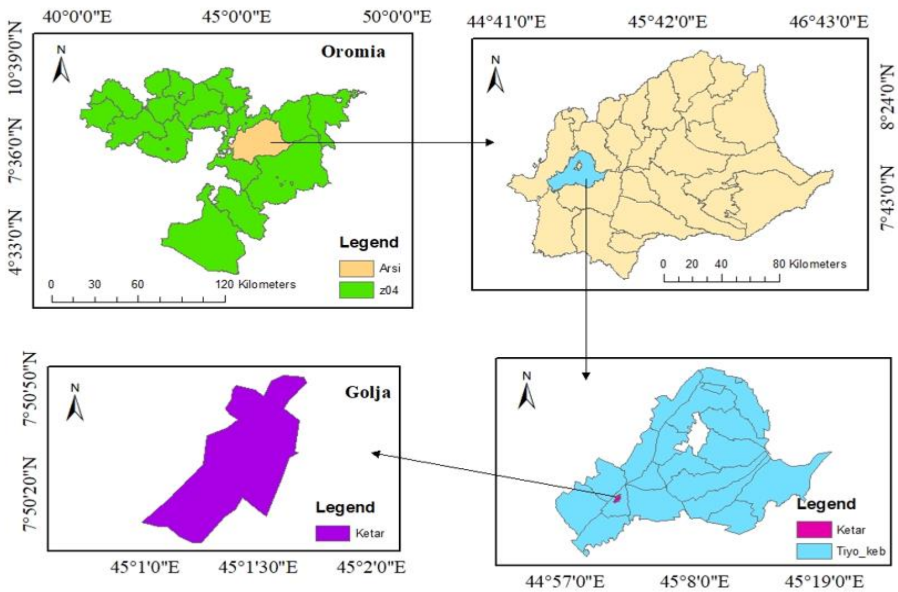

Fig 1:- Map of study area

Experimental Design and Treatments

The experiment had two factors, factorial design with three replications. The treatments considered were two factors namely two water levels and four mulching techniques. The mulching materials (white plastic, black plastic, wheat straw mulch and no mulch) as main plot and two water levels (100% ETc and 75% ETc) as sub-plot used.

Preparation of the experimental area

The total area of the experimental plot was 1080m^2(45m*24m) which was divided into 24 sub-plots each of 27m^2(4.5 m*6 m). The width of each ridge was kept as 0.45 m and furrow to furrow spacing of 0.70 meters.The ridges were covered with polyethylene plastic sheets (0.5 µm thick) and wheat straw mulch while furrow beds was kept uncovered. The plots and replications plot had a buffer zone of 1m and 1.5m between plots on none supplying and supplying canal sides, respectively to eliminate influence of lateral sub-surface water movement.

Crop Management Practices and application of fertilizer

The experimental plots were pre-irrigated three days before planting. Each treatment in a plot had consisted eight rows with total number of 88 plants per plot. After placing plastic film on the ridge, the tomato crops were planted at spacing of 40 cm distance. But in case of straw mulching the crops planted on ridge prior to straw mulching .The recommended rate of NPS and urea were uniformly applied to the plots through perforation or sowing in the furrow prior irrigation. NPS was applied at planting time only and urea was applied in Split application, half at planting and another half twenty days after planting. Light irrigations were applied prior to start of treatments applications for seven days. Water applications for control treatment or full irrigation (100%ETc) was based on the estimated crop water requirement calculated over the growing period and water deficit treatments 75%, was imposed as planned. In furrow irrigation, each plot was irrigated using Parshall flume.

Soil sampling and analysis

To characterize the soil at the study site samples was taken and determined. 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).

$$\rho_b = \frac{M_s}{V_t} \quad (1)$$

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 was 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)

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

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:

$$RAW = TAW * MAD \qquad (3)$$

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.

$$ET_c = ET_o \times K_c \qquad (4)$$

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;

$$I = \frac{d_{net}}{ET_c} \quad (5)$$

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. 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).

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

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. 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

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

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

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

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, $$Q = 0.1771 H^{1.550} \quad (9)$$

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

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

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).

$$WUE = \frac{Y_a}{ET_c} \quad (11)$$

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)

$$IWUE = \frac{Y_a}{IW} \qquad (12)$$

Where, IWUE- irrigation water use efficiency (kg/m^3), Ya - actual yield (kg/m^2)
IW - irrigation water applied (m^3/m^2),

Economic Analysis

Economic analysis was computed by using the results of this study based on investment, operation and production costs. Based on the irrigation amount of each treatment in the growing season; irrigation duration and labor cost were estimated. The mean tomato yield (kg ha^{-1}) was adjusted for yield losses by subtracting 10% of the tomato yield from total yield.

The production costs were computed by considering all production inputs (i.e. cost of seeds, cost of mulch material, plowing of land, transplanting, cultivating, weeding, pesticide application, fertilizer, harvesting). Finally, adjusted yield was multiplied by field price to obtain gross field benefit of tomato. The field price of tomato during the harvesting season was 20 Birr kg^{-1} and 3.8 Birr m^{-3} value for water was taken. The benefit cost ratio was calculated by dividing net benefit to total cost (Jansen *et al.,* 2007).

Statistical analysis

The collected data were statistically analyzed using Statistic version 8.0 and statistical package of using ANOVA. Mean comparisons were performed using least significant difference (LSD) at 5% probability level.

Result and Discussion

Physico-Chemical Properties of Soil

Table 1 below shows the soil particle size property of the study area. The average particle sizes of sand, silt and clay soil were 28, 33 and 39% respectively. The soil textural class of the study site was fall under clay loam according to Chandrasekaran *et al*., (2010) classifications

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

	Soil texture			
Samples	Sand %	Silt %	Clay %	Class
1	24	25	51	clay
2	24	35	41	clay
3	24	43	33	clay loam
4	30	32	38	Clay loam
5	26	36	38	clay loam
6	25	37	38	clay loam
7	34	24	42	clay
8	30	36	34	clay loam
9	36	30	34	clay loam
Average	**28**	**33**	**39**	**clay loam**

CL=Clay loam C= Caly

Table 2 below discussed the physico-chemical property of the study area. From this soil pH values were found in range of 5.51-7.40 and have average of 6.02. This indicates moderate acidic soil. Electrical conductivity (EC) of the stations was in range of 0.11-0.40 mmhos/cm at room temperature (25°C). Soil texture class of study area was clay loam. The average values of pH, Electrical conductivity and organic matter were 6.02, 0.2 and 3.49 respectively. The average of density, FC, PWP and TAW of the study site were 1.29 g/cm^3, 49.30%,32.42 % and 168.82 mm/m respectively . The result of soil density and TAW were fall at interval of clay loam soil. 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 2:- Soil pH, EC, OMC and texture determination of experimental site

Samples	P^H	EC (mmhos /cm at 25ºC)	OC %	OM	Bulk density (g/cm3)	FC (% Vol)	PWP (%Vol)	TAW (mm/m)
1	6.50	0.13	1.66	2.87	1.22	49.19	33.15	160.40
2	6.20	0.14	2.38	4.10	1.31	53.90	33.00	209.00
3	6.30	0.15	2.54	4.38	1.33	48.90	32.10	168.00
4	7.40	0.40	1.17	2.01	1.29	45.90	30.00	159.00
5	5.34	0.24	2.04	3.52	1.28	48.40	34.00	144.00
6	6.03	0.21	2.19	3.77	1.30	52.00	30.90	211.00
7	5.39	0.32	1.98	3.41	1.20	47.7	31.88	158.20
8	5.57	0.11	2.15	3.71	1.35	48.1	33.80	143.00
9	5.51	0.11	2.13	3.67	1.31	49.6	32.92	166.80
Average	**6.02**	**0.2**	**2.02**	**3.49**	**1.29**	**49.30**	**32.42**	**168.82**

Interaction effect of mulch and water level on soil moisture retention yield and water use efficiency

Table 3 show the interaction effect of mulch and water level on yield and water use efficiency of tomato. The total yield of tomato was 53.88-64.03 tone/ha. The result yield was agreed with the average yield of Galilae 57.9 tone/ha (Tesfa *et al.*, 2016). The soil moisture retention of WPM with 100%ETc was the highest and significant different from other mulch and water level interaction. The next was WPM*75%ETc but not significant different from BPM*100%ETC. The lowest was NM*75%ETc. These results agreed with the Awodoyin, *et al.*, (2007) plastic mulch increase soil moisture than organic mulch. The highest of branch per plant was registered in WPM*100%ETc but not significant different with WPM*75%ETc. The next was BPM*75%ETc and the lowest was NM*75%ETc. The highest marketable yield of tomato was registered at WPM*100%ETc. The WPM*75%ETc, BPM*100%ETc and BPM*75%ETc were the second, third and fourth respectively. The lowest yield was NM*75%ETc. The highest water use efficiency was recorded at WPM*75%ETc but not significant different BPM*75%ETc. The next was SM*75%ETc.

Table 3: Interaction effect of mulch and irrigation water level on soil moisture retention, yield component and water use efficiency of tomato

Treatment	SMR	BPP	NFP	MY	UY	TY	WUE
WPM*100%ETc	40.09^{A}	5.44^{A}	35.11^{A}	55.17^{A}	8.86^{A}	64.03^{A}	12.95^{D}
WPM*75%ETc	34.93^{B}	5.22^{A}	30.78^{B}	52.34^{BC}	8.30^{A}	60.643^{B}	16.35^{A}
BPM*100%ETc	35.66^{B}	4.78^{B}	31.56^{B}	52.86^{B}	8.54^{A}	61.41^{B}	12.41^{E}
BPM*75%ETc	32.07^{C}	4.34^{C}	29.22^{BC}	51.60^{C}	8.09^{A}	59.69^{B}	16.09^{A}
SM*100%ETc	31.33^{C}	4.01^{D}	26.22^{CD}	49.53^{D}	7.73^{AB}	57.26^{C}	11.57^{F}
SM*75%ETc	28.23^{D}	3.68^{E}	22.33^{E}	48.30^{E}	7.73^{AB}	56.08^{CD}	15.12^{B}
NM*100%ETc	28.12^{D}	3.50^{E}	25.33^{DE}	48.34^{E}	6.53^{B}	54.87^{DE}	11.09^{F}
NM*75%ETc	24.79^{E}	3.10^{F}	22.20^{E}	47.13^{F}	6.75^{B}	53.88^{E}	14.52^{C}
S.Em±	0.87	0.1196	1.5773	0.53	0.61	0.89	0.23
CV	3.33	3.44	6.94	1.29	9.53	1.87	2.01
LSD (5 %)	1.86	0.2565	3.39	1.14	1.31	1.92	0.48

WPM=white plastic mulch, BPM= Black plastic mulch, SM= Straw mulch, NM=Non mulch,SMR= Soil moisture retention,BPP= Brach per plant,NFP= Number of fruit per plant, MY= Marketable yield in tone/ha,UM= Unmarketable yield in tone/ha,TY =Total yield in tone/ha, WUE= Water use efficiency in kg/m3

Cost benefit analysis

From the table 4 the cost benefit ratio of WPM*75% Etc was the highest. The result was agreed with the (Kundu *et al*, 2019) of plastic much increase yield and net benefit.

Table 4:- Cost benefit analysis

Treatment	Total yield (kg/ha) (a)	Adjustable yield (kg/ha (b)=(a)-(a)*0.1	Total cost (ETB/ha)(c)	Grand benefit (ETB/ha) (d)=20*(b)	Net benefit (ETB/ha) (e)=(d)-(c)	Benefit cost ratio (f)=(e)/(d)
WPM*100%ETc	64000.0	57600.0	74,620	1,152,000	1,077,380	14.44
WPM*75%ETc	60600.0	54540.0	55,965	1,090,800	1,034,835	18.49
BPM*100%ETc	61400.0	55260.0	74,620	1,105,200	1,030,580	13.81
BPM*75%ETc	59700.0	53730.0	55,965	1,074,600	1,018,635	18.20
SM*100%ETc	57300.0	51570.0	69,620	1,031,400	961,780	13.81
SM*75%ETc	56100.0	50490.0	52,215	1,009,800	957,585	18.34
NM*100%ETc	54900.0	49410.0	67,620	988,200	920,580	13.61
NM*75%ETc	53900.0	48510.0	50,715	970200	919,485	18.13

Conclusion and Recommendation

Conclusion

Application of mulching material can potentially conserve soil moisture by reduce evaporation losses, and increase water use efficiency and yield of tomato. From the findings of this experiment, the highest soil moisture retention, marketable and total yield were obtained during interaction of white plastic mulch with 100% ETc but is WUE was the fourth. The second was white plastic mulch with 75% ETc but is WUE was the first. The last was recorded at non mulch. From eight treatment conducted on experiment two combination of mulching materials and water levels which are WPM * 100% ETc and WPM *75%ETc were not significantly different at ($p<0.05$) but WPM *75%ETc has highest value on water use efficiency. Therefore from eight treatment conducted on experiment the combination of mulching material and water level which is WPM *75%ETc was recommended at irrigation water shortage area.

The recommendation was also extended to researcher to conduct research on effect different thickness plastic much with respect to crop type, management practices, and climatic conditions.

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Effects of Mulching and Amount of Water on yield and yield components of Tomato (*Solanum Lycopersicum* L.) under Drip irrigation at Adola Rede, Southern Ethiopia

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Abstract

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. The aim of this study was to investigate effects of Mulching and Amount of Water on yield and yield components of Tomato (Solanum Lycopersicum L.) under Drip irrigation at Adola rede District, Southern Ethiopia. The treatments of the study comprised different combinations of three drip irrigation levels (100, 75, and 50% of ETc) and three mulches (No mulch, white polyethylene sheet, and wheat straw). The yield and yield components in the mulched treatments with high levels of irrigation were significantly higher compared to those in the unmulched treatments. The yield of tomatoes increased with the increasing amount of irrigation water in mulched treatments. The highest marketable fruit yield for white mulch 35478kg ha^{-1} and 28831kg ha^{-1} for straw mulch was obtained when 75% of the crop water requirement was applied. With 100% water application, the white plastic mulched treatment produced a lower marketable fruit yield than the straw-mulched treatment. The highest water productivity of (12.915kg m^{-3}) was obtained with 75% water application under white plastic mulch, But statistically non-significant with straw mulch under 75% crop water requirement application. The lowest water productivity (5.993kg m^{-3}) was obtained under white plastic mulch with 100% crop water requirement application. The highest net benefit of 563475.7ETB ha-1 was recorded from white plastic mulch with 75% ETc and followed by 484454.7ETB ha^{-1} with Straw mulch with 75% ETc. The lowest net benefit 285477.3ETB ha^{-1} was obtained from no mulch with 50% ETc. The highest benefit to cost ratio was obtained under treatment straw mulch with 75% ETc (15.04) and followed by no mulch with 100% ETc (14.32). This result revealed that wheat straw mulch with 75% ETc is economically feasible for tomato production in the Adola area of the Guji zone.

Keywords: *Crop water requirement; tomato, drip, mulching, water levels, fruit yield*

Introduction

Agriculture is the main water-consuming sector worldwide (Biswas, 1997), which accounts for 70 percent of all water withdrawn from aquifers, streams, and lakes (FAO, 2011). The global expansion of irrigated areas to feed the ever-increasing population and the limited availability of irrigation water are not balanced in a different part of the world. Rivers, lakes, groundwater, and different streams are dried due to unbalance between the inflow and outflow of water in the hydrologic cycle of that particular area. In arid and semi-arid areas where moisture stress is the main challenge for crop production, the spatial and temporal variations aggravate the problem.

Mulching practices have pronounced effects on enhancing water use efficiency (WUE). Kader *et al*., (2017) reported that both plastic and straw mulches increased the water use efficiency by 79% and 58%, respectively, compared to bare soil. Based on six years of experiments on rice crops in China, Wu *et al*., (2016) observed that the crop water use efficiency was increased by 70 to 80% and irrigation water use efficiency by 274% when the crop was raised under the plastic film mulch conditions compared to the traditional planting. Alongside the potential benefits of soil water conservation, better yield and higher water use efficiency, mulching also control weed infestation (Matković *et al*., 2015), improve soil texture (Nawaz *et al*., 2016), improve aeration, modify soil temperature (Ramakrishna et al.,2006), checking surface sealing and crusting of soil by protecting the topsoil surface from raindrop splashes(Brant *et al.*, 2017), decreasing nutrient losses and increase the infiltration rate (Lalljee, 2013), and increase sediment deposition by enhancing roughness of soil surface(Donjadee&Tingsanchali, 2016).

Drip irrigation is an irrigation method that allows precisely controlled application of water and fertilizer by allowing water to drip slowly near the plant roots through a network of valves, pipes, tubing and emitters (Simonne *et al.*, 2009). According to Michael (1978), drip irrigation is one of the latest of the systems and is becoming increasingly popular in areas with water scarcity and salt problems. Water from the source passes through plastic pipes, constituting the main and laterals, into emitters positioned to supply each plant with the calculated water requirement at the same delivery rate. Pressure head losses are encountered in lines which result in uneven distribution of the discharges from the emitters. Mofoke *et al*. (2021) reiterated that the most widely accepted hydraulic performance indices for assessing the drip irrigation system are emitter discharge, emitter flow rate variation, uniformity coefficient, and emission uniformity. Tomato (Lycopersicon esculentum Mill.) is one of the most common crops belonging to the nightshade family, Solanaceae. The fruit is consumed in diverse ways, including raw, as an ingredient in many dishes, sauces, and drinks. Tomatoes are rich in Vitamins A and B, and iron. Moreover, tomatoes are rich sources of lycopene, which is a very powerful antioxidant and helps prevent the development of many forms of cancer (You and Barker, 2004). Tomato plants are sensitive to water stress and show a high correlation between evapotranspiration and crop yield (Nuruddin *et al*., 2003).

Farmers in the study area producing this vegetable one per season using traditional furrow irrigation method for consumption and market sell. But due to shortage of irrigation water its production and land productivity is reduced and there is conflict among irrigators. The main reasons for shortage of water are inefficient use of irrigation water due to high percolation, runoff and evaporation loss which is caused due to over irrigation, resulting low water use efficiency. Shortage of capital and new technologies are the main constraints in the study area to implement and use modern irrigation method especially, drip irrigation.) A number of researches have been done to evaluate performance of drip irrigation under mulching practices in this country (Tegen *et al*., 2016 and Temesgen, 2018). However, no work has been done to study the combined effect of mulching and amount of water on yield and water use efficiency of tomato in the study area. Therefore, the objective of this study was to investigate the combined effects of mulching and amount of water on yield and water use efficiency of tomato (*Solanum Lycopersicum* L.) under drip irrigation.

Materials and Methods

Description of the Study Area

The experiment was conducted at Adola rede District of Guji zone, Oromia Regional State in the 2019 and 2020/21 during off season from December to March. Adola rede District is one of the most important tomato-producing areas of the region and located between 5^{o}44'10”- 6^{o}12'38” northing latitudes and 38^{o}45'10”- 39^{o}12'37” easting longitudes and at altitude of 1500-2000 meters above sea level. The District is bordered by Girja district in the northeast, Anna sora in North West, Oddo shakkiso in the south and Wodera in the Southeast direction. The long-term (thirty years) mean annual rainfall of the study area was 1126.0 mm with a maximum and minimum temperature of 21.4℃ to 28.5℃ and 9.9℃ to 15.0℃ respectively.

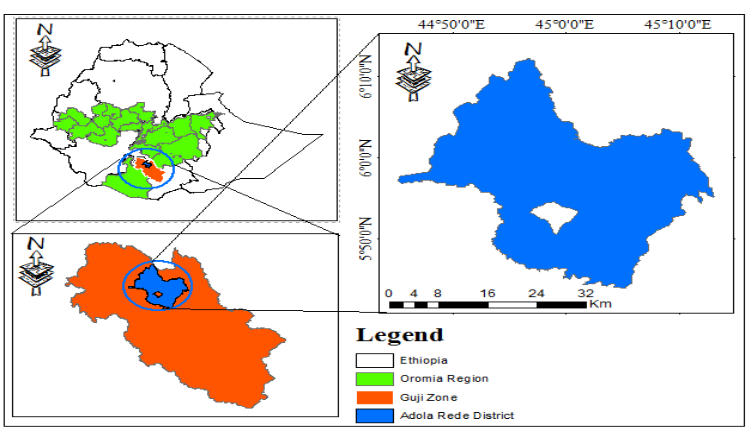

Figure 1: Location Map of the study area

Climatic characteristics

The average monthly climatic data of the study area (Maximum and minimum temperature, relative humidity, wind speed, and sunshine hours) were collected from the near meteorological station. The potential evapotranspiration ETo was estimated using CROPWAT software.

Table 1. Average of long-term (2004-2018) monthly climatic data of the experimental area

Month	T_{min}(°C)	T_{max}(°C)	RH (%)	Wind speed (m/s)	Sunshine hour(hr)	ETo (mm/day)
January	9.5	29.5	49.1	0.4	7.9	3.17
February	11.0	30.4	47.1	0.5	7.6	3.4
March	13.7	30.0	52.1	0.4	7.0	3.6
April	15.5	27.5	61.4	0.3	5.6	3.36
May	16.2	25.8	73.0	0.3	5.1	3.18
June	14.4	24.0	71.1	6.2	3.3	2.63
July	14.0	22.9	71.1	0.5	2.3	2.34
August	13.9	24.0	72.9	0.4	3.8	2.74
September	14.1	26.0	70.5	0.4	4.8	3.08
October	14.2	25.5	73.6	0.5	4.3	2.9
November	12.4	26.2	68.5	0.5	6.5	3.12
December	10.4	27.0	59.4	0.3	7.6	3.08
Average	13.3	26.6	64.2	0.9	5.5	3.05

Source: National meteorological station. (Tmin= Minimum temperature, Tmax= Maximum temperature, RH= Relative humidity, ETo = Reference Evapotranspiration)

Soil Sampling

To characterize the soil of the experimental field, a representative composite soil sample was taken using an auger from the whole experimental field before planting with two depths, 0-30 cm, and 30-60cm. These samples were randomly collected from 8 different locations of the experimental field by zigzag manner and mixed to form a representative sample. From these samples, selected soil chemicals (pH, total N, available P, OC, OM, and EC) and physical property (Texture, Bulk density, FC, and PWP) were analyzed following standard procedures at the Engineering Corporation of Oromia. The core sample volume was known and the oven-dry weight was computed, and the soil bulk density was determined by dividing the soil dry mass by the volume of the core sample using the following equation (Jaiswal, 2003).

$$Pb = \frac{Ws}{Vc} \tag{1}$$

Where: - Pb is soil bulk-density (g/cm^3), Ws is mass of dry soil (g) and Vc is the volume of soil in the core (cm^3).

Experimental Design and field management

The experiment has conducted with three rates of irrigation applications, full irrigation (100% ETc), ¾ irrigation (75% ETc) and half irrigation (50% ETc), and three mulching materials No

Mulch (NM), Straw Mulch (SM), and white Plastic Mulch (WPM) (Figure 2). Control irrigation was the amount of irrigation water applied following the computed crop water requirement with the aid of the CROPWAT program without mulch.

The treatments were arranged in Randomized Complete Block Design (RCBD) in factorial arrangements with three replications and a total of nine treatments. The experimental field plot was plowed using oxen, leveled, and made ready by dividing the field into 27 plots for transplanting. The experiment was conducted on an individual plot size of 3 m x 2 m (6 m^2) with 27 such plots. The spacing between adjacent plots and between replications was 1 m and 1.5 m respectively. The spacing between plants and rows was 40 cm and 75 cm, respectively, with a total of four rows per plot. A row consists of 5 plants and a total of 20 plants per plot.

The net harvesting area of a plot was 2 m by 1.5 m (3 m^2). More seedlings than those required for transplanting were raised so that vigorous, strong, and healthy ones were selected. The seedlings were transplanted to field plots five weeks after germination on the first week of January 2020 and 2021. Transplanting was done late in the afternoon to reduce the risk of poor establishment. The treatment was randomly applied to the area of each of the blocks (replications) and each treatment was assigned in the blocks. Tomato (Lycopersicon esculentum Mill.) seedling variety Gelila was used as a test crop. A commonly recommended fertilizer rate at the study area was applied manually in the experimental plots. All plots were received the same amounts of fertilizer consisting of 150 kg ha^{-1} of urea and 242kg ha^{-1} of NPS. The rooftop water harvested was used for irrigation to conduct the experiment.

Table 2: Details of treatment combination

Treatments	Descriptions
T_1	Without mulch with 100% ETc
T_2	Without mulch with 75% ETc
T_3	Without mulch with 50% ETc
T_4	White plastic mulch with 100% ETc
T_5	White plastic mulch with 75% ETc
T_6	White plastic mulch with 50% ETc
T_7	Straw mulch with 100% ETc
T_8	Straw mulch with 75% ETc
T_9	Straw mulch with 50% ETc

Figure2. No Mulch (NM), Straw Mulch (SM), and white plastic Mulch (WPM) of treatment

Crop water requirement

Crop water requirements were estimated with the CROPWAT computer software program using climatic, soil, and crop data as input. In this experiment, the reference evapotranspiration (ETo) and crop water requirement (ETc) were estimated from 15 years (2004-2018) climatic data collected from the National Meteorological Agency of Adola Station. Based on FAO CROPWAT output, crop water requirement (ETc) of tomato crops was found as 380 mm for growing periods of 135 days at full irrigation level (100% ETc). Accordingly, for treatment three-fourth (75% ETc) and a half (50% ETc), irrigation levels crop water requirements were deduced as 285 mm and 190 mm, respectively.

Drip irrigation system installation

The drip irrigation system was used for applying irrigation water. The drip system consists of Polyvinyl Chloride main lines, sub-main, and laterals. The plots were leveled manually to create uniform plots within the given treatment. The drip laterals were installed in such a way that the spacing between rows is equal to that between the lateral and spacing between plants is equal to emitters spacing. There were 27 plots laid out in 2 m length, four laterals per plot. Hence, each plot consisted of four drip lateral lines; each lateral has 2 m length with 5 emitters so that each emitter drops water to a single plant. The water from the source was collected in a water tanker of 1000 liters capacity, which was placed at a height of 2m above the ground surface to supply the required irrigation water to the experimental field. The water distribution system components (mainline) were laid and connected to the water container and to the sub-main pipe which is connected to individual drip lines. The drip lines (laterals) of 16mm diameter were unrolled and laid along the crop rows and each lateral served one row of the crop. The end of the laterals, sub-main pipe, and main lines were closed with end cups to avoid direct soil contact and thus prevent clogging.

Application of mulches

The mulching rate of 5 ton/ha wheat straw (Liu *et al.*, 2010) and white plastic mulch with 30 microns thickness were applied. White Plastic mulches were applied before transplanting tomato seedlings by making small holes at the desired intra row spacing and the seedlings were transplanted. However, straw mulches were applied immediately after the transplanting of seedlings. Transparent plastic mulch was selected because it provides more yields than black plastic mulch and it is characterized by the occurrence of higher soil temperature that it permits early germination, and increases water use efficiency than black plastic mulch (Ramalan *et al*., 2010).

Irrigation water application

Light irrigations were applied before the start of treatments applications for fifteen days. Water applications for full irrigation treatments (100% ETc) were based on the estimated crop water requirement calculated over the growing period and those water deficit treatments 75% and 50% ETc were executed as planned. Irrigation frequencies were the same for all treatments under drip irrigation, which was five days interval in the whole growing season.

Water productivity

Crop water productivity (WP) simply refers to the output (for example, crop yield or economic return) concerning water input during production. This means the output may be expressed either as physical production in kilograms per unit area or economic return in dollars per area. The water input is the amount of water applied to the cropped area per season. In this study crop, water productivity was estimated as the ratio of tomato yield to net irrigation depth applied to each treatment plot. It is expressed as:

$$\text{Water use efficiency } (\text{Kg/m}^3) = \frac{\text{Marketable grain yield}\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Seasonal net amount of water}\left(\frac{\text{m3}}{\text{ha}}\right)} \qquad (2)$$

Data collection

Related growth, yield, and yield components (plant height, number of fruits per plant, Marketable fruit yield, Unmarketable fruit yield, and Total fruit yield) data were collected. The agronomic data was collected from the middle rows to avoid border effects. *Plant height (cm):* The mean height of the plants was taken from the ground level to the tip of the uppermost part of 9 randomly selected plants at the first harvest and final harvest. *Marketable fruit yield (kg ha^{-1}):* Recorded by weighing all harvests of marketable fruits from the two middle rows of each plot and calculated to kilogram per hectare.*Unmarketable fruit yield (kg ha^{-1}):* Recorded by weighing all harvests of unmarketable fruits from the two middle rows of each plot and calculated to kilogram per hectare considering the reason for un-marketability. *Total Fruit yield (kg ha^{-1}):* Recorded by weighing all harvests of marketable and unmarketable fruits from the two middle rows of each plot and calculated to kilogram per hectare.

Data analysis

The collected data were statistically analyzed using Genstat 8th Edition software for the variance analysis. The two years' data were subjected to combined analysis over years and least significant difference (LSD) at 5% probability level was carried out for means separation.

Economic analysis

To assess the costs and benefits associated with drip and mulch materials the partial budget technique as described by CIMMYT (1988) was applied to the yield results. The net income (NI) was calculated by subtracting total variable cost (TVC) from total Return (TR) as follows:

$$NI = TR - TVC \qquad (3)$$

Results and Discussion

Physical properties of the soil at the experiment site

Laboratory analysis of particle size distribution indicated that the soil texture was clay. The average soil bulk density of 0-60cm soil depth was 1.38 g cm^{-3}. A representative value of TAW (102.7mm m^{-1}) was obtained by considering the average of the upper 0 - 60 cm soil depth. Average available soil moisture content for the top (0-30 cm) and lower (30-60 cm) soil depths were observed as 116 mm and 130 mm respectively. The basic infiltration rate in this experiment was found to be 5 mm/hr, which is within the range of clay soil (1 to 5) mm/hr (FAO, 1998).

Table 3: Physical of the soil at adola rede District, experimental site.

Parameters	**Results**
Basic Infiltration rate (mm/hr)	5
Bulk density (gcm^{-3})	1.38
Field Capacity (%)	25.9
P.W.P (%)	16.6
Total Available Soil Water (TAW)(mm)	102.7
Sand%	50
clay%	28.75
Silt%	21.25
Soil textural class	Clay

Selected soil chemical properties of experimental plot

The representative value of the soil pH (1:2.5 soil to water) was 5.9. As laboratory result shows the electrical conductivity (EC) of the soil was 0.099 ds/m (Table 4). The weighted average organic matter content of the soil was about 3.69%. As cited in Staney and Yerima (1992), the organic matter content of the soil is of medium class. The average value of total nitrogen was found about 0.32%.

Table 4: Soil chemical characteristics of the experimental site

Parameters	Chemical analysis
pH(H_2O)	5.9
Total N (%)	0.32
Organic carbon (%)	2.14
Organic matter (%)	3.69
EC (ds/m)	0.099

Yields and Yield Components

Plant Height

The results of the study showed that the different levels of drip irrigation and plastic mulching were non-significantly influenced the plant height of tomatoes (Table 5). Among the treatments, white plastic mulch with 75% ETc recorded maximum plant height (62.69 cm) and the minimum height (54.64 cm) was recorded in no mulch plot with 50% ETc (Table 5). Similarly, Yaghi et al. (2013) obtained faster crop development and earlier yields in cucumber with the application of plastic mulching.

The number of fruits per plant

A maximum of 28.9 numbers of fruits per plant was obtained for the treatment of white plastic mulch with 75% ETc. The study revealed that the use of plastic mulch resulted in a maximum numbers of fruits per plant but, its effect was not statistically significant from straw mulching (Table 5). The minimum (17.13) number of fruits per plant was recorded at no mulch with 50% ETc. These results were in line with the findings of Deep *et al*. (2021) who indicated that the treatment combination receiving drip irrigation at 80% Etc along with polythene mulch was recorded with the highest fruit yield per plant.

Table 5. Effect of drip Irrigation level and plastic mulching techniques on yield attributes and fruit yield of tomato

*Means followed by different letters in a column differ significantly and those followed by the same letter are not

Treatment Combination	Plant Height (cm)	Number of fruits per plant	Unmarketable fruit yield (Kg ha^{-1})	Marketable fruit yield (Kg ha^{-1})	Total Fruit yield(Kg ha^{-1})
T1; Without mulch with 100% ETc	60.39ns	20.77bc	2554ns	24570bc	27124b
T2; Without mulch with 75% ETc	58.88ns	25.37ab	2071ns	19291bc	25861b
T3; Without mulch with 50% ETc	55.64ns	17.13c	1974ns	17463c	19755b
T4; White plastic mulch with 100% ETc	61.51ns	23.13abc	2727ns	22772bc	25500b
T5; White plastic mulch with 75% ETc	62.69ns	28.90a	3406ns	35478a	38883a
T6; White plastic mulch with 50% ETc	59.89ns	24.00ab	2512ns	24538bc	26512b
T7; Straw mulch with 100% ETc	59.96ns	19.18bc	2001ns	23349bc	21292b
T8; Straw mulch with 75% ETc	57.26ns	19.67bc	3361ns	28831ab	30902ab
T9; Straw mulch with 50% ETc	61.05ns	23.13abc	2292ns	22474bc	25835b
$LSD_{0.05}$	6.92	6.01	1488.98	9607.1	9952.20
CV (%)	9.9	23.0	49	33.9	31.8
Mean	59.7	22.4	2544.3	24307.1	26851.4

significantly different at $p < 0.05$ level of significance, ns = non-significant at 5% probability level, LSD (%) = Least significant Difference at 5% o and CV (%) = Coefficient of variation

Marketable Fruit yield

The result of this study revealed that the combined effect of mulching and irrigation levels under drip exhibited a significant ($P<0.05$) influence on the marketable fruit yield. The highest marketable fruit yield (35478 Kg ha^{-1}) was obtained from the combined application of treatment received white plastic mulch with 75% ETc whereas the lowest marketable fruit yield (17463 Kg ha^{-1}) was obtained from treatment received no mulch with 50% ETc. However, there was no significant difference observed in marketable fruit yield between white plastic mulch with 75% ETc and straw mulch with 75% ETc (Table 5). For each mulching technique, the marketable yield was decreased with an increase in irrigation deficit levels. The trend tended to indicate marketable yield was significantly higher as the soil moisture stress decreased. Increased yield in mulched plots could be largely attributed to the increase in soil temperature and due to application of plastic mulch which resulted in an enhancement of soil environment around roots of tomato plants, which led to increased plant growth and, hence, increasing nutrient uptake. The increment of marketable fruit yield as irrigation levels increased is similar to the (Temesgen *et al.*, 2018) which indicated that yield reduction was associated with an increase in soil moisture tension which when allowed continuing resulted in the loss of turgidity, cessation of growth and yield reduction. On the other hand, a favorable environment for the growth of tomato plants maintained by application of plastic mulch followed by plots treated with straw mulch than no mulch along with the increased irrigation levels may have contributed to the production of the highest marketable yield. The present finding is also in agreement with the results of (Baye, 2011) who reported that the highest marketable yield was obtained through black plastic mulch followed by straw mulch (56.43 tons/ha) in tomato crop.

Unmarketable fruit yield

The analysis of variance showed that combination treatment of mulching and water amount resulted statically non-significant ($P<0.05$) effect on unmarketable fruit yield (Table 5). The highest unmarketable fruit yield (34060 Kg ha^{-1}) was recorded from plants grown under White plastic mulch with 75% ETc followed by the treatment that received Straw mulch with 75% ETc. The highest unmarketable fruit yield was recorded from the plot that received plastic mulch followed by straw mulch under increased water application levels. The lowest unmarketable tomato fruit yield was recorded under treatment no mulch with 50% ETc. This finding is disagreed with by findings of (Stapleton, 2005) who reported that the ability of transparent plastic mulches to produce soil temperatures high enough to control weeds, plant pathogens, and nematodes forms the basis for the soil solarisation process and help in reducing the amount of unmarketable yield in tomato.

Total fruit yield

Analysis of variance showed that the total fruit yield of tomatoes was significantly ($P<0.05$) influenced by the interaction effect of water amount and mulching techniques. Accordingly, the maximum total yield (38883 Kg ha^{-1}) was obtained from the treatment that received white plastic mulch with 75% ETc, followed by treatment Straw mulch with 75% ETc (30902 Kg ha^{-1}). The minimum total fruit yields (19750 Kg ha^{-1}) were recorded at the treatment of no mulch with 50% ETc. For each deficit irrigation level, maximum total yield was obtained from plots treated with plastic mulch which was followed by plots treated with straw mulch than that was obtained from no mulch (Table 5). Accordingly, for each mulching technique, total fruit yield decreased with an increase in the irrigation deficit level. The general trend from this result observed that the yield of tomato increased with high depth of water supply and decreased with low depth of water supply under different mulching techniques.

Water productivity

The Interaction Effect of irrigation levels with mulch type on water productivity of tomato under drip irrigation has shown a very highly significant ($p<0.001$) influence on water productivity of tomato (Table 6). Results indicated that the maximum water productivity (12.915kg/m^3) was observed at white plastic mulch with 75% ETc which was statistically non-significant with white plastic mulch with 50% ETc (12.448 kg/m^3). The minimum water productivity (5.993 kg/m^3) was observed at white plastic mulch with 100% ETc (Table 6). Mulches with irrigation gave higher water productivity over-irrigation alone under all levels of irrigation. Mulches reduced the rate of water loss through evaporation from the soil surface. So, the soil-water-plant relationship was better in low irrigation regimes than high irrigation regimes that might help produce higher yields and thereby higher water productivity. The lower water productivity might be attributed to higher irrigation water depth applied, much of which was lost through soil deep percolation. The higher amount of irrigation water application is associated with lower water productivity and the lower amount of irrigation water amount is associated with higher water use efficiency. The results were similar to the findings of Ayars *et al*. (1999), who reported that low irrigation regime reduced deep percolation and increased water use from root zone.

Table 6. Interaction effect of irrigation levels with mulch type on water productivity of tomato under Drip irrigation.

Treatments	**WP (kg/m^3)**
T1; Without mulch with 100% ETc	6.466bc
T2; Without mulch with 75% ETc	6.769bc
T3; Without mulch with 50% ETc	9.191abc
T4; White plastic mulch with 100% ETc	5.993c
T5; White plastic mulch with 75% ETc	12.915a
T6; White plastic mulch with 50% ETc	12.448a
T7; Straw mulch with 100% ETc	6.144bc
T8; Straw mulch with 75% ETc	10.116ab
T9; Straw mulch with 50% ETc	11.828a
$LSD_{0.05}$	3.615
CV (%)	34.1
Mean	9.10

*Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at ($P<0.05$)

Economic Comparison of Treatments

Data concerning economic comparison is presented in Table 7. Accordingly, the highest net benefit of 563475.7ETB ha^{-1} was recorded from white plastic mulch with 75% ETc and followed by 484454.7ETB ha^{-1} with Straw mulch with 75% ETc.

The lowest net benefit 285477.3ETB ha^{-1} was obtained from no mulch with 50% ETc. The highest benefit to cost ratio was obtained under treatment straw mulch with 75% ETc (15.04) and followed by no mulch with 100% ETc (14.32). This result revealed that wheat straw mulch with 75% ETc is economically feasible for tomato production in Adola area of the Guji zone.

Table 7. Economic analysis of marketable fruit yield of tomato under different treatments

Treatments	Marketable fruit yield (Kg ha^{-1})	Total Return (ETB /ha)	Total cost (ETB /ha)	Net Income (ETB /ha)	Benefit-cost ratio
T1; Without mulch with 100% ETc	24570	442260	30893.3	411366.7	14.32
T2; Without mulch with 75% ETc	19291	347238	29853.3	317384.7	11.63
T3; Without mulch with 50% ETc	17463	314334	29856.7	284477.3	10.53
T4; White plastic mulch with 100% ETc	22772	409896	75138.3	334757.7	5.46
T5; White plastic mulch with 75% ETc	35478	638604	75128.3	563475.7	8.50
T6; White plastic mulch with 50% ETc	24538	441684	75121.7	366562.3	5.88
T7; Straw mulch with 100% ETc	23349	420282	34513.3	385768.7	12.18
T8; Straw mulch with 75% ETc	28831	518958	34503.3	484454.7	15.04
T9; Straw mulch with 50% ETc	22474	404532	34506.7	370025.3	11.72

ETB = Ethiopian Birr and MRR = Marginal Rate of Return.
Note: - The price of tomato taken was 18 ETB Kg^{-1}.

Correlation of tomato yield, yield component, and water productivity

The calculated values of correlations coefficient (r) between yield, yield components, and water productivity are presented in Table 8. The number of fruits per plant was statistically no-significant (p<0.01) associate with all the studied parameters, but it shows a positive correlation. The highest Pearson correlation coefficient in the result provided a relationship between total fruit yield with marketable fruit yield (r =+0.92) followed by correlations between marketable fruit yield and water productivity (r =+0.80). The correlation was showed that plant height, unmarketable fruit yield, marketable fruit yield, and water use efficiency were correlated positively with marketable fruit yield. Marketable fruit yield (kg ha^{-1}) positively and significantly associated with plant height (r = 0.48**), unmarketable fruit yield (r = 0.41**), total fruit yield (r = 0.58*) and water productivity (r = 0.99**). These results were in lined with findings of Shamsi *et al*. (2010) reported WUE positively correlated with grain yield and yield components.

Table 8. Pearson's correlation coefficients (r) of tomato yields, yield component, and water use efficiency

	NFPP	PH	UMFY	MFY	TFY	WP
NFPP	1					
PH	0.160^{ns}	1				
UMFY	0.149^{ns}	0.482^{**}	1			
MFY	0.102^{ns}	0.405^{**}	0.414^{**}	1		
TFY	0.084^{ns}	0.415^{**}	0.491^{**}	0.921^{**}	1	
WP	0.098^{ns}	0.415^{**}	0.376^{**}	0.797^{**}	0.765^{**}	1

* and **. = Correlation is significant at 5 and 1% level, *. NFPP =Number of fruits per plant, PH = Plant Height, UMFY =Unmarketable Fruit yield, MFY =Marketable Fruit yield, TFY =Total Fruit yield and WP =water productivity

Conclusion and Recommendation

An experiment was conducted at Adola rede District of Guji zone for two consecutive years in the 2018/2019 and 2020/2021 cropping season. This study was aimed to evaluate the effects of mulching and the amount of water on yield and yield components of tomato (*Solanum Lycopersicum* L.) under drip irrigation. The experiment has conducted with three rates of irrigation water application; - full irrigation (100% ETc), ¾ irrigation (75% ETc) and half irrigation (50% ETc), and three mulching materials No Mulch (NM), Straw Mulch (SM), and white Plastic Mulch (WPM). The experiment was arranged in Randomized Complete Block Design (RCBD) with three replications. No mulch with 100% crop water requirement was considered as a control for this experiment. The parameters for evaluation include Water productivity, economic net benefit analysis and yield and yield components: such as plant height, number of fruit per plant, marketable and unmarketable fruit yield, total fruit yield.

The results of this experiment indicated white plastic mulch with 75% ETc recorded maximum plant height (62.69 cm) and the minimum height (54.64 cm) was recorded in no mulch plot with 50% ETc. The study revealed that the use of plastic mulch resulted in a maximum number of fruits per plant but, its effect was not statistically significant from straw mulching. The highest marketable fruit yield (35478 Kg ha^{-1}) was obtained from the combined application of treatment received white plastic mulch with 75% ETc whereas the lowest marketable fruit yield (17463 Kg ha^{-1}) was obtained from treatment received no mulch with 50% ETc. However, there was no significant difference observed in marketable fruit yield between white plastic mulch with 75% ETc and straw mulch with 75% ETc. The high total fruit yield was obtained from a high depth of water applied under plastic and straw mulch respectively and this was significantly different from a relatively low depth of water applied treatments. The Interaction Effect of irrigation levels with mulch type under drip irrigation has shown a very highly significant ($p<0.001$) influence on the water productivity of tomatoes. Results indicated that the maximum water productivity (12.915 kg/m^3) was observed at white plastic mulch with 75% ETc which was statistically non-significant with white plastic mulch with 50% ETc (12.448 kg/m^3). The minimum water productivity (5.993 kg/m^3) was observed at white plastic mulch with 100% ETc. Based on the partial budget analysis, the highest net benefit of 563475.7ETB ha^{-1} was recorded from white plastic mulch with 75% ETc and followed by 484454.7ETB ha^{-1} with Straw mulch with 75% ETc. Finally, we recommend that farmers can use wheat straw mulch with 75% ETc under drip irrigation, around Adola rede District and similar agro ecology especially in drought-prone areas where water is very scarce to produce crops. The test crop of the experiment was galila variety tomato; it is better if the test should be extended to other tomato variety and commercial crops.

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On Farm Evaluation Demonstration of Low-Cost Drip Irrigation on Waterand Crop Productivity Compared to Conventional Hand Watering System

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Abstract

Low-cost drip irrigation systems can provide a means of maximizing return on cropland by increasing the agricultural productivity per unit of land through saving water and increasing cropping intensity during the dry season. This experiment was conducted in moisture deficit areas of Goro district Nere Negaya peasant association (PA), Southeastern Ethiopia, to evaluate and demonstrate low-cost drip irrigation system in moisture deficit areas using runoff water harvesting pond of 60m^3. Low-cost drip set which operates with gravity installed at 1m height above the ground level to supply water for the crop. The highest Tomato yield of 40.8 t ha^{-1} which is 64.8% higher over farmer practice was recorded under drip Irrigation with recommended practice at the study area. Whereas, conventional hand watering of recommended management practice was gave the Tomato yield of 31.7 tone/ha (28%) over that of the farmers. The highest water use efficiency (3.76kg/m^3) was obtained from Drip Irrigation with recommended managements and saves 10% water over farmer practice and lowest water use efficiency (2.06 kg/m^3) was obtained from farmer practice. Consequently, an economic analysis shows that there is a significant difference, in terms of net income, between the various Irrigation methods. It can be concluded that Low-cost drip Irrigation system has the capability to saves water and increase tomato yield, over other conventional irrigation paractices.

Keywords*: low-cost, drip irrigation, water harvesting, water use efficiency and Tomato*

Introduction

Agriculture is only possible when there is availability of sufficient water which can meet the plant need for growth, not only because plants need water for their physiological processes but also because water contains nutrients in solution. Lack of water in rain-fed areas limits crop production to one, possibly two crops per year. Access to irrigation, which provides the means to cultivate an additional crop, is viewed as one of the best ways to boost productivity of small scale, dry land farming systems (Postel, 1998).

Irrigation is the artificial application of water to the land to provide adequate moisture for crop production (Solomon, 1990). Phocaides (2000) also defined irrigation as the application of water, supplementary to that supplied directly by precipitation, for the production of crops. Generally, the risk of yield reduction due to drought is minimized with irrigation. Irrigation is widely carried out through surface, sub-surface and pressurized systems, characterized by the mode of transport of the water onto the point of application (Keller and Bliesner, 1990). Surface irrigation methods are utilized in more than 80% of the worlds irrigated lands yet the field level application efficiency is often only 40–50%. When water is applied on the surface, a considerable amount is lost through evaporation, run off and deep percolation making it less efficient. In contrast, drip irrigation may have field level application efficiencies of 70–90%, as surface runoff and deep percolation losses are minimized (Postel, 2000).

Drip irrigation may allow more crops per unit water to be grown and to allow crop cultivation in areas where insufficient water exists to irrigate by surface methods. Drip irrigation is defined as "the slow, frequent application of small volumes of irrigation water to the base or root zone of plants" (Smeal, 2007). The system applies water slowly to keep the soil moister within desired range for plant growth, minimizing such conventional losses as deep percolation, runoff and soil water evaporation. Drip irrigation is the most effective way to convey directly water and nutrients to plants and not only save water but also increases yields of vegetable crops (Tiwari et al., 2003). Drip irrigation is an efficient method for minimizing the water used in agricultural and horticultural crop production. Frequency of water application is one of the most important factors in drip irrigation management because of its effect on soil water regime, root distribution around the drip holes, the amount of water uptake by roots and water percolating beyond the root zone (Coelho and or 1999; Assouline, 2002; Wang *etal.* 2006). Tomato is one of the high value crops which can grow under drip irrigation. With the use of drip irrigation, tomato growers benefit from higher yields, soluble solids (good quality) as well as savings on water, energy and labor (Netafim USA's, 2003).

In Ethiopia drip irrigation is largely restricted to the large-scale commercial farming community and has evolved to become a knowledge intensive, technology-oriented operation such that smallholder farmers have not adopted it extensively. Hence, this study aims to evaluate the feasibility of the system at the farmer's circumstances and to demonstrate its advantages to smallholder tomato grower farmers of in Goro district of Bale Zone.

Materials and Methods

Description of the study area

The experiment was conducted at Goro (Nere Negeya PA) district of Bale Oromia Region. The study areas lie at Latitude 6°58'56.9"N and Longitude 40°31'51.0"E while the elevation of the study area varies between 1600 m,a.s.l and 2000 m.a.s.l (Figure 1). The rainfall pattern of the study area is bimodal type, which divide the year into two main seasons: a main rainy season Kiremt (June to October) and short rainy season Belg (March to May). The mean annual rainfall of the study area was between 600 and 1000 mm with Mean maximum annual temperature 26.5°C and mean minimum temperature 12.4°C (Figures 2).

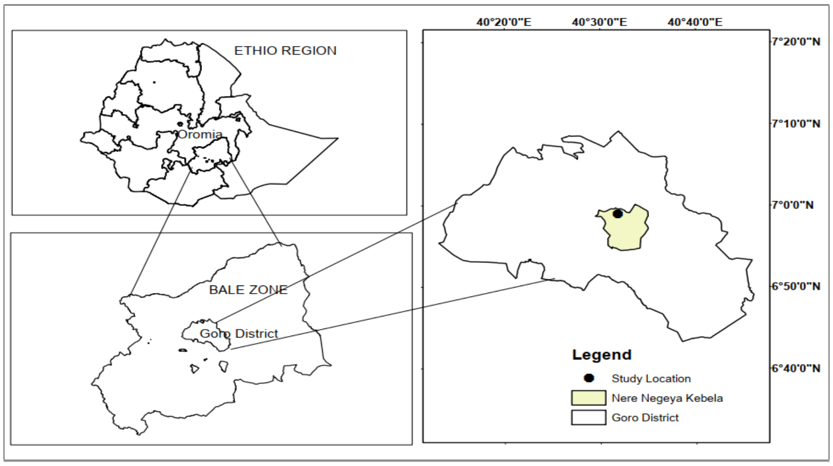

Figure1:Map of the Study area

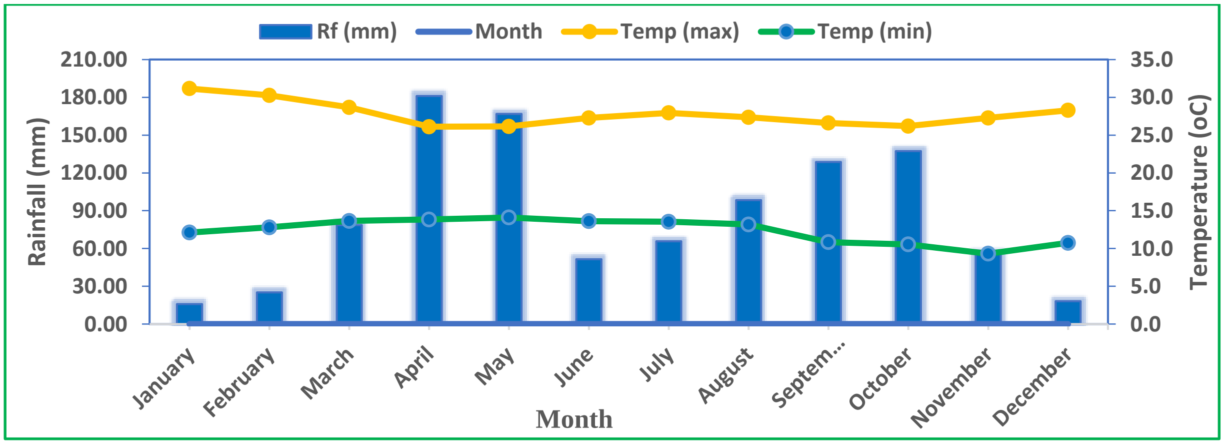

Figure 2: Mean monthly rainfall, maximum and minimum temperature at the study area, Goro.

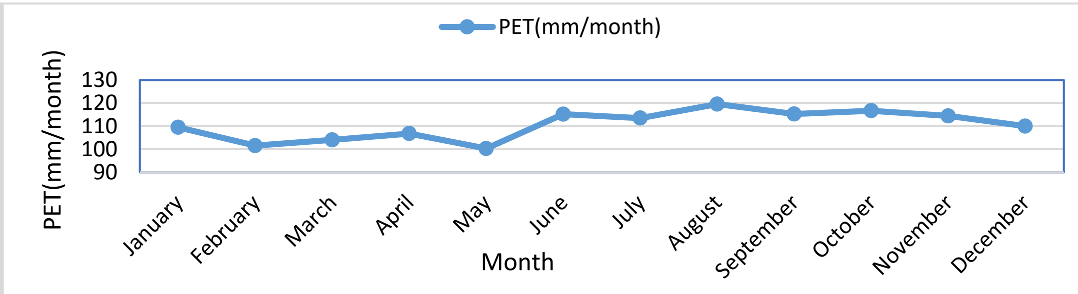

Figure 3: Monthly Potential Evapotranspiration (PET) of the study area

Experimental Design

The design used was RCBD in three replications. The treatments were Drip Irrigation system with recommended management (T1), Water Can with recommended management practice (T2) and Farmer practice as a control treatment (T3) that practiced commonly by farming community in the study areas. The demonstration and evaluation of Drip Irrigation from farm pond water harvesting for cultivating Tomato was made at Nere Negeya PA of Goro district-on farm, for two consecutive years (2019 up to 2020) on one farmer as a demonstration, where the farmer was having farm pond contracted by SARC and have suitable land near to the harvested water. The Pond is with side collectors, gutters (Chanel) were tied, stilling basin (to avoid direct entry of silt to ponds) and Geomembrane for lining of the ponds. The runoff water during rainy season was stored in the Pond (60m^3 total capacity) for using during off-season for high value crop tomato (Cochoro variety) during two years of practice. The low-cost drip set which operates with gravity installed at 1m height above the ground using barrel to supply water for tomato.

Data Collection

The data on yield (t ha^{-1}), total selling price (birr), water productivity (kg/m^3) and farmers' perception towards the technologies were taken. Effectiveness of the technology and farmers preference toward the technology was collected through supervision and organizing mini field day. Farmers' and experts' opinion was collected at the time of field visit. To collect their real feeling and opinion, group discussion was undertaken and checklist was used for interviewing. Finally, the collected data (quantitative data) was analyzed by using descriptive statistics mean and standard deviation. Mini-field day was arranged during the second year of practice which involved 40 participants.

The discharge per m length of tape can be calculated by:

$$\text{Discharge (L/m/hr)} = \frac{\text{Discharge (L/emitter/ hr)}}{\text{Emitter spacing (m)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Duration of irrigation water application for a given drip system is computed as follows:

$$\text{Duration (hr)} = \frac{\text{Water requriement(mm)}}{\text{Application rate (mm hr}^{-1})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Crop Water use efficiency for Tomato will be computed as follows;

$$WUE = \frac{\text{YO}}{\text{Total water used}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: *YO: Yield of Tomato (kg/ha) and WUE-Water Use Efficiency*

Economic analysis

Economic analysis of the Irrigation system s was computed, based on investment, operation and production costs **(**CIMMYT, 1988). In this research, a partial budgeting approach based on economic evaluation of the product was used**.** To assess the economic viability of the drip irrigation system under variable irrigation, both fixed and operating costs were calculated (çetin et al. 2004). The net income for each treatment was computed by subtracting all the production costs from the gross incomes. All calculations were undertaken, based on a unit area of 1 ha, according to Koral and Altun (2000).

Data analysis

The data collected was statistically analyzed using statistical analysis system (SAS) software version 10 using the general linear programming procedure (GLM). Mean comparison was carried out using least significant difference (LSD) at 5% probability level to compare the differences among the treatments mean.

Result and Discussion

Soil Property

The soil is Clay texture with sand, silt and clay in proportion of 22%, 34% and 44% respectively and pH of the soil is 6.88. The following table shows some physical and chemical property of the study area.

Table1: Some soil properties of the study area

Soil Parameters	**Value**
Soil pH	6.8
Organic Carbon (%)	1.43
Total N (%)	0.11
Available P	8.3
Sand	22
Silt	34
Clay	44
Textural Class	Clay
PWP (%)	38
FC (%)	20

Yield and yield component analysis

Effect of the technology on yield and yield components of Tomato in the study area is indicated in Table 2. As indicated in the Table there were mean yield and yield component differences between farmer practice, water can with recommended practice as well as drip irrigation with recommended practice described well. Accordingly, Tomato with Drip Irrigation had the highest Plant height (PH), number of fruits per plant, fruit length fruit wight and Yield flowed by water can with recommended practice (Table 2).

Table 2. Average yield and yield component of Tomato under different management practice

Treatments	Ph (cm)	No of branch/plant	No of fruit/Plant	Fruit length(cm)	Fruit weight(g)	Yield (t/h)	Water productivity (kg/hmm^{-1})
Drip Irrigation+RMP	53.8^{a}	6.7	32.3^{a}	5.3^{a}	77.56	40.8^{a}	3.76^{a}
Water Can + RMP	44.7^{ab}	5.1	28a^{b}	4.5^{b}	70.53	31.7^{ab}	2.74^{b}
Farmer Practice	37.8^{b}	4.9	23.6^{b}	4.1^{b}	66.56	24.8^{b}	2.06^{b}
CV	10.56	21.5	8.16	8.1	12.6	14.7	14.4
LSD $_{(0.05)}$	9.59	ns	4.56	0.75	ns	9.59	0.82**

Where: *Ph: Plant height, CV: coefficient of variation, LSD $_{(0.05)}$: Least Significant Difference and RMP; Recommended Management Practice*

Generally, Tomato growing using improved technology (Drip Irrigation system) techniques had better yield advantage as compared to farmers' practices. That means farmers' practices had the lowest yield and yield components, which is due to poor management practice effect on crop performance In line with results of this study Shushay et al., 2014 and Satyendra et al., 2013 reported that yield of tomato under drip system was found higher as compared to the surface irrigation method. The highest Tomato yield of 40.8 t ha^{-1} which is 64.7% higher over the farmers' practice (poor management practice), was recorded under Drip Irrigation systems. Similarly, the highest

Water productivity of 3.76 $kghmm^{-1}$ which is 9.6% water saved over the famers' practice was obtained when the Tomato was grown using Drip Irrigation with improved management. Similarly, Shah S K., 2011 reported that 44 % yield increment and 79 % water saving under drip irrigation in tomato production than furrow irrigation system. The Irrigation with water can using improved management practice also gave significantly higher values of plant height, fruit length, fruit weight and Yield over farmer practice (Table 2). Studies revealed that, drip irrigation increased the yield of tomato and water use efficiency (WUE) by 19 and 20% (Fekadu and Teshome, 1997) as compared to other irrigation system; and others found it significantly reduced the irrigation water requirement of a crop as it supply water only to root zone of the crop (Postel et al.,2001). This indicates that the design and management of the system was very adequate and fundamental to application efficiency and irrigation uniformity. Our results agree with findings of researchers in other regions, who used a trickle irrigation system (Alva et al. 1999; Fares and Alva 2000; Zotarelli et al. 2009a, b)

Economic Analysis

Table 3 presents the Partial budget analysis of Tomato cultivation under various irrigation methods. The cultivation of Tomato will be profitable after the first harvest with both LCDI and HW irrigation methods. Although a farmer will generate greater profits in the first season of use with HW, farmers do choose LCDI rather than watering by hand for a variety of reasons. First, when labour costs are included, long-term profits (more than four crops) will be greater with LCDI. In addition, labour associated with hand watering is physically more demanding.

Table 3: Partial budget Analysis of the management practice on the basis of Unit area 1 h

Treatment	Total Cost that Varies per h	Average Yield (kg/h)	Adjusted Yield(kg/h)	Gross Field Benefit (ETB/h)	Net Benefit (ETB/h)
Farmer Practice	85500	24800	22320	446400	360900
Water Can + RMP	142500	31733.3	28560	571200	428700
Drip Irrigation + RMP	200000	40833.3	36750	735000	535000

Where; *RMP: Recemented management practice*

This is not reflected in this analysis, as the cost of labour was considered equivalent irrespective of the degree of physical effort. Furthermore, hand watering requires a methodological and diligent application procedure, easy for a researcher, but considerably more difficult for a farmer managing a complex portfolio of livelihood options. The greater long-term profitability and reduced labour costs favour the use of LCDI over hand watering and Farmer practice. Other Studies also revealed that, low-cost drip irrigation has high net benefit when compared to Hand watering and farmer practice (Stefanie von W et al., 2003).

Farmer's preference of the technology

Mini-field day was organized to collect the preference of the technology by the farmers and other stakeholders at the end of the season. Accordingly, a total of 40 (30 male, 10 female) participants consisting of farmers, extension agents, experts and researchers were participated on the field day event. Yield advantage, crop performance and Cost effectiveness were criteria's set by participants to aid selection process of the best technology. The feedback of the field day participants toward the technology are as indicated in Table 4.

Table 4. Participants Feedback (N=40)

Irrigation method	Cost effectiveness of the technology		Easy to use (Easiness)		Crop performance		Yield advantage	
	N	%	N	%	N	%	N	%
Drip Irrigation +RMP	5	12.5	30	75	25	62.5	26	65
Conventional hand watering +RMP	15	37.5	5	12.5	10	25	9	22.5
Farmer practice	20	50	5	12.5	5	12.5	4	10

RMP: Recommended managements Practice

From farmer's feedback assessment, it is revealed that the yield of Tomato crop by Drip Irrigation is much advantageous than farmer practice and conventional hand watering. Farmers were also reported that Drip Irrigation enhances easy to use and better crop performance. Even though the cost effectiveness of the farmer practice is higher, farmers prefer Drip Irrigation because of the low yield. Generally, 90% of the participants were selected Drip Irrigation as best irrigation method technology options to cultivate tomato in the study area.

Conclusion and Recommendation

Water saving 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 WUE and sustainable water use for agriculture. Drip irrigation was found increased fruit yield of tomato and improved WUE due to consumption of less water. Generally, practicing rain water harvesting and using the collected water as supplementary or as complementary irrigation for double cropping is the better way of increasing agricultural crop production in moisture deficit areas of Southeastern Ethiopia, as low rainfall amount, high rainfall variability in space and time and decrease in reliability is the major impediment to the productivity of rural poor in these areas.

As this study reveals, water harvesting technology combined with water saving drip irrigation system is found effective in moisture deficit areas like Goro district and similar agro ecologies; especially for producing high value crops (onion, tomato etc) which have high return per plot of land and per drop of water during off-season or to supplement rain fed crops. But it needs careful planning for wise use of harvested water (increasing water use efficiency) to ensure increased production.

Acknowledgement

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Evaluation of Drip Lateral Spacing on Yield and Economic Return of Onion (*allium cepa l.*), at Awash Melkassa, Ethiopia

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Abstract

Water availability is becoming a critical issue in Ethiopia in semi-arid climate mainly in Rift Valley areas. Field experiment was carried out during the dry cropping season of 2019/2020 to evaluate the performance of drip lateral spacing on onion yield and its net return with two adjustment of drip lateral spacing at full irrigation application viz., lateral placed in every row and between two rows. The performance of drip lateral spacing system was evaluated on the basis of parameters like emitter flow rate (q), emission uniformity (EU), emitter flow rate (qvar), coefficient of variation (CV), uniformity coefficient (CU). The mean values of upper, middle and lower lateral spacing showed non- significant ($P \geq 0.05$) difference in emission uniformity of drip lateral spacing. An average emitter uniformity parameter value was 93.66%, 96.28%, 12.05 %, 1.68 % for emission uniformity, uniformity coefficient, emitter flow variation and coefficient of variation respectively. The designed drip lateral spacing was operated excellently as all values of emitter uniformity parameter were in the recommended range in each case. The average basic infiltration rate was found to be 18 mm/hr. From the result, onion yield and yield parameters was affected by the effects of drip lateral spacing. Maximum onion bulb yield of 41.44t ha^{-1} and 25.83t ha^{-1} were obtained from lateral spacing in every row and between two rows respectively. Total bulb yield was reduced by 37.65% when drip lateral between two rows were used. But the cost of drip lateral between two onion plant rows was 26.14% less than drip lateral in every onion plant rows. Therefore, onion could be irrigated by drip lateral spacing in every row to get better onion bulb yield.

Key words*: Bulb yield, lateral spacing, irrigation level, water productivity, economic return*

Introduction

In Ethiopia, irrigation 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). Drip irrigation system is one of the most efficient forms of irrigation technology. The experience from many countries show that farmers who switch from furrow system to drip system can cut their water use by (30 - 60) % and crop yields often increase at the same time (Sijali, 2001).

Drip irrigation adoption increases water use efficiency (60-200%), saves water (20-60%), reduces fertilization requirement (20-33%), produces better quality crop and increases yield (7-25%) as compared with conventional irrigation (Kaushal *et al.*, 2012).

The initial investment of drip irrigation is considerably higher as compared to conventional surface irrigation methods. The cost of laterals and emitters are the major factors influencing initial investment. Therefore, it is necessary to develop strategies in order to reduce the cost of lateral network and emitters per hectare to make drip irrigation affordable to the farming community (Kumar and Imtiyaz, 2007). Excessive irrigation can be seen especially in field areas with cheap irrigation water (Karasu *et al.*, 2015). Appropriate irrigation scheduling is to increase irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to desired level, save water resources and energy (Singh *et al.*, 2015).

In the Central Rift Valley, most of the farmers produce onion during the dry season (October-April) by irrigation due to high domestic and export markets, its yield per unit area, availability of suitable cultivable variety, and ease of propagation by seed and lower incidence of diseases The activity was accomplished with the objective of enhancing and evaluating onion production and water productivity through application of drip lateral spacing technology under Awash Melkassa climatic condition.

Material and Methods

Description of the Study Area

Field experiment was carried out at Melkassa Agricultural Research Center (MARC) during the dry cropping season of 2019/20. Its location is $8^{0}24'05''$ and $8^{0}25'58''$N latitude and $39^{0}18'55''$ and $39^{0}20'04''$E longitude with an average altitude of 1550 m.a.s (Figure 2.1).

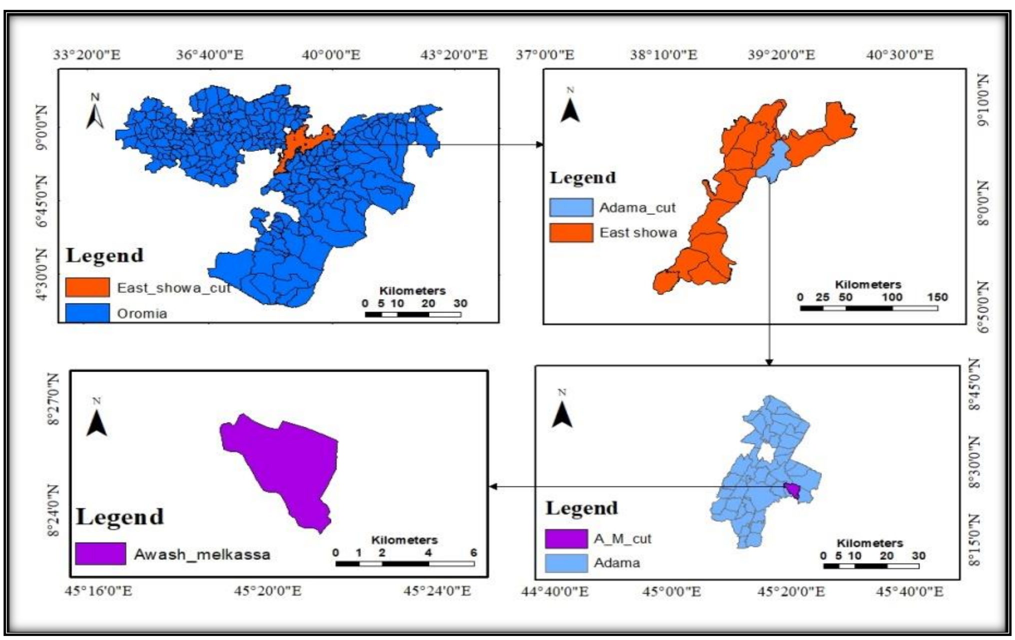

Figure 2. 1. Location map of the study area

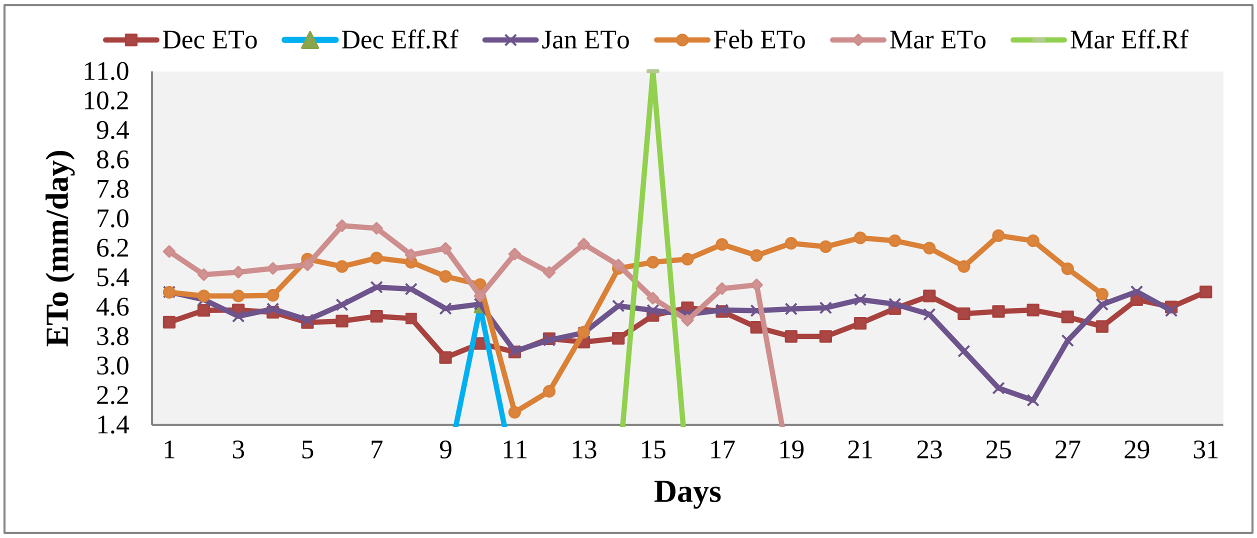

Figure 2. 2. Daily ETo of study area

Procedure of Drip Installation

One overhead plastic tanker for all replication was used to provide a pressurized water source for drip irrigation system. The stand for placing tanker was constructed at a height of 1.5 m above the ground from locally available wood (FAO, 2007). Main line with 32 mm, and manifold with 25 mm both made of HDPE pipe used to deliver irrigation water through in-line LDPE laterals of 16 mm was used. A control valve was provided to each plot and the laterals were connected to the manifold line at 0.60 m spacing for drip lateral between two rows and at 0.20 m spacing for drip lateral in every row.

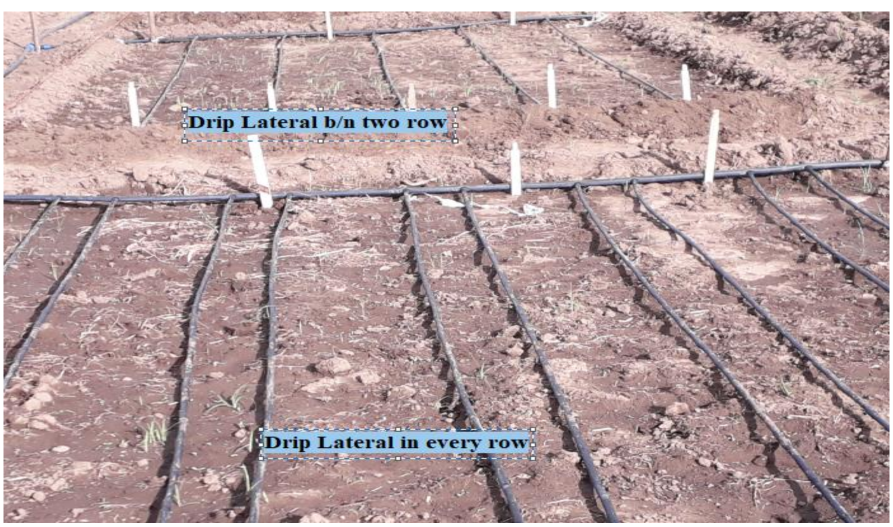

Figure 2. 3. Drip lateral space adjustment

Irrigation scheduling

Total available water (TAW) was computed from the moisture content of field capacity and permanent wilting point using the following Eq. (1).

$$\text{TAW} = (\text{FC} - PWP)\ x\ BD\ x\ Dz \quad (1)$$

where, TAW is the total available water in the root zone (mm), FC and PWP are moisture content at field capacity and permanent wilting point (%) on weight basis respectively and Dz is the root zone depth of onion at times of each irrigation.

For maximum crop production, irrigation schedule was fixed based on p-value. The ‘p’ value for onion used in this study was 25% of TAW (p = 0.25).

Hence, RAW was computed from the Eq. (2).

$$\text{RAW} = \text{TAW} \times \text{p} \quad (2)$$

Where, RAW is the readily available water or net irrigation depth, IRn (mm), p is allowable permissible soil moisture depletion fraction

Irrigation Water Application and Discharge Measurement for Plots

Water was pumped into the overhead tank using water pump to irrigate the experimental plot. Full irrigation application was calculated as the net depth of irrigation required to recharge soil moisture to field capacity.

Figure 2. 4. Experimental field layout

For the experimental test, volume of irrigation water application (liter) to each plot was computed by multiplying the net wetted area (m^2) of each plot (80% of plot area for lateral spaced in every row and 50% of plot area for lateral spaced between two rows) and gross irrigation depth (m). The gross irrigation depth (mm) was calculated by divided the net irrigation depth (mm) by application efficiency (90%). Net irrigation application was obtained by subtracting the effective rainfall (mm/day) from crop water requirement (mm/day) that was a multiplication of daily reference evapotranspiration and the respective stage of kc value.

The discharge measurement was varied based on the treatment with lateral adjustment (Lateral spaced in every row and lateral spaced between two rows). For both lateral space adjustments, the discharge (l/hr) was obtained by multiplying the mean discharge of an emitter and the total number of emitters per plot. The time (hr) required to irrigate each plot was calculated by dividing volume of irrigation water (liter) by the respective laterals space discharge (l/hr) (mean discharge of an emitter x the total number of emitters on each plots).

Uniformity of Water Application

The American Society of Agricultural and Biological Engineers (ASABE) had developed a standard for the uniformity of water application in drip irrigation. Design for a uniformity level less than the designed value will result in a reduction in the irrigation efficiency; and cause loss of water and fertilizer due to poor uniformity of water application. The application of water is by means of drippers that are located at desired spacing on a lateral line (Goyal, 2013).

Proper design and management of water are essential conditions to ensure uniformity of application. If irrigation is not uniformly applied, some areas will get too much water and others will get too little. As a result, plant growth will also be non-uniform, and water will be wasted where too much is applied. Excess water may reduce crop yields as a result of leaching of plant nutrients, results in an anaerobic rooting environment as well as increased disease or failure to stimulate growth of economically valuable parts of the plant (Griffiths and Lecler, 2001).

Percentage wetting area

Drip irrigation do not wet all cropped field like that of surface and sprinkler irrigation methods and hence the term wetting area (w.a) was introduced for partial wetting of drip irrigated field. The percentages of wetted area were determined using (Keller and Bliesner, 1990) method. It was the average horizontal area wetted in the top 15–30 cm of the crop root zone as a percentage of each lateral line area.

Data Collection

Drip emitters uniformity parameters

After the installation of drip irrigation system, the hydraulic characteristics of the drippers that were determined include emitter flow rate, emitter flow variation, and uniformity coefficient,

coefficient of variation and emission uniformity. Water application uniformity test of irrigation system was determined for drip lateral spacing in every row and lateral spacing between two rows at the beginning and end of the experiment.

Emitter flow rate, q - the average flow rate of emitters used in the experiment was measured from plots using catch cans and volumes of flow caught over a time period. The discharge, or flow rate out of a single outlet emitter at a specified head was estimated using eq. (3).

$$q = \frac{v}{\Delta t} \tag{3}$$

Where: q is single emitter discharge (liter/hour); V is volume of water collected from emitter, (liters) and Δt is time duration (hour).

i. Emission Uniformity, EU

Emission uniformity is a measure of the uniformity for all emitter emissions along drip irrigation lateral line. The most useful system performance indicator for drip systems is the emission uniformity EU (%) which, in the case of field evaluation is defined as distributions uniformity, DU and calculated using Eq. (4).

$$\text{EU} = 100\ (\frac{q_{min}}{qa}) \tag{4}$$

Where: - Eu is Emission uniformity (%); qmin = minimum emitter flow rate (l/h) and qa is average discharge rate of all observed emitters (l/hr).

ii. Emitter flow variation, q_{var}

It is calculated using Eq. (5)

$$\text{qvar} = (\frac{qmax - qmin}{qmax}) \tag{5}$$

Where, qmax is maximum emitter flow rate (l/h); qmin is minimum emitter flow rate (l/h)

iii. Coefficient of variation, CV

It is used to identify the relative variability among the treatments and calculated using Eq. (6)

$$\text{CV} = \frac{S}{qa} \tag{6}$$

Where: S is standard deviation of emitter flow rates (l/h) and qa is average emitter flow rate (l/h)

iv. Uniformity Coefficients, UC

It is often described in terms of the coefficient of variation defined as the ratio of the standard deviation to the mean and is calculated using Eq. (7)

$$\text{UC} = \left(1 - \frac{sq}{qa}\right) * 100 \tag{7}$$

Where, UC is uniformity coefficient (%); Sq is average absolute deviation of all emitters flow from the average emitter flow (l/h) and qa is average emitter flow rate (l/h).

Growth parameters

Growth parameters of onion such as Plant height (cm), Leaves height (cm) and Number of leaves per plant was collected at physiological maturity stage.

Yield and yield parameters

The matured onion bulbs were harvested after more than 75 % of its necks falls/bends down with its necks and after putting under shade for about three to four days to dry/cure and then necks was cut at 2 cm height from the bulb neck (Olani and Fikre, 2010). Yield and yield parameters collected was Bulb diameter (cm), Bulb height (cm), Average weight of bulb (gm) and total yield of bulb (t/ha).

Economic Analysis

Economic analysis was computed by using the results of this study based on investment, operation and production costs. Based on the irrigation amount of each treatment in the growing season; irrigation duration and labor cost were estimated. The mean bulb yield (kg ha^{-1}) was adjusted for yield losses by subtracting 10% of the bulb yield from total yield (CIMMYT, 1988).

The production costs were computed by considering all production inputs (i.e. cost of seeds, cost of drip material, drip installation, plowing of land, transplanting, cultivating, weeding, pesticide, pesticide application, fertilizer, harvesting). Finally, adjusted yield was multiplied by field price to obtain gross field benefit of onion. The field price of onion during the harvesting season was 13 Birr kg^{-1} and 3.8 Birr m^{-3} value for water was taken (Jansen *et al*., 2007).

Statistical Analysis

Data collected were subject to analysis of variance (ANOVA) appropriate to RCBD using SAS software. Whenever treatment effects were found significant, treatment means were compared using the least significant difference, LSD.

Results and Discussions

Uniformity of In-lined emitter lateral system

Uniformity parameters were determined by measuring emitter flow rates. The flow rate test of irrigation system was carried out at the beginning and end of the experiment. For all experimental plots, three laterals at center and three emitter (upper, middle and lower) positions was selected randomly for the two lateral spacing adjustments.

Uniformity of water application was calibrated from the dripper outflow collected in the buried plastic bottle under the lateral line for 30 minute. A graduated cylinder was used to measure the volume of water. The mean values of upper, middle and lower lateral spacing showed non- significant ($P \geq 0.05$) difference in emission uniformity of drip lateral spacing (Table 3.1).

Figure 3.1. Water collection using catch can

Table 3. 1. The mean emission uniformity (%) of the system for emitter position

Lateral space	Upper	Middle	Lower
Laterals in Every Row	94.96	93.79	93.82
Laterals Between Two Row	95.14	95.08	95.18
S.Em±	1.52	0.90	0.38
LSD (5%)	Ns	Ns	Ns
CV (%)	2.77	1.64	0.69

LSD (%) = least significant difference at 5% of significance, CV (%) = Coefficient of variation and Ns = non-significant difference, S.Em± = standard error of mean.

Table 3.2 shows the average field evaluation of all uniformity parameters (emission uniformity, uniformity coefficient, emitter flow variation and coefficient of variation) were 93.66%, 96.28%, 12.05% and 1.68% respectively. Emission uniformity (90 – 100) % was categorized as excellent (ASABE, 1999). Therefore, in all replication and the average result for this experiment for uniformity parameters was classified as excellent.

Table 3. 2. Application uniformity measures for the drip system

Uniformity parameter	unit	Replication 1			Replication 2			Replication 3			Aver.
		Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	
EU	%	94.61	95.15	93.02	93.19	93.64	93.05	94.02	92.51	93.78	93.66
UC	%	96.81	96.82	95.52	96.49	96.68	96.25	96.05	96.38	95.50	96.28
qvar	%	10.08	9.86	11.04	10.03	9.60	10.94	13.84	16.28	16.79	12.05
CV	%	1.35	1.43	2.11	1.45	1.39	1.53	1.84	1.90	2.15	1.68

Uniformity coefficient value (>90%) classified as excellent. (Bralts, 1984) classified field evaluation of emitter flow variation having (10 – 20) % as acceptable. Moreover, a mean coefficient of variation (Cv) for the experiment was 1.68 % and categorized as excellent (<5) %. Generally, the overall average results obtained on application uniformity parameters were within the best recommended categories. This could be due to proper pressure head, good water quality, good installation and management. The average basic infiltration rate was found to be 18 mm/hr. The range of infiltration rate of loam soil is 10 - 20 mm/hr (FAO, 2001).

Irrigation Water Requirement of Onion

Crop water requirement of onion determined based on the seasonal water application depth from transplantation to harvest and vary based on the lateral spacing. The seasonal water applied was 375.04 mm and 234.40 mm for lateral spacing in every row and lateral between two rows respectively (Table 3.3).

Table 3. 3. Seasonal net irrigation water depth applied

Treatments	Dnet (mm)	Ea (%)	w.a (%)	Dgross (mm)
DLER	421.92	90	80	375.04
DLBTR	421.92	90	50	234.40

DLER = Drip lateral in every row, DLBTR = Drip lateral between two rows

Effects of Lateral Spacing on Onion Growth Parameter

Drip lateral spacing had significant ($P \leq 0.05$) effect on onion growth parameter such as plant height, leaf height and leaf number as shown in (Table 3.6).

Plant height (cm)

The mean values of plant height showed significant ($P \leq 0.05$) difference due to the effects of drip lateral spacing (Table 3.4). The highest mean value (63.80cm) of onion was recorded under drip lateral spaced in every row and the lowest mean value (55.43 cm) was recorded under drip lateral spaced between two rows as (Oli *et al*., 20019).

Table 3. 4. Effect of Irrigation water levels and Lateral spacing on onion growth parameter

Treatment	PH (cm)	LH (cm)	LN
Lateral Spacing (LS)			
DLER	63.80^{a}	61.40^{a}	13.67^{a}
DLBTR	55.43^{b}	53.00^{b}	9.67^{b}
S.Em±	1.04	0.96	0.41
CV	3.03	2.92	6.06
LSD (5 %)	6.34	5.87	2.48

PH = plant height, LH = Leaf height, LN = Leaf number

Leaf height (cm)

From (Table 3.4), there was a significant ($P \leq 0.05$) difference observed on leaf height due to drip lateral spacing. The highest mean value of leaf height (61.40cm) of onion was recorded under drip lateral spaced in every row and the lowest mean value (53.00cm) was recorded from onion grown under drip lateral spaced between two rows. Lower volume of irrigation water applied by drip lateral spaced in between two rows results in lower value of leaf height.

Number of Leaf per plant

As shown in (Table 3.4), there was a significant ($P \leq 0.05$) difference observed on leaf number per plant due to drip lateral spacing. The higher mean value (14) of leaf number per plant of onion was recorded under drip lateral spaced in every row and the lowest mean value (10) was recorded from onion grown under drip lateral spaced between two rows. (Bhasker *et al*., 2018) reported that in drip irrigation system plant receive favorable conditions for enlargement of root system thereby plant growth and vigor is high. Leaf number per plant was increased under drip lateral spaced in every row due to sufficient depth of irrigation water.

Effects of Lateral Spacing on Yield and Yield Parameters of Onion

The data showed that there was significant ($P \leq 0.05$) difference on bulb weight due to effects for lateral spacing but no significant difference on bulb diameter and bulb height.

Average weight of bulb (gm)

There was significant ($P \leq 0.05$) effect of lateral spacing on average weight of bulb (Table 3.5). The higher mean value of average bulb weight (86.40 gm) was recorded from onion grown under drip lateral spacing in every row and the lowest mean value of average bulb weight (76.90 gm) was recorded from onion grown under drip lateral between two rows.

Table 3. 5. Effect of Irrigation water levels and lateral spacing on onion yield, yield parameters and WUE

Treatment	BD (cm)	BH (cm)	BW (gm)	MBY (t/ha)	TBY (t/ha)	WUE (kg/m^3)
Lateral Spacing (LS)						
DLER	7.47^a	6.27^a	86.40^a	33.98^a	41.43^a	11.05^a
DLBTR	6.13^a	5.97^a	76.90^b	24.44^b	25.83^b	11.02^a
S.Em±	0.24	0.07	1.05	0.38	0.66	0.01
CV	6.09	2.00	2.23	2.28	3.38	0.23
LSD (5 %)	1.22	0.17	6.25	2.34	3.99	0.10

BD = Bulb diameter, BH = bulb height, BW = bulb weight, WUE = Water use efficiency, MBY = Marketable bulb yield, TBY = Total bulb yield

Marketable bulb yield (ton/ha)

Lateral spacing affected marketable bulb yield of onion as shown in (Table 3.5). There was high significant ($P \leq 0.05$) difference on mean marketable yield of onion due to effects of drip lateral spacing. Significantly higher marketable bulb yield of (33.98 t/ha) onion was recorded from onion grown under drip lateral in every row and the lowest marketable bulb yield (24.44 t/ha) was recorded from onion grown under drip lateral spacing between two rows. The yield was reduced by 28.07% when drip lateral between two rows were used.

Total bulb yield (ton/ha)

As shown on (Table 3.5), there was significant ($P \leq 0.05$) difference on mean total bulb yield of onion due to effects of drip lateral spacing. Significantly higher total bulb yield of (41.43 t/ha) onion was recorded from onion grown under drip lateral in every row and the lowest total bulb yield (25.83 t/ha) was recorded from onion grown under drip lateral spacing between two rows. Total bulb yield was reduced by 37.65% when drip lateral between two rows were used. (Tirkey *et al*., 2017) explained that lateral spacing in every row gave highest mean crop yield that is similar to this study. Yields up to 400 qt/ha for Bombay red were observed on farmer's fields in CRV areas (Olani and Fikre, 2010) which is in agreement with this study.

Figure 3.2. Onion marked for agronomic data and its yield

Drip lateral spacing in every row was irrigated near the root zone of onion as compared to that of drip laterals between two onion plant rows. Because drip laterals installed at 10 cm apart from the plant (drip laterals between two rows) cause onion plant roots unable to extract the water as it drips beyond the root zone. This indicates that installing drip laterals spacing in every row (one drip lateral for one onion plant row) is more efficient in terms of water use than drip lateral spacing between two rows. So drip lateral spacing influenced the mean total bulb yield of onion. Which means total bulb yield was increased as one drip lateral is installed for one onion plant row. This result indicates that as we put drip laterals far from plant root zone, water losses increase resulting in reduced yield. Therefore, drip lateral in every row performed best in reducing soil-water losses and increasing total onion bulb yield.

Economic Analysis

Effect of drip lateral spacing on B/C ratio and MRR of onion

Table 3. 6. Effect of drip lateral spacing on cost of production and net return of onion

Treatment	Total bulb yield (Kg/ha)	Adjusted bulb yield (Kg/ha)	Gross field benefit (ETB ha^{-1})	TVC (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Benefit cost ratio	MRR (%)
DLER	41,430	37,287	484,770	200,041	284,729	1.4	240.44
DLBTR	25,830	23,247	302,211	146,428	155,783	1.1	

TVC = Total Variable Cost and ETB = Ethiopian Birr and MRR = Marginal Return Rate.

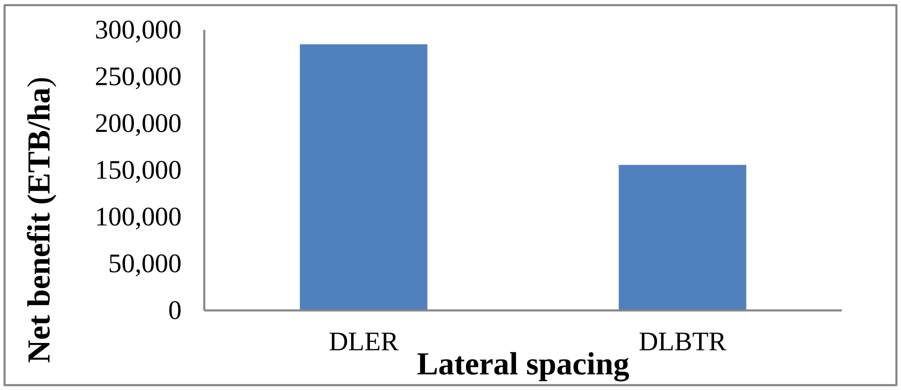

Figure 3.3. Economic return of drip lateral spacing

Based on drip lateral spacing, the cost of treatment in which the drip lateral between two onion plant rows was 26.80% less than the treatment in the drip lateral in every onion plant rows (Table 3.6). (Wondatir *et al*., 2013) found that investment costs in the design of one lateral for two crop rows were 27% less. Even though the total variable cost of implementing drip lateral in every row greater than that of drip laterals between two rows, it gave the maximum net income 284,729 ETB ha^{-1}. On the other hand, less net income 155,783 ETB ha^{-1} was obtained from drip lateral between two rows. Farmers installing drip laterals in between two onion plant rows for production of onion losses 128,946 ETB ha^{-1} and the Net benefit were reduced by 45.3% in the study area.

The net benefit value to cost ratio for drip lateral in every row is 1.4 and for that of drip lateral between two rows is 1.1. This result generally revealed that drip lateral in every row gave high net income than the drip lateral between two rows for drip irrigated fresh marketable bulb yield of onion. The result is due to significantly higher total bulb yield obtained from onion grown under drip laterals in every row. Similarly, (Himanshu *et al*., 2012) reported that drip lateral in every row resulted in higher gross benefit, net benefit and benefit cost ratio. In spite of high initial investment, drip irrigation method is profitable for onion production with drip lateral in every row for the study area.

Conclusion and Recommendations

Conclusions

Analysis of drip irrigation uniformity test showed that there is no significant uniformity variation between drip lateral in every rows and drip lateral between two rows. All uniformity determination parameters are within the recommended range. The maximum onion bulb yield of (41.43 t/ha) were obtained from drip lateral spacing in every. Highest value of water productivity and highest net benefit were obtained at drip lateral spacing in every row. In conclusion, this study point out that drip lateral in every onion plant row is economically profitable for the production of onion around Awash Melkassa climatic condition.

Recommendation

The following recommendations have been made based on the findings from one cropping season:

- Drip lateral in every row is economical for onion bulb producers under drip irrigation at Awash Melkassa climatic condition on loam soil since drip material can be reused.
- Onion production with drip lateral spacing between two plant rows of onion is used as an option method for onion producers of limited resource at this area.
- However, further work is required because lateral spacing adjustment have an effect on different soil type, climate, crop varieties and seasonal variation with drip irrigation to strengthen the study.

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Effects of In-Situ Moisture Conservation on Maize (*Zea Mays L.*) Yield in Moisture Deficit Area of Negele Arsi and Shala Districts, West Arsi Zone, Ethiopia

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Abstracts

Runoff and sediment yield estimation is important in the watershed to alleviate soil erosion and identify hotspot area for intervention strategies. The objectives of this study is to estimate runoff *and sediment yield in sub watershed; and prioritize and map the watershed in terms of sediment yield rate and runoff potential using SWAT model. From the result of the Global sensitivity analysis 14 highly sensitive parameters were identified and used for calibration and validation. The model was calibrated manually by adjusting sensitive parameters using observed data from 1990 to 2001, and validation was done using observed data from 2002 to 2007. The model performance was checked by statistical model performance evaluators such as the coefficient of determination (R^2), Nash–Sutclife model efficiency (ENS) and Percent bias (PBIAS) and it shows that the model has a high potential in the estimation of runoff and sediment yield. The highest annual surface runoff and sediment yield were 4.94 MCM (Million Cubic Meter)/yr and 22 $tha^{-1}yr^{-1}$ and the lowest were 0.04 MCM/yr and 1 $tha^{-1}yr^{-1}$ losses from watershed respectively. The average annual surface runoff and sediment yield were 1.26 MCM/yr and 7 $tha^{-1}yr^{-1}$ losses from the whole watershed. Statistical model performance evaluator of calibration result (R^2=0.51, NSE=0.51 and PBIAS=-0.8 for stream flow and R2=0.54, NSE=0.50 and PBIAS=21) shows a satisfactory agreement between the observed and simulated stream flow and sediment yield parameters. Whereas, statistical model performance evaluator of validation result (R^2=0.61, NSE=0.60 and PBIAS=-1.3 for stream flow and R2=0.69, NSE=0.61 and PBIAS=24.9) shows a good agreement between the observed and simulated stream flow and sediment yield parameters. Among 29 sub-watersheds, nine sub watersheds were more vulnerable/hotspot area to soil loss and potentially prone to erosion risk. Based on the hydrological simulation integrated watershed management plan should be implemented for effective land and water resource development. Hence, the outputs of this study will be used by decision to plan and implement appropriate soil and water conservation strategies in the hot spots area.*

***Key word**: Tied Ridge, Furrow closed at both end, Compartment, Flat bed,*

Introduction

The efficient use of water in agricultural systems is needed to improve crop production and resilience to environmental adversities that may be caused by climate change and extended droughts, especially in arid and semi-arid areas. Marginal and erratic rainfall aggravated by the loss of water by runoff and evaporation are the main causes of low crop production in this area (Yosef and

Asmamaw, 2015). Ethiopia has been dependent on subsidence rain-fed agriculture for centuries, and crop production has thus been heavily reliant on the availability of rainwater (Araya and Stroosnijder, 2010; Yosef and Asmamaw, 2015)**.** Out of these a biotic stresses, moisture stress is the most pronounced problem in the study area (Fuad *et al.*, 2017).

Out of the 13.6 million ha of cultivated land in Ethiopia, close to 97% is rain-fed implying that the nation's annual harvests depend heavily on the patterns of the seasonal rains (Awulachew *et al.,* 2005; FAO, 2005). Analysis of maize crop yield patterns since the 1970s shows that crop yields are mainly dependent on season quality (rainfall quantity and distribution) thereby making rainfall the most important crop yield determinant and depression (MLARR, 2001) and crop failure due to moisture stress is thus a common phenomenon in the semi-arid areas. Moisture stress is a prolonged period of short precipitation resulting to water deficiencies and lack of soil moisture to support crop production (Solh and van Ginkel, 2014). It is a great hazard in the world that frustrates the productivity of agricultural crops (Muhammad and Cengiz, 2015). Water deficits are triggered when the soil is drying from field capacity and evaporative loss of water exceeds passive water movement into plant roots.

In study area, high moisture deficit is the primary problem that is highly constrains the productivity of farmers of the district (priority problems raised by farmers). In moisture scant environments like Central Rift valley in generally, particularly in Negele Arsi and Shala districts crop would face shortage of moisture available in the soil throughout the growing season. In Negele Arsi and Shala, there is an uneven distribution of rainfall, late start and early finish of rainfall. In addition, the distribution of rainfall is not sufficient to sustain crop growth and development in the study area. The moisture deficit is leading to low crop production and productivity in the study area.

Farmers in the semi-arid zones have developed strategies, including Rain Water Harvesting (RWH), to cope with this uncertain and erratic rainfall patterns. Water harvesting techniques (WHTs) have played a key role in improving the efficient use of rainwater and have increased the sustainability and reliability of rain-fed agriculture (Biazin *et al*., 2012). Planting crops using in-situ moisture conservation reduces problems of soil moisture stress by reducing runoff through increased infiltration and storage of water in the soil profile, the onset and occurrence of severe water stress is delayed thereby buffering the crop against damage caused by water deficits during dry periods (Nyamadzawo *et al*., 2013).

In general, Central Rift Valley (CRV) is one of those environmentally vulnerable areas, particular in some parts of Arsi Negelle and Shala districts where poverty and natural resource degradation are intertwined. The problems of semi-arid regions are so complex that there is little interest to solve them through intervention or research. Unfortunately, most dry spells occur during critical crop growth stages and hence the need of dry spells mitigation by improving water productivity in the study area. Apart from soil nutrient loss, water stress is also a major limiting factor to food production in rain fed farming systems. The maize crop failed at development stage before seed setting in some parts of study area and farmers obtained low yield from their farmland. Thus, most of the population living in the lowland of study area is under aid by Safety Net programs, Catholic Relief Service and other NGOs.

In-situ moisture conservation structures were expected to give solution to the dwindling maize yield production in study areas. So far, the significance of the problems of soil moisture deficit in the study area leading to low crop productivity of maize yield. Therefore, this research was conducted to investigate the effects of in-situ moisture conservation techniques on maize yield and recommended relevant treatment with a view to improve the yield of maize under rain-fed farming in moisture stress areas of Negele Arsi and Shala districts, West Arsi zone.

Materials and Methods

Description of Study Area

The experiment was conducted in Negele Arsi and Shala districts, which is found in West Arsi zone of Oromia regional state. It is located at a distance of 282 km south- west of Addis Ababa and 32 km south-west of Shashemene town on the main road of Shashemene to Arba Minch. Geographically, it is located between 38°21’ E latitude and 7°18’ N longitude (Figure 1). The altitude of the study area ranges from 1500 to 1926 m above sea level. In addition, the experiment was conducted in Negele Arsi district, which is found in West Arsi zone of Oromia regional state. It is located at 225 km south of the Addis Ababa. Geographically, it is situated in the central rift valley system between 7° 09’-7° 41’ N longitude and 38°25’-38° 54’ E latitude (Figure 1). The altitude of the study area ranges from 1500 to 2300 m above sea level and falls in weyna dega Agro-ecological Zone (Husen *et al*, 2017). The average annual temperature of Negele Arsi district varies from 10 to 25°C, while the annual rainfall varies between 800 and 1200 mm (ORS (2004)).

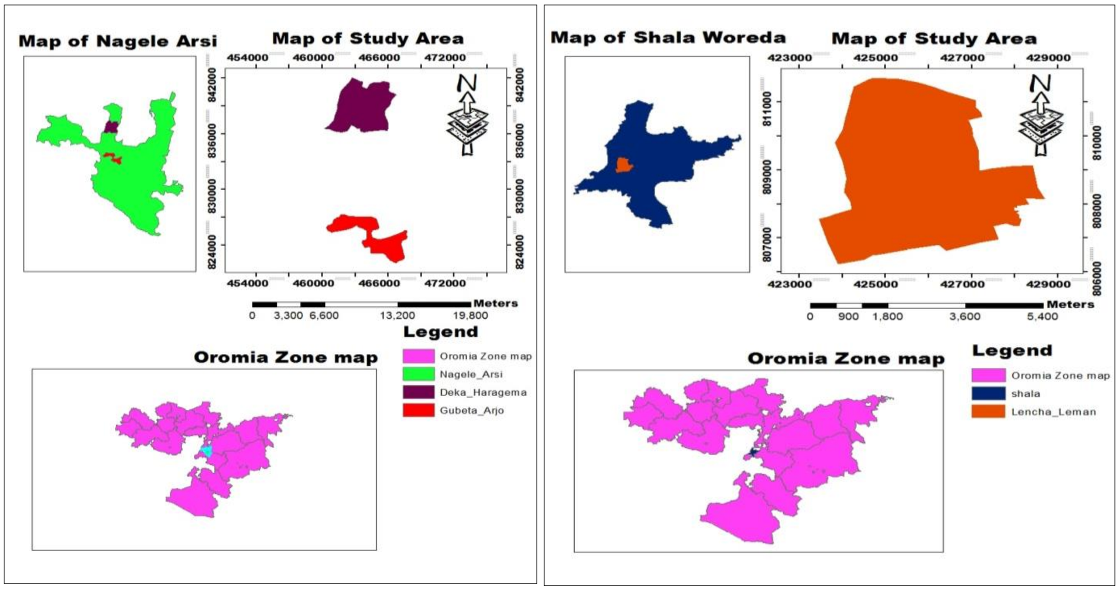

Figure 1: Map of study areas

Methods

The experiment was carried out at the Negele Arsi and Shala districts, on farmers' farmland to investigate the effects in situ moisture conservation on maize yield and yield components. The three kebele were extracted from Ethio kebele shape file by using Arc GIS version 10.3. The three kebele were selected purposively based on its maize production, moisture deficit and dominant soil type. The one (Vitric Andosols) dominant soil type was selected from Shala ditrict. Whereas, two (Eutric Cambisols and Mollic Andosols) selected major soil types were from Negele Arsi. The farmers in each kebele were selected purposively based on their willingness and recommendation by districts agricultural expert and Development Agents (DAs) for conducting experiment. The experiment was conducted on similar slope. All experimental plots were ploughed three times by oxen before imposing any treatments. The BH540 maize variety was used as testing crop. Based on previous recommendations of fertilizer application on maize by Debelle and Friessen (2001), 100 kg ha^{-1} Urea in two applications (50 kg ha^{-1} during sowing and another 50 kg ha^{-1} was applied 45 days after sowing) and 100 kg ha^{-1} of DAP in one application (only during sowing) were applied.

Experimental design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) in factorial arrangement with three replications. The experiment was conducted for three years under rain fed condition. Two levels of treatments (tied ridge and furrows closed at both end) and flatbed (without in-situ moisture conservation structure) as control were used. In tied ridging, ridge furrows were blocked with earth ties spaced at 1.75m apart from each other in the field. The tied ridge, compartment and furrow closed at both ends were prepared manually by hand hoe. Each treatment was applied on a plot size of 5.25*4.5m (23.631m^2) separated by a distance of 1.5 m between blocks and 1 m within plots. The height of tied ridge was 30cm and planted at spacing of 25cm between plant and 75cm between plots.

Figure 1: Preparing layout by hand hoe (A) and planting of BH-540(B)

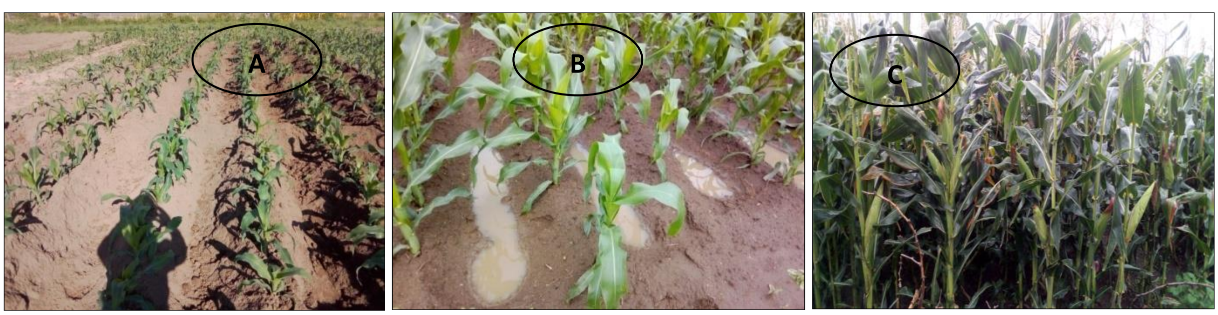

Figure 2: Preparation of In-situ moisture conservation structure (A), harvested water in the structure (B) and status of maize (C)

Agronomic data collected

Measured parameters include plant height, yield per hectare, number of cobs per hectare, thousand seeds weight and yield advantages. The plant height was recorded by taking the random five plants from the central three rows of each plot. Yield and other yield components were recorded from the net area of 4 m^2 (2 m*2 m). Yield recorded was air dried weight of seeds and expressed as $Qtha^{-1}$. The number of cobs (heads) per hectare were determined by counting the number of cobs in the net area and converted into hectare. Seed weight was determined by taking a random sample of thousand seeds. Thousand seeds weight were determined by taking a random sample of thousand seeds and their weight recorded in grams. The yield advantage (%) of in-situ moisture conservation structure on control was determined by Eq.1

$$.\ \text{Yield advantages } (\%) = \frac{\text{Yield with structure} - \text{Yield without structure}}{\text{Yield without structure}} * 100 \ldots \ldots .\ \text{Eq. } 1$$

Statistical analysis

All the agronomic data was recorded and being subjected to analysis. Analysis of variance was performed using the GLM procedure of SAS Statistical Software Version 9.0. Mean separation least significant difference (LSD) was used to compare and separate treatments mean at 1 to 5% probability level.

Results and Discussions

Effects of In-Situ Moisture Conservation structures and soil types on grain yield and yield components of maize

Table 1: Summary of grain yield and yield components of maize as affected by selected in-situ moisture conservation in Negele Arsi and Shala districts

Negele Arsi district						**Shala district**				
Trts	Plh (cm)	$NCha^{-1}$	Yld ($Qtha^{-1}$)	1000 SW(gm)	Yld.ad(%)	PH (cm)	$NCha^{-1}$	Yld ($Qtha^{-1}$)	1000 SW(gm)	Yld.ad(%)
TR	202.58[a]	58,303[a]	84.30[a]	427.70[a]	**24.41**	231.9[a]	58,740[a]	84.6[a]	443.3[a]	**17.86**
FCE	204.42[a]	55,650[a]	78.60[a]	422.15[a]	**17.86**	224.7[a]	55,031[a]	82.7[a]	445.6[a]	**15.21**
FB	200.76[a]	52,850[a]	66.69[b]	380.14[b]		212.2[a]	51,163[a]	71.78[b]	392.2[a]	
Mean	**204.50**	**55,733**	**75.82**	**408.14**		**222.9**	**54,978**	**79.67**	**427.04**	
CV (%)	18.70	21.90	25.07	14.55		8.65	25.81	12.61	13.60	
P- value	0.7	0.34	**<0.001****	**<0.001****		0.11	0.64	**<0.05***	0.11	
LSD(0.05)	19.06	5840.2	9.36	28.03		18.85	13873	9.82	56.77	

*Treatment values within a column followed by the same letter are not significantly different at 5%.
TR: Tied Ridge, FCE: Furrow closed at both Ends, FB: Flat Bed (FB), CV: Coefficient of variation, %= percent, LSD: Least of significance Difference, Trts=Treatments, Yld=Yield, $Qtha^{-1}$ = Quintal per hectare, Plh=Plant height, $NCha^{-1}$= Number Cobs per hectare, MC=Moisture Conservation, ,*, ** and *** level of significance at P<0.05 and P<0.001 respectively and NS = not significant difference

Effects of In-Situ Moisture Conservation structures on grain yield and yield components

Grain Yield

The grain yield of maize was highly significant difference ($P < 0.001$) on tied ridge and furrow closed at both end as compare to flatbed (without conservation) in Negele Arsi district for three consecutive cropping seasons (Table 1). Also the grain yield of maize was significant difference ($P<0.05$) on tied ridge as compare to flatbed (without in-situ moisture conservation structure) in Shala district for two consecutive cropping seasons (Table 1). In this study, it was noted that the higher grain yield of maize obtained from tied ridges than other moisture conservation practices. The recorded maximum yield on the tied ridge might be attributed to the efficiency of tied ridge to conserve and retain moisture and more infiltration of water in the soil. This implies that in-situ moisture conservation structures enhance moisture in the soil. This result fully agreed with findings of Solomon (2015), Yoseph (2014), Ahmed *et al.,* (2018), Naba *et al.*, (2020), Husen, D .and Shalemew, Z. (2020) and Legese and Gobeze (2015) who reported that maize grain yield and sorghum was significantly affected by moisture conservation practices. In addition, this result agreed with the findings of Ramachandrappa *et al*. (2012), reported that the higher yield and yield components of rabi sorghum in moisture conservation treatments could be attributed to vigorous crop growth resulting from increased availability of soil moisture. And Milkias *et al*. (2018) studied different in situ RWH methods on soil water storage and on the growth, grain yield and water-use efficiency of sorghum in the Central Rift Valley and concluded that in-situ moisture conservation structures were increased soil moisture when compared to flatbed/control/. Thus**,** efficiently conserving rainwater through in-situ moisture conservation structures boosting production when compared with control and practicing in-situ rainwater harvesting structures is imperative for enhancing maize yield per unit area.

Thousand seed weight (gm)

The thousand seed weight was significantly ($p< 0.001$) difference on tied ridge as compared to flatbed in Negele Arsi district for three consecutive cropping seasons (Table1). However, there is no significant ($p<0.05$) difference on thousand seeds weight in Shala district for two consecutive cropping seasons. Even though, there was no significant difference between the treatments, but the mean of thousand seeds weight increased on in-situ moisture conservation than flatbed. This implied that in-situ moisture conservation structures improve thousands seeds weight by retaining surface runoff and increase infiltration within the catchment. In fact, the seeds which were supplied with adequate moisture did mature well to have heavier seed weight than flatbed (without conservation). This could be attributed to the fact that the relatively higher soil moisture accumulated in the in-situ moisture conservation permitted late maturity of the crop and as a result giving enough time for the maize plant to develop their seeds properly with adequate and continued moisture supply. This result agreed with Dagnaw et al. (2018) reported that, tied ridge was harvest more water than flat bed. In addition, this result agreed with the Gebreyesus (2004) and Husen, D .and Shalemew, Z. (2020), reported that in-situ soil moisture conservation had a significant effect on thousand seeds weight.

Yield advantage (%)

The tied ridge and furrow closed at both end were gave yield advantages of 24.41 and 17.86 over flatbed in Negele Arsi district respectively. And the tied ridge and furrow closed at both end were gave yield advantages of 17.86 and 15.21 over flatbed in Shala district respectively. This result agreed with the previous findings of Heluf and Yohannes (2002), reported that tied ridge has resulted in yield increments of 15 to 50% for maize and 15 to 38% was recorded for sorghum on different soil types of eastern Ethiopia and Biazin and Stroosnijder (2012) reported an increase of 26% in maize grain yield under tied ridging as compared to flat bed in the Central Rift Valley of Ethiopia around Langano.

Similarly, Tekle (2014a) and Hailemariam (2016) reported that tied ridge had a grain yield advantage of 26% for cowpea and 34.5% for sorghum over flatbed/control. Barron and Okwach (2005) showed that, rainwater harvesting technique increased maize yield by about 70% in semi-arid Kenya and Yoseph and Gebre (2015) and Amisalu *et al.,* (2018) reported that, the average sorghum and maize grain yield under tied ridges increased 55.72% and 143.14% over flatbed respectively. In addition, Husen, D. and Shalemew, Z. (2020) reported that the average maize grain yield under tied ridge and furrow closed at both end increased 45.5 and 30.6% for maize over the flatbed respectively in Dudga district. According to this result, it concluded that the highest grain yield and yield components obtained from in-situ moisture conservation structure might be attributed to the fact that the availability of the retained moisture in the in-situ moisture conservation structures.

Effects of selected soil types on yield and yield components

Table 2: Summary of grain yield and yield components of maize as affected by selected major soil types in Negele Arsi and Shala districts

Soil Types	Yield ($Qtha^{-1}$)	1000 Seed weight (gm)	Number of cobs ha^{-1}	Plant height (cm)
Vitric Andosols	79.69^{a}	421.11^{a}	$54,978^{a}$	222.92^{a}
Eutric Cambisols	73.41^{a}	426.89^{a}	$55,984^{a}$	216.03^{ba}
Mollic Andosols	81.03^{a}	442.89^{a}	$56,502^{a}$	208.17^{b}
Mean	**78.04**	**431.13**	**55,898**	**215.05**
CV (%)	24.25	12.05	21.02	9.35
P-value	0.20	0.22	0.88	**<0.05***
LSD(0.05)	9.32	25.63	5797	9.92
Soil types*MC	NS	NS	NS	NS

MC- moisture conservation

The plant height was significant difference (P<0.05) on Vitric Andosols than Mollic Andosols (Table 2). The grain yield and thousand seeds weight of maize were higher under crop grown on Mollic Andosols than others. The increments of grain yield and thousand seeds weight of maize on Mollic Andosols (site) might be due to good climate (rainfall) condition than Vitric Andosols and Eutric Cambisols (sites). On other hand, this result is in lines with Bagegnehu .B and Yenealem .G (2021) who reported that Mollic Andosols which have excellent water holding and nutrient capacity and good aggregate stability and high permeability. In addition, according to Bagegnehu .B and Yenealem .G (2021) reported that on their inherent characteristics, cambisols are erodible soil type. Thus, Mollic Andosols was best for retaining more moisture and better for boosting maize yield in the study area. The soil types did not have any interactions with in-situ moisture conservation.

Conclusions and Recommendations

The low crop productivity in the country particularly in the study area caused by shortage of rainfall, irregular distribution of rainfall and erratic rainfall characteristics are the major limiting factor for crop production at rain fed agricultural system. However, the problem of moisture stress for rain fed agricultural systems can be mitigated by using in-situ moisture conservation practices that improved storage of soil moisture at root zone. The in-situ moisture conservation structures were vital for successful and boosting crop production and it is necessary to adopt in the study area. The selected in-situ moisture conservation structures were affects the maize yield and yield component in the in study area. In this respect, the tied ridges showed significant difference at these specific areas. The tied ridge structure gave higher mean grain yield of maize than other treatments. In addition, furrow closed at both end was also high in mean grain yield and yield components as compare to flat bed in both districts. In general, in-situ moisture conservation structure was provided a better yield advantages over flat bed and showed a promising result on maize grain yield and yield components.

Generally, planting maize under tied ridge and furrow closed at both end gave high yield advantages over flat bed. The magnitude of yield response to in-situ water harvesting techniques and the relative effectiveness of the different harvesting methods tend to vary with in-situ moisture conservation techniques.

Therefore, tied ridge was better for mitigation moisture stress and boosting maize production and productivity in both districts. In addition, furrow closed at both end was gave better yield and yield component next to tied ridge in the study area. The Mollic Andosols was good in retaining more moisture and boosting maize yield and recommended as the soil that retain more moisture in the study area. Finally, it could be recommended that tied ridge technique is crucial to agricultural operations for successful maize production in the study area and similar areas. As future recommendations, strong extension worker is need for demonstration and popularization of this technologies and recommended technologies should have great attention in the study area and similar agro-ecology. On other hand, use of in-situ moisture conservation structures (tied ridge and furrow closed at both end) are advisable and could be appropriate for maize production in the study area even though further (like soil moisture determination) testing is required to come up with strong recommendation.

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Estimation of Runoff and Sediment Yield Using Soil and Water Assessment Tool Model for Dedeba Watershed, Rift Valley Lake Basin, Ethiopia

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Abstract

Runoff and sediment yield estimation is important in the watershed to alleviate soil erosion and identify hotspot area for intervention strategies. The objectives of this study is to estimate runoff and sediment yield in sub watershed; and prioritize and map the watershed in terms of sediment yield rate and runoff potential using SWAT model. From the result of the Global sensitivity analysis, 14 highly sensitive parameters were identified and used for calibration and validation.
The model was calibrated manually by adjusting sensitive parameters using observed data from 1990 to 2001, and validation was done using observed data from 2002 to 2007. The model performance was checked by statistical model performance evaluators such as the coefficient of determination (R^2), Nash–Sutclife model efficiency (ENS) and Percent bias (PBIAS) and it shows that the model has a high potential in the estimation of runoff and sediment yield. Statistical model performance evaluator of calibration result shows a satisfactory agreement between the observed and simulated stream flow and sediment yield parameters. Whereas, statistical model performance evaluator of validation result shows a good agreement between the observed and simulated stream flow and sediment yield parameters. Among 29 sub-watersheds, nine sub watersheds were more vulnerable/hotspot area to soil loss and potentially prone to erosion risk. Based on the hydrological simulation integrated watershed management plan should be implemented for effective land and water resource development. Hence, the outputs of this study will be used by decision to plan and implement appropriate soil and water conservation strategies in the hot spots area.

Keyword*:* Runoff, Sediment Yield, SWAT model and Watershed

INTRODUCTION

Each year, in Ethiopia it is estimated that 1.5 billion tons of top soil is washed away from their original location (Hurni, 1987) and degradation of land through soil erosion is increasing. The Central Rift Valley (CRV) of Ethiopia is greatly affected by soil erosion, sediment transport and land degradation. The CRV is one of the environmental vulnerable areas in the country. The land and water resources of the area are adversely affected by the rapidly growing population, deforestation, absences of SWC, over cultivation, overgrazing and rising demand for cultivated land have been the driving force to a series of soil erosion in the basin in general and in Dedeba watershed in particular (MOARD, 2004).

Runoff and sediment yield modeling is important in the watershed (Arnold J, Fohrer N (2005) SWAT 2012 and Borah D, Bera M (2003)). Even though watershed has only one outlet point, it is characterized by different socio-economic activities, spatial, hydrological and climatic variability. Spatial and temporal variability have the visible change in the quantity of runoff decreased or increases with the size of watershed and shape Raghunath HM (2006).

There are many erosion prediction models worldwide. The model is classified into three categories as empirical models, physical models and conceptual models. The use of models depends on the availability or adequacy of input data. Empirical models are models based on inductive logic, and generally are applicable only to those conditions for which the parameters have been calibrated or used for identifying the sources of sediments since they are developed from the experimental measurement or field measurement (Merritt *et al.* 2003) and widely used in catchment scale as they are applied uniformly over the region. However, they are unable to analyze the dynamics of sediment erosion and deposition in the watershed as it contains fewer amounts of input data. Physical models are models which are based on solving fundamental physical equations describing stream flow and sediment and associated nutrient generations in a specific catchment (Merritt *et al.* 2003). The demerit of this model is the requirement of large amount of data. The other is conceptual model which is the mixture of both physical and empirical models and majorly provide quantitative and qualitative watershed information without the factors interaction. Empirically, plot-based soil loss due to water erosion has been reported by many researchers (for example: Veihe *et al.* 2001). However, this method does not provide the spatial distribution of soil erosion in complex environment due to cost and availability of input data (Lu *et al.* 2004). Recently, the SWAT model has been used worldwide and considered as a versatile model that can be used to integrate multiple environmental processes, which supports more effective watershed management and the development of better informed policy (Gassman *et al*., 2005).

In order to reverse soil erosion, several efforts have been exerted since the 1970s (Menale *et al.* 2009; Nigussie *et al*. 2012). However, past soil conservation efforts did not bring significant changes to the ongoing soil degradation problems (Menale *et al.* 2009). Most recently, watershed management is an approach followed by the government of Ethiopia to protect soil from erosion in particular and to reverse land degradation in general (Desta *et al*. 2005; Gete 2006; Nigussie *et al.* 2012). Although dramatic reduction has been made in arresting soil erosion (AgWater Solutions 2012; Nigussie *et al.* 2012; Tongul and Hobson, 2013), the approach has not been supported with intervention prioritizing techniques that identify highly susceptible areas using geospatial analysis.

Watershed management is vital to reduce catchment soil erosion that can be caused by several anthropogenic and natural activities. Soil erosion is usually responsible for depleting soil productivity, destroying agricultural land and reducing canal capacity. Unless the magnitude of the erosion–sedimentation problem is understood and appropriate watershed management intervention implemented, the increasing amount of soil erosion suggests that lakes in the CRV face a similar fate to the reservoirs of northern and eastern Ethiopia. Modeling the hydrological process such as runoff and sediment yield of the watershed is useful to manage the natural resources. In turn, this can be helped for sustainable soil and water management, which are key resources of the community living in the watershed. Thus, estimations of soil loss and identifications of hotspot regions are important to in order to preserve naturally balanced watershed. Dedeba watershed has been under intensive commercial and public use over the past decade, leading to rapid decline in the natural vegetation, water availability and productivity.

The rift valley river watersheds suffer severe land degradation and soil erosion due to extended dry seasons in some parts of the Basin, torrential rain and geological nature, bringing large quantities of sediment in the drainage systems (Mengist, 2017). Human occupation of the rift valley has placed extreme pressure on the natural flora and fauna, which is rapidly disappearing. During the last three decades there has been large-scale clearing of natural vegetation for agriculture, overgrazing of natural grasslands, and clearing of forests for construction material and fuel. Moreover, intensive cultivation of annual crops and deforestation of forest has caused serious erosion problems in the Dedeba watershed, resulting in soil nutrient depletion or soil fertility reduction. In addition, steeper slopes are cultivated without protective measures against land erosion and degradation in the study area. Land degradation due to soil erosion by water not only reduced the productivity of the land in this watershed, but also causes siltation at the downstream of watershed. This process has aggravated degradation in the area resulting in on-site soil erosion and off-site heavy sedimentation.

One of the possible solutions to alleviate the problem of land degradation (soil erosion) is to understand the processes and cause of erosion at a micro watershed level and to implement watershed management interventions. The estimation of soil erosion loss and evaluation of soil erosion risk has become an urgent task before implementing soil conservation practices in the study area. Identification of the hotspot areas that are significantly affected is essential to prioritize problem-oriented and site–specific watershed management efforts. However, there is no sufficient research work on this issue before in the watershed. The total amounts of surface runoff volume and sediment yields annually leaving the watershed are not easily quantified. Therefore, surface runoff and sediment yield estimation is important for future watershed management by knowing the amount of losses. SWAT model is important to predict reliable quantity and rate of sediment transport from land surface and identify erosion prone areas within a watershed. Hence, identifying and prioritizing erosion susceptible areas for soil conservation measures are quite essential. Therefore, the objectives of this study is to estimate runoff and sediment yield in sub watershed; and prioritize and map the watershed in terms of sediment yield rate and runoff potential using SWAT model.

Materials and Methods

Description of study area

The study area is found in the Ziway shala sub basin and darins to Lake Shala. Geographical, it situated between UTM zone of 778000 meter N to 820000 meter N ($7^0$20'N - $7^0$25'N) and 460000 meter E to 495000 meter E ($38^0$38'E - $38^0$57'E) as shown in the Figure 1 below. The catchment covered three woredas administrations; these are Shashemene, Negele Arsi and Kofal. From this, most part of watershed was fallen in kofale woreda, which accounts 88.073 Km^2. Moreover, the small watershed was fallen in Shashemene woreda, which accounts 22.127 Km^2 and 26.45% was fallen in Negele Arsi woreda. The total land area is estimated about 141.64Km^2.

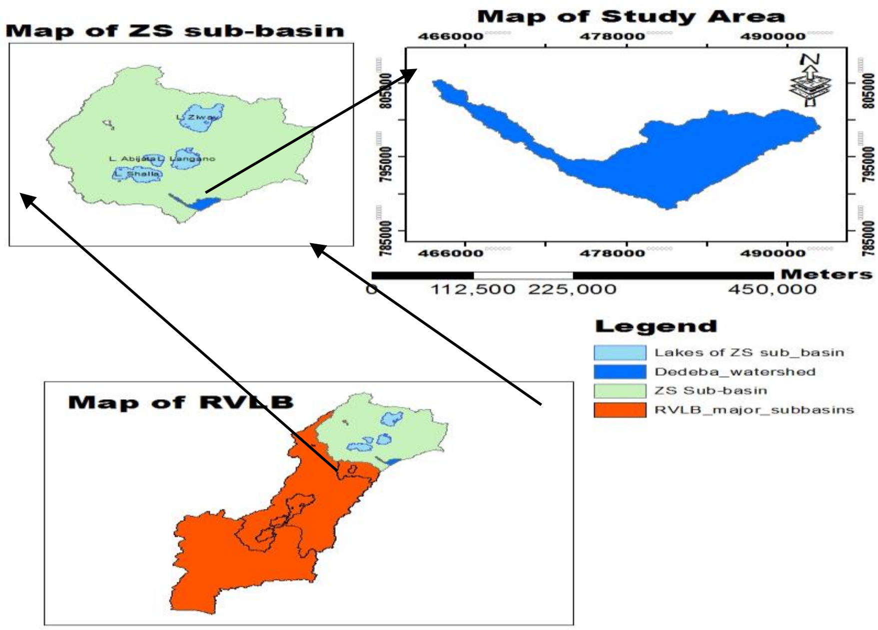

Figure 1: Study watershed

Hydro meteorological data

Hydro-meteorological data is needed by the SWAT model to simulate the hydrological behavior of the watershed. The three meteorological data obtained from the National Meteorological Agency (NMA) and one from National Centre for Environmental Prediction’s (NCEP) Climate Forecast System Reanalysis (CFSR) grid stations (Global Weather, 2014) for the time range from 1988 to 2014 for this study watershed. The meteorological data collected daily value for precipitation, maximum and minimum air temperature, wind speed, relative humidity and solar radiation. The data was prepared on daily basis and organized using the Microsoft Excel program and formatted as note pad, which is the required format by SWAT model. To manipulate and use point rainfall in SWAT, the missing weather data were filled by negative (-999) and saved in notepad format. Daily precipitation data was used by the weather generator of the SWAT model (Userwgn.dbf) and calculated using pcpSTAT.exe computer program for each station using daily precipitation data.

The stream flow data were collected from Ministry of Water, Irrigation and Electricity from the hydrology and water quality directorate department in the time series data (1988–2014) for Dedeba River at near Kuyera (No. 081003) gauging station with a catchment area of 141.71Km^2.

Checking data consistency

To check the change in magnitude of rainfall data stations, Double Mass -Curve (DMC) analysis was used to check whether the existence of an inconsistency in rain gauge stations in Dedeba watershed. For Dedeba catchment, the missing data were first estimated, and then consistency analysis was applied. The cumulative rainfall data of a specific station is plotted against the accumulative average rainfall of the remaining stations. The data plotted for the periods 30 years (1988-2017), all the stations are internally consistent for all the stations. The observed gauging stations data shows that the collected data was homogeneous. The results of the consistency analysis are plotted in Fig 2.

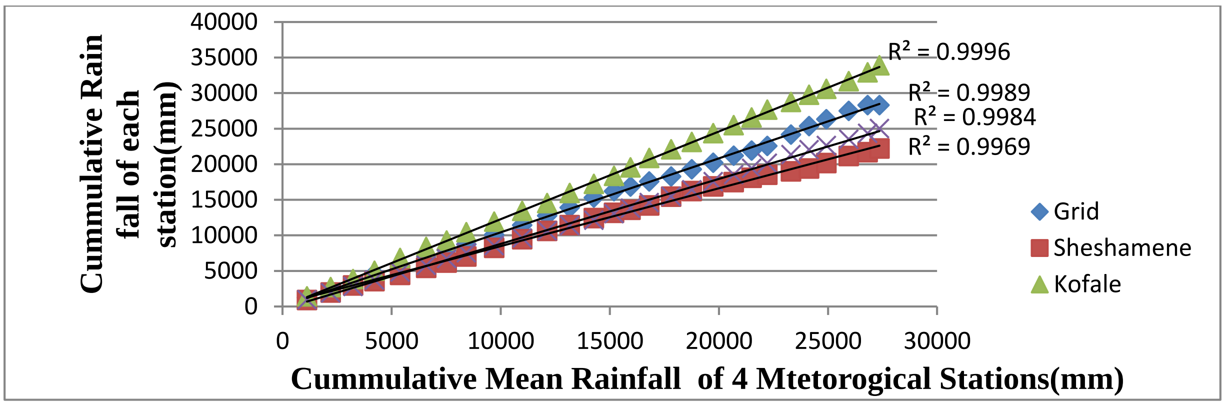

Figure 2: Double Mass Curve for the Stations of Dedeba Watershed

Sediment data

The gauging stations for which flow measurement and sediment sampling was made at Dedeba near Kuyear. The sediment data collected from Ministry of water, Irrigation and Energy (MOWIE) is not data of all monthly days rather it was sample taken in different seasons within different years. On other hand, due to discontinuous time series sediment record data measured using stream flow and measured suspended sediment data, sediment load data was generated in the continuous time step by developing sediment-rating curve. Therefore, it was important to develop relationship between river discharge and sediment concentration for the existing data to get the daily sediment loads (sediment rating curve). Suspended sediment flux estimation was calculated using a relation of discharge to suspended sediment discharge known as a sediment-rating curve (SRC) (Khassaf and Hassan, 2014)

$$Qs = aQ^b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \text{Eq. 1}$$

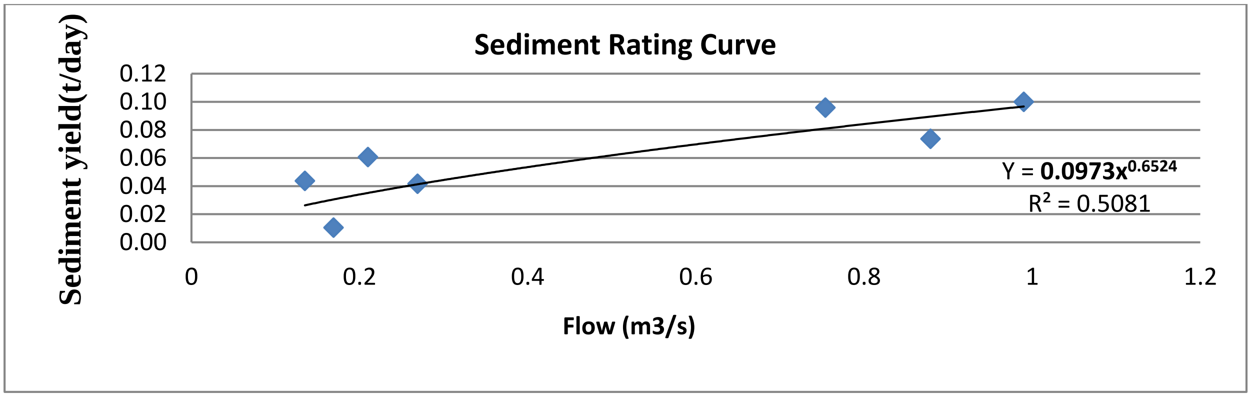

Figure 3. Sediment rating curve at Dedeba watershed gauging station (Dedeba Nr. Kuyera)

The relation of sediment load and discharge at the gauging station with R^2 value of 0.508 was derived as:

$$Qs = 0.0973Q^{0.6524} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. Eq. 2$$

SWAT model

SWAT is a relatively recent model used to assess the watershed hydrology (Jha, 2011). According to Kannan *et al.* (2007) and Jha (2011), it is the best among the different hydrological models due to its capability for application to large-scale watersheds (> 100 km2), interface with a Geographic Information System (GIS), continuous-time simulations performance, and generation of the maximum number of sub-basins and ability to characterize the watershed in enough spatial detail.

Model Inputs

Digital Elevation Model (DEM)

The DEM used in this study was obtained from Ministry of Irrigation, Water and Electricity (MOIWE), GIS and Remote sensing department with a spatial resolution of 1 Arc– second (30 x 30 m). The required spatial data sets were projected to the same projection called Adindan UTM Zone 37 N, which is the transverse Mercator projection to correct the errors and fit into the model requirement. It was used to delineate the topographic features of watershed in order to determine the hydrological parameters of the basin such as, slope, flow direction and accumulation, outlet points and stream network. A masking polygon (in grid format) was loaded into the model in order to extract the area of interest, delineate the boundary of the watershed and digitize the stream networks in the study area. Arc SWAT was used Digital Elevation Model (DEM) data to automatically delineate the watershed into several hydrologically connected sub-watersheds. After the DEM grid was loaded and the stream networks superimposed, the DEM map grid was processed to remove the non-draining zones. The initial stream network and sub-basin outlets were defined based on drainage area threshold approach. A Digital Elevation Model (DEM) gives the elevation, slope and defines the location of streams network in a basinand used for slope classification.

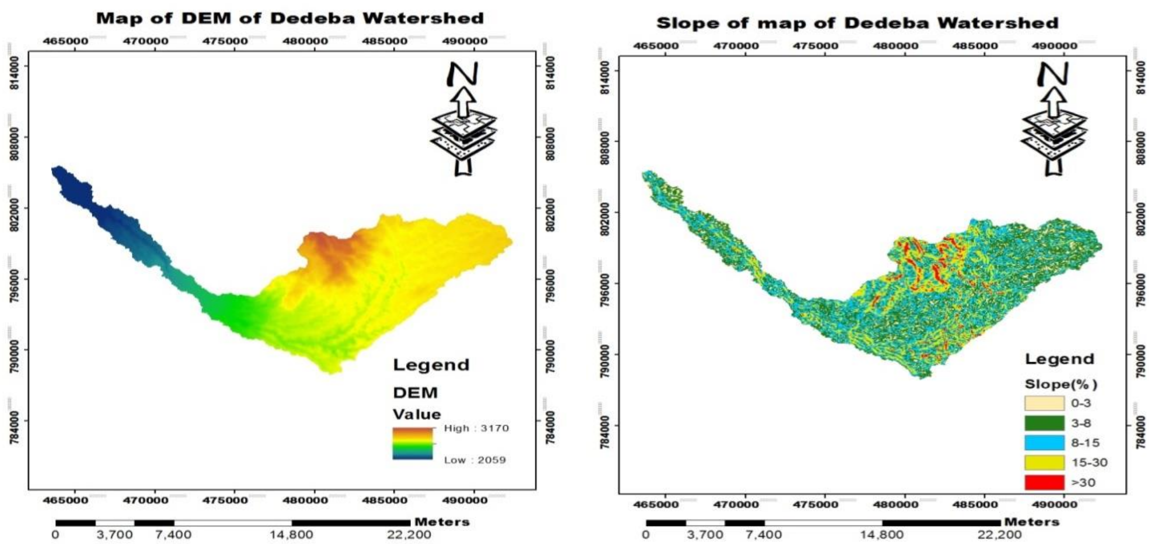

Figure 4: Map of DEM (left) and slope (right)

DEM of Dedeba watershed was mapped. The highest and lowest elevation was identified. The 3170 and 2059 m.a.s.l is highest and lowest elevation respectively. According to MoARD, (2005), slopes of study area were classified into 5, namely slopes from 0-3,3-8, 8-15,15-30 and 30 %. The slopes ranges from 3-8% of slope is covered more area (34.51%) of watershed and >30% of slope is covered least area (3.10 %) of watershed.

Table 1: Slope classes and the area occupied in ha and percent (ha &%) of the study area

Slope range (%)	Kater Watershed		
	Land form	Area (ha)	Area Coverage (%)
0-3	Flat or almost flat	1258.90	8.88
3-8	Gentle slopping, undulating plain	4892.64	34.51
8-15	Rolling plain	4718.03	33.28
15-30	Hilly plain	2868.46	20.23
>30	Steep hilly, very steep slopes, ridges and mountains	440.22	3.10
Total		**14178.25**	**100**

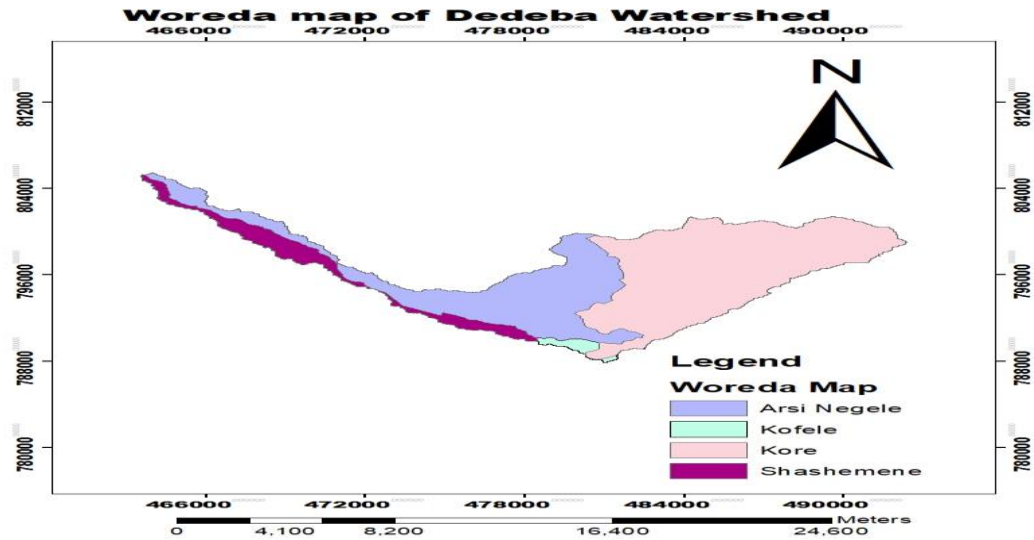

Figure 5: Map of Woredas found in the sub watershed and its area coverage (Sq.km)

Table 2: Woreda fallen into Sub watershed and it's area coverage

	Dedeba Watershed
Name of Woreda	**Area (Sq.km)**
Kofale	3
Negele Arsi	49
Shashemene	13
Kore	77
Total	**142**

The large area of Dedeba watershed is fallen in Kore (77 Sq.km) woreda. Whereas, the smallest (3 Sq.km) area of watershed fallen in Kofale woreda.

Land use/Land cover

Land use/land cover data has also a significant effect on the hydrology. Land use/land cover affects the runoff and sediment transport in the watershed. Land use land cover (LULC) is one of the furthermost significant spatial input data by SWAT model that disturb water runoff, evapotranspiration, surface erosion and other hydrological execution in a given basin. The digital land use and land cover of the Dedeba watershed was obtained from Ethiopian Rift Valley Lake Basin Master Plan study (2010). On the basis of land use and land cover map of Ethiopia, the extracted land use and land cover (LU/LC) map of the study watershed was reclassified using the SWAT model in order to correspond with the parameters in the SWAT database (Fig. 5). For successful reclassification, a look up table that identifies the 4-letter SWAT code was prepared in notepad format to relate the grid values to SWAT land use/land cover classes for the different categories of land use/land cover.

Table 3: Original Land use/ land cover types and their SWAT code in the study area

Original Land Use	**SWAT Code**
Intensively Cultivated	AGRC
Moderately Cultivated	AGRL
Distributed Forest	FRST

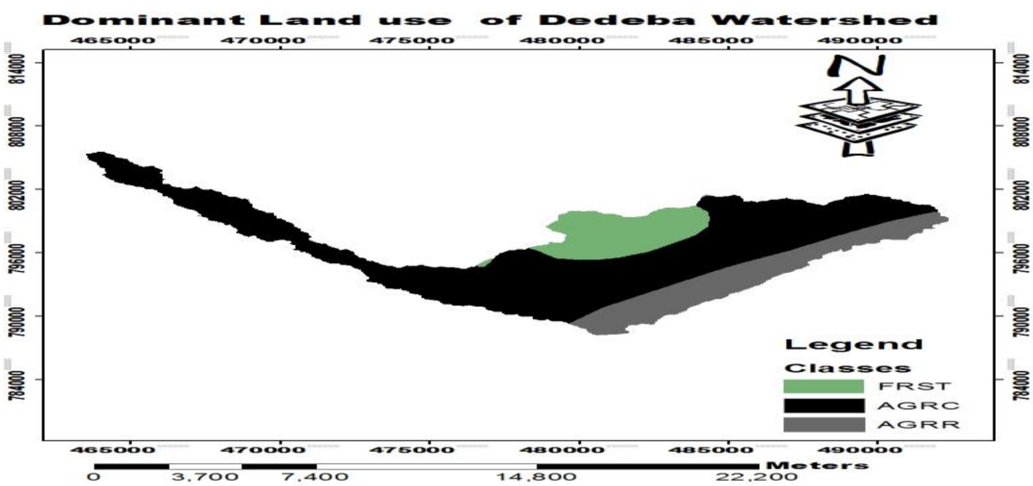

Figure 6: Map of Land use Land cover 2010 (source: Master plan of MoIWR, 2010)

After LU/LC, SWAT code was assigned to all map categories, the estimated values of the area and percent (%) coverage by each land use land cover is illustrated below in Table 4. The Dedeba watershed was classified into 3 major land uses classes, namely intensively cultivated Land (AGRC), Moderately Cultivated Land (AGRR) and Forest (FRST) lands. Intensively cultivated land is the dominant land use type in the study area which covers 67.84% of total watershed and distributed Forest land is covered 13.70 % of watershed of watershed (Table 4).

Table 4: Area coverage by each land use/Land cover in ha and percent (ha & %) of the study area

	Dedeba Watershed	
Major LULC	**Area (ha)**	**Area (%)**
Intensively Cultivated	9619.02	67.84
Moderately Cultivated	2616.62	18.46
Distributed Forest	1942.61	13.70
Total	**14178.25**	**100.00**

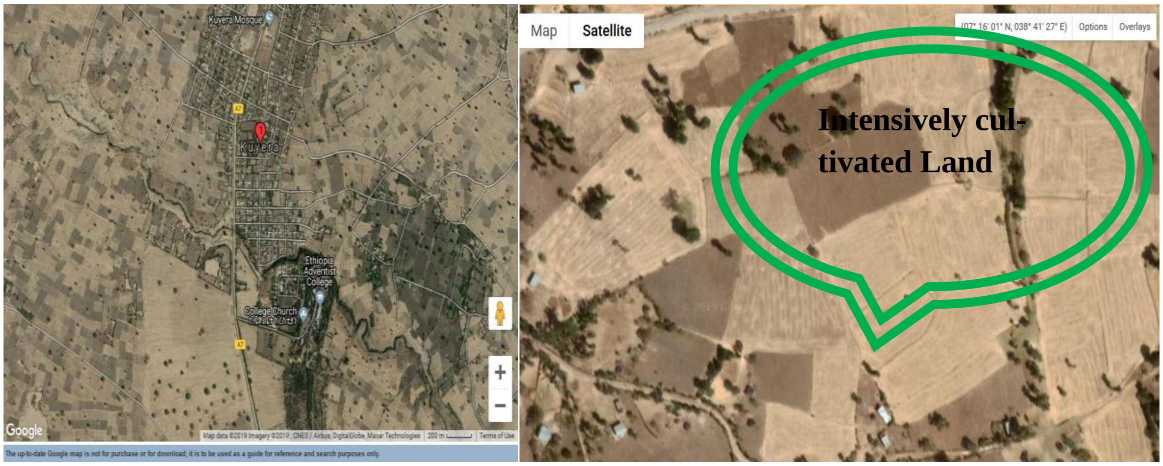

Figure 7: Partial overview of the study watershed (Source: Google earth, 2019)

Soil data

The digital 2010 soil map of the Dedeba watershed was obtained from Ethiopian Rift Valley Lake Basin Master Plan study. The physio-chemical properties were analyzed in Ethiopia Water Works, Design and Supervision Enterprise soil laboratory. The SWAT model requires soil property data such as the texture, chemical composition, physical properties, and available moisture content, hydraulic conductivity, bulk density and organic carbon content for the different layers of each soil type. Therefore, these soil laboratory results were obtained from Rift valley lake basin Master Plan study document Halcrow, G. (2010). And some SWAT soil parameters were calculated by using Pedo Transfer Function (PTF) developed by Saxton and Rawls (2006).

In the same manner, the soil map of the study watershed also reclassified in order to correspond with the parameters in the SWAT user soil database.

The soil data needed into physical and chemical characteristics of the soil that both play a large role in determining the movement of water within the HRU. By using SWAT model, erosion prone area of the watershed was identified based on the estimated values of soil erosion from each HRU and soil erosion prone area of the watershed is categorized according to FAO degree of erosion classification.

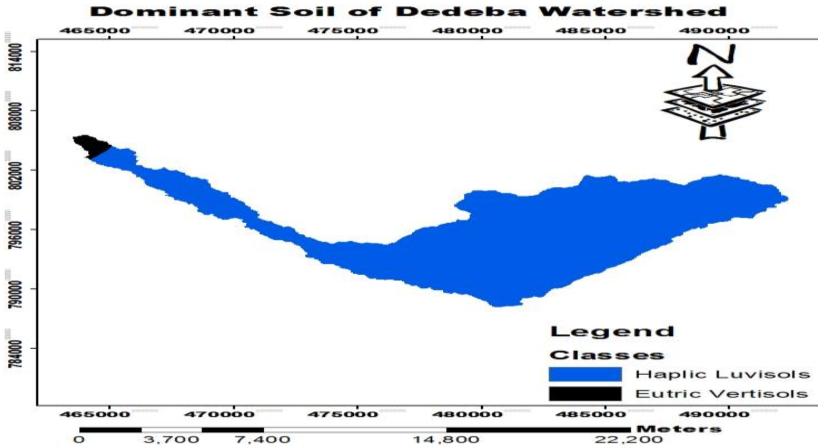

Figure 8: Map of soil of study area 2010 (source: Master plan of MOIWR, 2010)

The Dedeba watershed was classified into two major soils, namely Haplic Luvisols and Eutric Vertisols. The Haplic Luvisols is the dominant soil type in the study area which covered 98.77% of watershed. Eutric Vertisols is the least soil type in the study area which covered 1.23 % of watershed.

Table 5: Slope classes and the area occupied in ha and percent (%) of the study area

Major soil	Dedeba Watershed	
	Area (ha)	Area Coverage (%)
Haplic Luvisols	14003.72	98.77
Eutric Vertisols	431.26	1.23

Hydrologic response unit analysis

Sub watersheds were subdivided, after watershed delineation, into areas having unique land use, soil and slope so called hydrologic response unit (HRUs). After the land use/land cover, SWAT code was be assigned to all map categories, calculation of the area covered by each land use/land cover and reclassification was done. As of the land use, the soil layer in the map was linked to the user soil database information by loading the soil look-up table and reclassification was applied. After projection of the land use, soil and slope datasets were reclassified, overlapped and connected with the SWAT catalogues and ready for HRU definition. To define the distributions of HRUs multiple HRU definition options was selected. The threshold level set for land use, soil and slope was used to define the number of HRUs within the sub watersheds. The reclassifications of the soil type map and land use were done to represent the soil and land use according to the specific soil types and land uses and overlaid to obtain a unique combination of land use, soil and slope within the watershed to be modeled. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. Most of the time the default of SWAT recommends that 10% soil, 20% LULC, and 20% slope thresholds have been used (Neitsch *et al*., 2005).

Sensitivity analysis

In order to make calibration processes, it will crucial to find out the sensitive parameters using sensitivity analysis. Sensitivity analysis is important for a model to reduce the number of model parameters for calibration and to examine the more sensitive parameters, which in turns determines the main causes of water yield or sediment load from different practices and physical conditions. In other words, sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters) (Abbaspour, 2013).

The sensitivity analysis of this study was done using Global sensitivity analysis methods. The inputs were the observed daily flow data, the simulated monthly flow in period (1988-2014) and the sensitive parameter in relation to flow with the absolute lower and upper bound and default type of change to be applied used. This was done to identify the influential parameters on the modeled stream flow. It is important to identify sensitive parameters for a model to avoid problems known as over parameterization (van Griensven, 2005). The sensitivity analysis can be categorized into four classes

Table 6: Sensitivity analysis index

Class	**Index (I)**	**Sensitivity**
I	$\|I\|\geq 1.00$	Very high
II	$0.2\leq\|I\|<1.00$	High
III	$0.05\leq\|I\|\|<0.2$	Medium
IV	$0.00\leq\|I\|<0.05$	Small to neglible

(Source: Lenhart, 2002)

Model calibration

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. Model calibration is an effort to better parameterize a model to a given set of local conditions thereby reducing the prediction uncertainty. The simulated flow was calibrated from observed surface flow gauged at the outlet of the sub watershed. The runoff was calibrated by adjusting the sensitive parameters which affect runoff. Similar to runoff, the model was also calibrated for the prediction of sediment yield. The simulated versus observed values for each adjustment will be evaluated with coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE).

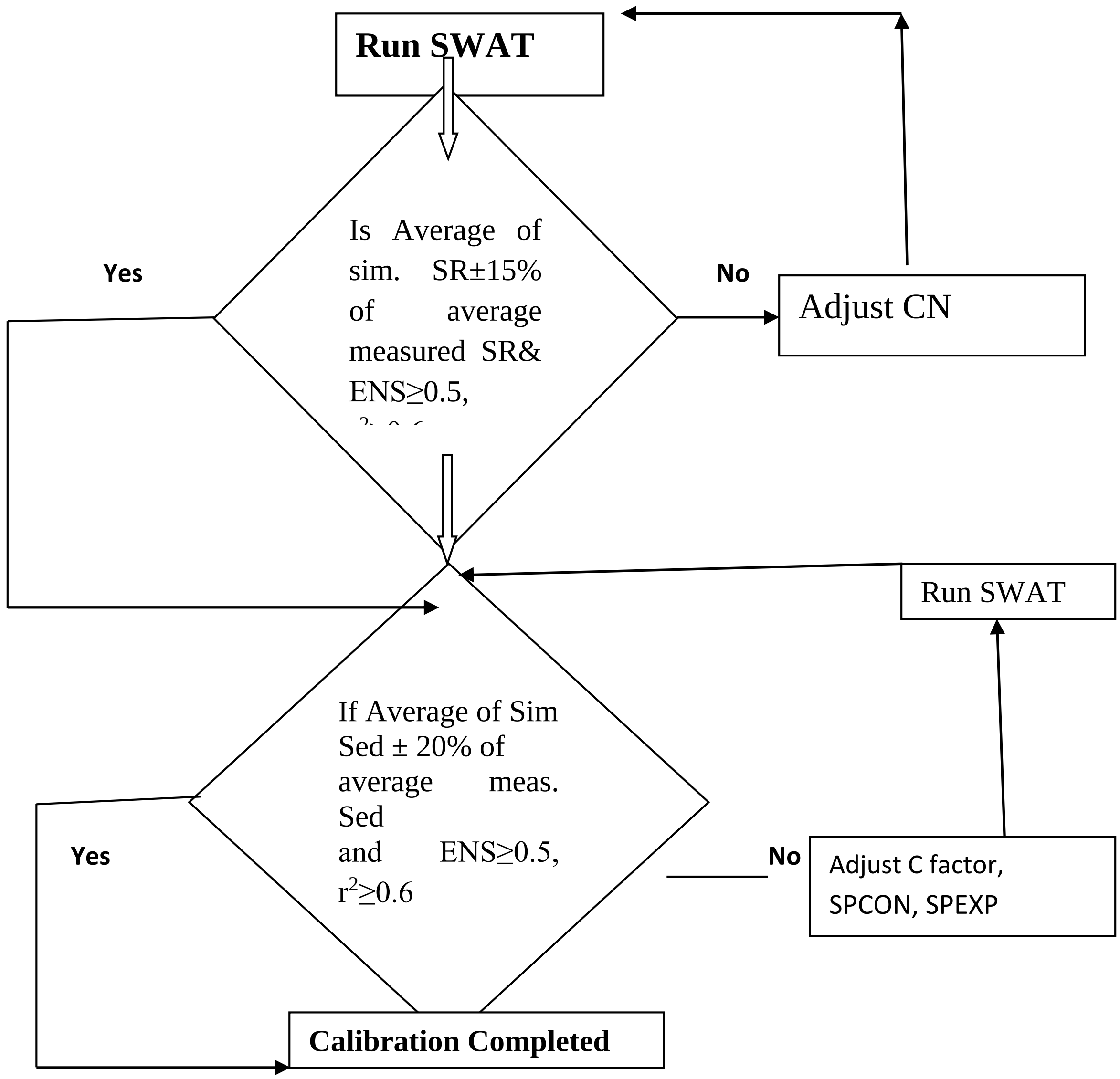

Figure 9: Calibration procedure for flow and sediment in the SWAT model.

Where; ENS: is Nash and Sutcliffe simulation efficiency ,R^2 : is Coefficient of determination ,SR: is Surface runoff; ,Sed: is Sediment; ,Sim: is Simulated; ,Meas: is Measured; ,CN: is Curve number,C: is Crop cover management factor; SPCON and SPEXP, respectively are the linear and exponential factors for calculating sediment in the channel routing.

Model validation

The purpose of the validation will be observe visually how much the simulated pattern seems to be the measured one based on monthly basis. Besides the visual observation, statistical investigation will be done to see the correlation between the measured and simulated. As it will be discussed in the SWAT approach, surface runoff volume and discharge are the basic parameters for MUSLE for simulating soil loss of the watershed. Hence it is necessary to validate the runoff discharges to have a better estimation of the soil loss. In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, the model was tested against an independent set of measured data. This testing of a model on an independent set of data set was used.

Model performance evaluation

The performance of the model was evaluated by assessing the correlation between simulated and observed values. SWAT-CUP 20012 version was used to calibrate the model using Sequential uncertainty fitting (SUFI ver2) (Abbaspour et al., 2007). In this study, during both calibration and validation periods, the goodness of-fit between the simulated and measured runoff was evaluated using the coefficient of determination (R^2), percent difference or percent bias (PBIAS) and the Nash-Sutcliffe coefficient of efficiency (Nash and Sutcliffe,1970). The R^2, ENS and PBIAS value measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion (Krause *et al*., 2005). The closer the model efficiency is to 1 and PBIAS value close to 0% is best and the more accurate the model. To decide the accuracy of the model the value of each index obtained by the model were compared with the value of hydrologic model performance ratings.

Table 7. General performance evaluation for stream flow on monthly time step (Moriasi et al., 2007 and Nash et al., 1970):

	Objective functions		
R^2	ENS	PBIAS	Performance Rating
$0.7 < R^2 < 1.00$	0.75 <ENS≤1.00	PBIAS<±10%	Very Good
$0.6 < R^2 < 0.7$	0.65 <ENS≤0.75	±10% < PBIAS <±15%	Good
$0.50 < R^2 < 0.6$	0.50 <ENS≤0.65	±15% < PBIAS <±25%	Satisfactory
$R^2 < 0.50$	ENS ≤0.50	PBIAS≥±25%	Unsatisfactory

The R^2 is the magnitude of the linear relationship between the observed and the simulated values, and calculated as:-

$$R^2 = \left\{ \frac{\sum_{i=1}^{n} (O_i - \bar{O})\,(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2}\,\sqrt{\sum_{i=1}^{n} (S_i - \bar{S})^2}} \right\}^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 3}$$

Where: Oi is the observed flow, Si is the modeled flow, and O is the mean of the observed flow and *S* is of the simulated flows.

The Nash–Sutcliffe efficiency proposed by Nash and Sutcliffe (Nash et.al,1970) is related to the deviation from unity of the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values. The normalization of the variance of the observation series results in relatively higher and lower values of NSE in catchments with higher and lower dynamics, respectively

$$\text{ENS} = 1S \left[\frac{\sum_{i=1}^{n} (Q_m - Q_s)^2}{\sum_{i=1}^{n} (Q_m - Q_s)^2} \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{y th}$$

Where: Q_m is the observed flow, Q_s is the simulated flow of the simulation.

The percent difference or percent bias (PBIAS) describes the tendency of the simulated data to be greater or smaller than the observed data values over a specified period (usually the entire calibration or validation period). A value close to 0% is best, with lower values indicating satisfactory model simulation

$$\text{PBIAS} = \frac{\sum_{i=1}^{n} (\text{Qm-Qs}) * 100}{\text{Qm}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 5}$$

Where Q_m is the observed flow, Q_s is the simulated flow of the simulation and $\bar{Q}$ is average stream flow.

Identifying hotspot area

The evaluated model was applied for identifying and prioritizing critical hot-spots of runoff and soil losses in the catchment. Hot spot area was known after knowing sediment and runoff amount, land use land cover map, and slope of each sub-watershed in Dedeba watershed area. Since SWAT overlay and divide the watershed in to a number of sub watersheds had its own runoff and sediment yield. Then, the runoff and sediment yield of each sub-watershed with their area coverage in the watershed was known from SWAT output. Sub-watersheds which were smaller area, steep slope and higher value of runoff and sediment yield were considered as most severe area (hotspot area). Based on runoff and sediment amount, area coverage and slope steepness ranking was done. Sub-watershed which have smaller area, steep slope and higher value of runoff and sediment load was considered as most severe area (hotspot area)

Results and Discussions

Sensitive Parameters for Stream flow and Sediment yield

The first step in the calibration and validation process in the SWAT model is the identification of the most sensitive parameters for a given watershed that have a significant impact on specific model outputs such as stream flow and sediment yields (Lenhart, 2002). The results of the sensitivity analysis indicate that, twenty parameters viz, Curve Number (CN2), Base flow alpha factor (ALPHA_BF), Soil Evaporation Compensation coefficient (ESCO), Plant Evaporation Compensation Coefficient (EPCO), Soil Available Water Capacity (SOL_AWC), Soil Hydraulic conductivity (SOL_K), Hydraulic conductivity in main channel (CH_K2), Surface runoff lag coefficient SURLAG, Average slop steepness (HRU_SLP), Groundwater “revap” coefficient (GW_REVAP), Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), Deep aquifer percolation fraction(RCHRG_DP), Depth of soil (SOL_Z), Bulk density (SOL_BD), Average slope length (SLSUBBSN),Manning's "n" value (CH_N2), Baseflow alpha factor for bank storage (ALPHA_BNK), Manning's "n" value for overland flow (OV_N), Maximum canopy storage(CANMX), Temperature lapse rate (TLAPS)and Ground water Delay (GW_DELAY) are the most essential parameters for the studied watershed. The sensitivity analysis indicated the overall importance of the twenty parameters in determining the stream flow and fourteen (14) parameters were found to be the highly sensitive parameters than others at the study area (Table 8). Therefore, attention was given to most twelve highly sensitive parameters during model calibration. From twenty parameters, two and three parameters were medium and small sensitive to the stream flow for the study watershed (Table 8).In Table 8, Surface runoff is less sensitive than other parameters. This might be because of Base flow alpha factor was high in sensitive index (Table 8).

Table 8: Dedeba watershed stream flow parameters, sensitivity index, degree of sensitivity and Rank

Descriptions	SWAT-Code	Sensitivity index	Rank	Degree of sensitivity
Groundwater "revap" coefficient	GW_REVAP	$9.7*10^{-1}$	1	High
Plant uptake compensation factor	EPCO	$9.6*10^{-1}$	2	High
Average slope length	SLSUBBSN	$9.2*10^{-1}$	3	High
Depth of soil	SOL_Z	$8.1*10^{-1}$	4	High
Manning's "n" value	CH_N2	$7.9*10^{-1}$	5	High
Effective hydraulic conductivity	CH_K2	$7.4*10^{-1}$	6	High
Temperature lapse rate	TLAPS	$7.0*10^{-1}$	7	High
Treshold depth of water	GWQMN	$6.3*10^{-1}$	8	High
Deep aquifer percolation fraction	RCHRG_DP	$6.2*10^{-1}$	9	High
Available water capacity of the soil layer	SOL_AWC	$5.7*10^{-1}$	10	High
Manning's "n" value for overland flow	OV_N	$5.2*10^{-1}$	11	High
Soil evaporation compensation factor	ESCO	$5.1*10^{-1}$	12	High
Curve Number	CN2	$5.0*10^{-1}$	13	High
Base flow alpha factor(days)	ALPHA_BF	$4.5*10^{-1}$	14	High
Average slope steepness	HRU_SLP	$3.9*10^{-1}$	15	High
Ground water delay	GW_DELAY	$1.8*10^{-1}$	16	Medium
Maximum canopy storage.	CANMX	$1.1*10^{-1}$	17	Medium
Surface runoff	SURLAG	$2.7*10^{-2}$	18	Small
Saturated hydraulic conductivity	SOL_K	$1*10^{-3}$	19	Small
Bulk density	SOL_BD	$4.5*10^{-34}$	20	Small

Table 9: Dedeba watershed calibrated flow parameters and fitted values

Descriptions	SWAT-Code	Range	Initial Value	Fitted Value
Curve Number	CN2	± 25%	-1.759776	-2.182975
Base flow alpha factor(days)	ALPHA_BF	0-1	0.490839	0.486471
Deep aquifer percolation fraction	RCHRG_DP	0-1	0.022748	0.022784
Treshold depth of water	GWQMN	0-5000	212.929062	231.367264
Depth of soil	SOL_Z	± 25%	0.390929	2.502454
Available water capacity of the soil layer	SOL_AWC	± 25%	0.408060	0.420958
Manning's "n" value	CH_N2	-0.01-0.3	0.402341	0.345006
Effective hydraulic conductivity	CH_K2	-0.01-500	4.713148	4.718277
Groundwater "revap" coefficient	GW_REVAP	0.02-0.2	0.059279	0.059368
Average slope length	SLSUBBSN	10-150	37.82249	45.544811
Manning's "n" value for overland flow	OV_N	0.01-30	0.355081	0.357971
Soil evaporation compensation factor	ESCO	0.01-1	0.655509	0.682006
Plant uptake compensation factor	EPCO	0.01-1	0.463488	0.466515
Temperature lapse rate	TLAPS	-10-10	-0.490839	-0.829824
Average slope steepness	HRU_SLP	0-1	0.402341	0.444549
Ground water delay	GW_DELAY	0-500	26.264736	-26.151794
Maximum canopy storage.	CANMX	0-100	7.748510	7.761445

Also, sensitivity analysis was done for sediment yield and found that the parameters such as Exponential factor for channel sediment Routing; SPEXP, Linear factor for channel sediment Routing; SPCON, Channel erodibility; CH_EROD, USLE_P support practice factor and Channel cover factor- CH_COV were the most highly sensitive parameters for sediment yields in the study watershed (Lenhart 2002) (Table 10). And USLE_C Cover and management factor and CN2_ Initial SCS value were small sensitivity in the sediment yield in the study watershed (Lenhart 2002). Hence, the most (highly) significant parameters were considered for further model calibration and validation (Tables 10)

Table 10: Dedeba watershed stream flow parameters and sensitivity index and Rank

Descriptions	SWAT-Code	Sensitivity index	Rank	Degree of sensitivity
Exponential factor for channel sediment Routing	SPEXP	$8.32*10^{-1}$	1	High
Linear factor for channel sediment Routing	SPCON	$7.64*10^{-1}$	2	High
Channel erodibility factor	CH_EROD	$7.37*10^{-1}$	3	High
USLE support Practice factor	USLE_P	$4.23*10^{-1}$	4	High
Channel cover factor	CH_COV	$3.36*10^{-1}$	5	High
Cover and management factor	USLE_C	$9.8*10^{-3}$	6	Small
Initial SCS CN II value	CN2	$3.95*10^{-27}$	7	Small

Table 11: Final calibrated parameters and fitted values of sediment yield for Dedeba watershed

Descriptions	SWAT-Code	Range	Initial Value	Fitted Value
Exponential factor for channel sediment Routing	SPEXP	1.0-1,5	1.0321	1.4223
Linear factor for channel sed-iment Routing	SPCON	0.0001-0.08	0.000811	0.0029
Channel erodibility factor	CH_EROD	-0.5-0.6	0.1734	0.7246
USLE support Practice factor	USLE_P	0.0-1.0	0.0	0.7900
Channel cover factor	CH_COV	-0.001-1	-0.001	0.3469

Model Performance Evaluation

Model calibration for stream flow

The first two years (1988 – 1989) data were used for stabilization of model runs (warm up period). Therefore, the calibration performed for 12 years from Jan/1/1990 to Dec/31/2001 for stream flow and sediment yields of the Dedeba watershed. The calibration process was done manually until the acceptable agreement happens between observed and simulated data (Neitsch et al,.2005). Moreover, the fit between observed and simulated stream flow and sediment yield data was checked by statistical techniques provided below in Table 11. Stream flow and sediment yield hydrographs were developed to compare observed and simulated stream flow and sediment yield values for the calibration periods in monthly time step (Figs. 11 and 13). Statistical model performance evaluator of calibration result shows a satisfactory agreement between the observed and simulated stream flow and sediment yield parameters for R^2 (coefficient of determination) and NSE (Nash-Sutcliffe model efficiencies) (Table 11) and the model recommended for the monthly time basis (Moriasi et al., 2007 and Nash et al., 1970). In addition, for the PBIAS (percent Bias) there was very good and satisfactory agreement between the observed and simulated stream flow and sediment yield parameters respectively (Table 11) and the model recommended for the monthly time basis (Moriasi et al., 2007 and Nash et al., 1970). As indicated in Fig 11, the model slightly under estimated the simulated stream flow result in most months of the years during the calibration period and underestimated the sediment yield simulation results in some months (Fig 13).

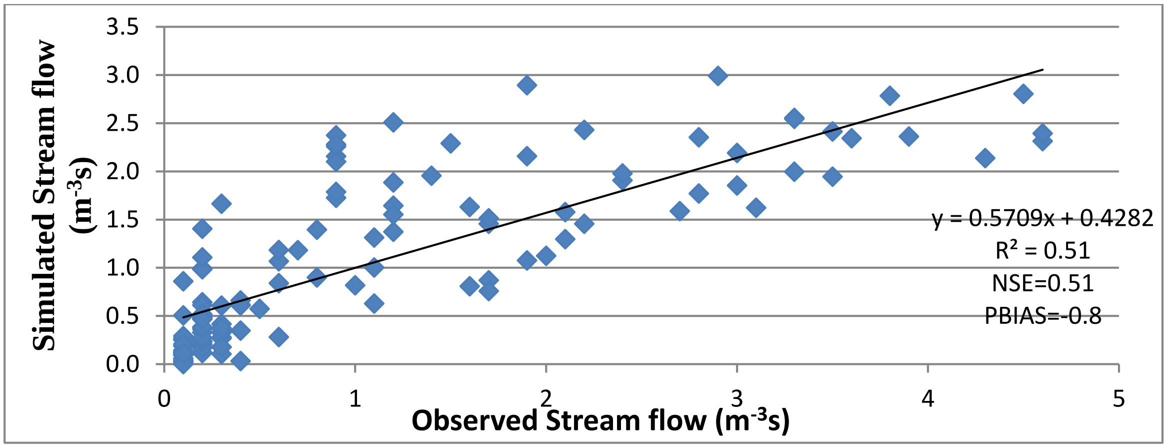

Figure 10. Comparison between observed and simulated Stream flow Calibration period (1990–2001) at Kuyera gauging station

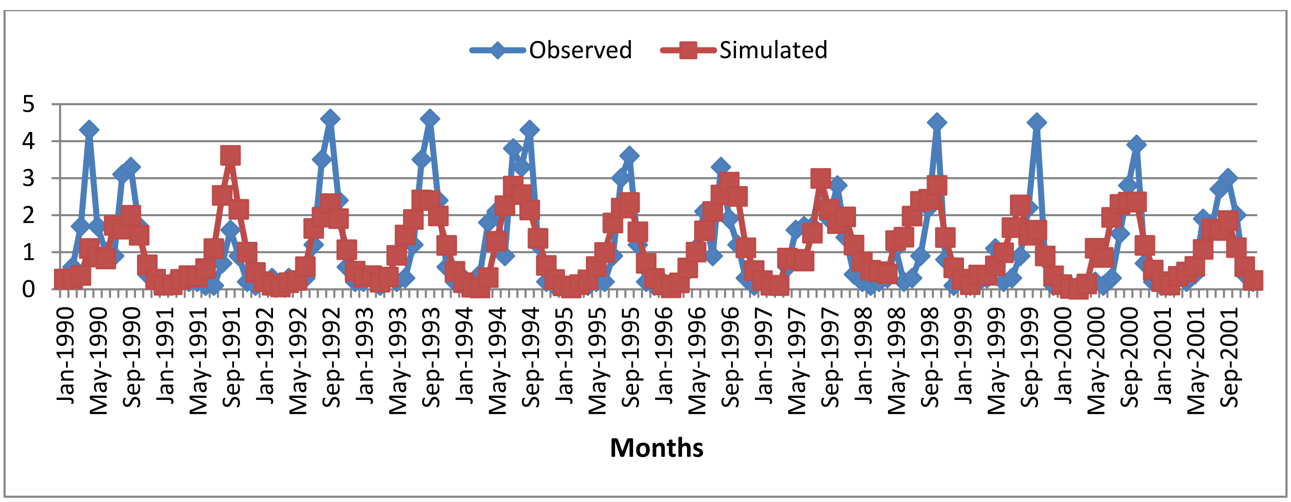

Figure 11. Simulated and observed monthly Stream flow during Calibration period (1990–2001) at Kuyera gauging station

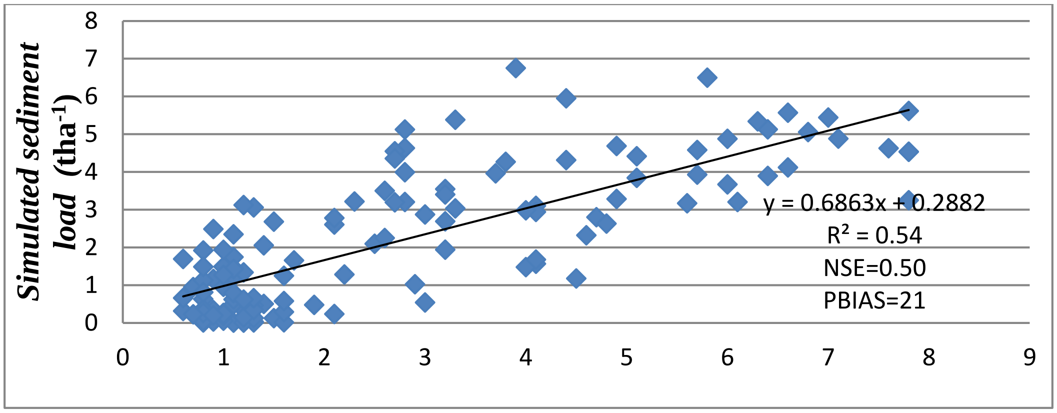

Figure 12. Comparison between observed and simulated sediment yield Calibration period (1990–2001) at Kuyera gauging station

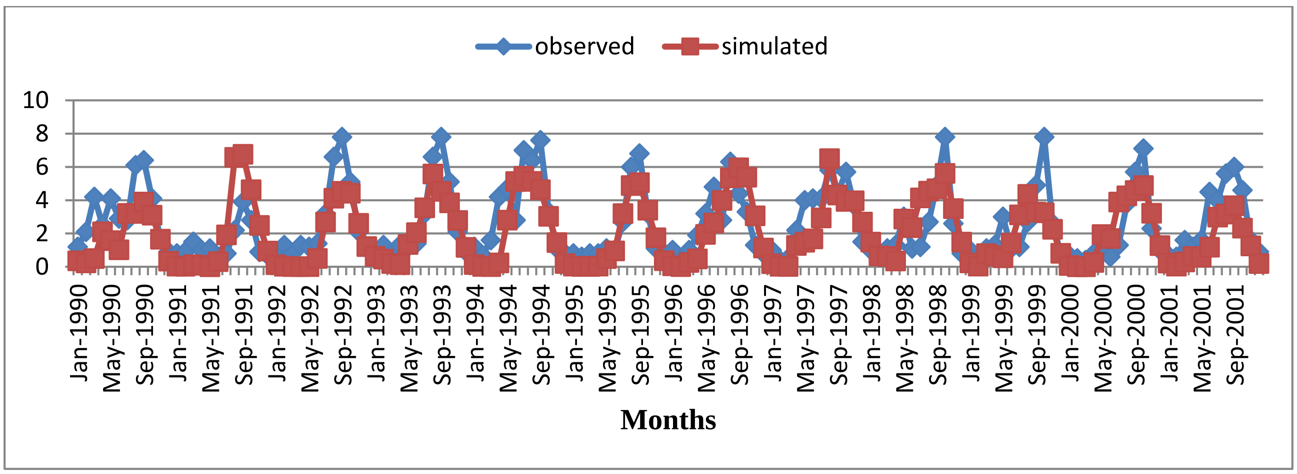

Figure 13. Simulated and observed monthly sediment yield during Calibration period (1990–2001) at Kuyera gauging station

Table 12: Monthly calibration statistical results

Parameter	Stream flow	Sediment yield
	Calibrated (1990-2001)	Calibrated (1990-2001)
R^2(coefficient of determination)	0.51	0.54
NSE(Nash-Sutcliffe model efficiencies)	0.51	0.50
PBIAS (percent Bias)	-0.80	21

Model validation for stream flow

Model validation was carried out for 6 year period (Jan/1/2002 to Dec/31/2007) for both stream flow and sediment yield parameters. An agreement between measured values (stream flow and sediment concentration) and simulated outputs (stream flow and sediment concentration) on monthly time steps as shown by R^2, NSE and PBIAS (Table 12), the model parameters represent the processes happen in the Dedeba watershed. Figures 15 and 17 clearly show a reasonably good agreement between observed and simulated stream flow and sediment yield for R^2 (coefficient of determination) and NSE (Nash-Sutcliffe model efficiencies) for monthly time steps during the validation period (Moriasi *et al*., 2007 and Nash *et al*., 1970). In addition, according to Moriasi *et al*. (2007) and Nash *et al*. (1970) reported that for the PBIAS (percent Bias) was very good and satisfactory agreement between the observed and simulated stream flow and sediment yield parameters respectively (Table 12). The long-term results of the flow a seasonal variation (Fig. 15) show that there was a good agreement between observed and simulated average values of stream flow; even though the model overestimates stream flow. This shows that there was a low measured flow value which less than the simulated results. The long-term results of the sediment load a seasonal variation (Fig. 17) show that there was a good agreement between observed and simulated average values of sediment load; even though the model underestimates sediment load.

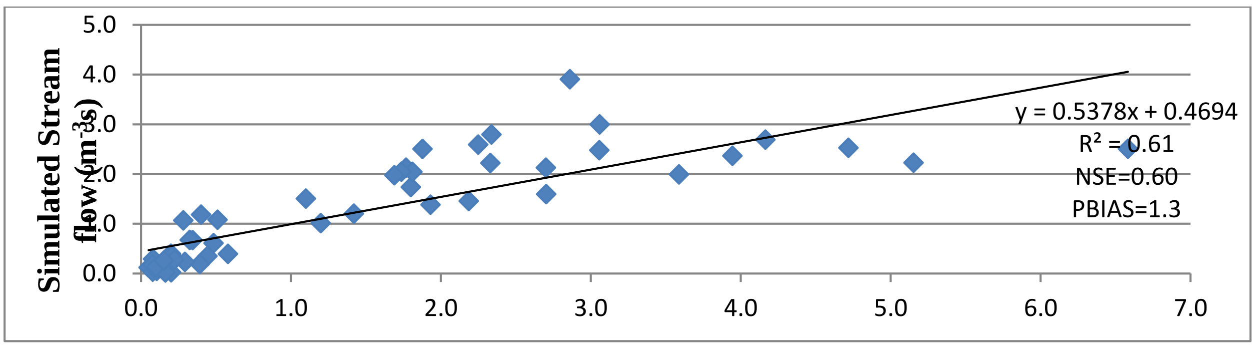

Figure 14. Comparison between observed and simulated stream flow Validation period (2002-2007) at Kuyera gauging station

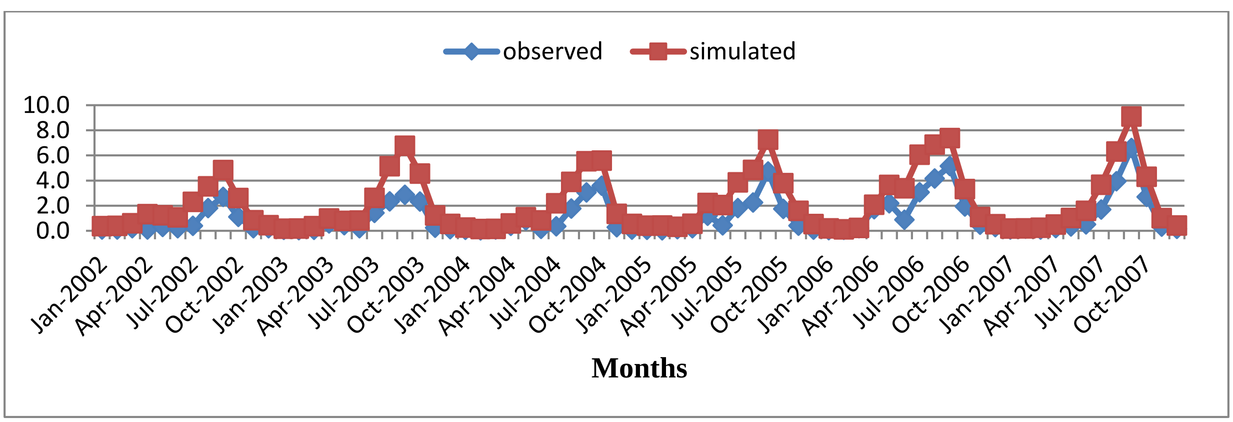

Figure 15. Simulated and observed monthly Stream flow during Validation period (2002-2007) at Kuyera gauging station

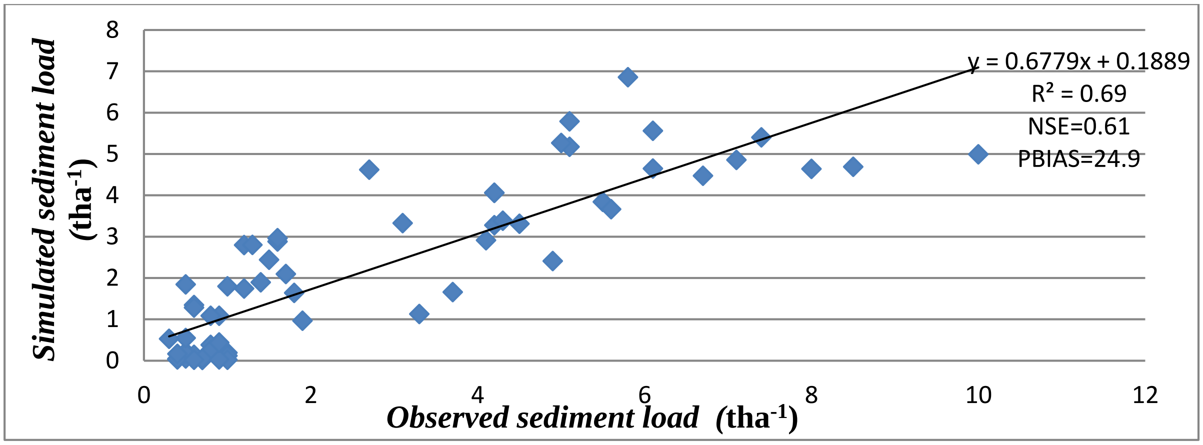

Figure 16. Comparison between observed and simulated sediment yield Validation period (2002-2007) at Kuyera gauging station

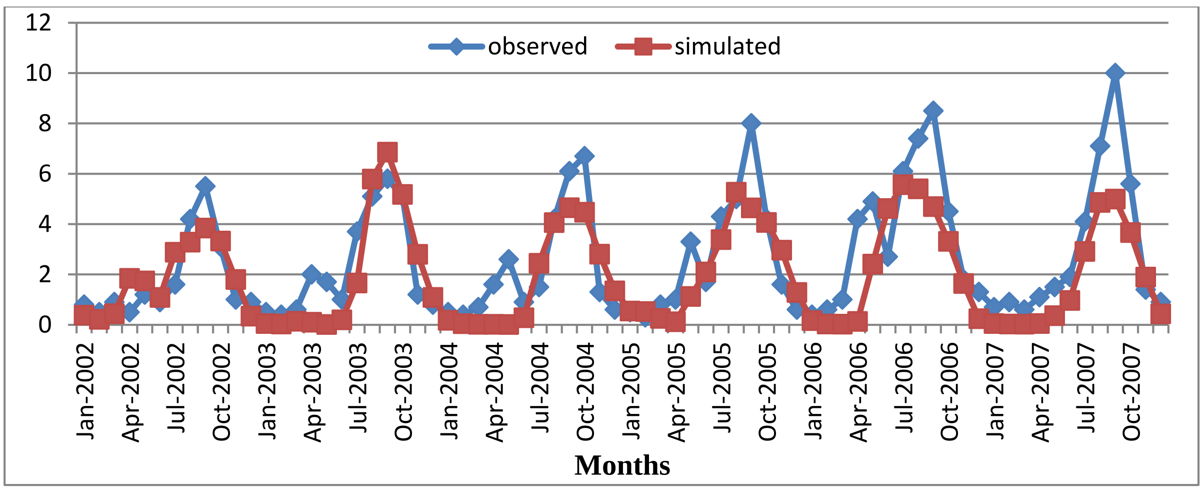

Figure 17. Simulated and observed monthly sediment yield during Validation period (2002-2007) at Kuyera gauging station

Table 13: Monthly validation statistical results

Parameter	Stream flow	Sediment yield
	Validated(2002-2007)	Validated(2002-2007)
R^2(coefficient of determination)	0.61	0.69
NSE(Nash-Sutcliffe model efficiencies)	0.60	0.61
PBIAS (percent Bias)	1.30	24.9

Spatial Distribution of Sediment Yield and Runoff in Dedeba sub Watershed

Assessing the soil formation rates of an area is vital for the evaluation of soil loss rate and the potential of soil regeneration once soil erosion is substantially reduced. SWAT is powerful in spatial visualization of sub basin or HRU level detail so that one can see which area produces high sediment and which area produces less. Based on the data, average annual surface runoff and sediment transport from the watershed were summarized for each sub basin (Table 14). From this result, the highest average annual surface runoff and sediment loss were 4.94 MCM/yr and 22. $tha^{-1}yr^{-1}$ respectively and generated from cultivated land use system, Haplic Luvisols and slope ranges from 3-8% (undulating slope) and observed in sub watershed 23

The slope gradient created opportunity for the surface runoff to get high velocity. Besides to this, the cultivated land use system facilitated the surface runoff to wear out the top soil in a higher rate. Because of this factor, high surface runoff and sediment loss increased. Whereas, the lowest surface runoff and sediment yield were 0.04 MCM/yr and 1 $tha^{-1}yr^{-1}$ respectively (Table 14). The land use, soil type and slope, thus lowest surface runoff and sediment load generated from forest land, conserved and slope ranges from 8-15%. In this case even though the slope increased, the land use land cover plays the major role in reducing surface runoff and sediment loss.

Table 14: Mean annual surface runoff and sediment yield of Dedeba watershed

Sub water-shed	Surface runoff (MCM/yr)	Sediment yield (t/ ha)	Sub water-shed	Surface runoff (MCM/yr)	Sediment yield (t/ ha)
1	1.36	1	16	1.03	4
2	1.55	16	17	0.31	2
3	0.91	1	18	1.32	2
4	0.77	2	19	2.90	3
5	0.35	2	20	0.86	1
6	0.36	1	21	0.16	2
7	0.30	3	22	1.73	4
8	0.05	1	23	4.94	22
9	1.48	15	24	1.60	21
10	0.04	2	25	3.66	16
11	0.15	2	26	2.20	2
12	1.59	14	27	0.08	14
13	1.40	4	28	0.74	21
14	1.39	4	29	1.03	21
15	2.22	2			
Average basin Value	Surface runoff 1.26				
	Sediment yield 7.00				

The degree of erosion hazard in the Dedeba sub-watershed was reclassified in to four (Table 15) different erosion hazard classes.

Table 15: Sediment yield losses and Severity classes of Dedeba Watershed

Sub basin	Sediment yield loss(t/ha/yr)	Area	Area (%)	Severity classes	Rank
1,3,4,5,6,8,10,11,15,17,18,20,21,26	1-2	6678.7	47.12	low	4
7,13,14,16,19,22	3-4	3696	26.00	Medium	3
2,9,12,25,27	5-18	2057	14.51	High	2
23,24,28,29	>18	1743.3	12.30	Very High	1
Total		**14175**	**100**		

According to prioritization map, sediment loss categorized into four (4) classes, such that 1-2, 3-4, 5-18 and >18 tonha^{-1}year^{-1}.

According to this study, sub watershed 2, 9,12,25,27 and 23,24,28,29 tonha^{-1}year^{-1} were categorized under high and very high sediment yields and covered an area of 12.3 and 14.51 % from total watershed of study area respectively (Table 15). The sediment loss from four sub watershed (23, 24, 28, 29) were above tolerable soil loss rate (>18 tonha^{-1}year^{-1}) and the sediment losses from five watersheds were above the range of soil formation rate in the study area ranges from 6-10 tha-1yr-1 (Hurni, 1983) (Table 15). Hence, these sub watersheds was identified as erosion prone area in Dedeba watershed (Table 15). Among all sub-watersheds, four (4) sub watersheds were highly vulnerable to sediment loss and potentially prone to erosion risk (Table 15).This study agreed with the study of Hurni (1985), who stated that range of the tolerable soil loss level for the various agro-ecological zones of Ethiopia, was found from 2 to 18 tonha^{-1}year^{-1}.

The result is consistent with the finding of Bekele et al. (2019) in the Karesa watershed south west Ethiopia who found a comparable result ranging from 0 to 25 tonha^{-1}year^{-1}. The finding was also consistent with the finding of Belayneh et al. (2019), who estimated the annual soil loss ranges from 0.01 to 442.92 tonha^{-1}year^{-1}. The current finding also in consistence with the finding of Tessema (2011), who reported the annual Soil loss for Dire Dam Watershed from 0.00 to 263.25 tonha^{-1}year^{-1} and Amsalu and Mengaw(2014) reported that, the annual soil loss in Jabi Tehinan Woreda ranges from nearly 0 in south and central parts of the area to 504.6 tonha^{-1}year^{-1} in steeply sloping mountainous areas of the north and northeastern parts of the catchments.

The soil type, topography and agricultural activity are the principal factor for the sediment loss and surface runoff. Highest sediment yield loss was correlated with Haplic Luvisols with cultivated land use system and gradient of 3-8, 8-15 and 15-30 %. This implies than high soil losses from undulating and steep slope and cultivated land. Erosion is more aggravated on wide range of agricultural land uses, and susceptible to structure deterioration with tillage. The sediment yield losses mentioned in the above sub watersheds were above range of soil formation, thus way it needs immediate intervention to protect this resource from the loss. The main reason for eroding more sediment yield from these sub-watersheds could be land degradation, poor land cover, improper land management (lack of soil and water conservation) and intensive cultivation without conservation. These factors were responsible for aggravating the soil loss and facilitated the surface runoff to wear out the top soil in a higher rate from watershed.

Among 29 sub watershed, six sub-watersheds (7, 13, 14, 16, 19 and 22) were fallen under medium sediment losses with area coverage of 26% from total area of watershed, which were given medium priority class and the annual soil loss from this watershed ranges from 3 to 4 $tonha^{-1}year^{-1}$ (Table 15). The rest 21 sub-watersheds were fallen under low soil loss rate from 1 to 2 $tonha^{-1}year^{-1}$ (Table 15). The area classified under low soil loss is 47.12%, covered large area of watershed (Table 15). However, higher/steep slopes are found along the boundaries of the watersheds and had less impact on the soil loss because it has been covered by forest. Actually, good land use land covers have positive effect on the reduction of runoff and sediment yield. Several studies prevail that land use land cover can be controlled erosion by covering the soil surface by the canopy and reduce the mechanical action happen at the soil surface by intercepting the raindrop (Francis CF and Thornes JB (1990)). A report from China (Luo, 2014) indicated that, land with lower vegetation cover implying the extent of soil erosion. Similarly, a Nigerian study by (Oruk, 2012) reported greater soil erosion in lands with poor vegetation cover. Hence, land cover plays a major role in reducing soil erosion and runoff potential by increasing infiltration capacity.

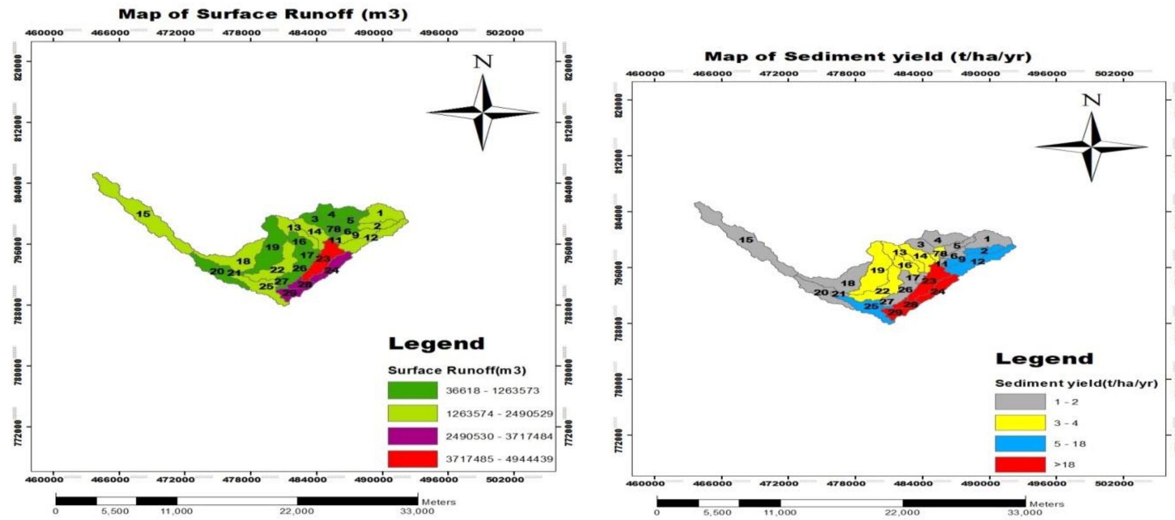

Figure 18. Map of sediment loss (left) and Runoff (right) of Dedeba watershed.

Prioritization for Intervention Planning

Reasonable assessment of soil erosion is the core of any decision making. Because of resource limitations, implementing of soil conservation measures or watershed management in the entire watershed at a time is impractical. Thus, prioritization of intervention based on the severity and risks of soil erosion is imperative. The Dedeba watershed was classified and ranked into four priority classes indicated in Table 15 and Figure 18. Hence, based on the results, sub watersheds 2,9,12, 25 and 2, 9,12,25,27 were hotspot erosion area and prioritized for intervention (Table 15). According to this study, soil formation rate in the study area ranges from 6 - 10 tonha^{-1} year^{-1} (Hurni, 1983) which is in the range of tolerable soil loss level in the study area that covers 26.81% of the entire watershed. These sub watersheds implies that, the soil erosion rate above the soil formation (6-10 tonha^{-1}year^{-1}). In addition, similar studies stated that, undertaking soil conservation measures based on the given priority is a better option as also suggested by Bewket and Teferi (2009) Abate, (2011), Amare et al, (2014) and Gizachew, A. (2015) for their respective study sites.

Therefore, priorities for intervention should be focused on high and very high eroded sub watershed to keep natural balance and minimized the effects siltation at downstream of the study area. In generally, agricultural practice without conservation measure will aggravate the runoff processes in the study area. On flat slopes, deposition of sediments is the major constraint that can affect the down watershed mainly small irrigation project and hydrology of watershed, and this constrains can be improved by applying integrated watershed management.

Conclusions and Recommendations

From the result of the Global sensitivity analysis 14 highly sensitive parameters were identified and used for calibration and validation. The model was calibrated manually by adjusting sensitive parameters using observed data from 1990 to 2001 and validation was done using observed data from 2002 to 2007. The model performance was checked by statistical model performance evaluators such as the coefficient of determination (R^2), Nash–Sutclife model efficiency (ENS) and Percent bias (PBIAS) and it shows that the model has a high potential in the estimation of runoff and sediment yield. Statistical model performance evaluator of calibration result (R^2=0.51, NSE=0.51 and PBIAS=-0.8 for stream flow and R2=0.54, NSE=0.50 and PBIAS=21) for sediment yield) shows a satisfactory agreement between the observed and simulated stream flow and sediment yield parameters. Whereas, statistical model performance evaluator of validation result (R^2=0.61, NSE=0.60 and PBIAS=-1.3 for stream flow and R2=0.69, NSE=0.61 and PBIAS=24.9) for sediment yield) shows a good agreement between the observed and simulated stream flow and sediment yield parameters.

The spatial distributions of the runoff and sediment yield show nine sub-basin (2, 9, 12,25,27,23, 24, 28 and 29) have high runoff rates and sediment yields among the 29 sub watershed (Table 14). The infrastructures in these sub-watersheds may be damage due to the critical sediment yields and therefore, the study watershed needs conservation measures for the future sustainable uses and infrastructure development.

The developed SWAT model also helped in identifying erosion prone area of the watershed and also estimate runoff and soil loss from watershed. Accordingly, the nine sub-watersheds were highly exposed to soil erosion and more attention has to be given to sub watersheds. The estimated soil loss rate from 29 sub-watershed ranges from 1t/ha/year to 22 t/ha/year. According to reclassification of SWAT model sediment yield output about 47.12% of the watershed area is under low, 26 % under medium, 14.51% under high and 12.30% under very high degree of soil erosion respectively. On the gentle slopping and undulating plain, agricultural practice with conservation measure will be recommended in the study area. On the other hand, on slope greater than 30% (3.1% of entire watershed) no need of conducting any agricultural activities, rather the area should be protected and conducting rehabilitation.

There is a lot of work to improve in the future for this study area regarding suspended sediment data at outlet. Therefore, responsible bodies should give due attention to took sampling of sediment at the time of flow measurement for further testing the model. The model could be further tested for calibration and validation of sediment yield when suspended sediment data is available. Therefore, appropriate watershed management policies be put in place in order to promote a more sustainable environment, and future study will be focused on further analysis of the impacts of climate and land use change as well as management scenarios on the stream flow flows and sediment yield in the study watershed.

Generally, the output of this study may support planners and decision makers to take relevant soil and water conservation measures and thereby reduce the alarming soil loss and land degradation problems in the watershed.

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Performance evaluation of Irrigation scheduling methods on water use efficiency, Yield and Economic return of Potato under furrow irrigation system at Jima Genati and Wayu Tuka Districts, Western Oromia

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Abstract

Irrigation scheduling is one of the factors that influence the agronomic and economic viability of small farms. It is important for both water savings and improved crop yields. The study was undertaken to evaluate the performance of irrigation scheduling methods on water use efficiency, yield and economic return from Potato under furrow irrigation system. Accordingly, the performance of four irrigation scheduling methods; Hand Feel Method, Soil moisture sample method, Calculating evapotranspiration losses and Farmer Practice were evaluated under furrow irrigation. Based on this study Farmer Practice was more frequent (15 irrigation events) than Hand Feel Method (13 irrigation events). However Hand Feel Irrigation scheduling method was more frequent than Soil moisture sample method and Calculating evapotranspiration losses. This indicates that the Calculating evapotranspiration losses and Soil moisture sample method irrigation scheduling methods saved water by approximately 36.5% and 22% (two-season means), respectively, as compared to Hand Feel Method. The highest marketable tuber yield (21620 Kg/ha) was obtained from soil moisture sampling method, whereas the lowest marketable tuber yield (13953.4 Kg/ha) was recorded from Farmer Practice. The highest WUE (6.6 kg m^{-3}) was recorded for Evapotranspiration irrigation scheduling method, followed by 5.9 kg m^{-3} for Soil moisture sampling irrigation scheduling method, whereas the lowest WUE (2.1 kg m^{-3}) was recorded for the Farmer practice. From those, two irrigation scheduling methods evapotranspiration losses and Soil moisture sample method were best performed at both locations. This study, therefore, concluded that irrigating by using evapotranspiration losses irrigation scheduling method save more irrigation water regardless of minimum yield difference when compared with Soil moisture sample irrigation scheduling method.

Key words: *Irrigation scheduling, Water use efficiency, and potato yield.*

Introduction

Ethiopia has abundant water resources suitable for irrigation but smallholder farmers continue to face challenges of water scarcity leading to low crop productivity (Worqlul, 2017). Irrigation has a multi-faceted role in contributing towards food security, self-sufficiency, food production and exports. The traditional and small-scale irrigations cover the lions share in the Ethiopian irrigated agriculture (Yalew *et al.* 2011). The main sources of water for irrigation in Ethiopia are diversion from rivers, spring development, and surface reservoirs, whereas the common method of water application is furrow irrigation. Nearly 90% of the irrigated land of the world is watered using the least efficient traditional methods of irrigation (Koech *et al,* 2014). Among such traditional methods is conventional furrow irrigation (CFI) method, which is widely practiced across Ethiopia for watering row crops.

Irrigation scheduling is one of the factors that influence the agronomic and economic viability of small farms. It is important for both water savings and improved crop yields. The irrigation water is applied to the cultivation according to predetermined schedules based upon the monitoring of the soil water status and the crop water requirements. The type of soil and climatic conditions have a significant effect on the main practical aspects of irrigation, which are the determination of how much water should be applied and when it should be applied to a given crop. Poor management, uniformity and distribution of water have been cited as the most frequent problems of surface irrigation, resulting in waterlogging, salinization and less water use efficiency (Abou-Kheira, 2009). Potato (*Solanum tuberosum L.*) is one of the most important vegetable crops grown in the high and mid altitude areas of Ethiopia. It serves as food and cash crop for small scale farmers, occupies the largest area compared to other vegetable crops and produces more food per unit area and time compared to cereal crops. Thus, the objective of this study was to evaluate the performance of irrigation scheduling methods on water use efficiency, yield and economic return from Potato under furrow irrigation system.

Materials and Methods

Description of the study area

This study was conducted at the farmer's field in the district of Jima Ganati, Horo Guduru Welega Zone (09°21′06.98″ N and 37°06′49.36″ E), and in the district of Wayu Tuka, East Welega (09°01′00.95″ N and 36°40′19.37″ E) which is located in the humid climatic region of western Ethiopia. The experiment was undertaken during the dry season (November–March) in 2019 and 2020.

Climatic Conditions

Table 1 Climatic Condition of Jima Ganti site

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sunshine hours	Radiation MJ/m²/day	ETo mm/day
January	11.2	26.3	47	130	8	19.3	3.88
February	12.1	27.4	43	147	7.6	20	4.36
March	12.8	27.4	45	147	7.1	20.3	4.53
April	12.7	27.2	52	138	7	20.3	4.4
May	12.4	26.5	57	130	6.3	18.8	4.03
June	11.7	24.6	71	95	5.1	16.6	3.3
July	12.2	22	84	104	3.4	14.2	2.68
August	11.9	23.3	84	95	8.1	21.6	3.74
September	11.1	23.5	76	104	5	17	3.2
October	10.7	25	53	156	7.6	20.1	4.09
November	10.2	25.1	43	147	8.7	20.5	4.12
December	10.3	25.5	49	147	8.6	19.7	3.88
Average	11.6	25.3	59	128	6.9	19	3.85

Table 2 Climatic Condition of Wayu Tuka site

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sunshine hours	Radiation MJ/m²/day	ETo mm/day
January	11.7	25.8	46	95	7.9	19.2	3.67
February	12.3	26.7	43	112	7.7	20.1	4.12
March	13	27	52	121	7.4	20.7	4.29
April	13.4	26.7	46	112	7.2	20.6	4.4
May	12.8	24.4	58	78	5.6	17.7	3.61
June	11.5	21.7	75	69	4.3	15.5	2.94
July	11.2	20.7	81	104	3.3	14.1	2.66
August	11	20.7	81	78	3.4	14.5	2.67
September	10.6	21.9	71	78	4.2	15.7	2.95
October	11.4	23.2	62	104	6.7	18.8	3.5
November	12	24.2	56	104	7.3	18.5	3.52
December	11.7	24.8	50	104	7.3	17.9	3.47
Average	11.9	24	60	96	6	17.8	3.48

Experimental Design

A Complete Randomized Block Design with three replications was implemented for this study in which three irrigation scheduling methods (Hand Feel Method, Soil moisture sample method and, Calculating evapotranspiration losses) and Farmer Practice (Irrigation scheduling done by farmer) were included. All experimental plots were planted with germinated potato tuber seeds (Belete) manually by hand on the ridge of furrows and maintaining a 0.30m plant-to-plant distance along the row (ridge) and 0.75m between rows. Thus, there were a total of 8 rows (rides) with in each plot and 33 plants within a row comprising of 264 plants per plot. For preventing the lateral movement of water during irrigation from plot to plot, each block and treatment plot was kept 2 and 1 m, respectively, apart.

Table 3 Treatments setting for the field experiment

No	Treatment Name	Remark
1	Hand Feel Method	Irrigation scheduling by Hand Feel
2	Soil moisture sample method	Irrigation scheduling by Soil sampling
3	Calculating evapotranspiration losses	Irrigation scheduling using ETo
4	Farmer Practice	Irrigation scheduling done by farmer

The recommended rates of UREA (150 kg ha^{-1}) and NPS (100 kg ha^{-1}) for potato in the study area were uniformly applied to all plots. All NPS and half dose of UREA fertilizers were applied at sowing as basal placement while the remaining half of UREA was side dressed 1 month later during hilling (earthing up) operation. The experimental plots were always kept free from weeds by manual clearing and hoeing. The Ridomil gold fungicide was applied against late blight disease of potato. All other agronomic practices were carried out as per the recommendation for potato crop.

Determination of Crop Water and Irrigation Requirements

The reference evapotranspiration (ETo) from the potato field was computed employing FAO Penman–Monteith equation (Allen *et al*, 1998) and implemented in the CROPWAT 8.0 model (Martin, CROPWAT, 1996). The ETo of the experimental sites were computed from minimum and maximum air temperatures, wind speed, relative humidity, sunshine hours, and solar radiation using the FAO CROPWAT 8.0 model. The crop evapotranspiration (ETc) was calculated by multiplying the ETo with crop coefficient (Kc) at each crop growth stage using CROPWAT 8.0 model. Since there were no site specific K_C for potato in the study area, the values set by FAO (Allen *et al*, 1998) for the 4 crop development stages were adopted for this study:

$$ETc = ETo * Kc \qquad 1$$

Where: ETc, ETo, and K_C are crop evapotranspiration ($mmday^{-1}$), reference crop evapotranspiration (mm day^{-1}), and crop coefficient (dimensionless), respectively.

The total length of the test crop's growing period in the study area ranged from 120–130 days. The growing period of potato was divided into initial, development, middle, and late stages. Irrigation scheduling was also computed employing CROPWAT 8.0 model by considering the crop, climatic and soil properties of the study area over the growing period. Three irrigation scheduling methods tested in our study differed from each other in the way to estimate the amount of water stored in the soil during the growing season.

Determination of Water Use Efficiency

The field water use efficiency was calculated by dividing the marketable (economic) potato tuber yield with the total amount of irrigation water applied per treatment and per period as shown in the following equation (Bos, 1985)

$$WUE = \frac{Y}{ETc} \qquad 2$$

Where: WUE is the water use efficiency (kgm^{-3}), Y is the potato tuber yield ($kgha^{-1}$), and ETc is the total irrigation water supplied during the experimental period (m^3ha^{-1}). The total water included only the supplied irrigation water.

The irrigation water saved with Calculating evapotranspiration losses (ETo), Soil moisture sample (SMS), Hand Feel Method (HF) to Farmer Practice (FP) was calculated using the following equation (Chapagain and Yamaji, 2010):

$$water\ saving\ (\%) = \frac{\Theta FP - \Theta ETo, SMS\ OR\ \Theta HF)}{\Theta FP} * 100 \qquad 3$$

Where: ϴFP, ϴETo, ϴSMS and ϴHF are the total amount of irrigation water (mm) used with the Farmer Practice, Evapotranspiration method, Gravimetric soil moisture sample methods Hand Feel and appearance of soil method respectively.

Data Collection

The data collected (computed) during the experimental period were weight of tuber per plot, plant height, and marketable tuber yield and water use efficiency. The plant height was measured from 20 plant samples from the soil surface to the plant apex at the end of the growing season. Potato tubers were dug out from all plants weighed and recorded from each of the plots potato plants for weight of tubers per plot. The marketable potato tubers from the central 6 rows of each plot ($45m^2$; 4.5 m by 10 m) were harvested manually, the fresh weight was measured for tuber yield determination and the values were converted to $Kgha^{-1}$. Soil samples were collected before planting the crops from both the experimental sites. Collected soil samples were analyzed for Soil texture, bulk density, field capacity and Permanent wilting point.

Data Analysis

Data were analyzed using analysis of variance procedures on the appropriate statistical analysis software (SAS, 2010) version 9.0. Whenever the treatment differences show significance, mean differences was tested by LSD at 5% level of significance.

Results and Discussion

Soil physical characteristics of the experimental sites

The analyzed soil sample showed that bulk density of the experimental site (1.34 g/cm3 and 1.31 g/cm^3 Wayu Tuka and Jima Genati respectively) were ideal for plant growth**.**

Table 4 Soil physical characteristics of the experimental sites

Sampling Depth	Wayu Tuka			Jima Genati		
	Bulk density	Average bulk density g/cm^3	Soil texture	Bulk density	Average bulk density g/cm3	Soil texture
0-5cm	1.32	1.34	Clay	1.18	1.31	Sandy clay loam
5-10cm	1.34			1.29		
10-15cm	1.36			1.38		
15-20cm	1.37			1.4		
FC (%)	61.72			52.6		
PWP (%)	50.18			34.87		

Applied irrigation water (Wa)

The number of irrigation events and amount of applied water (Wa) for each treatment are shown in Table 2. The treatment 4 (Farmer Practice) was more frequent (15 irrigation events) than Treatment 1 (Hand Feel Method) (13 irrigation events). However Hand Feel Irrigation scheduling method was more frequent than Soil moisture sample method and Calculating evapotranspiration losses. The seasonal amount of Wa was the mean of the two seasons at both sites and amounted to 474.1mm (4745 m3 ha^{-1}), 369.8 mm (3698 m^3 ha^{-1}), and300.8 mm (3008 m^3ha^{-1}) for Hand Feel Method, Soil moisture sample method, and Calculating evapotranspiration losses, respectively. This indicates that the Calculating evapotranspiration losses and Soil moisture sample method irrigation scheduling methods saved water by approximately 36.5% and 22% (two-season means), respectively, as compared to conventional Hand Feel Method.

Table 5. Number of irrigation events and amount of applied water (Wa) for each treatments at both sites

Jima Genati and Wayu Tuka						
Hand Feel Method		Soil moisture sample method		Calculating evapotranspiration losses		Farmer practice
Date	Net Irr(mm)	Date	Net Irr(mm)	Date	Net Irr(mm)	
15-Nov	18.5	16-Nov	19.5	20-Nov	22.5	
26-Nov	22.4	28-Nov	21.4	7-Dec	24.4	
8-Dec	27.0	11-Dec	26.0	22-Dec	28.0	
18-Dec	30.1	22-Dec	31.1	4-Jan	30.1	
27-Dec	34.7	2-Jan	32.7	16-Jan	35.7	
5-Jan	38.6	12-Jan	39.6	28-Jan	37.6	
14-Jan	40.3	22-Jan	42.3	8-Feb	42.3	
23-Jan	40.9	31-Jan	38.9	21-Feb	40.9	
31-Jan	37.3	9-Feb	39.3	14-Mar	39.3	
8-Feb	38.8	19-Feb	40.8			
16-Feb	39.2	5-Mar	38.2			
26-Feb	46.6					
13-Mar	59.7					
Total	474.1		369.8		300.8	643mm

Growth Performance and Yield Components

Marketable tuber yield: Marketable was highly significantly (P<0.005) affected by different irrigation scheduling methods. The highest marketable tuber yield (21620 Kg/ha and 21236.7 Kg/ha) were obtained from soil moisture sampling method at Jima Genati and Wayu Tuka respectively, whereas the lowest marketable tuber yield (13953.4 Kg/ha and13953.4 Kg/ha) were recorded from Farmer Practice at Jima Genati and Wayu Tuka Sites respectively. These results were in line with other researchers who reported that marketable tuber yield was significantly affected by frequency of irrigation (Elfinesh, 2008; Kumar et al., 2007).

Unmarketable tuber yield: The results showed that no significant difference (P>0.05) was observed between soil moisture sample method and Evapotranspiration method at Jima Genati and Wayu Tuka while it was significantly affected by irrigation scheduling methods. The highest unmarketable tuber yield (942.9 Kg/ha and 1050.4 Kg/ha) were obtained from Framer Practice at Jima Genati and Wayu Tuka sites respectively, whereas the lowest un marketable tuber yield

(459.3 Kg/ha and 488.9 Kg/ha) were recorded from soil moisture sample method at Jima Genati and Wayu Tuka respectively.

Plant height: The results showed that no significance difference (P>0.05) between soil moisture sample method and Evapotranspiration method at Jima Genati and Wayu Tuka sites.

Table 6: Mean of tuber Yield and plant height for both seasons at Jima Ganati

Treatments	Marketable Yield (kg/ha)	Un Marketable Yield (kg/ha)	Total Yield (kg/ha)	Plant Height (cm)
Hand Feel and appearance of soil method	16406.7c	718.5b	17125.2c	54.5b
Gravimetric soil moisture sample method	21620a	459.3c	22079.3a	61.5a
Evapotranspiration method	19243.4b	518.5c	19761.9b	59.2a
Farmer Practice	13953.4d	942.9a	14896.3d	51.2b
LSD	467.8	83.32	512.53	3.96
CV	11.4	14	15.3	9.4

Table 7: Mean of tuber Yield and plant height for both seasons at Wayu Tuka

Treatments	Marketable Yield (kg/ha)	Un Marketable Yield (kg/ha)	Total Yield (kg/ha)	Plant Height (cm)
Hand Feel and appearance of soil method	15870.0c	762.9b	16633.0c	54.2b
Gravimetric soil moisture sample method	21236.7a	488.9c	21725.6a	60.5a
Evapotranspiration method	18783.3b	533.3c	19316.7b	58.5a
Farmer Practice	13493.3d	1050.4a	14543.7d	50.2a
LSD	490.83	191.7	467.6	3.22
CV	12	14	15	12

Water use efficiency

Crop water use efficiency (WUE) for Evapotranspiration irrigation scheduling method substantially increased as compared with Farmer irrigation scheduling method table 8. The highest WUE values were 6.6 and 6.4 kg m^{-3} recorded for Evapotranspiration irrigation scheduling method, followed by 6 and 5.9 kg m^{-3} for Soil moisture sampling irrigation scheduling method at Jima Ganati and Wayu Tuka sites, respectively, whereas the lowest WUE value was 2.2 and 2.1 kg m^{-3} recorded for the Farmer practice at both sites. These results indicate that both Evapotranspiration method and Gravimetric soil moisture sample method4 achieved high WUE values as compared with Hand Feel and appearance of soil method. This could be due to the high yield obtained with Evapotranspiration method and lower CWU obtained with Hand Feel and appearance of soil method.

Table 8: Mean of Water use efficiency (WUE) for both seasons at Jima Ganati and Wayu sites

Treatments	Water Use Efficiency (Kg/m^3)		Water Saved (%)
	Jima Ganati	Wayu Tuka	
Hand Feel and appearance of soil method	3.6	3.5	26.3
Gravimetric soil moisture sample method	6	5.9	42.5
Evapotranspiration method	6.6	6.4	53.2
Farmer practice	2.2	2.1	-

Economic Analysis

The purpose of Economic analysis was to evaluate the differences in cost and benefits among different irrigation scheduling methods. In the preparation of economic analysis, all the costs of production and the cost that varied among different irrigation scheduling method were taken into account. Yield of all crops were adjusted downward by 30% to reflect probable lower yields expected by the farmers due to differences in factors like management, plot size, harvest data and harvesting technology (Byerlee *et al.* 1984). The field prices of the crops were calculated by adjusting the average market prices of those crops downward by 10 percent. The total cost mainly includes operating and variable costs. Operating costs (labor, land preparation, seeds, fertilizers, and chemicals) were based on the planted area. Variable costs depended on the number of irrigation events and water unit price. The indigenous irrigation farmers in the study area do not pay for water for their farms.

Table 9 Economic analysis for treatments at Jima Ganati and Wayu Tuka sites

	Jima Genati				Wayu Tuka			
Components	Hand Feel Method	S.moisture sample method	Calculating evapotran-spiration losses	Farmer Practice	Hand Feel Method	S.moisture sample method	Calculating evapotran-spiration losses	Farmer Prac-tice
Average Mar.Yield	16407	21620	19243	13953	15870	21237	18783	13493
GFB (Eth Birr/ha)	164067	216200	192434	139534	158700	212367	187833	134933
Fertilizer, seed cost and Chemical (Eth Birr/ha)	29450	29450	29450	29450	29450		29450	29450
Labor cost (Eth Birr/ha)	19975	19075	18175	20875	19975	19075	18175	20875
Total costs (Eth Birr/ha)	49425	48525	47625	50325	49425	48525	47625	50325
NB (Eth Birr/ha)	114642	167675	144809	89209	109275	163842	140208	84608

Conclusion and Recommendation

Results of our field study demonstrated that potato yield, yield attributes, and water use efficiency (WUE) were significantly influenced by irrigation scheduling methods. Four Irrigation scheduling methods are Hand Feel Method, Soil moisture sample method, Calculating evapotranspiration losses and Framer Practice were tested as a treatments in 2019/2020 and 2020/2021 cropping season both at Jima Ganati and Wayu Tuka districts. Among those Calculating evapotranspiration losses and Soil moisture sample method were the best performing irrigation scheduling methods. From those, two irrigation scheduling methods evapotranspiration losses and Soil moisture sample method were best performed at both locations. Irrigating by using farmer irrigation scheduling method consumed more than half volume of irrigation water relative to irrigation scheduling methods evapotranspiration losses. Irrigation schedule by Soil moisture sample method provided the highest tuber yield regardless of the reduction in the total volume of irrigation water when compared with Irrigation scheduling method by Hand Feel Method.

This study, therefore, concluded that irrigating by using evapotranspiration losses irrigation scheduling method save more irrigation water regardless of minimum yield difference when compared with Soil moisture sample irrigation scheduling method. Adoption of this technique suggests the great potential of doubling the cultivable land and production using the existing irrigation water resource by shifting from the conventional (farmer practice) to watersaving irrigation scheduling method. Adoption of the water-saving irrigation scheduling method further helps to minimize the adverse effects of excess irrigation to the environments and the conflicts among the community for the limited water resource.

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Post-Harvest and Agricultural Product Processing Engineering Technologies

Integrating and Evaluation of Corm Grating and Leaf Sheath Decorticating Machine

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Abstract

Enset processing, is labour demanding and time consuming activity which calls for technology to reduce women work drudgery. To overcome women burden in enset processing,engine operated enset processing machine was adapted and evaluation was carried out at three drum speed levels of 1900, 2000 and 2100rpm for corm grating and four levels of drum speed (800, 900, 1000 and 1100rpm) for leaf sheath decorticating were used for the most dominate two varieties (Baladat, and Lemate local names) at farmers farm. Performance of the machine was evaluated interms of grating capacity (Kg/hr) and Decorticating capacity for both varieties. Based on the results obtained, the grand mean grating capacity of 1658Kg/hr (~1.6ton/hr) for corm and decorticating capacity, decorticating efficiency of 497.00Kg/hr and 90.33% for leaf sheath was recorded for the prototype at 1mm concave clearance respectively. Fuel consumption of 0.6lit/hr was recorded at drum speed of 1100 rpm and strongest variety as the farmers' response (Baladati variety) for leaf sheath decorticating. While, 1.1lit/hr was recorded at drum speed of 2100 rpm and baladeti variety for corm grating. The machine can be used for all varieties at drum speed range of 2000 – 2100rpm for corm grating while, 900 – 1100rpm and 1mm concave clearance for leaf sheath decorticating.

Keywords– *Development, Evaluation, Grating, decorticating and Enset*

Introduction

Enset (*Enset ventricosum*) is commonly known as "false banana" and it is a traditional staple crop or co-staple food in the densely populated South and South-Western parts of Ethiopia. It serves as food security for about twelve million people in Southern region of Ethiopia (Brandt *et al.*, 1997). It is a multipurpose crop used as human food, animal feed, to shade other crops like coffee, decoration, is a drought resistant crop which makes it risk avoidance crop. It resembles the banana plant, but is somewhat larger, up to 10 m tall with a pseudo stem up to 1 m in diameter and is produced primarily for the large quantity of carbohydrate rich food found in the false stem (pseudo stem) and an underground bulb (corm).

The major foods obtained from enset are *kocho, bulla* and *amicho*. *Kocho* needs a lengthy period of processing and preparation, which is carried out by women. The first stage involves removing the leaf stalks and grading of the corm. *Kocho* is increasingly exported to urban markets. *Bulla* is the unfermented starch of a mature plant, which can be prepared as a pancake or porridge. *Amicho* is the core of a young plant, which is boiled and consumed as other tuber crops. Due to their low protein content these foods are eaten in combination with protein rich products like milk. The fiber is used to make sacks, bags, ropes, mats, construction material and sieves. Fresh enset leaves are used as food wrappers, serving plates and for stall feeding of cattle. There are many other uses, e.g. for medicines.

It is expected that enset can be introduced in many other regions to improve food security. However, this needs further study and work on trial demonstration farms. Further research is needed on: diseases, processing technologies, improvement of the livestock component, and production of protein-rich food crops in enset systems, marketing of *kocho* and sustainability of enset farming under increasing population pressure and marketing.

However, little effort or research was made to improve the processing aspect of the crop especially corm grating and thus traditional processes are predominantly used by farmers. Both men and women are involved in growing and managing enset at field level in most cases, however, there are places where it is most commonly associated with women. Women are mainly responsible for harvesting and processing enset. Enset processing requires more labour and thus it is additional burden for women beside to handling daily house routines. Some enset processing technologies (e.g. scraping and squeezing tools) was developed by Bako Agricultural Engineering Research Center, Sodo Rural Technology promotion Research Centre and Melkassa Agricultural Research Center.

However, the technologies that farmers used for enset corm grating and leaf sheath decorticating still in the area were traditional. The introduced technologies mainly differ from traditional methods in terms of time and labour requirement, and quantities and qualitiesof yield. The traditional harvesting and post harvesting procedures are cumber some; labour intensive, unhygienic, impose a lot of inconvenience man power, and associated with great lose of yield. Traditionally, 2-3hr per tuber is required for grating operation.

Statement of the problem

Women, in rural community of Ethiopia, have more workload in general as compared to men. Almost all the household activities (including child care, farm and social activies) are performed by women alone. Therefore, women are busy all the day from very early in the morning to late in the evening. Women are also involved in farm operations mainly at planting, weeding and harvesting of different crops. Some crops are more managed by women than men. Such crops include enset, vegetables and spices. Moreover, milking and managing calves is among the daily routines work for women. Processing of enset is entirely done by women because traditionally men are not allowed to involve on such activities.

Enset processing is labour demanding and time consuming activity which calls for technology to make it efficient and lighten the burden on women. It is unimaginable to perform social activities such as wedding, funeral and circumcisions ceremony without active involvement of women. Due to all these workload, women may not have enough time to have adequate care for their child and may not perform the house needs to the satisfaction of menwhich creates conflict among spouses. In general the existing enset processing besides with other farm and household activities has negatively affected the relationship between men and women biasing the work load to women and affecting maternity health (Sodo Rural Technology Promotion Center report document, 2010). Thus, different development programs have introduced enset processing technologies as a solution to reduce drudgery of women. The tubers of enset cannot be stored longer after harvest before decaying, and so processing follows immediately after harvesting. Enset processing leading to size reduction includes decorticating, grating, and squeezing. A typical enset processing plant should therefore consist of units produced to achieve all the stages or steps mentioned above.

Traditional processing method has low productivities and tedious.threfore, to combat these problems, BAERC develops and evaluates the machines that can grate the corm of enset at high quality in a short period of time and reduce human drudgery. Performance of the machine was evaluated interms of Grating capacity (Kg/hr) and Grating uniformity (%) for all varieties. Grating efficiency (%) and Fuel consumption (Kg/ml) were taken for Baladati variety. Based on the results obtained, the grand mean grating capacity of 1048.3Kg/har (~1ton/hr) is recorded for the prototype. The optimum grating capacity of 1277Kg/hr was observed when the drum was operated at velocity of 2200rpm at Sharte variety; whereas the minimum grating capacity of 604.0Kg/hr was observed when the drum speed was 2000 rpm at Baladati variety. Fuel consumption of 1.32lit/hr was recorded at drum speed of 2400rpm and Baladati variety. The machine can be used by farmers for all varieties at drum speed range of 2200 – 2400rpm (Gelgelo, 2018).

Additionally, BAERC also developed and evaluated enset decorticating machine for leaf sheet solely. The maximum decorticating capacity of 255.38 kg/hr was obtained at drum speed of 850 rpm, when the concave clearance was 1 mm and the feeding rate was 0.074 kg/s. Nonetheless, the decorticating capacity of the prototype machine decreased with increasing concave clearance and increased with increasing feeding rate. The highest decorticating efficiency of 98.97% was obtained at drum speed of 850 rpm, concave clearance of 1 mm and feed rate of 0.074 kg/s while the lowest decorticating efficiency of 72.41% occurred at drum speed of 950 rpm, concave clearance of 6 mm and feed rate of 0.037kg/s. The mean decorticating efficiency with respect to the feeding rates of 0.037, 0.056 and 0.074 kg/s were 86.77, 89.41 and 89.91 %, respectively (Merga, 2019). Even though, the center develops and evaluate the machines that are effective for enset corm grating and leaf sheet decorticating solely, taking one rather than two machines to the farmers for one crop is compulsory.

Therefore, this paper was initiated to integrate and evaluate corm grating and leaf sheath decorticating machine that is a cheaper and more affordable to the farmers.

Material and Method

Experimental Site

The modification of the machine was done at Bako Agricultural Engineering Research Center (BAERC), which is located in West Shoa zone of Oromia National Regional State, Western Ethiopia. The experiment (evaluation of the machine) was conducted in South West Shoa Zone of Oromia Regional State, South West highlands of Ethiopia.

Materials

- Angle iron, Stainless steel sheet,
- Stainless steel Electrode, Wooden planks,
- Diesel engine, L-angle (stainless steel angle), etc.

The instruments used during performance evaluation and data collection were: digital balance, spring balance, tachometer and stopwatch

Design Analysis and Calculations

Design Considerations

The machine that should be efficient during use in the household
-Movable (portability) and
-Safety or ease of operation was considered.

Modified Parts of the Prototype

Frame

The frame carries the entire components of the machine. It is a trapezoidal shaped structure, 374 mm by 760 mm at the top and 600 mm by 760mm at the base, constructed from 40 mm by 40 mmmildsteel angle iron. The standard minimum ratio of the frame lengths was $L_1/L_2 = 0.5$, (Shirgley 1980, Hannah and Stephens 1980). For this project, it was taken as 0.49 and 0.79 for base and top respectively, therefore the above condition is satisfied. This was done to provide stability and make it easily transportable.

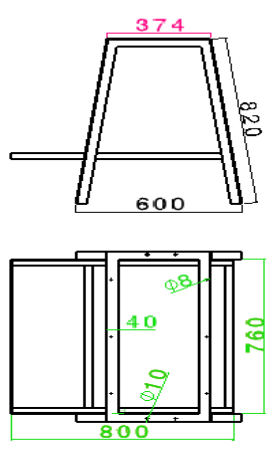

Figure1. Modified frame part

Hopper

The hopper is the receptacle through which corm and leaf sheath were admitted into the machine for grating and decorticating. Corm grating and leaf sheath decorticating hopper were separately produced then incorporated to make one part. Corm grating hopper has a two trapezoidal structure and rectangular shape at the bottom and made of stainless steel sheet of 1.5mm thickness.

$$V = (\frac{H_t}{2}(b_{1_t} + b_{2_t}) + \frac{H_b}{2}(b_{1_b} + b_{2_b}) + (b_{2_b} * h)L = 0.06m^3$$

Where V = Volume of the hopper, m^3, L = Hoppers' length, m, b_{1t} and b_{2t} = bases' length of top trapezoidal, m, b_{1b} and b_{2b} = bases' length of top trapezoidal, m and H = Hoppers' height of top and bottom trapezoidal, m.

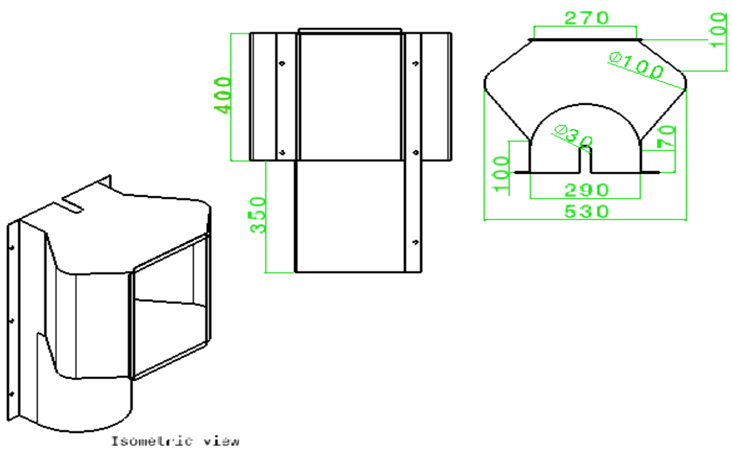

Figure 2. Modified hopper part

Grating and decorticating drum

Cylindrical drum of 367mm length and 220mm diameter and 338mm length and 243mm diameter was formed by rolling 1.5mm thickness stainless steel sheet metal for corm grating and leaf sheath decorticating respectively. Drums were welded on the shaft that pass through the center and L – angle of 20x20 and 30x30 welded on it for corm grating and leaf sheath decorticating. Twenty and fifteen of them were welded on surface of corm and leaf sheath drum at equal distance spacing which served as the grating and decorticating respectively.

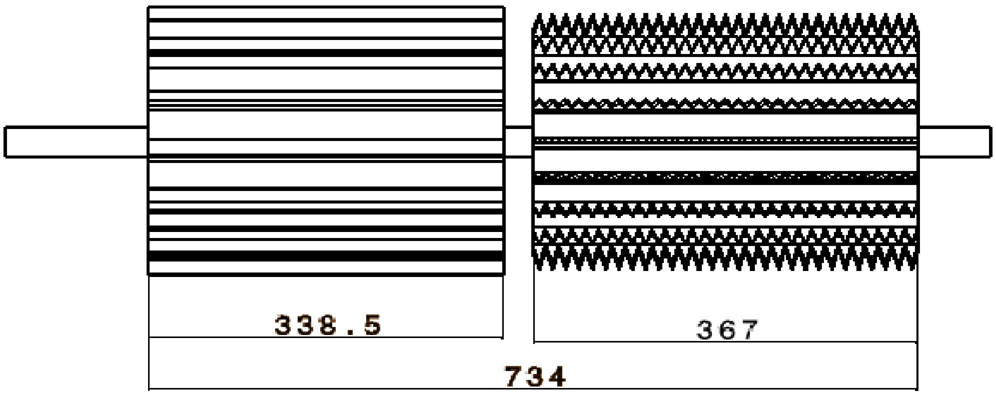

Figure3. Modified drum part

Selection of pulley

The speed ratio of the larger pulley on the machine shaft to the smaller pulley on the engine is givens as (Khurmi and Gupta, 2004):

$$N1\ D1 = N2\ D2$$

Where: N1 = speed of engine, N2 = speed of machine driving shaft, D1 = diameter of engine pulley, and D2 = diameter of machine drive pulley.

Let N1 = Speed of the driver in r.p.m. = 1200rpm and D1 = 210mm; Nd = maximum speed of the driven in r.p.m. = 2100rpm

$$1200 \times 210 = 2100 \times D2, \quad D2 = 120mm$$

Based on availability and cost, aluminum pulley was selected for corm grating while vice versa for leaf sheath decorticating in order to use one belt for the operations.

Selection of belt

Length of belt was calculated by Equation (Khurmi and Gupta, 2004),

$$L_p = 2C + 1.57(D_p + d_p) + \frac{(D_p - d_p)^2}{4C}$$

Where: L_p**:** effective length of belt (mm), C: center distance (mm), D_p**:** pitch diameter of large pulley (mm), d_p**:** pitch diameter of small pulley (mm)

Assume C = 460mm based on the height of frame.

Lp = 2x460 +1.57(210+120) + ((210-120)^2)/4*460

= 1442.5mm

Based on the driven and driving pulley diameter, the length correction factor for belts shorter or longer than average length determine and the closest belt length B – 51 belt type was selected.

Selection of Shaft

The shaft was considered for satisfactory performance is to be rigid enough while transmitting load. Determination of belt tensions (T_t and T_s) and torsional moment (Mt) according to Khurmi and Gupta, 2004, was done from the following equations.

$$\frac{T_t - T_c}{T_s - T_c} = e^{\mu\theta \operatorname{cosec}\frac{\beta}{2}} = e^{0.3*2.95*2.92} = T_s = 32.57N$$

$$T_t = T_{\max} - T_c = 4.2 - 32.88 = -28.68N$$

$$T_{\max} = \partial a = 2.1 * 2 = 4.2N$$

$$T_c = mv^2 = 0.189*13.19^2 = 32.88N$$

From the maximum drum speed (2100rpm) and pulley (120mm), drum velocity (m/s):

$$V = \frac{\pi D_1 N}{60} = \frac{\pi x.12x2100}{60} = 13.19m/s$$

Wrap angle determination was determined) for drum pulley.

$$\theta = 180 - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) = 2.95rad$$

$$M_t = (T_t - T_s)\frac{D_1}{2} = (28.68 - 32.56)0.06 = 0.23Nm$$

Where T_t, T_s, Tmax, Tc, ẟ, a ,m, v, μ, β and θ are the tension at tight side, tension at slack side, maximum tension in belt (N), centrifugal tension of a belts (N), maximum safe normal stress (N/mm2), a is cross sectional area (mm^2), mass per unit length (kg/m) of belts, speed of belt (m/s), coefficient of friction between belt and pulley, groove angle and angle of wrap respectively.

According to standard table Khurmi and Gupta (2005) the value of ẟ, a ,m, μ, β and θ are 2.1 N/mm^2, 2mm^2, 0.189 kg/m, 0.3, 40^o and 2.95rad respectively. From above equations T_t, T_s, Tmax, Tc and Mt are 28.69N, 32.25N, 4.2N, 32.88N and 0.23 N-m respectively.

The diameter of the shaft was calculated as follow. The maximum bending moment of 40Nm was obtained at point A. Assume K_b = 1.5 and K_b = 1 and $\tau_{\max}$ = Allowable Stress; 40MPa (for steel shaft with keyway).

$$d^{3} = \frac{16}{3.14 \times 40MPa}\left[(1.5 \times 40)^{2} + (0.23)^{2}\right]^{\frac{1}{2}}$$

= 19.7mm but by taking 1.5 safety factor, 30 mm diameter of shaft was selected.

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 205 bearing were selected.

Description of the machine

The machine was consists of basically 3 units; the hopper unit, the grating drum and the delivery channel. All these components are mounted on a mild steel angle iron frame that has trapezoidal shape. The machinewas operated by 5Hp engine.

igure 4. Major parts of modified enset processing machine

Performance Evaluation

Series of tests were conducted using the machine. The hardest and best yielded variety (baladati) and the easiest variety (lemate) while processing were used.

The experiment was conducted in a factorial RCBD with three replications. The treatments considered for this experiment was two factors, namely drum speed and variety for corm garting and drum speed and concave clearance for leaf sheath decorticating.

Evaluation was carried out on using 21kg of corm for three (5, 7 and 9kg) samples with combination of three levels drum speed (1900, 2000 and 2100rpm (Adetunji and Quadri. 2011) and four levels of drum speed 800, 900, 1000 and 1100rpm and 1 and 3mm concave clearance for leaf sheath decorticating with 10 and 5kg samples were used. The time taken for each treatment was accurately checked and recorded.

The following parameters were taken to determine the performance of the machine

The grating efficiency is given as:

$$GC = \frac{W_{tg}}{T_g} , \qquad GE = \frac{W_{col}}{W_{feed}} x100\%$$

Where: GC – Grating capacity, kg/hr, W_{tg} – Total weight grate, kg, T_g – Grating time, hr, W_{col} = Weight of sample at collector, kg, and W_{feed} = Weight of sampled feed in, kg

Fuel consumption (Kg/ml) – amount of fuel consumption for sample of corm and leaf sheath was recorded by refill mechanism the hardest variety.

Decorticating efficiency and capacity was determined as follows,

$$DC = \frac{W_d}{Td} , \qquad DE = \frac{W_d}{W_d + W_{ud}}$$

Where: DC – Decorticating capacity, kg/hr, W_d–Total weight decorticated, kg, T_g – decorticating time, hr, η_d = decorticating efficiency, %, W_d = Total decorticated weight recovered, kg, and W_{un} = weight of un decorticating, kg.

Statistical Analysis and Interpretation

The experimental was conducted in a factorial experimental analysis of variance. Analysis was made using genstat 15th edition statistical software. Mean comparisons were carried out to estimate the differences between treatments using Fisher's least significant difference (LSD) at 5% probability level

Result and Discussion

This study was undertaken to adapt and evaluate corm grating machine to enset processing machine. Performance of the machine was evaluated in terms of Grating capacity (Kg/hr), Grating efficiency (%) and Fuel consumption (Kg/ml), Decorticating capacity (Kg/hr) and efficiency (%).

Corm Grating capacity (Kg/hr) and Efficiency (%)

The overall grand mean grating capacity and efficiency of the prototype was 1658Kg/hr (~1.6ton/hr) and 96.64% respectively. The optimum grating capacity of 1703Kg/hr was observed when the drum was operated at velocity of 2100rpm; whereas the minimum grating capacity of 1606Kg/hr was observed when the drum speed was 2000 rpm. The optimum grating efficiency of 97.51%r was observed when the drum was operated at velocity of 2000rpm. Generally, increasing drum speed increases grating capacity and efficiency.

Table 1. Effect of drum speed on Corm grating capacity (Kg/hr) and Efficiency (%)

Velocity (rpm)	**Mean**		**Grand mean**	
	Grating capacity (Kg/hr)	Grating Efficiency (%)	Grating capacity (Kg/hr)	Grating Efficiency (%)
1900	1664A	95.42A	1658	96.64
2000	1606A	97.51A		
2100	1703A	97.00A		
Lsd (5%)	296.3	3.315		
CV (%)	21.2	4.1		

Leaf sheath decorticating capacity (Kg/hr)

The overall grand mean decorticating capacity of the prototype is 577.00Kg/hr. Maximum and least decorticating capacity of 782 and 431kg/hr was recorded at 3mm concave clearance and 1000rpm and 1mm and 900rpm drum speed respectively. Decorticating capacity of the prototype at 1mm concave clearance is 497.0 Kg/hr. Drum speed and concave clearance has direct relationship to decorticating capacity. Similar trend was obtained by Ahmed I. Imam *et al*., 2016.

Table 2. Effect of drum speed, concave clearance & combination on leaf sheath decorticating capacity (Kg/hr)

Velocity (rpm)	**Concave Clearance**		**Velocity (rpm)**	**Mean**	**Concave Clearance**	**Mean**	**Grand mean**
	1mm	3mm					
800	462^{A}	591^{DE}	800	526^{AC}	1mm	497A	577.00
900	431^{A}	638^{BCF}	900	535^{A}			
1000	507^{BC}	782^{CG}	1000	645^{CD}	3mm	657B	
1100	586^{D}	618^{BCH}	1100	602^{DE}			
Lsd (5% level)	112.8		79.7		56.4		
CV (%)	24.1						

Leaf sheath decorticating efficiency (%)

The optimum decorticating efficiency of 94.56% was observed when the drum was operated at velocity of 900rpm and 1mm concave clearance; whereas the minimum decorticating efficiency of 78.66% was observed when the drum speed was 900 rpm and 3mm. Drum speed and concave clearance has direct and indirect relationship to decorticating efficiency respectively. The overall grand mean decorticating efficiency of the prototype is 87.05%. Decorticating capacity of the prototype at 1mm concave clearance is 90.33%.

Table 3. Effect of drum speed, concave clearance & combination on leaf sheath decorticating efficiency (%)

Velocity (rpm)	**Concave Clearance**		**Velocity (rpm)**	**Mean**	**Concave Clearance**	**Mean**	**Grand mean**
	1mm	3mm					
800	87.63^{A}	81.50^{DE}	800	84.57^{A}	1mm	90.33A	87.05
900	94.56^{A}	78.66^{BCF}	900	86.61^{A}			
1000	87.42^{BC}	84.34^{CG}	1000	85.88^{A}	3mm	83.76B	
1100	91.71^{D}	90.54^{BCH}	1100	91.12^{B}			
Lsd (5% level)	5.04		3.56		2.52		
CV (%)	7.1						

Fuel Consumption

Fuel consumption of 0.6lit/hr was recorded at drum speed of 1100 rpm and strongest variety (Baladati) as the farmers' response for leaf sheath decorticating While, 1.1lit/hr,was recorded at drum speed of 2100 rpm for corm grating machine.

Conclusion and Recommendations

Conclusion

Enset processing, in Ethiopia at present, is labour demanding and time consuming activity which calls for technology to make it efficient and reduce the workload on women. Engine operated enset processing machine was adapted and evaluated at the most enset produce farmers farm. Based on the results obtained, the grand mean grating and decorticating capacity of 1658Kg/hr (~1.6ton/hr) and 577Kg/hr was recorded for the prototype respectively. The optimum decorticating efficiency of 94.56% was observed when the drum was operated at velocity of 900rpm and 1mm concave clearance; Whereas, the minimum decorticating efficiency of 78.66% was observed at drum speed of 900 rpm and 3mm concave clearance. Fuel consumption of 0.6lit/hr was recorded at drum speed of 1100 rpm and strongest variety (Baladati) as the farmers' response for leaf sheath decorticating. While, 1.1lit/hr was recorded at drum speed of 2100 rpm for corm grating machine

The machine can be used by farmers for all varieties at drum speed range of 2000 – 2100rpm for corm grating while 900 – 1100rpm and 1mm concave clearance for leaf sheath decorticating. Also it solves the quality problem compare to the traditional method andit can be concluded that the machine can be efficiently used and solve the problems of the farmers.

Recommendation

From obtained results, the machine performs very well for both activities (corm grating and leaf sheath decorticating). But, it can be more efficient if extra work is done so far on it, particularly splashing out of grated "amicho" through inlet and concave clearance at leaf sheath decorticating part for better fiber quality producuction.

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On Farm Evaluation of Engine Driven Coffee De-Huller

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Abstract

The modified coffee de-huller machine was evaluated at different drum speed and feeding rate. The results obtained indicated that the de-hulling efficiency, bean damage and cleaning efficiency increased as the drum speed increased from 400 to 600rpm. The highest average de-hulling efficiency, cleaning efficiency, percentage of breakage and capacity were 97.34 %, 98.77 %, 3.18 % and 358.7 kg/hr respectively. High de-hulling and cleaning efficiencies and low percentage of breakage obtained indicate that the machine is very appropriate to handle coffee processing. Considering the reasonable performance achieved at wide range of the machine operating conditions, this work has a good prospect for commercial coffee production.

Key word: *coffee, percentage of breakage, de-huller efficiency*

Introduction

Coffee production is vital to Ethiopian economy with about 15 million people directly or indirectly deriving their livelihoods from it. Coffee is an important export commodity for Ethiopia, contributing 41% of the country's total foreign exchange earnings (IMF, 2006) and about 10 % of the gross domestic product. Over 25% of the populations of Ethiopia, representing 15 million people, are dependent on coffee for their livelihoods (LMC, 2000). This includes 8 million people directly involved in coffee cultivation and 7 million in the processing, trading, transport, and financial sectors (Charveriat, 2001; Oxfam, 2002). Almost 95% of the Ethiopian coffee is produced by about 1 million small-scale farmers, with an average farm size of 0.5ha, while state-owned plantations account for 4.4% and private investor plantations 0.6% (FDRE, 2003). The quality of Ethiopian coffee is determined by two main factors namely the geographic origin (Nicholas, 2007) and the post-harvest processing techniques. It is estimated that 40 % of the quality of coffee is determined in the field, 40 % at post-harvest primary processing, and 20 % at secondary/export processing and handling including storage. In order to enhance quality and market value of Ethiopian coffee, improved primary processing by farmers at the village level is a prerequisite. An improvement in coffee quality, and therefore income, has a direct impact on the livelihoods of a large number of resource-poor people in the rural populations.

In addition to processing Technologies, Coffee production in Ethiopia is constrained by lack of competitiveness, poor access to market, lack of infrastructure, in adequate access to services, low value addition, and in adequate technology transfer and research (Jose, 2012). Another constraint of coffee production in Ethiopia is limited extension and research facilities (World Bank, 2015).

In Oromia Regional State, 417,557.38 ha of land was allocated and 2,586,654.70 quintal was produced with average yield of 6.19 quintal/ha in 2015/16 Meher Season (CSA, 2016). From top 25 coffee producing districts in Ethiopia, Oromia dominates with 18 coffee producing districts and the remaining top coffee producing districts are located in SNNP (James et al., 2015). Arsi Zone is one of tehe Oromia region's zones which have potential of coffee production like Chole, Aseko, Merti, Guna and Gololcha districts but only Gololcha coffee is recognized in national market (Tamirat *etal*,2017). In addition to these woreda Shirka, seru and Kolu Shan is districts also have great potential. In 2015/16 Meher season, 6,476.56 ha of land was allocated and 40,248.25 quintal was produced with average yield of 6.21quintal/ha (CSA, 2016). Coffee plantation enterprise is also found in Gololcha district which is one of the districts in the Arsi Zone. Gololcha district is 14th from top 25 coffee producing districts in Ethiopia and 7th from top 18 coffee producing districts in Oromia (James *et al*., 2015).

Even though, coffee is produced by many farmers they face constraints of processing technologies like de-huller. In order to solve this problem the BAERC and JAERC were involved in developing, demonstrating and introducing of the technology. BAERC developed and evaluated engine driven coffee de-huller with the capacity of 251.7 kg/hr and with de-hulling efficiency 93 % (Gelgelo and Ashebir, 2018). JAERC also developed and tested manually operated dry bean coffee de-huller with capacity and de-hulling efficiency of 81 kg/hr and 96 % respectively (Tamiru *etal*, 2019). But it was not adapted and demonstrated to Arsi and Bale zone of coffee farmers. This may be attributed to inadequate processing technology as result of the high level of drudgery involved in the de-hulling of the coffee bean by manual method in order to maintain quality and secure reasonable market value or the farmer forced to sell their produce to coffee collectors and other illegal traders who set price themselves.

On the other side, ADPLAC of Arsi zones also asked AAERC to solve this problem. To alleviate problems associated with coffee de-hulling process, it was felt appropriate to adapt machine that can solve the problem mentioned above. Therefore, this study was aimed with objectives to evaluate the performance BAERC type coffee de-huller machine and to adapt the de-huller.

Materials and Method

In this particular paper, attempt has been made to on farm evaluation of coffee de-huller. The designed and developed de-huller machine at Bako Agricultural Engineering Research Center (BAERC) was collected and tested on station against their respective technical specification. But, this machine was not used by farmers due to unavailability and poor awareness of farmers.

The operators were performed the entire test based on the recommended de-huller test format. After test on the station some modification was done on the parts for better and manufactured in the center for full package performance evaluation of de-huller machine. The site and Farmer selection was done based on potential area of coffee production in Arsi zone, Gololcha and Chole districts were selected. Then, performance evaluation and data collection were done.

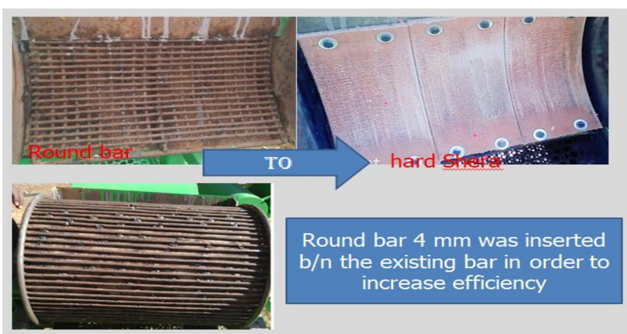

Figure 1. Modified parts

Machine Description

The overall length, width and height of the machine were 152, 93 and 133 cm respectively. The machine consisted of major components as follows: (1) Hopper (2) drum (3) The frame stand assembly, (4) The power transmission assembly (belt and pulley), and (5) cleaning system (fun and sieve). Figure 2 shows the modified machine used in the experiment. The specification of materials and dimension for machine components are mentioned in table in detail 1.

Figure2. The pictorial picture of the coffee de-huller (1.Hopper, 2.Drum, 3.Sieve, 4.Frame, 5.Pulley, 6.Fun)

Table 1. Materials specification and dimension of machine components

Specification	Dimensions
Pulley drum which attached to fun and eccentric double line	25.5 cm
Eccentric pulley	25.5 cm
Eccentric diameter	8 cm
Fun pulley	9 cm
Pulley on engine shaft	8 cm
Pulley on drum which attached to engine single line	28 cm
Sieve 12,10 ,6 mm diameter	40 x 92 cm
Bearing (P206)	# 2
Bearing (P204)	#2
Shaft 30mm diameter for drum	93 cm
Shaft 20mm diameter for fun and eccentric	93 cm

Hopper

The material used for the construction was mild steel sheet metal of 1.5mm thickness. The hopper was semi circularly shaped and extended upwards, with the inlet tilted 30 degree to the horizontal to prevent splashing outof coffee bean during shelling and depends on the angle of repose of unshelled coffee bean. It has control gate to regulate beans fall for shelling into it.

Drum

The shelling drum carried out the function of actually breaking the bean, releasing the kernel from the coffee bean. It was closed ended rotating cylinder with round bar welded on drum and made up of two circular plate's diameter of 40 cm and length of 40 cm, which was drilled at the center to allow 30 mm diameter shaft to pass through.

Concave

The concave clearance was adjustable and round bar of 6mm diameter was welded at space of 6mm and fitted to the cylinder length. The size of kernel was measured using caliper to measure the minor (thickness), major (length) and intermediate (width) diameters to determine the space or concave clearance.

Cleaning unit

Fan: It is centrifugal type. The fan was consists of straight blades, welded on shaft inside a casing. The fan casing was spirally shaped for greater blowing efficiency.

Sieves: Additionally three stage sieve was used in order to separate shelled and unshelled coffee. The sieve hole of oval shape was used by shifting two sieve drilled by 12mm based on the geometric mean diameter the kernel.

Frame: The frame carries the entire components of the machine. It is a trapezoidal shaped structure constructed from 40 by 40 mm square pipe based on standard minimum ratio of the frame lengths, given as L1/L2 = 0.5, (Shirgley 1980, Hannah and Stephens 1980 as cited by Gelgelo and Ashebir,2018). This was done to provide stability and make it easy for transportation.

Working principles of the machine

The de-huller was driven by a 5 Hp diesel engine which rotates the drum via a coupling joint (pulley and belt). The material was introduced into the machine manually through hopper. The beans, to be shelled, fall into the shelling unit by gravity through the feeding table and the feeding rate was controlled by the control gate.

Performance evaluation

The performance of the machine was evaluated in terms of dehulling capacity, dehulling efficiency, cleaning efficiency and percentage of damage using the following equation

$$\text{Shelling capacity (kg/hr)} = \frac{Q_T}{t} \quad (1)$$

$$\text{Mechanical damage (\%)} = \frac{Q_T}{Q_{ud} + Q_d} * 100 \quad (2)$$

$$\text{Cleaning efficiency (\%)} = \frac{W_t - W_c}{W_t} * 100 \quad (3)$$

$$\text{Shelling efficiency (\%)} = \frac{Q_t}{Q_t + Q_{us}} * 100 \quad (4)$$

Where,

Q_t = mass of shelled grain outlet (kg)
T = time of decorticating (hr)
Q_{us} = quantity of unshelled grain (kg)
Q_{ud} = quantity of undamaged grain (kg)
Q_d = quantity of damaged grain (kg)
Q_t = weight of total mixture grain and chaff received at grain outlet (kg)
Q_c = weight of chaff at the main outlet of the machine (kg)

Fuel consumption

To measure the fuel consumption, firstly, De-huller machine kept on leveled surface. The fuel tank was filled up to its full capacity before the test started. After the completion of the de-hulling operation, the engine was stopped and then the tank was refilled to its full level. The amount of fuel filled in the tank was measured using graduated measuring cylinder. The difference between amount of fuel prior to and after de-hulling was used to estimate fuel use efficiency.

Cost analysis of the coffee de-huller

A Simple cost analysis was done for the coffee de-huller. The analysis included the actual cost of the device, annual fixed cost and variable cost. The annual fixed cost included depreciation, interest and shelter cost. Variable cost included repair and maintenance cost, labor cost and electricity cost. Assumption was made as interest 13%, shelter 0.01% per year; repair and maintenance cost 0.01% per hr, operation per day 8 hrs, annual use 700 hrs and estimated life span 7 yrs of the machine. The cost was calculated using following formulas: The annual depreciation was calculated as

D = (P – S)/L (5)

Where, D is the depreciation; P is the purchase price of the machine; S is the salvage or selling price and L is the time between buying and selling.

Interest on investment was calculated as

I = [P + S/2] ×i (6)

Where, I is the interest on investment; P is the purchase price of the machine; S is the salvage or selling price; i is the current interest rate.

Total cost per year calculated as Total cost = Annual fixed cost + Variable cost (7)

Break-even point of the device was considered in this study which can be expressed in terms of the amount of dry coffee needed to de-hull per year. Break even cost of the devicewas given by Equation 8 (Valentin et al., 2016).

$$BEP = \frac{AFC}{CR - VC}$$

(8)

Where, CR is the custom rate; AFC is the annual fixed cost and VC is the variable cost.

Experimental Design

The experiment was conducted in a factorial design having drum speed and feed rate as treatment with three replications.

The details of the treatments were:

- Three levels of drum speeds V1 = 400 rpm, V2= 500 rpm and V3 = 500 rpm (Ogunlade et al.,2014, Gelgelo and Ashebir,2018 and Adeleke andOgunjobi,2016)
- Three levels of feed rate FR1 = 4, FR2= 5 and FR3 = 6 Kg/hr,

Data 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 10 statistical software. The treatment means that were different at 5% levels of significance were separated using LSD. Level of significance (P) for these relations was obtained by F- test based on analysis of variance.

Results and Discussion

Performance of the prototype machine was discussed interms of de-hulling capacity (C), percentage of breakage (PB), De-hulling efficiency (DE) and cleaning efficiency (CE).

De-hulling Efficiency

Table 2. Effects of drum speed on de-hulling efficiency and bean damage

RPM of Drum	Percentage of damage (%)			De-hulling Efficiency (%)		
	Feed rate (kg/min)			Feed rate (kg/min)		
	4	5	6	4	5	6
400	0.89	1.1	1.89	96	94	93.66
500	1.01	1.4	2.2	97	95.67	95.19
600	1.23	2.3	3.18	98.03	97.81	97.34
Grand mean	1.04	1.6	2.42	97.01	95.83	95.39
CV	11			3.63		

The de-hulling efficiency was relatively high, above 93.66 %, at 400 rpm drum speed and the minimum average de-hulling efficiency achieved by each drum speed was over 93 per cent as indicated by Table 1. This was an indication that the impact and shearing mechanism was very efficient for dehulling coffee which agrees with the report of Adewumi (2005) that shearing strip mechanism was efficient for threshing legumes. The dehulling efficiency increased with increase in drum speed. Dalha and Dangora (2011) said the threshing efficiency varies with increase in cylinder speed at different feed rates with similar results reported by Raji and Akaaimo (2005), Adekanye and Olaoye (2013) and Adekanye et al (2016). Abo El-Naga et al (2013) who also postulated the same result, observed that threshing efficiency of Lentil decreased by increasing drum speed further from 11.78 m/s. The increase in the efficiency may be justifiedby the fact that dehulling was by shearing force which increased due to increase in drum speed (Raji and Akaaimo, 2005 and Gbabo et al, 2013 and Adekanye et al, 2016) and had the tendency of making more materials to collide with one another as earlier observed. Relative low corresponding change in efficiency due to increase in drum speed suggests that the initial drum speed was sufficient to cause reasonable collision and stripping of materials fed into the machine. The ANOVA Table 2 indicated that no significant difference at 0.05 levels among the drum speeds. However, Raji and Akaaimo (2005) observed significant difference in threshing Prosopis africana at the same Significance level using similar mechanism: the situation experienced in this project may be attributed to what was mentioned earlier that, the initial drum speed was enough to cause reasonable dehulling efficiency or difference in crop properties.

ANOVA revealed that both main effects were significant at 5 % level. The optimum shelling efficiency of 98.03 % was observed when the drum was operated at velocity of 600 rpm and 4kg/min feeding rate; whereas the minimum de-hulling efficiency of 93.66 % was observed when the drum speed was 400 rpm & feeding rate was 6 kg/ min. Similar finding was obtained with Gelgelo and Ashebir, 2018.

Table 3. Analysis of Variance Table for the result of the experiments

F - Value					
Source of variation	Degree of freedom (DF)	DE	PB	C	CE
FR	2	305.36*	97.51*	4510.34*	284.15*
RPM	2	67.25*	168.06*	63.36*	65.6*
FR * RPM	4	22.66**	87.93**	26.71**	25.1**
Error	18				
Total	26				

Percentage of breakage

As shown in table 2. Percentage of breakage has direct relationship with drum speed and feed rate. Maximum percentage of coffee bean breakage, 3.18 %, occurred when the coffee bean were dehulled at cylinder speed of 600 rpm and 6kg/min feed rate, while the least percentage of damage, 0.89%, was recorded at drum speed of 400 rpm and 3 kg/min feed rate.

Generally percentage of damage ranges from 0.89 – 3.18 per cent for drum speeds of 400 – 600 rpm. According to Adekanye and Olaoye (2013) and Adekanye et al (2016), percentage grain damage increased slightly with an increased drum speed and decrease in moisture content. They attributed the occurrence to increased frequency of shearing force between the crop and threshing members, hence more severe rubbing of the crops. The percentage of damaged grain increased by increasing the drum speed (El-Nono and Mohamed, 2000) as a result of increased impact force (Abo ElNaga et al, 2015). This implies that using high drum speed for this machine would result in high bean damage which may render hulling operation worthless. Most of the damaged beans were those initially infected or broken during pulping. In this context, it could be said that there were little or no damaged beans. Table 3 shows that there was significant difference in bean damage among drum speeds at tested levels which further prove the suitability of the machine for producing quality beans even at high drum speeds. Dalha and Dangora (2011) had observed that the effects of variables (including cylinder speed) on grain damage were significant at 5% level.

Capacity of de-hulling

The maximum shelling capacity of 358.7 kg/hr was recorded 600 rpm of drum speed. Generally, shelling capacity has direct relationship with drum speed.

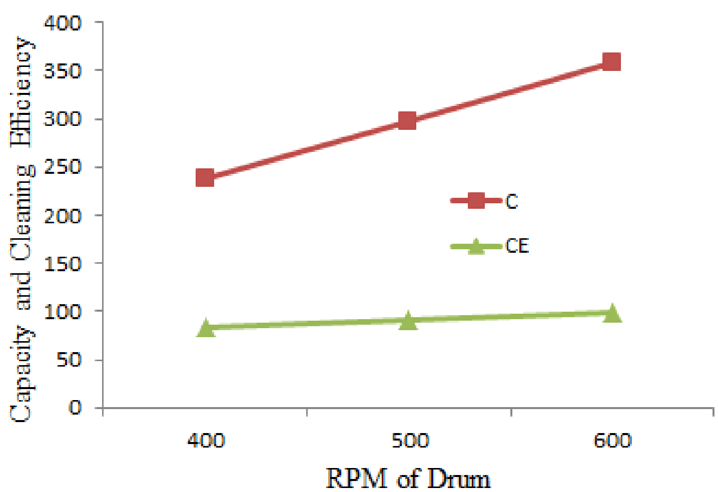

Figure 3. Effect of drum speed on capacity and cleaning efficiency

Cleaning efficiency

As shown Figure 3 Increasing drum speed from 400 to 600 rpm which mean increasing fun speed from 1133 to 1700 RPM changed cleaning efficiency from 83.57 to 96.77 %. Raji and

Akaaimo (2005) had reported that increase in fan rotation increased cleaning efficiency while increase in air blowing rate increased cleaning efficiency (Bello and Odey, 2011), using centrifugal fan. According to Muhammad et al (2013), fan speed exhibited positive linear relationship with cleaning efficiency with co-efficient of determination of 0.93 – 0.97 for three different crops. All the results can be justified by the report of Simonyan and Yiljep (2008) that grain conveyance on the sieve is influenced by air velocity which leads to initial distribution of grains from MOG. This could be attributed to increased velocity of air current above the terminal velocities of dirt/chaffs due to increase in fan speed assisted with diffusion of materials due to screen agitation which led to proper drag of MOG. Therefore, it may be said that a combination of reciprocating screen and blowing fan was effective for cleaning coffee beans. The trend may be attributed to better diffusion and spread of materials achieved at moderate screen speeds which resulted in efficient removal of MOG by air current from the blowing fan. The cleaning efficiency was significant at 0.05% significance level as shown in Table 3. This indicates that relatively high fan speed was necessary for good cleaning efficiencies of coffee beans. Raji and Akaaimo (2005) observed there was significant difference among fan speeds at 5% level. The significant difference observed at high fan speeds in this work may be caused by better dispersion achieved at these speeds.

Cost analysis of coffee de-huller

Table 4 shows the cost factors and items of the Coffee de-huller. The price of the machine without engine was around 12518.68 birr and 37518.68 Birr with 5hp diesel engine. The fix cost consists of three cost item namely depreciation, interest and shelter whereas variable cost consists of fuel cost, oil cost, labor cost, repair and maintenance cost. From the table, it can be seen that the cost of the coffee de-huller was only 0.22 Birr per kilogram.

Table 4. The cost factors and items of the coffee de-huller

	Cost items/factors	BIRR (ETB)
1	Cost of coffee de-huller	
A	Raw Material cost	8231.6
B	Materials wastage = 2.5 % of a	205.79
C	Production cost (machine + labor)	1389.33
D	Overhead cost = 5% of c	69.47
E	profit = 10 % of (a + b + c + d)	989.62
F	sell tax =15% of (a + b + c + d + e)	1632.87
G	selling price = (a + b + c + d + e + f)	12518.68
8	Engine cost (Assume)	25,000
	Total cost	**37518.68**
2	Life of the de-huller	7 yrs
3	Annual use	700 hr
4	Annual fixed cost	
	a. Depreciation	5627.8
	b. Interest (13 %)	2682.59
	c. Shelter (0.01 of P)	5.751
	Total	8316.14birr/yr
	Total	11.88 birr/hr
5	Variable cost	
	a. Repair and maintenance (0.01 % P)	3.75 birr/hr
	b. Labor (two labours, 150/day)	37.5 birr/hr
	c. Fuel (0.29lit/quint = 6.79bir/quintal)	23.75 birr/hr
	d. Oil (3 % of fuel)	0.71 birr/hr
	Total	65.71 birr/hr
6	Total cost	77.59 birr/hr
7	Cost de-hulling (350 kg/hr)	0.22 birr/kg

Break-even point

From Table 4 shows that the device has an initial cost of 37518.68 Birr with an estimated life span of 7 years. With basic assumptions and current market practice the annual fixed cost of operating the device was 8316.14 Birr. Assumptions include: interest, 13%, shelter 0.01% per yr, repair and maintenance 0.01% per hr, operation per day 8 hr, annual use 700 hr and custom rate 1.25 birr/kg. The de-huller needs to grade a quantity of 8 tons of dry bean coffee in one year to break-even the cost of fabrication. Figure 4 shows the cost curve emphasizing the break-even quantity. If available quantity of dry bean coffee is greater than the break-even quantity, the use of the grader can result profit. Otherwise, the machine can be expensive to use when available quantity would be less than the break-even quantity.

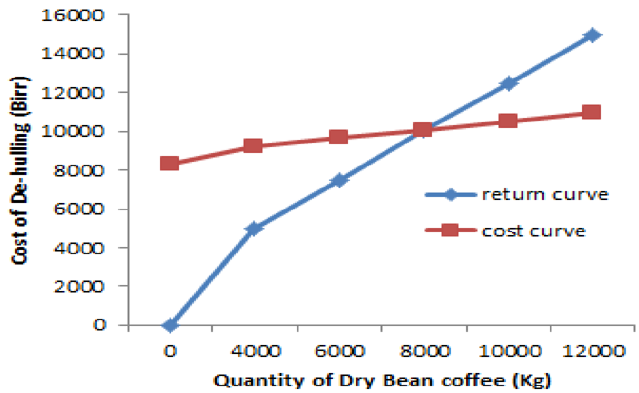

Figure 4. Relationship of the cost of operation of the de-huller and the quantity of dry bean coffee for de-hulling

Conclusion and recommendation

Conclusion

Performance evaluations of the machines were done to determine DC, DE, PB and CE at different drum speeds and feed rate. Three levels of drum speed (400, 500 and 600 rpm) were investigated to identify the optimum combination of the variables in question. The drum speed of the machine and feed rate was affecting the performance of the machine. The coffee de-hullerwas a simple, low-cost and versatile prototype powered by a 5.0 Hp diesel engine that can be used to de-hull dry coffee bean materials. Throughput capacity increased from 238.8 to 358.7 when RPM of drum increases from 400 to 600. Whereas, cleaning efficiency, percent of breakage and de-hulling efficiency increases from 83.57 to 98.77, 1.89 to 3.18, and 93.66 to 97.34 as RPM of the drum increases from 400 to 600. The combination effect of RPM and Feed Rate was highly significant on all performance of the machine parameters.

Recommendation

Based on the findings obtained, the following recommendations are made:

Since the size of dry bean coffee is different in size (small, medium and large), setting the concave clearance for the bigger size the tendency of unde-hulled of smaller size was high, the uniformity of de-hulling was not consistent. When concave clearance arranged for the smaller size the percentage of breakage increase hence for further improvement the dry bean coffee must be graded and used. By this machine, de-hulling operation is possible, the service provider can also use this machine which could generate income source of rural people.

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Development and Performance Evaluation of Manual Operated Coffee Bean Demucileger

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Abstract

Coffee is the most important crop in the national economy of Ethiopia and continues to be still the leading export commodity. Despite the economic importance, productivity and quality of the crop is very low. Improper postharvest processing techniques such as harvesting immature cherries, lack of sorting during grading and processing, improper drying without considering drying time, drying place, thickness layer and drying material, transportation, storage, over fermentation etc largely contribute to the decline in coffee quality of Ethiopia. The aim of the study was to develop and evaluate manual operated coffee bean demucileger. The result obtained for efficiency and capacity of the machine were 87.41% and 86.86 kg/h respectively. Based on the result obtained, the machine was recommended for further demonstration.

Key words: *Coffee, efficiency, fermentation,*

Introduction

Coffee is the major source of foreign currency for Ethiopia and contributes more than 35% of the total export earnings (FAO/WFP, 2008). Thus, it is a cornerstone in the export economy of the country and it supports directly or indirectly the livelihood of some 15 million people (EEA, 2001). In Ethiopia, coffee is produced in four production systems, namely: forest, semi-forest, garden and plantation coffee in the Western, Southern, and Southwestern parts of the country (CFC, 2004).

Jimma Zone is one of coffee growing zones in the Oromia Regional State, which has a total area of 1,093,268 hectares of land (JZARDO, 2008). Currently, the total area of land covered by coffee in the zone is about 105,140 hectares, which includes small-scale farmers' holdings as well as state and private owned plantations. Out of the 40–55 thousand tons of coffee annually produced in the Zone (JZARDO, 2008), about 28-35 thousand tons is sent to the central market, while the remaining is locally consumed (Alemayehu *et al*., 2008). Now a day, Jimma Zone covers a total of 21% of the export share of the country and 43% of the export share of the Oromia Region (JZARDO, 2008).

Coffee is the major cash crop of the Zone, which is produced in the eight districts namely, Gomma, Manna, Gera, Limmu Kossa, Limmu Seka, Seka Chokorsa, Kersa and Dedo, which serves as a major means of cash income for the livelihood of coffee farming families (JZARDO, 2008). According to the report from the same source, 30-45 % of the people in Jimma Zone are directly or indirectly benefited from the coffee industry.

Despite the favorable climatic conditions, variety of local coffee types for quality improvement and long history of its production in Jimma Zone, coffee quality is declining from time to time due to several improper pre-and post-harvest management practices. This is still practiced by the majority of coffee farmers/traders, from which the larger portion of the produce is obtained. Improper post-harvest processing and handling practices such as drying on bare ground, improper storage and transportation are some of the causes associated with coffee quality problems among many other (Desse, 2008). In addition to this, natural impediment such as prolonged rainy weather, particularly during harvesting and drying season can also contribute to reduced coffee quality (Desse, 2008).

For instance, Desse (2008) reported that out of Jimma coffee sent to the coffee quality inspection center laboratory from 2003 to 2007, more than 60% of dry processed coffee classified into grade as compared to 80% of wet processed into grade 2 and grade 3. The author indicated the problem of post-harvest processing and handling in the area resulted in poor quality as the main contributing factor. The poor quality and the subsequent drop in earnings had severely affected coffee farmers in woredas like Gomma, Limmu Kossa, and Manna, where coffee provides a larger portion of their annual income. But Jimma Zone is known for some quality coffee types such as Limmu Enaria (Limmu) coffee, which is known for its best quality in the world market.

Processing is a very important activity in coffee production and plays a crucial role in quality determination (Mburu, 1999). Coffee is either processed by the wet or dry methods, which vary in complexity and expected quality of the coffee (Wrigley, 1988). Both sun-drying as well as wet-processing methods are operated in Ethiopia, which accounts for 70% and 30% of coffee produced in the country, respectively.

Despite the favorable climatic conditions, variety of local coffee types for quality improvement and long history of its productions, still there are gaps like lack of improved small scale wet coffee pulpier and washer to enhance wet coffee process that can minimize coffee quality problems in Jimma zone and lack of adequate information on the effects of post-harvest processing and handling techniques on coffee quality. Hence, the small scale wet coffee pulpier is introduced to promote the coffee production by minimizing the above mentioned problems of coffee growers and processors for quality coffee produce in the study areas.

Among the problem of post-harvest processing and handling, wet coffee washing after fermentation being practiced in the study area to facilitate the removal of mucilage is one in which the pulped coffee is soaked to be fermented naturally in a concrete storage tanks where it is kept for 12 to 40 hours. The fermentation is followed by washing through scrubbing the soaked beans against the concrete floor passage manually requiring 3 to 4 rinses of clean water remove all traces and decomposed products of the mucilage which is time consuming and laborious activity (A., Abasanbi. 2010.) However, mechanical demucilaging process allows the quick removal of the mucilage with many advantages compared to the natural fermentation process. Some of the advantages reported by Ethiopian Science and Technology Agency include significant reduction of human labor required for the operation, maintenance of coffee quality, saving of foreign currency that would otherwise be used for the import of mechanical demucilagers and significant reduction in the consumption of water (GMSE. 2014).

The existing coffee mucilage removal method practiced around the study area is mainly the natural fermentation process and followed by washing through scrubbing the soaked beans against the concrete floor which need high infrastructures and high initial cost and mostly adapted by high level investors. Taking these problems in we develop manually operated wet coffee bean washing machine with the objective of developing and evaluation of the machine.

Material and Method

Material

Some of the materials used for manufacturing the machine were: Sheet metal, Square pipe, Round bar, Water pipe and Bolt and nut

Methods

The washing machine was manufactured in Jimma Agricultural Engineering Research Center (JAERC) by using readily available materials. The experiment was carried out at Jimma zone, Gomma district located at 7° 59'N & 36°42'E. The location lies at 1500 m.a.s.l. and average maximum and minimum temperature of 31°C and 18°C, respectively with an annual average rainfall of 1143mm.

Machine description

Hopper: This is a wide chute made from galvanized sheet; it is situated at the top left of the washer and serve as inlet for the material to be washed.
Washing Chamber: This is main component of the washer and itis made from thick galvanized sheet. It comprises of washing drum and sieve.
Volume of the wash drum = A*L

Where, l= length of drum
r = radius of the drum

Discharge Outlets: The washer has two outlets; the first outlet is beneath the cylinder and serves as the waste material (slurry) outlet while the second one is at the upper side of the cylinder which serve as inlet and outlet of the coffee bean.
Volume of Trough = ½

Frame: The frame will made from angle iron and serves for footing the whole system in a rigid position.

Figure 1: The developed manual operated coffee bean demucileger

Bearing Selection

Bearings selection was made in accordance to American Society of Mechanical Engineers (ASME) standard as given by Hall *et al.* (1988). The selected bearings was UCP-205 pillow block bearing (single row, deep groove radial bearing). as recommended by Khurmi and Gupta (2005).

Working Principle

The main function of the manual coffee demucilager is to separate the seeds from the fermented or softened demucilage. The fermented and pulpy material was poured into the machine through the hopper, and then as the shaft and brushes rotate, the materials are move along the length and diameter of the washing chamber. The shaft and brushes rub the materials against the wall of the drum, thereby separating the seeds from the demucilages as the materials move along the length of the washing chamber. The pulpy slurry and water first pass through the perforated holes (sieve) of the drum in the washing chamber to the outlet, while the coffee bean discharge to outlet by rotating the cylinder and then discharge into a collector.

Performance Evaluation

The data collated was used to determine the performance parameters of the machine as follows:
Washing Efficiency, (EW) % - this determines how efficiently the machine is cleaning, it is expressed as

$$\text{EW (\%)} = \frac{weight\ before\ washing}{weight\ after\ washing} \times 100$$

Input Capacity (IC) (kg/hr): - This determines the input capacity of the washer and expressed as:

$$\text{IC, (kg/hr)} = \frac{W1}{T1}$$

Where: *W1 = Original weight of pulp containing the coffees fed into the washer, kg T1 = time taken to feed in the material, hr*

Machine Capacity, (Mc) kg/hr: - This determines the quantity of coffees washed by a machine per unit time.

$$\text{Mc (kg/hr)} = \frac{weight\ of\ washed\ coffee}{time\ taken\ to\ wash\ the\ coffee}$$

Experimental design and Statistical Analysis

The experimental design was RCBD with three replications. Treatments consisted of factorial combinations of three fermentation times (0 hr, 12 hr, and 24 hr) and three feed rate (5 kg, 6 kg, 7 kg). Data was subjected to analysis of variance following a procedure appropriate to the design. Analysis was done using R- software. The treatment means that were different at 5% level of significance was separated by using LSD.

Result and Discussion

Efficiency of machine

Effect of fermentation time, feed rate, and Age of operator

Table 1 shows the effect of fermentation time, feed rate and weight of operator on cleaning efficiency of machine. The analysis of variance (ANOVA) revealed that the fermentation and feed rate had significant effect ($p<0.05$) on cleaning efficiency of a machine. Also the combination of feed rate and fermentation, feed rate and Age of operator, feed rate, fermentation time and Age of operator had significant effect ($p<0.05$) on cleaning efficiency of machine. Age of operator and other combinations of other parameters had no significant effect, ($p<0.05$) on cleaning efficiency of a machine.

Table1. Effect of feed rate and fermentation time on efficiency of a machine

	Fermentation time(hr)			
Feed rate(kg)	0	12	24	Mean
5	75.93^{b}	91.08^{a}	89.67^{a}	84.12^{b}
6	88.02^{a}	**91.10^{a}**	85.96^{a}	**90.92^{a}**
7	88.40^{a}	90.58^{a}	85.95^{a}	87.19^{ab}
Mean				87.41
CV				6.74

Table 2. Effect of Age of operator and feed rate on capacity of a machine

	Age of operator(year)			Mean
Feed rate(kg)	20-25	25-30	30-35	
5	88.77^{a}	80.51^{b}	87.39^{a}	88.06^{a}
6	87.44^{a}	89.75^{a}	87.89^{a}	86.39^{a}
7	87.95^{a}	88.28^{a}	88.91^{a}	87.96^{a}
Mean				87.41
CV				4.90

Capacity of machine

Table 2 shows the effect of fermentation time, feed rate and Age of operator on capacity of machine. The analysis of variance (ANOVA) show that time of fermentation, Age of operator and feed rate had significant effect ($P<0.05$) on capacity of machine. Also the combination of feed rate and fermentation time, feed rate and Age of operator and also the combination of feed rate, fermentation time and Age of operator had significant effect ($p<0.05$) on the capacity of machine.

Table 3. Effect of feed rate and fermentation time on capacity of machine

Feed rate(kg)	Fermentation time(hr)			Mean
	0	12	24	
5	70.78^{bcd}	100.49^{b}	137.94^{a}	61.53^{c}
6	55.21^{d}	96.62^{bc}	136.87^{a}	86.12^{b}
7	58.59^{d}	61.25^{d}	64.02^{cd}	112.95^{a}
Mean				86.86
CV				13.35

Table 4. Effect of feed rate and Age of operator on capacity of machine

Feed rate(kg)	Age of operator(kg)			
	20-25	25-30	30-35	
5	73.38^{c}	98.76^{b}	137.07^{a}	66.82^{b}
6	68.25^{cd}	89.78^{b}	130.68^{a}	81.18^{b}
7	58.83^{d}	61.56^{d}	64.44^{cd}	116.52^{a}
Mean				87.41
CV				4.90

Conclusion and Recommendation

Based on the result obtained, regarding cleaning capacity (kg/hr), cleaning efficiency (%) it was concluded that the machine performance was acceptable with prospect for extending the technology. But the machine needs addition parts which separate coffee float on the water during operation which affect the quality of coffee. It was recommended that the machine is good for more demonstration and demonstrating the machine solve the problem of coffee washing at house hold level to increase income of coffee producers. Recommendation was made that, operating the machine for 12 hr, fermentation time is best to gate good efficiency and capacity for the machine than that of operating the machine by 0 and 24 hr coffee fermentation time.

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Development and Performance Evaluation of Engine Operated Pulses (Faba-bean, Pea and Lentil) splitting Machine

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Abstract

In some parts of Ethiopia still, milling and splitting are accomplished traditionally, by grinding the pulse between two stones and this traditional practice of pulse splitting is time consuming, more labour requirement, high-energy consumption and loss of material. An engine operated pulses (faba bean, pea and lentil) splitting machine was developed at Bako Agricultural engineering Research Centre. The machine had two emery discs which are fixed and revolving type. Gap between the two disks can be increased or decreased depending on size of pulses by screw mechanism operated by hand wheel. The experimental design conducted in a RCBD having two treatments disc speeds and feeding rates. The performance of the machine was evaluated in terms of splitting capacity, splitting efficiency, cleaning efficiency, percentage of mechanical damage and percentage loss. The developed machine was more efficient for pea and faba bean at 650 rpm disc speed and feeding rate of 11kg/min and 6 kg/min, respectively. So during split the machine parameters such as disc speed, clearance, size of disc etc. have vital role to play on dal recovery.

Key words: *splitting capacity, splitting efficiency, emery disc*

Introduction

Pulse crops were first domesticated at the beginning of agriculture more than 8000 years ago in a fertile band of land stretching from Turkey to Iran (Zohary and Hopf, 1973). Present world production of the pulses is estimated to be 92.4 million tonnes (FAO 2018). Pulses are second in area coverage and production in Ethiopia after cereals, with over 1.5 million hectares and 2.8 million tons of production (CSA 2016). From a world market perspective, Ethiopian exports of pulses represent 3% of world pulse exports. With this, Ethiopia ranks among the top 10 countries in world pulse exports (CSA 2015). They are important constituents of the diets of a very large number of people, especially in the developing countries like India, Ethiopia etc. Pulses are very good source of protein so that they were often regarded as poor man's meat.

Pulse crops are playing a critical role in agricultural production as a driver for economic growth and food security. Pulses occupy an important place in the world food and nutrition. They contribute to smallholder income, as a higher-value crop than cereals, and to diet, as a cost-effective source of protein that accounts for approximately 15 % of protein intake (CSA, 2008 / 09). Pulse crops are the third-largest export crop after coffee and sesame, contributing USD 90 million to export earnings in (CSA, 2007/08).

Even though Pulse crops are produced in Ethiopia, the productivity and yield obtained was less due to poor post-harvest technology availability. The potential and prospect as source of income and its capacity to generating household income was low due to lack of appropriate machine. So, the farmers offer the raw pulse by low cost for the market and buy the split one with expensive value. Therefore, the farmers cannot get the value of their tiredness and losses about 40% of income obtain from it (according to current market assement).

The available technology can be done by using either manual or mechanical means. In some parts of the Ethiopia still, milling and splitting are accomplished traditionally by grinding the grain legume between two stones as shown in fig.1. The grinding stone consists of a lower stationary one, called the Quern stone and an upper stone which is mobile and called the hand stone (Williams and Rosentrater, 2007). Traditional practice of dhal milling is time consuming, more labour requirement, high-energy consumption and loss of material.

Figure 1 traditional pulse and milling stone.

Now days, the gringing and splitting stones are artificial and coated with carborundum (derived from silicon carbide) of various abrasive grades /grit size (Jennifer A. Wood and Linda J. Malcolm son 2011). The abrasiveness of stones (grit), speed of stones/rollers, gap size, feed rates and time of grain retained within the mill will all influence milling performance. These new improved attrition-type mills are often called under runner disk shellers (URD Shellers). The orientation of the stones can be either horizontal (as in the original chakkis) or vertical, and the gap between the stones can be adjusted to the grain size to optimize de-hulled grain and dhal yields.The other modern mill type is a carborundum roller mill. It has a cylindrical carborundum stone that is tapered and rotates inside a perforated metal casing so that the gap between the roller and casing decreases from the inlet to the outlet. The stone or casing can sometimes be moved to adjust the gap depending on the grain size. These mills are often mounted horizontally or on a slight downward angle to facilitate passage of the seed. So the aim of this activity was to develop and evaluate the appropriate pulses splitting machine.

Material and Method

Experimental site description

The experiment was conducted at Bako Agricultural Engineering Research centre (BAERC), which is located in west shewa Zone of Oromia Regional state of Ethiopia.

Material

Sheet metals, Square pipe, Rectangular pipe and Different varieties of pulses

Measuring Instruments

Anemometer, Tachometer, measuring tape, stops watch, sensitive balance and Grain moisture meter

Methods

Design considerations

Physical properties of pulses grains

The physical parameters affecting the process are grouped into the following two factors:-

Machine factors: gap between two disc, feeding rate and sharpness of these discs are the machine factors which affecting capacities of pulses. Crop factors: crop varieties, maturity stage, grain moisture content and size of pulses (Huynh *et al*, 1982).

Description of the Machine Components

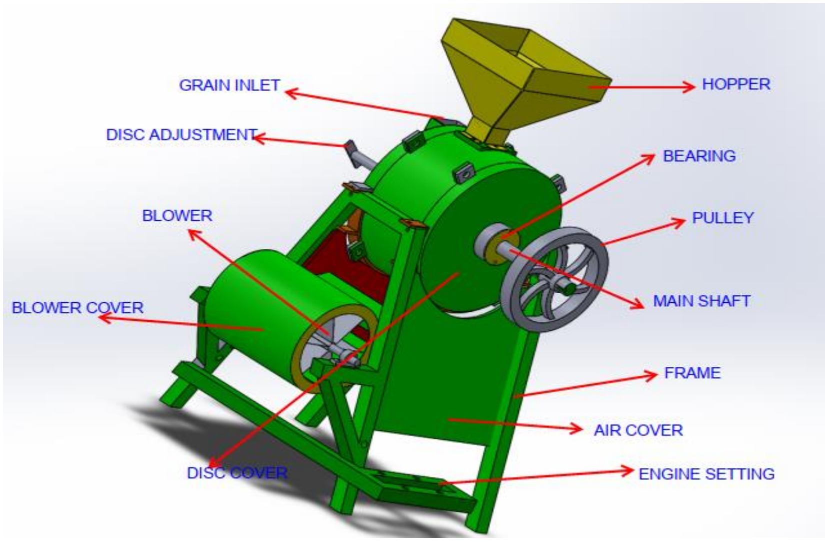

Figure 1.The isometric view of developed pulses splitting machine

Frame: The frame carries the entire components of the machine. It is a trapezoidal shape of 550 mm by 280 mm at the top and 700 mm by 550mm at the base, constructed from 40 mm by 40 mm square pipe. The standard minimum ratio of the frame lengths was L1/L2 = 0.4, (Shirgley 1980,Hannah and Stephens 1980).

Fan: The fan consisted of four straight blades,welded on shaft and housed in a casing. The casing and blades are constructed from 1.5 mm thick sheet metal

Hopper: The part which is used to hold the pulse grain before splitting.

The splitting unit: The splittingunit will have two stone discs which is covered by sheet metal to seal the scattering of splits or dal.

Delivery unit: The delivery system used to transfer motion from part to another it has the following units belts,pulley and etc.

Working principle of the machine

The developed machine consist of splitting unit,cleaning unit, hopper and frame.The splitting unit had two emery discs which the one of the discs was fixed and another was revolving type. Gap between the two disks can be increased or decreased depending on pulse grain size of the cultivars or in other word the clearance between them was adjusted by screw mechanism operated by hand wheel.The machine was developed to split the pulses by abbrasion type stone by diesel engine . The raw pulse grain fed into the hopper and falls down to the chamber where it rotated against the emery disc and abrased by the second disc.So the impact of the disc results in the pulse grain split. The splitted pulses were ejected through the drum outlet. The husk and brokens were separated by winnowing and sieving. Cleaning was done throgh the air stream produced by the fan and then the splitted clean grain pass down to the discharge outlet. So the parameters such as disc speed, clearance, size of disc etc. have vital role to play on dal recovery.

Design Analysis and Calculation

The pulse grain splitting machine had designed for split pulses grain and separating hask. In order to meet the splitting and cleaning requirements, different parameters such as determination of pulley diameters, shaft diameter, belt length, center distance between pulleys were determined. Accordingly, the following dimensions were selected, the maximum fan speed 2140 rpm and air speed at fan exit 7.6 m/s which measured by anemometer.

Selection of pulleys and belts

The machine was operated by four pulleys; the driving pulley is mounted on the crank shaft of the engine and the driven pulley is mounted on fan shaft and the other two pulleys are mounted on main shafts. Based on availability and cost aluminum pulleys were selected. The diameter of the pulleys used on the crank shaft of the engine was 120 mm .The power, from the engine shaft to the fan shaft and main shaft, running at different angular speeds, was transmitted through V-belts. Since the selected engine was 7 hp, slightly greater than 4kw, B type V-belt was selected and used. According to Sharma and Aggarwal (2006) the diameter of driven pulleys, center distance, belt length and belt speeds were calculated as follows:

$$N1 \times D1 = N2 \times D2 \quad (1)$$

$$L=2C+1.57(D-d)+(D-d)^2/4C \quad (2)$$

$$V=N\pi D \quad (3)$$

$$C= (D1+D2)/2 +D1 \quad (4)$$

Where: D1 and D2 = diameters of driving and driven pulleys (mm),

N1 and N2 = rpm of driving and driven pulleys,

C = center distance between two adjacent pulleys (mm),

L = length of belt (mm)

V = speed of belts (m/s)

The diameter of driven pulleys was calculated based on the following values;

The speed of diesel engine shaft is 1620 rpm

Diameter of the engine shaft pulley is 120 mm

Rotational speed of the roller varies between 600–1000 rpm (Kulkarni, 1989). However, in our case the Maximum speed of driven pulley is 650 rpm.

Therefore, the diameters of pulleys mounted on main shaft were found 210 mm and 300 mm respectively. The centre distances between the diving pulley and driven pulleys were found 202.5 mm for fan shaft and 330 mm for main shafts. However, to minimize vibration and maintain stability 570 mm and 600 mm center distance between fan shaft and engine crank shaft pulleys was used since it lies between $(D1+D2)/2+D1 \leq C \leq 2(D1+D2)$ as recommended by Maciejczyk and Zbigniew (2000). The lengths of belts were found 1872 mm and 1520 mm to connect pulleys on engine crank shaft and main shaft and fan shaft and main shaft, respectively. Based on the calculations made B-60 and B-74 belts were selected to connect pulleys fan shaft and main shaft and engine crank shaft and main shaft, respectively. The linear speed of the belt connecting the fan pulley to the main pulley was 7.2 m/s while the linear speed belt connecting main pulley to the engine pulley was 10 m/s at maximum operating speed.

Determination of pulses power requirement

There are three power required to operate the machine to split pulses(bean,pea and lentil) and determined as follows**.**

Fan Power Requirement (P_f)

The power required to drive the fan was determined as follows:

$$P_f = \frac{\Delta P Q}{\eta} \quad (5)$$

Where: Q = Air discharge, m^3/s;

ΔP = Static Pressure, Pa

η = assuming transmission efficiency of the motor 95%-98%.

Determination of blower Static Pressure (ΔP)

$$(\Delta P) = \frac{\rho * V^2}{2} \quad (6)$$

Where: $\rho = air\ density$ (kg/m^3)
v= Air velocity (m/s)

Determination of Air Discharge (Q)

The air discharge for any is given as:

$$Q=V*A \quad (7)$$

Where: A=Outlet cross-section area,m^2 and
v= Air velocity (m/s)

Determination of outlet cross-section area(m^2)

$$A=l*w \quad (8)$$

Where : l=length of the blower outlet mm and
w=width of blower outlet mm

From the above equations, air Discharge (m^3/s), blower Static Pressure (pa) and Outlet cross-section area(m2) were list in the table below. Hence, the calculated fan power requirement was 29W.

Table 1. The calculated value of blower specification

Item		Specification
Air velocity	V	7.5 m/s
Outlet cross-section area	A	0.098 m^2
Air discharge	Q	0.735 m^3/s
Static Pressure	ΔP	36.4

Power required to drive the shaft

According to (Shanmugam. A et al, 2016), the power required to drive the shaft was determined as follows.

$$\text{Power required (P)} = T \times \omega \quad (9)$$

$$\text{Torque (T)} = F \times r \quad (10)$$

$$\text{Angular Acceleration}(\omega) = \frac{2\pi N}{60}$$

Where : r= radius of the driven pulley of the disc (m)
F = force applied in the shaft ,
T =torque and
N = maximum speed of the cylinder, rev/min.

By using the above formula power required to drive the shaft was 3731.9W . However, considering 10% power loss due to friction, the total power required to drive the shaft was computed as 4.1KW.

Power required to split the pulses grain

According to kick's law energy required to split the pulses grain(bean,pea) was determined as follows.

$$E = K * Fc * \ln(L1/L2) \quad (11)$$

Where :E=energy required to split pulses(j/kg)

K= Kick coefficient (k=1.2)

L1= average length of un split bean(mm)

L2=average length of split bean (mm)

Fc =bean grain crushing strength(kg/m^2)

Determination of bean grain crushing strength(Fc)

$$Fc=\frac{F}{A*g} \quad (12)$$

Where :F=rupture force of bean 542.4–551.4N (Vishwakarma , 2018 *et al)*

A=area of bean, m^2

g=9.81m/s^2

Determination of the geometric mean diameter(D_g)

The geometric mean diameter of pod can be determined using the following formulae:

$$Dg = (abc)^{1/3} \quad (13)$$

Where: Dg = pod geometric mean diameter mm,

a = pod length mm,

b = pod width mm

c = pod thickness mm.

Determination of the pod cross-section area of bean (A)

The cross-section area of the pod can be determined using the following equation:

$$A = Dg * L \quad (14)$$

Where: A = the cross-section area of the bean (mm^2)

L = length of the pod (mm)

Dg=Determination of the geometric mean diameter (mm)

From the above equations,the calculated value of cross-section area of bean(m^2), geometric mean diameter(mm), grain crushing strength(kg/m^2), energy required to the pulses(j/kg) are presented in table 2.

Table 2. The calculated value of Power required to split the pulses grain specification

Item		Specification
cross-section area of bean	A	$1.9*10^{-4}m^2$
E=energy required	E	12306.56 kg/J
bean grain crushing strength	Fc	284873.95 kg/m^2
geometric mean diameter	Dg	11.2 m^2

Therefore, $P_S=W*F_C*K*\ln(L1/L2)$

Where :

W= capacity kg/hr,

L1=length of bean before split and by the thickness of hull =0.3 mm

L2=L1-(2*X) ,X= thickness of hull coat.

Finally,from the above equations the calculated Power required to split the pulses grain was 849W. However, considering 10% power loss due to friction, the total power required to split the pulses grain was computed as 933.9W. The total power required to operate the machine can be calculated by the sum of power required to split pulse grain, power required to drive fan and the power required to drive shaft which was 5072.9 W (5.073 Kw) that means 6.8 Hp .Therefore, to drive this pulse machine morethan 7 Hp engine required.

Determination of the shaft diameter

The diameters of the fan shaft and main shaft were determined using maximum shear stress theory. Shaft may be subjected to torsion, to bending, to axial tension or compression or to a combination of any or all of these actions. For a solid shaft having little or no axial loading, the diameter of the shaft would be calculated as the ASME code equation as given by (ASME 1995), assuming axial load is zero.

$$\boldsymbol{D^3} = \frac{\mathbf{16}}{\boldsymbol{\pi\delta}}[\sqrt{(\boldsymbol{KbMb})}^{\mathbf{2}} + (\sqrt{(\boldsymbol{KtMt})}^{\mathbf{2}}] \qquad (15)$$

Where

δ = Allowable shear stress (42N/mm^2 for shafts with keyways), according to ASME Code

K_b = 1.5 (constant)

M_b = Maximum bending moment (kNm)

K_t = 1.0 (constant)

M_t = Maximum torsional moment (kNm)

To determine the diameter of shafts, the following procedure /steps were used.

Step 1.determination the direction of belts on the pulleys.

$$\text{Sin}\alpha=\frac{\textbf{opposite}}{\textbf{hypothness}} \qquad (16)$$

By using this formula the calculated direction of belts on the pulleys was 30^0

Step 2.determination of belt tensions (T1 &T2) and torsional moments.

To determine belt tensions (T1 &T2) and torsional moments (M_t) (Khurmi and Gupta, 2005) were develop the following formula;

1. $T1=T_{max}-T_c$ (17)
2. $T_{max}=\delta A$ (18)
3. $T_c=mv^2$ (19)
4. $T1/T2=e^{\mu\Theta}$ (20)

By using these equtions belt tensions (T1 &T2) and torsional moments(M_t) were 510,217.55N and 44Nm, respectively.

Step 3.determination of maximum bending moments for fan and main shafts.

To determine maximum bending moments,it is important to analysis vertical and horizontal reaction forces acting on shafts shown as figure below.

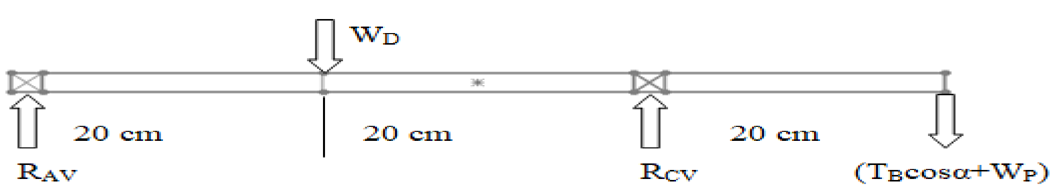

Figure2. Free body diagram of the main shaft on vertical (YZ) plane

Therefore, from this diagram the forces acting on the shafts were determined as follows

$W_D=m*g$ (21)

$W_D=196N$ where, m =mass of disc and g=9.81 m/s

$W_P= m*g$ (22)

$W_P=9.81N$ where, m =mass of pulley and g=9.81 m/s

$T_B\cos\alpha + W_P = T1 + T2\,(\cos\alpha) + W_P$ (23)

$T_B\cos\alpha + W_P = 640N$ where, T1&T2 are belt tensions

From here, the calculated value of R_{AV} and R_{CV} were -222N and 1058N, respectively.

❖ Forces acting on the disc (XY) plane

Figure3. Free body diagram of the main shaft on horizontal (XZ) plane

From the above diagram, the calculated value of R_{AH} and R_{CH} were -181.9N and 545.66N, respectively.

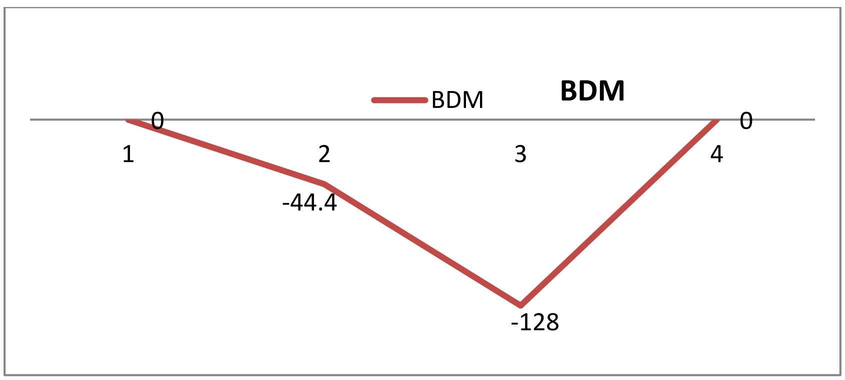

Fig 4 the bending moment of main shaft on vertical (YZ) plane

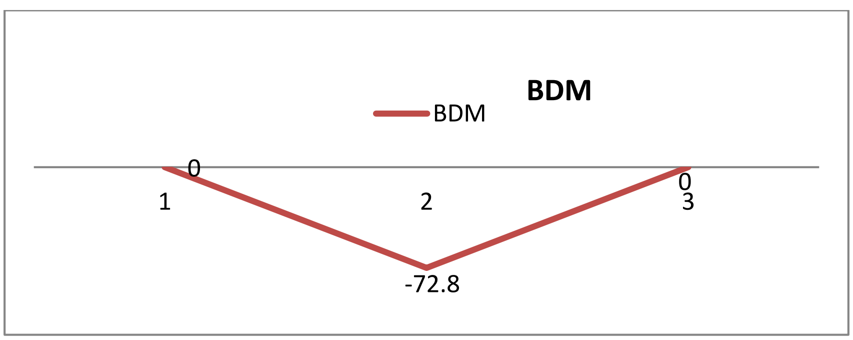

Fig 5 the bending moment of main shaft on horizontal (XZ) plane

Based on bending moment, the maximum bending moment on vertical and horizontal plane were 72.8Nm and 128Nm. The maximum bending moment of the main shaft was 147.25N-m.

The diameters of the fan shaft and eccentric drive wheel shafts were determined as follows

$$d^3 = \frac{16}{\pi Sa}\left(\sqrt{(K_b M_b)2 + (K_t M_t)^2}\right)$$

For main shaft Mt=44 N-m, Mb = 147.25 N-m, kt=1 kb = 1.2 and τmax = 42 M pa then d = 26.7 mm. Assuming a safety factor of 3, *d* = 38.5 mm

$\therefore d$ = 40 mm

By following the same procedure for fan shaft Mt=38.8 N-m, Mb = 60.33 N-m, kt=1.2 kb = 1 and τmax = 56 Mpa then d = 19.04 mm. Assuming a safety factor of 2, $\therefore d$ = 25 mm

Experimental Design

The experimental design was conducted in a RCBD having two treatments disc speeds and feeding rates.

Independent variable

Disc speed

Three different speed were selected for determining the performance of the machine on pulses grain. The selected disc speed for bean and lentil were 500 rpm , 550 rpm , 650 rpm and 500 rpm,600 rpm and 650 rpm was used for pea.

Feeding rate

The amount of pulses materials fed inside the unit would affect the overall performance in terms of efficiency and grain damage percentage.Two feed rates were selected for pulse grain. The selected feed rate for pea and lentil was as 6 kg/min, 11 kg/min and 4.5 kg/min , 6 kg/min for faba bean ,respectively.

Dependent variable

The following dependent variables splitting efficiency, cleaning efficiency, total grain loss, grain breakage and splitting capacity were measured during the experiments.

Performance evaluation

Researchers were used several common calculations to determine the effectiveness of test, alt-hough the descriptive names of the calculations often vary: The machine was tested and evaluat-ed in terms of Capacity, efficiencies, kibble or broken percentage and percentage loss.

Splitting Efficiencies

It also known as dhal yield is essentially the yield of de-hulled and split product material (dhal) as a percentage of original seed weight and determine according to the following equation (Burridge et al., 2001).

$$\textbf{SE (\%)} = \frac{\mathbf{D}}{\mathbf{W}}\mathbf{100} \qquad \textbf{(24)}$$

Where:

D=mass of pulses split

Wt. =original weight of Pulse

Percentage kibble or broken: is essentially the yield of kibble or broken product material as a percentage of the original seed weight (from APQ Method 104.1, Burridge et al., 2001).

$$\textbf{Kibble (\%) = (K/Wt.)100} \qquad \textbf{(25)}$$

Where:

K = mass of kibble or broken

Wt. =original weight

Capacity, Sc (kg/h)

This is the capacity of the splitter to split a quantity per unit time (Ndrika, 1994)

$$Sc = \frac{Qs}{T} x100 \qquad \textbf{(26)}$$

Where:

Qs = Quantity of material that pass through the grain collector splatted (kg)

T = Time taken to complete operation (hour)

Percentage loss: is essentially the sum of all defective products as a percentage of the original seed sample. The constituents that may or may not be included as defective will vary depending on the pulse species, the milled product of interest and individual researcher preferences.

$$L = \frac{\mathrm{Lg}}{\mathrm{Qs+Lg}}\mathrm{x100} \qquad \textbf{(27)}$$

Where:

Qs = quantity of pulse sample (kg)

Lg = Mass of loss pulse (kg)

%L=percentage loss

Result and Discussion

Splitting capacity for bean

The maximum splitting capacity of the machine was 387.14 kg/hr, obtained at maximum rpm (650) and 6 kg/min feed rate. As the feeding rate increase 4.5 kg/min to 6 kg/min and disc speed increase 500 rpm to 650 rpm, the splitting capacity increase (387.58 to 261.56 kg/hr. Generally, as the feeding and speed of the disc increase, the splitting capacity will increase.

Splitting efficiency for bean

The maximum splitting efficiency of the machine 92.24 % was recorded at 4.5kg/min feed rate and **650** rpm of disc. As the feeding rate increases from 4.5 kg/min to 6 kg/min, the splitting efficiency also increases from 75.13 to 92.24 %. And as speed of the disc increase 500 rpm to 650 rpm, the splitting efficiency also increase 75.13 to 92.24 %. Generally, as the feeding and speed of the disc increase, the splitting efficiency will increase.

Cleaning efficiency for bean

The maximum cleaning efficiency of the machine 96.06 % was recorded at 4.5 kg/min feed rate and 650 rpm of disc. As the feeding rate increase 4.5 kg/min to 6 kg/min, the cleaning efficiency decrease 96.06 to 82.55 %. And as speed of the disc increase 500 rpm to 650 rpm, the cleaning efficiency also increase 82.55 to 96.06. This means high speed of disc cause cleaning efficiency and high feeding rate would subject to low cleaning efficiency. In other word, when the high amount of bean feed into the hopper, the blower cannot clean all chaff from split grain, this process will decrease cleaning efficiency of the machine.

Breakage percentage for bean

The maximum percentage of breakage of the machine 9.12 % was recorded at 4.5 kg/min feed rate and 650 rpm of disc. And the minimum percentage of breakage of the machine 3.34 % was recorded at 6 kg/min feed rate and 500 rpm of disc. This means high speed of disc cause high broken percentage and high feeding rate would subject to low break percentage.

Loss with chaff for bean

The maximum percentage of loss of the machine 3.02 % was recorded at 4.5 kg/min feed rate and 650 rpm of disc speed. But, the minimum percentage of loss of the machine 0.5 % was recorded at 6 kg/min feed rate and 650 rpm of disc. This means high speed of disc cause high loss percentage and high feeding rate would subject to low loss percentage.

Table1: Effect of the disc speed & faba bean feed rate on performance of the splitting machine

Disc speed rpm	Feeding rate kg/min	Splitting efficiency %	Cleaning efficiency %	Splitting capacity kg/hr	Bean breakage %	Loss with chaff %
650	6	**92.24[a]**	92.08[b]	**387.14[a]**	7.25[b]	2.60[ab]
	4.5	89.22[b]	**96.06[a]**	315.21[abc]	**9.12[a]**	3.02[a]
550	6	84.20[c]	87.28[cd]	347.54[ab]	7.05[b]	1.78[bc]
	4.5	83.45[c]	88.15[c]	279.45[bc]	5.23[c]	1.30[cd]
500	6	78.47[d]	82.55[e]	290.01[bc]	**3.34[e]**	0.50[e]
	4.5	75.13[e]	85.26[d]	261.06[c]	4.26[d]	0.52[de]
SE		1.006968	1.080156	85.42631	0.1398611	0.1975778
LSD		2.004843	2.07634	1828.26	0.747173	0.8880588
CV		1.194093	1.171621	13.6286	5.940907	25.85957

Splitting capacity for pea

The maximum splitting capacity of the machine was 813.13kg/hr, obtained at maximum rpm (650) and 11 kg/min feed rate. As the feeding rate increase 6 to 11 kg/min and disc speed increase 500 rpm to 650 rpm, the splitting capacity increase 356.01 to 813.13 kg/hr. Generally, as the feeding and speed of the disc increase, the splitting capacity will increase.

Splitting efficiency for pea

The maximum splitting efficiency of the machine 98.52 % was recorded at 4.5kg/min feed rate and 650 rpm of disc. As the feeding rate increase 4.5 kg/min to 6 kg/min, the splitting efficiency decrease (98.52 to 82.53 %). And as speed of the disc increase 500 rpm to 650 rpm, the splitting efficiency also increase 82.53 to 98.52 %. This means high speed of disc cause high splitting efficiency and high feeding rate would subject to low splitting efficiency.

Cleaning efficiency for pea

The maximum cleaning efficiency of the machine 98.06 % was recorded at 6 kg/min feed rate and 650 rpm of disc. As the feeding rate increase 4.5 kg/min to 6 kg/min, the cleaning efficiency decrease 98.16 to 88.13 %. And as speed of the disc increase 500 rpm to 650 rpm, the cleaning efficiency also increase 88.13 to 98.06 %. This means high speed of disc cause high cleaning efficiency and high feeding rate would subject to low cleaning efficiency.

Breakage percentage for pea

The maximum percentage of breakage of the machine 6.23 % was recorded at 6 kg/min feed rate and 650 rpm of disc. And the minimum percentage of breakage of the machine 1.23 % was recorded at 11 kg/min feed rate and 500 rpm of disc. This means high speed of disc cause high broken percentage and high feeding rate would subject to low break percentage.

Loss with chaff for pea

The maximum percentage of loss of the machine 4.01 % was recorded at 6 kg/min feed rate and 650 rpm of disc. But, the minimum percentage of loss of the machine 1.04 % was recorded at 11 kg/min feed rate and 650 rpm of disc. As the feeding rate increase 4.5 kg/min to 6 kg/min, the loss percentage decrease 4.01 to 1.04 %. And as the disc speed increase 500 rpm to 650 rpm, the loss percentage increase 1.04 to 4.01 %. This means high speed of disc cause high loss percentage and high feeding rate would subject to low loss percentage.

Table1: Effect of the disc speed and pea feed rate on performance of the splitting machine

Disc speed rpm	Feeding rate kg/min	splitting efficiency %	Cleaning efficiency %	splitting capacity kg/hr	Bean breakage %	Loss through outlet %
650	6	**98.52[a]**	**98.06[a]**	756.22[b]	**6.23[a]**	**4.01[a]**
	11	95.09[ab]	96.12[b]	**813.13[a]**	5.23[b]	3.37[ab]
600	6	93.14[bc]	95.02[b]	556.06[d]	4.13[c]	2.73[bc]
	11	91.18[c]	92.47[c]	638.57[c]	3.23[d]	2.03[cd]
500	11	88.04[d]	88.13[e]	439.13[e]	**1.23[f]**	**1.04[e]**
	6	82.53[e]	90.10[d]	**356.01[f]**	2.13[e]	1.36[de]
SE		2.998674	0.465	215.8952	0.1816661	0.2033923
LSD		2.252745	1.362326	29.35518	0.8515503	0.9010332
CV		1.636465	0.7302678	2.476765	11.31545	17.84514

Splitting capacity for lentil

The maximum splitting capacity of the machine was 890.61kg/hr, obtained at maximum 600 rpm and 13 kg/min feed rate. As the feeding rate increase 7 to 13 kg/min and disc speed increase 450 rpm to 600 rpm, the splitting capacity increase 362.67 to 890.61kg/hr. Generally, as the feeding and speed of the disc increase, the splitting capacity will increase.

Splitting efficiency for lentil

The maximum splitting efficiency of the machine 69.51 % was recorded at 7kg/min feed rate and 600 rpm of disc. As the feeding rate increase 7 kg/min to 13 kg/min, the splitting efficiency decrease (69.51 to 60.4 %). And as speed of the disc increase 500 rpm to 650 rpm, the splitting efficiency also increase 60.4 to 69.51 %. This means high speed of disc cause high splitting efficiency and high feeding rate would subject to low splitting efficiency.

Cleaning efficiency for lentil

The maximum cleaning efficiency of the machine 96.13 % was recorded at a 7kg/min feed rate and 600 rpm of the disc. As the feeding rate increased from 4.5 kg/min to 6 kg/min, the cleaning efficiency decreased from 96.03 to 89.16 %. And as the speed of the disc increased from 500 rpm to 650 rpm, the cleaning efficiency also increase from 89.16 to 96.13 %.

Breakage percentage for lentil

The maximum percentage of breakage of the machine 66.67 % was recorded at a 7 kg/min feed rate and 600 rpm of the disc. And the minimum percentage of breakage of the machine 54.79 % was recorded at 6 kg/min feed rate and 500 rpm of disc. This means high speed of disc cause high broken percentage and high feeding rate would subject to low break percentage.

Loss with chaff for lentil

The maximum percentage of loss of the machine 14.02% was recorded at 7 kg/min feed rate and 600 rpm of disc. But, the minimum percentage of loss of the machine 5.59 % was recorded at 13 kg/min feed rate and 600 rpm of disc. This means high speed of disc cause high loss percentage and high feeding rate would subject to low loss percentage.

Table1: Effect of the disc speed and lentil feed rate on performance of the splitting machine.

Disc speed rpm	Feeding rate kg/min	Splitting efficiency %	Cleaning efficiency %	Splitting capacity kg/hr	Bean breakage %	Loss through outlet %
600	7	**69.51[a]**	**96.13[a]**	**890.67[a]**	**66.67[a]**	**14.02[a]**
	13	67.43[ab]	93.79[ab]	764.67[b]	63.89[ab]	12.23[b]
550	7	66.45[b]	93.58[b]	696.55[c]	63.23[ab]	11.06[c]
	13	63.56 [c]	91.79[bc]	564.67[d]	60.23[bc]	8.79[d]
450	13	63.45 [cd]	91.56[c]	494.78[e]	57.45[cd]	8.1[e]
	7	60.4[d]	89.16[d]	362.67[f]	54.79[d]	5.59[f]
SE		1.714422	1.126611	25.59189	6.422201	0.1822202
LSD		2.61575	2.12021	10.1066	5.063026	0.8528508
CV		2.004314	1.144172	0.8041843	4.145734	4.24027

Conclusion and Recommendation

Conclusion

Based on the performance evaluation made and results obtained, the following conclusions can be drawn:

The performance of the machine was significantly affected by feed rate and speed of disc.

Splitting and cleaning efficiency in general increased when increasing speed of the disc and decrease as increase feeding rate these three pulses.

The loss and broken percentage of the pulse increase, when speed of disc increase and decrease as the feeding rate increase for each pulse.

The splitting capacity of the machine increases as both feeding rate and disc speed increase for each.

Recommendation

The developed machine was more efficient for pea and bean at 650 rpm disc speed and feeding rate 11kg/min and 6 kg/min, respectively.

Due to the size of pulse affect the splitting efficiency, the grain which split should be uniform size. Therefore, the machine needs grading system which grade pulses in their size.

From this crop lentil has small size of cotyledon, for this reason it broken than splitting. And such kind of pulse need special treatments and cylindrical carborundum which tapered rotates inside the metal.

For simple and easy transport, weight of the machine should be light. So that the weight of the machine should be minimized as it becomes appropriate technology.

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Adaptation, Evaluation and Selection of Brick Granary, Fiber Reinforced Plastic Tank, Pics and Metal Silo for Maize Storage in Jimma Zone

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Abstract

The effectiveness of four different storage technologies for maize under conditions of small holder farmers were tested in Kersa District,Jimma Zone ,Oromia Regions of Ethiopia were conducted for 12 months to evaluate three different technologies. The storages were metal silo, reinforced plastic tank, bricks granary, and pics bag. Pics bag and metal silo had the lowest mean percentage of grain weight loss of 0.57 % to 1.57 % and 0.57 % to 11.73 %, 12 months after storage and where as, the grain stored in reinforced plastic tank and bricks granary had the highest weight loss, 0.57 % to 26.04 % and 0.74 % to 56.21 %. Therefore, pics bags and metal silo storages are recommended as effective alternative non-chemical methods of grain storage for small holder farmers.

Key words: *Brics, granary, maize, metal silo, pics, plastic tank, post-harvest, loss*

Introduction

Many poverty alleviation or development programs have focused on increasing agricultural production and productivity through encouraging smallholder farm households to increase the use of improved seed varieties and chemical fertilizer. However, many programs did not considered what happens to the extra grain that was produced in the post-harvest season. For instance, maize is the most important staple food in Eastern and Southern Africa (Gitonga et al., 2013); and increasing its productivity has a positive impact on the welfare of poor households in sub Saharan Africa (Bezu et al., 2014; Mason and Smale, 2013; Smale et al., 1995). However, the softer kernel high-yieldied hybrid maize varieties commonly promoted in sub-Saharan Africa (SSA) offer less natural protected to storage insect attacks relative to the lower-yielded traditional varieties which stored well (Golob, 2002). Therefore, smallholder farmers faced a rational decision of making a choice between the improved seed varieties to increased production, but with storability concerns vs. the low yielded traditional seed varieties which were less susceptible to storage pest attacks. Previous studies have focused on the estimated postharvest losses in SSA (Affognon et al., 2015; Kaminski and Christiaensen, 2014; Hodges et al., 2011), and retrospective studied of postharvest grain management practices or storage technologies to reduced such losses (Murdock and Baoua, 2014; De Groote et al., 2013; Gitonga et al., 2013; Bokusheva et al., 2012; Tefera et al., 2011).

Traditional storage practice in developing countries cannot guarantee protected against major storage pests of staple food crops like maize. The lack of suitable storage structures for grain storage and absence of storage management technologies often forced the smallholders to sell their produce immediately after harvested. Consequently, farmers receive low market prices for any surplus grain they may produce. Safed storage of maize is crucial, as it directly impacted on poverty alleviation, food and income security and prosperity for the smallholder farmers. Without appropriate grain storage technologies, farmers were forced to sold maize when prices were low to avoid post-harvest losses from storage pests and pathogens, cannot used their harvest as collateral to accessed credit, and ultimately their food security was undermined. Therefore, the aim of this research was to adapt, evaluate and sellect brick granary, fiber reinforced plastic tank, pics and metal silo for maize storage in Jimma Zone.

Materials and Methods

Materials

Fiber reinforced plastic tank, Concrete, Wood, Cement, Polyethylene sheet, Bricks, Galvanized sheet, Aluminum paint, Anti-rust, Nails and pics.

Instrument used during the evaluation of the storage

- Weighing balance
- Oven dry

Methodology

The four storage structures and technologies (brick granary, fiber reinforced plastic tank, picsand metal silo) were constructed at farmers site and in shop. The metal silo, 1000 Kg holding capacity, was fabricated by trained local tinsmith from galvanized iron sheet (gauge No. 26) with a top loading inlet and a lateral unloading spout at the bottom ,the bricks granary 2m x1.5m wih roof was constracted at kersa district ,and both fiber reinforced plastic tank of 1000 kg holding capacity and pics of 100kg holding capacity were purchased from local marketand evaluated for maize storage.

Figure 1. Evaluated thecnologies

Performance Evaluation and Data Collection

Before storing the maize grain, prerequisite data particularly on storage and surrounding condition were collected and recorded. Temperature, relative humidity of surrounding environment and storage and grain sample were collected within fourty five days interval since both are important parameters for determining shelf life of stored maize.

As a whole, ambient temperature, humidity of storage and grain sampling was done every 45 days from the same storage structures and also germination rate was tested. At each assessment, the storage structures were opened on top from 5 point. Samples were then separated into grain discoloured ,insect damaged ,fungi damaged ,undamaged and stunted grain by counting method from1000 grain sample for each storage were weighed on a precision digital balance. To estimate the percentage weight loss, the collected grain samples were assessed by the ‘count and weigh’ method. Sampled grains were separated into damaged and undamaged and percentage weight losses for each sample were determined as follows (Adams and Schulter, 1978).

$$Weight\ Loss(\%) = (Wu \times Nd) - (Wd \times Nu) \div Wu(Nd + Nu) \times 100$$

Where Wu=Weight of undamaged grain

Nu =Number of undamaged grain

Wd =Weight of damaged grain, and

Nd =Number of damaged grain

$$Discolored\ Grain(\%) = Number\ of\ discolored\ grain \div Total\ number\ of\ grain \times 100$$

Percentage of seed germinationwas carried out from randomly selected 100 grain samples were put in Petri dishes lined with moist filter news paper for 7 days at ambient conditions, after which germinated (with first shot and roots) and non-germinated (with no or deformed first shots and roots) seeds were recorded.

Statistical Analysis

Data was subjected to descriptive analysis for mean of weight loss, discolored grain, temperature, humidity and germination rate by statical Microsoft excel application and moisture content analysis with SAS with three replication lab sample analysis.

Results and Discussion

Weight Loss and Discolored of Grain

Table 1 shows the mean percentage weight loss and grain discolored after 12 month storage.

Table1. Mean of Weight Loss and Discolored Grain for Metal silo

Round Results(days)	Weight Loss(%)	Discolored (%)
initial day	0.57	0.60
45	0.66	0.62
90	0.87	0.66
135	1.08	0.68
180	1.15	0.94
225	1.27	0.96
270	2.18	1.04
315	5.32	1.06
360	11.73	1.20

Mean of weight loss and discolored grain for metal silo, shows an increasing pattern in weight loss and discolored grain over the storage time from 0.66 % to 11.73 %.

Table2. Mean of Weight Loss and Discolored Grain for Reinforced plastic tank.

Round Results(days)	Weight Loss(%)	Discolored (%)
Initial day	0.57	0.60
45	1.07	0.78
90	1.23	0.82
135	1.92	0.96
180	5.32	1.06
225	13.65	8.30
270	21.16	8.80
315	23.36	9.36
360	26.04	9.46

Mean of weight loss and discolored grain for reinforced plastic tank, shows an increasing pattern in weight loss and discolored grain over the storage time from 1.07% to 26.04%.

Table 3. Mean of Weight Loss and Discolored Grain for Bricks granary.

Round Results(days)	Weight Loss(%)	Discolored (%)
Initial day	0.74	0.70
45	1.28	0.72
90	5.10	1.10
135	5.76	1.66
180	9.82	1.67
225	45.36	1.76
270	48.47	1.77
315	52.07	1.78
360	56.21	1.84

Mean of weight loss and discolored grain for bricks granary , there was an increasing pattern in weight loss and discolored grain over the storage time from 1.28% to 56.21%.

Table 4. Mean of Weight Loss and Discolored Grain for Pics.

Round Results(days)	Weight Loss(%)	Discolored (%)
Initial day	0.57	0.60
45	0.77	0.65
90	0.77	0.65
135	0.77	0.75
180	0.82	0.80
225	0.93	0.85
270	1.32	0.85
315	1.45	1.10
360	1.57	1.20

Mean of weight loss and discolored grain for pics, shows an increasing pattern in weight loss and discolored grain over the storage time from 0.77% to 1.57%.

Germination Rate

Number of germinated seed from 100 counted sample shown below**.**

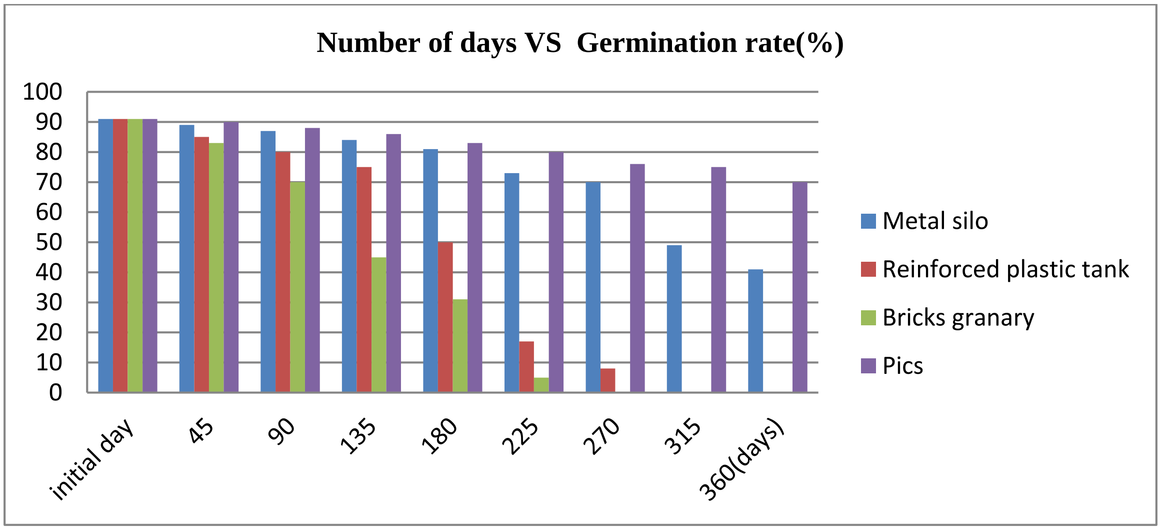


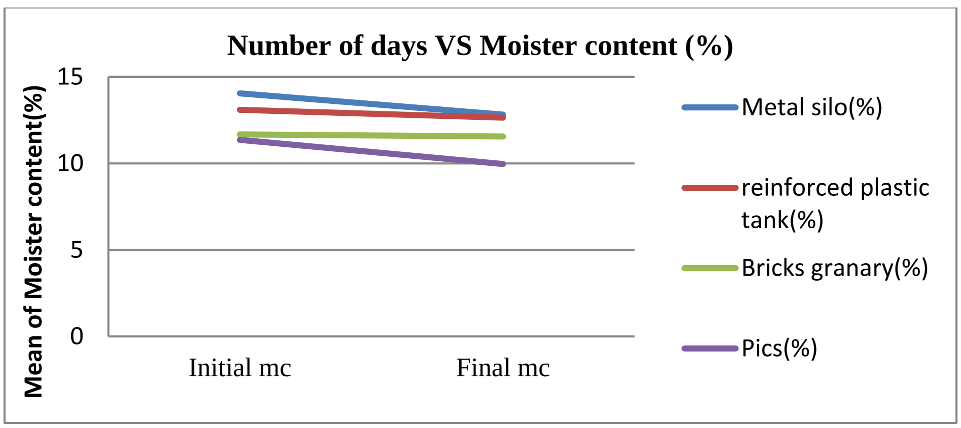
Figure 2. Number of days vs. germination rate graph

Figur 2, shows a decreasing pattern in germinated rate over the storage time from 90% to 70% for pics, 90% to 40% for metal silo, 90% to 0% for plastic tank and 90% to 0% for bricks granary for 12 months during stored maize.

Table 5. Mean values of Tempirature and Humidity

No. Days	Metal silo				Reinforced plastic tank				Bricks granary			
	Tempirature(°c)		Humidity (%)		Tempirature(°c)		Humidity (%)		Temprature(°c)		Humidity (%)	
	In	Out	In	Out	in	out	in	out	in	Out	In	Out
Initial day	25.75	26.75	48.5	49	25.75	26.75	48.5	49	23.9	37.33	73	25.25
45	26.41	36.47	27.29	22.14	26.41	36.47	27.29	22.14	23.51	37.34	56.25	21.25
90	21.45	25.12	39.25	74.75	21.45	25.12	39.25	74.75	24.99	33.63	60.1	57.8
135	20.94	27.59	66.13	51.13	20.94	27.59	66.13	51.13	24.64	29.05	74.13	44.13
180	19.24	26.05	77.25	51	19.24	26.05	77.25	51	24.99	33.63	61.1	57.8
225	22.55	34.15	65.6	31	24.99	33.63	72.8	27.2	27.97	34.35	60	47.7
270	22.68	27.49	55.33	30.44	21.19	23.72	74.22	29.89	26.98	29.72	50.5	27.5
315	23.04	29.34	35	26.44	29.63	31.17	63.56	30.11	26.36	28.57	45.6	26.6
360	22.74	27.08	69.78	31	22.96	25.78	82	35.78	25.44	28.08	58.25	27.75

The Mean values of tempirature and humidity of internal temperatures and humidity of all storage, stored in the primary quarantine room correlated closely with environmental temperature and humidity.



Figur 3. Number of days vs moisture content

Figure 3 shows a decreasing pattern in moisture content over the storage time for metal silo, reinforced plastic tank, bricks granary and pics. Maize stored in both storages lost significant amounts of moisture across the study period were much drier over 12 months.

Table 6. Nutritional composition of maize at the mid lab test and at end lab test

Types of nutrition	At the mid in lab test result				At the end in lab test result			
	Me silo	pics	Re plastic	bricks	Me silo	pics	Re plastic	Brics
ash	0.76%	0.90%	1.19%	0.3%	0.78%	0.92%	1.42%	0.49%
protein	6.16%	6.04%	6.36	6.7%	5.84%	7.13%	7.32%	7.10
crude fiber	2.26%	2.17%	2.00%	2.34%	2.24%	2.28%	2.46%	2.88%
total carbohydrates	75.16%	74.39%	75.27%	72.2%	75.66%	73.67	76.28	75.66%

Conclusion and Recommendation

Conclusion

Pics and metal silo had the least weight loss and grain discolored . But reinforced plastic tank and bricks granary scored the highest weight loss and discolored grain. The metal silo and pics kept the grain safe for 270,315 days after storage; however, there were a slow increase in weight loss 270,315 days after storage. Where as, bricks granary and reinforced plastic tank kept the grain safe for 135,180 days after storage, however, there were a high increase in weight loss 270,315 days after storage. The initial germination for the grain stored in those storage were around 90%. Slightly declines in the rate of germination, over storage, days after storage in all storage. While grain stored in metal silo and pics retained germination longer with minimal progressive decline. The rate of germination decline corresponds to the increase in the number of damaged grains. It can be concluded that pics and metal silo can effectively stored with minimum damage and weight loss without chemical used. Metal silo had durability than pics but pics was low in cost .So capacity building and awareness creation at all farmers levels on general post-harvest management practices and proper handling and use of these technologies should be supported.

Recommendation

- It is recommended that the pics and metal silo demonstration to solve the problem of post-harvest loss.
- It is recommended that the pics and metal silo are safe the maize for 10.5 monthes with minimum damage and weight loss without chemical use and in the house with good shade

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Improvement and Evaluation of Honey Extractor

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Abstract

Traditional method of extracting honey leads to reduction in nutritional value and quality thus, a honey extractor; a mechanical device that extracts honey from its comb was improved and evaluated using locally available materials. The main objective of this study is the improvement and performance evaluation of a honey extractor. The main functional parts of the machine are frame, wire mesh driving shaft, driving gear, operating handle to facilitate the winding process and basket designed to hold and spin three honeycomb frames, constructed using 1.5mm thick aluminum sheet, placed vertically into the extractor. The honey extractor is cylindrical in shape and operated by manually turning the operating handle. The time taken for honey extraction had significant effect on the performance of the honey extractor; the machine capacity and efficiency decreases as the time taken for extraction increases, optimum values of 93.37%, 40.46 kg/hr for machine efficiency, capacity respectively. The machine is portable and can be operated without any special training. , The machine also has the ability to preserve and leave the honeycomb undamaged after honey extraction.

Key words: *Honey, Extractor, Machine*

Introduction

Honey extraction is the central process in beekeeping. It involves removing honey from combs so as to isolate it as pure liquid. There are three major different ways employed in extracting honey from the combs. These are floating; centrifuging and pressing. The floating is the simplest, but time consuming because the chopped combs are kept in an air tight container for two to three days after which the waxes are skimmed off while the remaining foreign materials are filtered.

The squeezing method is where the chopped /crushed combs are poured into a strainer of screen wire using hands to turn the end (s) of the strainer forcing the honey to drip into a container. This is tedious and results in low output. The centrifugal extractor varying in designs and the capacity from 2 to 72 frames are the modern and most appropriate technology because they guarantee re-placement of the honey combs, thereby increasing honey production efficiency by the bee colony as no energy is required for rebuilding the combs.

However, the hand contaminates the honey and unripe honey ferments within few days after extraction, the materials collected are left untouched until the next morning and bee-wax which has become hardened at the top of the honey is removed and the harvested honey is later poured into bottles (Crane and Ethel, 2013). The traditional methods of extracting honey leads to reduction in nutritional value and quality; the unripe and capped honeycomb are collected at night and the extraction is achieved by squeezing manually with the hand. It involves the use of bare hands with a knife to cut open the comb of the honey before extracting it into a container thereby damaging the honey comb. Thereafter, an extracting knife is used to pull of the uncapped comb and then put inside the bucket or container. After the extraction, the honey is then taken home and pressed with the hands to separate the honey from the residue. The raw honey is filtered with a sieve to remove the remaining particles after this the honey is ready and fit for consumption. Although, this techniques seems to be the quickest for an average honey tapper who cannot afford a honey extractor the hand contaminates the honey and unripe honey ferments within few days after extraction.

South western Oromia has a good potential of honey production and they extract their honey traditionally, which is tedious, time consuming, inefficient, reduces the quality, and contaminate the honey. Therefore, to reduce the honey extracting problem this activity was initiated with the objective of improve and evaluate the existing JAERC plastic type of honey extractor.

Materials and Method

Materials

The materials used to construct the machines are;

- ✓ Bevel gears
- ✓ Aluminum sheet
- ✓ Rivet
- ✓ Stainless wire mesh
- ✓ Flat bars and paint (silver paint),

Instrument used during the evaluation of the machine

- ✓ Stop watch
- ✓ Weighing balance

Methodology

Description of study areas

The experiment was carried out at Jimma zone, Gomma district located at 7° 59’N & 36°42’E. The location lies at 1500 m above sea level and average maximum and minimum temperature of 31°C and 18°C, respectively with an annual average rainfall of 1143mm.

Machine Description

The improvements undertaken were the power transmission system was changed from chain to gear, the extracting chamber changed from plastic to aluminum, Outlet of the extractor changed from side to the bottom of the extractor and size reduction. The machine mainly consists of extracting chamber, frame holders and power transmitting unit.

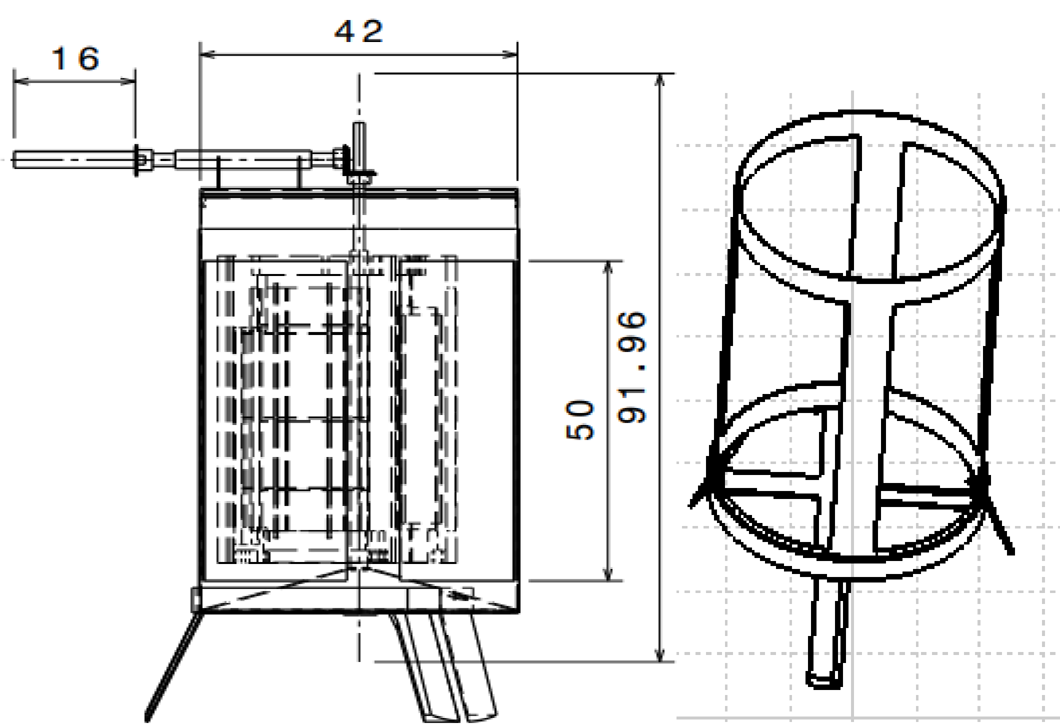

Figure 1. Pictorial View of Honey Extractor

A. Extracting unit

It made from aluminum sheet and connected by rivet with the shape of cylinder and the bottom cover of the cone shape. It has the volume of 0.09 m^{3}.

B. The frame holder

It holds three frame at once and attached on driven shaft at the center

C. Power transmittion unit

The main power source for the machine is man power and power transmitting unit consists of three main components of driver shaft with handle, Driven shaft and two bevel gear with 1:2 ratio for changing the rotation of driver shaft and increasing rotation speed by the ration of driven and driver gear.

Operation principles of Honey Extractor

The developed extractor was made of axial solid shaft carrying the gear driving system on its accommodations, the bearing topmost part of the shaft. This solid shaft accommodates the triangular shaped basket which holds the matured honey comb ready for extraction. The whole mechanism was housed in a galvanized stainless steel cylindrical container for honey collection and withdrawal. The driving mechanism which gives the machine a drive (rotary motion) consists of a gear, shaft and handle which transmits the motion from the handle to the shaft, connected to the shaft that always drives the basket inside the drum due to the gear mechanism incorporated. The driver gear set in motion the driven gear which regularly set the basket in motion. The machine operates by the principle of radial motion of the basket inside the drum. The basket was loaded with matured honey combs, and the metal basket was turned to rotation by force on the handle. The rotational effect caused centrifugal force that made the honey to flow out of its comb. As the centrifugal force increases, the rate of honey outflow increases until the combs are empty of their honey. The extracted honey flows down by gravity into the collector for collection.

Figure 2. Developed Honey Extractor

Performance Evaluation of honey extractor

Honey comb was obtained from local farmers and used for the evaluation of the extractor. The extraction was repeated four times. The efficiency and capacity of the machine were computed using the following Equations

1. Efficiency of machine

$$Ee = \frac{We}{Wbe} \times 100 ---------------------1$$

2. Capacity of machine

$$Mc = \frac{We}{Tt} --2$$

Where: Ee is the extracting efficiency in percentage, %

We is the weight of honey extracted, (kg)

Wbe is the total weight of honey extracting by machine and manually, (kg)

Mc is the capacity of machine, (kg/hr) and

Tt is the time taken for extraction of the honey, (hr)

Experimental design and Statistical Analysis

The experimental design is spilt-spilt plot with three replications. Treatments consisted of factorial combinations of three operating time (3 min, 5 min ,7 min), two type of machine (Improved and Imported) and three operator weight (55kg, 65 kg, 75 kg). Data was subjected to analysis of variance following a procedure appropriate to the design. Analysis was done using R-software. The treatment means that were different at 5% level of significance was separated by using LSD.

Result and Discussion

Effect of Time, weight of operator and type of extractor on efficiency of machine

Table 1 and 2 shows the effect of operating time, weight of operator and type of extractor on mean percent of efficiency of machine. The analysis of variance (ANOVA) revealed that the operating time had significant effect ($p<0.05$) on efficiency of machine and also the combination of weight of operator and type of extractor and the combination of time and type of extractor had significant effect ($p<0.05$) on efficiency of machine, Whereas, type of extractor, weight of operator, their combination had no significant effect.

Table 1. Effect of Time and type of extractor on efficiency of machine

Time * Type of extractor						
Time(min)	Type of extractor		Time (min)	Mean	Type of extractor	Mean
	Imported	Improved				
3	87.99^{c}	86.90^{d}	3	87.45^{b}	Imported	93.51^{a}
5	96.49^{ab}	95.91^{b}	5	96.20^{a}	Improved	93.23^{a}
7	**97.15^{a}**	95.78^{b}	7	**96.47^{a}**		
Mean						93.37
LSD						0.77
CV						1.19

Table 2. Effect of Weight of operator and type of extract on efficiency of the machine

Weight of operator * Type of extractor						
Weight of operator(kg)	Type of extractor		Weight of operator(kg)	Mean	Type of extractor	Mean
	Imported	Improved				
55	93.73^{ab}	92.51^{c}	55	93.21^{a}	Imported	93.51^{a}
65	93.44^{abc}	92.97^{bc}	65	93.21^{a}	Improved	93.23^{a}
75	**93.37^{abc}**	94.21^{a}	75	**93.79^{a}**		
Mean						93.37
LSD						1.08
CV						1.19

Capacity of machine

Table 3 and 4 show that the effect of operating time, weight of operator and type of extractor on mean percent of capacity of machine. The analysis of variance (ANOVA) show that operating time had extremely significant effect ($p<0.05$) on capacity machine and also weight of operator and type of extractor had significant effect ($p<0.05$) on capacity of machine. Whereas, other combination of the parameters had no significant effect ($p<0.05$) on the capacity of machine.

Table 3. Effect of operating Time and Weight of Operator on capacity of machine

Weight of operator * Operating Time							
Weight of operator(kg)	Operating Time			Weight of operator(kg)	Mean	Operating Time (min)	Mean
	3	5	7				
55	54.66^{b}	34.20^{c}	24.57^{d}	55	37.81^{b}	3	**59.77^{a}**
65	61.00^{a}	34.60^{c}	24.71^{d}	65	40.10^{ab}	5	34.80^{b}
75	**63.66^{a}**	35.60^{c}	31.14^{c}	75	**43.46^{a}**	7	26.80^{c}
Mean							40.46
LSD							5.65
CV							14.37

This shows that effect of weight of operator on capacity of the machine. The age of operator has direct relationship with capacity of machine i.e. as age of operating increase the capacity of the machine was increased.

Table 4. Effect of operating Time and Type of extractor on capacity of machine

Time * Type of extractor						
Time(min)	Type of extractor		Time (min)	Mean	Type of extrac-tor	Mean
	Imported	Improved				
3	**62.44^{a}**	57.11^{a}	3	**59.77^{a}**	Imported	43.28^{a}
5	37.60^{b}	32.00^{bc}	5	34.80^{b}	Improved	37.64^{b}
7	29.81^{c}	23.80^{b}	7	26.80^{c}		
Mean						40.46
LSD						4.00
CV						14.37

The above tables shows that the effect of operating time on the capacity of the machine. The operating time has inverse relationship with the capacity of machine i.e. as the operating time increase the capacity of the machine was decrease. Because as operating time increased the honey comb was start broken.

Conclusion and Recommendation

Conclusion

Hand operated honey extractor was improved form preexisting machine by changing chain driving method to gear driving method to solve the problem occurred on the existing machine i.e. removal of chain from the teeth of sprocket during operation and also the replacing of plastic container to aluminum to improve the durability of the machine. The improved honey extractor was compared with imported honey extractor with three parameters i.e. operating time, weight of operator and types of extractor for capacity of machine and efficiency of machine and we gate 93.51% and 93.23% efficiency for imported and improved respectively and 43.28 kg/hr and 37.64 kg/h capacity for imported and improved respectively. The improved honey extractor is effective on extracting honey from the honey comb without damaging the comb. Also it is simple for operating for long time without being tired and the user of this machine will find it interesting to operate.

Recommendation

It is recommended that operating the machine for 5 minute is best time to gate good efficiency and capacity for the machine and demonstration is recommended.

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On Farm Evaluation of Locally Available Animal Feed Choppers

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Abstract

The research was conducted to evaluate performances of two locally available animal feed choppers; Asella (AERC) l and selam model Animal feed choppers in terms of cutting efficiency, chopping efficiency throughput capacity and fuel consumption. The treatments of the study were; operating speed, feed rate and stalk types, by using factorial experiment with three replications. Accordingly, the Asela model animal chopper have mean cutting efficiency (94.88%), chopping efficiency (94%), throughout capacity (389.3 kg/hr) and mean fuel consumption of 121ml/kg on elephant grass and have cutting efficiency (96.25%), chopping efficiency (96.9%), throughout put capacity (1063.3 kg/hr) and mean fuel consumption of 120ml/kg on maize stalk. Whereas, the Selam model animal chopper have mean cutting efficiency (97.47%), chopping efficiency (97.39%), throughout capacity (700.8kg/hr) and mean fuel consumption 31.67ml/kg on elephant grass and have mean cutting efficiency (94.39%), chopping efficiency (97.21%) , throughout put capacity (645.45 kg/hr) and mean fuel consumption 40.9ml/kg on Maize Stalk was recorded. From the result obtained both animal feed chopper have best cutting efficiency, chopping efficiency and throughout put capacity and recommended to use to solve animal feed chopping problems.

Keyword: *Animal Feed Choppers, Aslela model, Selam model, Elephant Grass, Maize Stalk*

Introduction

Ethiopia has the largest livestock population in Africa. However, feed and nutritional factors are the main constraints to sustaining livestock productivity in Ethiopia. Feed shortage becomes very critical in most areas of the country, mainly due to the high population pressure which leads farmers to cultivate grazing land (Getinet et al, .2004).

Eventhough, Ethiopia has large livestock population, but still the country's demand for animal sourced foods is high and not met. This is mainly due to poor animal productivity that is compounded by inefficiencies in the input (feed, genetic material and veterinary services) and output.

Among these, feed shortage in terms of quantity and quality is considered as a major factor that hinders sustainable development of the sector (FAO, 2018 and Getahun, 2019).

In Ethiopia natural pasture is the primary feed resource throughout the wet season while crop residues play a substantial role during long dry season (CSA, 2017). However, as the productivity of grazing lands in most parts of the country is getting extremely low due to conversions of the natural pasture into crop lands, some adopted improved forage varieties and the crop residues become considerable feed sources in wet and dry seasons in most mixed farming areas of the country (Demeke et al., 2017).

In contrast to the natural pasture grazing, most locally available feed sources; crop residues and locally available protein sources, such as improved forage types, legume residues, tree pods, green fodder from multi-purpose trees are fibrous and limited by their low value of voluntary intake as feed, thus, efficient utilization of these resources need correct harvesting and physical treatments to improve their palatability for livestock feeding (M. Jamshidpouya, et al., (2018).

Feed treatment and processing in basic terms can be physical treatment which primarily comprising of their size reduction that can be achieved by using hand operated or power driven cutters and choppers, but in Ethiopia, there is limited experience in treatment and processing methods for improving the nutritional value of crop residues (Abera et al., 2014).

In Ethiopia, most farmers usually used to harvest grass and crop residues as forage and cut them into short lengths for livestock. But, as feeds' size bulkiness and fibrous nature can restrict intake by livestock, and it is common to see significant feed wastage attributed partly to selection of palatable and/or refusal of unpalatable fodder parts by animals. In this regard, studies showed that, appropriate chopping of forage to proper size of particles can improve the physical characteristic, that can stimulates rumination, boost feed intake, lower feed rejection and consequently reduce feed wastage (Devries T. et al., 2008). In addition to increasing feeds' intake, the chopping technologies can help in rapid removal of residues from field after grain harvest; reduces leaf loss and senescence, homogenize the plant material by mixing small and large particles that allows benefiting of medium and low quality forages, timely storage and reduction in space for storage as well as transportation.

Western part of Oromia region is commonly known as the major production hub for livestock and crops such as maize, sorghum and other similar crops of dominant sources of the crop residues, however, as there is no tradition of utilizing the abundant feed resources in the area and it is common to leave the most crop residues on the field without any use and burn them down for land preparation, while the local livestock are solely dependent on subsistent grazing and known for their lower output. To complement this paradox, it is vital to introduce the methods & technologies for improved utilization of the crop residues & other fibrous fodders in the area.

In Ethiopia, farmers used to use feed chopping by manual choppers that includes traditional tools such as sickle, machetes and knives, that are too labor intensive and tiresome, especially in dry and fibrous materials, while it is also associates with dangers of cutting worker's fingers. However, some Non-governmental organizations and Research institutions have imported and or adopted different types of small and medium power driven forage choppers, for solving the feed resources utilization problems in some other parts of the country. Therefore, this study was aimed for on farm evaluation of locally available animal feed choppers of Asella AERC model and selam model chopper for Elephant grass and Maize Stalk.

Materials and Methods

Experimental Site

prototypes production for both machines were done at Bako Agricultural Engineering Research Center (BAERC), which is located in Western Shoa Zone of Oromia National Regional State, Ethiopia and the evaluation of the machines were done at Bako Agricultural research center, Dambi Gobu and 02 kebele around Bako Tibe woreda West Shoa Zone of Oromia region.

Materials

Asela AERC Model Animal feed chopper, Selam Model animal feed chopper (figure.1), 12 HP ACME engine, 10hp Lombard engine, Tachometer, digital weight balance, a stopwatch, spring balance, measuring cylinder, elephant grass and Maize Stalk

Machines Description

The overall length, width and height for Asela AERC machine were 148, 188 and140 cm respectively and for the Selam type chopper were 150, 100 and146 cm respectively. Both machines consisted of five major components are feeding table, the cutting assembly, the frame stand assembly, the power transmission assembly and the material outlet. Selam type chopper contain additional parts of sieve and out let for milling maize and cereal grain as additional purpose.

(A) (B)

Figure.1 Selam Animal Feed Chopper (A) and Asela AERC Animal Feed Chopper (B)

Performance Evaluation

The performances of the choppers were evaluated using maize stalk and elephant grass. For each testing run, 4 and 5 kg of chopping material was weighed using a digital balance and the length of materials were measured using measuring tape. The materials were fed into the cutting chamber of the chopper via feeding table. The chopped materials were collected in a sack to determine the length of the chop and weight. The time taken to chop the fodder was recorded using a stop watch.

Evaluation and data collection carried was by using the two machines (AAERC and Selam Choppers), by three levels drum speed (600, 700 and 800rpm) and by two feeding rate (4 and 5 kg/min) for elephant and maize stalk. The following parameters were taken to determine the performance of the machine:

Cutting efficiency: Cutting efficiency for both animal feed choppers were calculated by measuring the stem length before cutting and the size or length of particles after cutting (Elfatih et al , 2010).

$$C_E = \frac{(L_b - L_a)}{L_b} x100\%$$

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 for both animal feed chopper machines were calculated by dividing total weight of samples for total weight of chopped out as (Khope and Modak, 2013).

$$C_o = \frac{W_c}{W_f} x100$$

Where: Co = Chopping efficiency, Wf = Total weight of samples fed in, Wc = Total weight of chopped out

Throughput capacity

Throughput, defined as the amount of materials chopped per hour when the machine is operating at optimal capacity (Harry and John, 2007). Throughput was assessed by chopping a known amount of elephant grass and maize stalk in a given time period. The quantity of forages was measured by a digital 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

Fuel consumption

To measure the fuel consumption, the fuel tank was filled up to top of the tank before the test started. After the completion of the chopping operation the tank refilled to the original level. The quantity of fuel refilled in the tank was taken as fuel consuption.

Exprimental Design and Statistical Analysis

The experiment was conducted in factorial experiment having two different machine, three level of speed, two stalk type and two feed rate with three replicationThe data was subjected to statistics 8 software. All significance pairs of treatment means were compared using the Least Significant Difference Test (LSD 5%).

Result and Discussion

The machines were evaluated using maize stalk and elephant grass at two different feed rates of 4 and 5 kg with three different machine operation speeds of 600,700 and 800 rpm.Table 1 shows the mean values of cutting lengths (mm) and efficiency (%), chopping capacity (kg/min) and efficiency (%), fuel consumption (l/h) and the analysis of variance (ANOVA).

Table 1.summarized performance evaluation result of the two prototype choppers

No	**Parameters**	**AAERC Model Animal feed chopper**								
		(1)Elephant Grass								
1	Speed (Rpm)	600rpm		700rpm		800rpm		Grand Mean	CV	SEM
2	Feed Rate kg/min	4	5	4	5	4	5			
3	Cutting Efficiency (%)	94.86^{a}	95.6^{a}	90.7^{b}	96.2^{a}	96.8^{a}	95.2^{a}	94.89	1.19	0.65
4	Chopping Efficiency %	91.67^{a}	87.3^{a}	89.2^{a}	88.7^{a}	85^{a}	87.3^{a}	88.20	4.97	2.53
5	Throughput(kg/hr)	402.6^{a}	314^{a}	338.2^{a}	361.8^{a}	496.2^{a}	423^{a}	389.3	41.6	93.5
6	Chop length(cm)	21.1^{b}	17.6^{bc}	38.8^{a}	14.9^{bc}	12.4^{c}	18.2^{bc}	20.5	21.8	2.57
7	Fuel Used (ml/kg)	120		120		125		121.7	0	
No	**Parameters**	**(2) Maize Stalk**								
1	Speed (Rpm)	600rpm		700rpm		800rpm		Ground Mean	CV	SEM
2	Feed Rate kg/min	4	5	4	5	4	5			
3	Cutting Efficiency (%)	96.7^{a}	96.5^{a}	95.7^{a}	96.9^{a}	95.3^{a}	96.4^{a}	96.3	1.4	0.8
4	Chopping Efficiency %	97.92^{a}	100^{a}	97.9^{a}	96.7^{a}	91.8^{a}	96.3^{a}	96.7	5.5	3.1
5	Throughput (kg/hr)	1001.2^{ab}	945.6^{b}	1179.4^{ab}	998.6^{ab}	1042.4^{ab}	1214.4^{a}	1063	45.9	97.3
6	Chop length (cm)	7.8^{a}	7.2^{a}	9.5^{a}	7.3^{a}	9.4^{a}	8.3^{a}	8.3	24.3	1.16
7	Fuel Used (ml/kg)	120		120		120		120		

No	**Selam Model Animal feed chopper**									
	Parameters	**(1) Elephant Grass**								
1	Speed (Rpm)	600Rpm		700 Rpm		800 Rpm		Grand Mean	CV	SEM
2	feed rate	4	5	4	5	4	5			
3	Cutting Efficiency (%)	95.6^{a}	97.25^{a}	97.71^{a}	97.8^{a}	98.2^{a}	98.24^{a}	97.47	0.59	0.33
4	Chopping Efficiency %	97.9^{a}	96.67^{a}	95.83^{a}	99.3^{a}	96.3^{a}	98.3^{a}	97.38	3.7	2.10
5	Throughput (Kg/hr.)	540.2^{c}	558.4^{c}	629^{bc}	792^{ab}	738.6^{abc}	946.8^{a}	700.8	19.8	79.9
6	Chop length (cm)	11.9^{a}	10.1^{a}	10.2^{a}	9.4^{a}	8.1^{a}	8.3^{a}	9.6	18.14	1.014
7	Fuel Used ml/kg	47.5		22.5		25		31.67	0	
No	**Parameters**	**(2) Maize Stalk**								
1	Speed (Rpm)	600rpm		700rpm		800rpm		Grand Mean	CV	SEM
2	Feed Rate	4	5	4	5	4	5			
3	Cutting Efficiency (%)	95.27^{a}	93.6^{a}	95.07^{a}	95^{a}	95.1^{a}	94.37^{a}	92.63	1.57	0.86
4	Chopping Efficiency %	97.92^{a}	98.33^{a}	100^{a}	99^{a}	100^{a}	96.67	98.65	1.42	0.81
5	Throughput (Kg/hr)	450.6^{b}	596.4^{b}	488.6^{b}	522.7^{b}	846^{a}	968.4^{a}	645.6	15.4	52.3
6	Chop length (cm)	14.67^{a}	13.13^{a}	9^{a}	9.7^{a}	10.23^{a}	12.2^{a}	11.54	30.04	2
7	Fuel Used ml/Kg	40		25		57.8		40.93		

Tables 1- shows the results obtained from the analysis of the data collected after the evaluation of both animal feed machines on elephant grass and Maize Stalk. These comprised the mean values of the performance parameters and the analysis of variance (ANOVA) tables which describes the significance of the treatments in affecting the performance of the machine. Table 1 show the mean values of cutting lengths (m), cutting efficiency (%), chopping efficiency (%), throughput Capacity (kg/min) and fuel consumption (kg/ml).The machine was evaluated with two feed rates of 4 and 5 kg with two machines at operation speeds of 600,700 and 800 rpm.

Table 2.Grandmean of length before cutting, length after cutting and cutting efficiency (%)

No	***Parameter***	***Asela Model Chopper***		***Selam Model Chopper***	
		Elephant Grass	***Maize Stalk***	***Elephant Grass***	***Maize Stalk***
1	Length before (cm)	397.4	228.2	360	217
2	Length after(cm)	20.5	8.3	9.6	16
3	Cutting efficiency (%)	94.84	96.36	97.5	92.63

Table 2 shows the mean chop length of both elephant grass and maize stalk was decreased from 397.4 to 20.5 cm and 228.2 cm to 8.3 cm on Asela model chopper and from 360 cm to 9.6 cm and 217 cm to 16 cm on selam model chopper respectively. 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 near to the acceptable range of 1 to 4 cm required to maintain proper rumination and salivation (Moharrery, 2010) as sited by Kiggundu M, 2018. Analysis of Variance revealed there has no significant pair-wise differences among the means of chopping length.

Asela AERC Model Animal feed chopper

The highest mean cutting efficiency (96.8%) for elephant grass was attained when the machine was obtained at 4 kg feed rate and operation speed of 800 rpm and the highest mean cutting efficiency (96.9%) for maize stalk was attained at 5kg feed rate and operation speed of 700 rpm. There are no significant pairwise differences among the means at 95% confidence level.

The highest mean chopping efficiency (91.67%) for elephant grass was attained at 4 kg feed rate and operation speed of 600rpm and the highest mean chopping efficiency (100%) for maize stalk was attained at 5kg feed rate and operation speed of 600rpm.The highest mean throughput Capacity (496.2kg/hr.) for elephant grass was attained at 4 kg feed rate and operation speed of 800rpm and the highest mean throughput capacity (1214.4kg/hr.) for maize stalk was attained at 5kg feed rate and operation speed of 800rpm.The finest (shortest) mean cut length (12cm) for elephant grass was obtained at 4kg feed rate and operation speed of 800 rpm and the finest (shortest) mean cut length (7.2cm) for elephant grass was obtained at 4kg feed rate and operation speed of 600rpm.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 elephant grass and maize stalk was 121.7ml/kg and 121ml/kg respectively.

Selam Model Animal feed chopper

The highest mean cutting efficiency (98.24%) for elephant grass was attained at 5kg feed rate and operation speed of 800 rpm and the highest mean cutting efficiency (95.27%) for maize stalk was attained at 4kg feed rate and operation speed of 600 rpm. The highest mean chopping efficiency (99.3%) for elephant grass was attained at 5kg feed rate and operation speed of 700rpm and the highest mean chopping efficiency (100%) for maize stalk was attained 4kg feed rate and operation speed of 700rpm and 5kg operation speed of 800rpm.The highest mean throughput Capacity (946.8kg/hr.) for elephant grass was attained at 5kg feed rate and operation speed of 800rpm and the highest mean throughput capacity (968.4kg/hr.) for Maize Stalk was attained at 5kg feed rate and operation speed of 800rpm.The finest (shortest) mean cut length (8cm) for elephant grass was obtained at 4kg feed rate and operation speed of 800 rpm and the finest (shortest) mean cut length (9cm) for maize stalk was obtained at 4kg feed rate and operation speed of 700rpm.Selam model animal feed chopper have the milling capacity of maize 102.5kg/hr that used for feeding poultry when machine was operated at speed of 920rpm.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 70.1kg of elephant grass and 64.542kg maize stalk was 0.19 and 0.2456 liter respectively.

Previous study by Yonas Mulatu (2020), performance of the Animal feed chopper machine was evaluated using sorghum forage variety and obtained mean chopping capacity of (581.24 kg/h), the finest of (shortest) mean cut length (6.23 mm), the highest chopping efficiency of (0.97) and the mean lowest fuel consumption of (0.50 ml/s) was recorded. According to another study by Abayineh (2019), 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

Conclusions and Recommendations

The performances of the choppers were evaluated using maize stalk and elephant grass. For each testing run, 4 and 5 kg of chopping material was weighed using a digital balance and the length of materials were measured using measuring tape. As the machine operates at higher speed the capacity increases to its highest possible performance. The speed of the machine also affects the length of cut of the feed, the machines efficiency, machine chopping efficiency, throughout put capacity and fuel consumption. Asela model animal chopper have 94.8%, 88.20% and 6.49 kg/min cutting efficiency, chopping efficiency and throughout capacity for elephant grass and 96.25%, 96.77 % and 1063.2 kg/hr for maize ftalk respectively. Selam model animal chopper have 97.47%, 97.38% and 718.8kg/hr. cutting efficiency, chopping efficiency and throughout capacity for elephant grass and 92.63%, 98.65 % and 645.6kg/hr for maize stalk respectively as presented in table 1.

Based on the result obtained, both animal feed chopper have best cutting efficiency, chopping efficiency and throughout put capacity, therefore, farmers can use these animal feed choppers at speed of 800rpm and 5kg/min feeding rate,but using greater than the above speed may affect the machine specially Asela model chopper. So, It is recommended that, these machine can be go to extension for demonstration.

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Adaptation and Evaluation of Small Scale Portable Wood Powered Bread Baking Oven

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Abstract

Bread is a closely related food to people's daily life and bread making is an important operation in food production. Baking is the final and most important step in bread production, and can be defined as the process which transforms dough, basically made of flour, water and leavening agents, in a food with unique sensory features by application of heat inside oven. In Ethiopia, most bakers are found in towns and utilize tradional mud-bricks made wood fired oven or imported modern ovens, which are usually complained by high wood consumtion and unaffordable to small-scale or household, respectively. Thus, this study was conducted to Adapt and Evaluat a Small Scale Portable Wood Powered Bread Baking Oven (WPBBO). The oven that consists of two baking compartments with in one chamber and two combustion chambers was evaluated in terms of the baking capacity, baking efficiency and weight loss of the baked bread. When fully loaded it has the carrying capacity of 160, 32 and 8 pieces of loaf bread per batch of operation at the two compartments with baking efficiency and baking capacity of (86.9% and 96.6%) respectively and by average weight losses of 12.6%. The stove's performance in terms of baking time was observed that for 100g, 500g and 2000g loaf of bread and the average baking time lies between 15-25minutes and 25minute were observed with single biomass fuel feed of 5kg for each fire chamber. Thus, the study was concluded that, the stove showed good performances in between 15-20 minute for kind of bread loaf baking. By this evaluation, the wood-powered oven is recommended for domestic and small scale business (job creating) purposes as it can be used in the rural where there is lack of electricity and also in pre-urban and urban settlement.

Key words: *Wood powered oven, Bread, Bread baking, portable oven,*

Introduction

Bread is closely related to people's daily life and baking, the bread making, is an important unit operation in food sector (Mondal and Datta, 2009; Adegbola et al., 2012).

Baking is the final and most important step that plays an important role in determining the quality of the final product in bread production, and can be defined as the process which transforms dough, basically made of flour, water and leavening agents, in a food with unique sensory features by application of heat inside an oven (Mondal and Datta, 2009; Adegbola et al., 2012). These happen as a consequence of heat (radiation, convection and conduction) and mass transfer (water vapor–air movement in the oven, water evaporation within the product and sometimes water generation by wood burning).

Oven is one of the key food processing equipment that uses complex simultaneous heat and mass transfer process in the food industries. It is a thermally insulated chamber used for heating, baking, cooking, or drying of food substances (Mondal and Datta, 2009; Adegbola et al., 2012). In baking oven, the hot air flows over the material either by natural convection or forced by a fan, the convection heat transfer from air, the radiation heat transfer from the oven heating surfaces, and the conduction heat transfer across contact area between product and metal surface.

Bread production occurs on a number of different scales, from the artisan bakeries serving the local community, to the large commercial bakeries, as well as in-store supermarket bakeries, small chain outlets and anything in between. Similarly, baking ovens come in a variety of different configurations, from small domestic units to large tunnel ovens (Keskin *et al*., 2004; Mirade, *et al*., 2004; Sakin et al., 2009; Khatir *et al*., 2012; Khater and Bahnasawy, 2014).

In Ethiopia, until recently, most of the bread making sectors used traditional bread ovens, usually made of refractory material such as stone, brick, adobe, or refractory concrete, and recently, large numbers of the country's bakeries are using the imported electric ovens of various scales, mainly in urban parts of the country.

The traditional baking ovens usually used large wood logs as fire woods and some other locally available combustible materials (William R, 2022). Their shortcomings are: longer baking time, non-homogenous heat distribution and thermal energy losses which resulted to increase in the cost of production, likewise air pollution. Although the Electric baking stoves are known for their improved features, but they are limited to electrified part of urban and cities, which is un-accessible for majority of the rural dwellers of the developing countries, like Ethiopian, where the vast majorities are living in rural areas without the access to the electricity.

For solving the problems associated with both of the existing baking ovens conditions, various wood fired ovens have been developed and tested effective in some other parts of the world.

Among them, Wood fired oven is an enclosed, ovens, made of varying qualities and thick-nesses of steels and stainless steel, comes in a range of sizes and shapes, and has various extra added values, like the ability to fill the chamber, easy loading and unloading it. They often have some sort of fuel control and comfortable working area with/for the operator (Sourdough baker, 2018, B.S. Kosemani, *et al*, 2021).

In Ethiopia, increasing population, rapid urbanization, and changing food habits have resulted to preference for ready to eat convenient foods such as bread and other baked products. However, in Ethiopia, the existing baking ovens are mud made wood fired or imported electric types, most-ly found in cities and towns.

Hence, still the vast majority of the Ethiopian rural dwellers have no access of electricity, thus, the mud made wood fired can be an option for the vast majority of the rural Ethiopia. However, the existing mud made wood fired baking oven found in Ethiopia are the oldest massive non portable models and energy intensive that consume more wood for heating and backing.

Therefore, this study was conducted to adapt and evaluate a small scale wood powered bread baking oven suitable for the non-electrified rural areas of the country. The developed oven is Small Scale Portable Wood Powered Bread Baking Oven made of mild steel and stainless steel metals that has been evaluated and reported as effective oven for the intended purpose, as it is made to be thermally insulated chamber, uses less fuel, comfortable for operators of both genders and used for the baking of bread for domestic, small and medium scale bakery purposes, that might help in creating jobs for the users.

Materials and method

Materials

Materials and apparatus used in this experiment for construction and evaluation were:

- ✓ Mild steel, stainless steel, round bar, flat irons, square pipes, angle iron, water pipe, bat hinge, Stop watch, digital balance, Digital thermometer, aluminum reinforced fiberglass, infrared radiation, wheel, shafts, cement and fine sand
- ✓ K-type thermocouple probe, oven dry, Hygrometer ,Fuel wood, wheat flour, ingredients and water

Experimental Site description

The experiment was conducted at Bako Agricultural Engineering Research Center, which is located in West Shewa Zone of Oromia National Regional State, Ethiopia. The Center lies between 90 04‟45"" to 90 07‟15""N latitudes and 370 02‟ to 370 07‟E longitudes.

The test was conducted in Bako (BAERC) with the local atmospheric conditions of ambient temperature 20-30 ^{O}C, Air pressure 75.7Pka, Relative humidity more than 35% and Altitude/elevation 1650m.

Design calculation

Heat Transfer

Heat is energy in transit under the motive force of a temperature difference. Any theory should be able to explain the facts below;

i. whenever there is an exchange of heat is consumed (heat lost by the hot body always equal to heat gained by the cold body

ii. The heat flow takes place from higher to lower temperature.

ii. The substances expand on heating.

iv. In order to change the state of a body from solid to liquid or liquid to gas without rise in temperature, certain amount of heat is required.

v. When a body is heated or cooled its weight does not change. According to the modern or dynamical theory of heat, Heat is a form of energy. The mean kinetic energy per molecule of the substance is proportional to its absolutes temperature (Rajput, R K., 2004).

Heat transfer many be defined as the transmission of energy from one region to another as a result of temperature gradient. It takes place by the following three modes: (i) Conduction (ii) Convection (iii) Radiation.

Heat transmission in majority of real situations occurs as a result of combustion of the modes of heat transfer in a baking, heat transfer from the wood burned to the baking space and heat conduction through the oven walls. Heat always flows in the direct of lower temperature.

Conduction

Conduction is the transfer of heat from one part of a substance to another part of the same substance, or from one substance to another in physical contact without appreciable displacement of molecules forming the substance. In solid, the heat is conducted by the following two mechanisms:

By lattice Vibration (the faster moving molecules or atoms in the hottest part of a body transfer heat by impacts some of their energy to adjacent molecules.

By transfer of free electrons (free electrons provide an energy flux in the direction of decreasing temperature for the major portion of the heat flux except at low temperature.

Heat Emitted by wood: The heat emitted by wood of recommended mass of 5.0 kg for each fire wood combustion chamber was (Armando M. *et al*, 2012).

Fouriers Laws of Heat Conduction: Fourier's laws of heat conduction are an empirical law base on observation and state as follows: The rate of flow of heat through a simple homogeneous solid is directly proportional to the area of the section at right angles to the direction of heat flow and to changes of temperature with respect to the length of the path of the heat flow. Mathematically calculated emitted heat as follows:

$$Q = A\frac{dt}{dx}$$

Where Q = heat flow through a body per unit time (watt), A = surface area of heat flow (perpendicular to the direction of flow) m2, dt = temperature difference of the face of block (homogeneous solid) of thickness dx through which heat flows **^{O}C**, or **^{O}K** , and dx = thickness of body in the direction of flow, m.

Thus $$Q = Ak\frac{dt}{dx}$$

Where, K = constant of proportionality and is known as thermal conductivity of the body (stainless steel 304) = 0.04w/m^{o}c.

For composite materials*:* Total heat flow is given by (Armando M. *et al*, 2012)

$$Q = \frac{dT}{\sum R} = \frac{T1 - T2}{\sum R} \text{ , where, } \quad \sum R = \frac{1}{hiA} + \frac{1}{hoA} + \frac{La}{kaA} + \frac{Lb}{kbA} + \frac{Lc}{kcA}$$

Where: R=resistance to heat flow Hi and ho = inner and outer convective heat transfer coefficient A= cross sectional area la, lb and lc= thickness of materials a, b, c Ka, kb and kc =conductive heat transfer co-efficient for materials a, b, c (stainless steel, aluminum reinforced fiberglass and steel sheet metal) respectively.

Convection

Convection is the transfer of heat with a fluid by mixing of one portion of the fluid with another. Convection constitutes the macro form of the heat transfer since macroscopic particles of a fluid moving in space cause the heat exchange. The heat flow depends on the properties of the fluid and is independent of the properties of the material of the surface. However, the shape of the surface will influence the flow and hence the heats transfer.

Newton law of cooling*:* - states that the heat transfer from a solid surface of area A at a temperature tw, to a fluid of temperature t, is given by

$$Q = hA(tw - t)$$

Where: h is called the heat transfer co-efficient. It is used for heat transfer from a solid to a liquid and vice versa.

Radiation

Radiation is the transfer of heart through space or matter by means other than conduction or convection. Radiation heat is thought of as electromagnetic waves or quanta; an emanation of the same nature as light and radio waves. All bodies radiate heat so a transfer of heat by radiation occurs because hot body emits more heat than it receives and a cold body receives more heat than it emits. Radiant heat energy (being electromagnetic radiation) requires no medium for propagations and will pass through vacuum. The properties radiant heat in general is similar to those of light.

Laws of Radiation

***The Stefan Boltzmann law**:* – states that the emissive power of a black body is proportional to fourth power of its absolute temperature. i.e. $Q \alpha T^4$

Thus, $Q = F\sigma A\left(T1^4 - T2^4\right) = \varepsilon\delta A(T1^4 - T2^4)$

F= a factor depending on geometry and surface properties,σ= Stefan - Boltzmann constant = $5.67*10^{-8}$w/m2 k ^{4}, Ɛ= emmisivity of stainless steel=0.074, A = area, m^2 T1, T2= Temperature degree Kelvin (^{O}K)

This equation can also be re-written as;

$$Q = \frac{T1 - T2}{T1 + T2}$$

Heat Emitted by Wood:

The heat emitted by wood of recommended mass of 5kg, 5kg for each fire chamber was Qe=5.06MJ. Mathematically calculated emitted heat as follows: (Armando M.,*etal*,2012)

$$Qcond = Ak\frac{dt}{dx}$$

Where: Q = heat flow through a body per unit time (watt) , A = surface area of heat flow (perpendicular to the direction of flow) m2, dt = temperature difference of the face of block (homogeneous solid) of thickness dx through which heat flows in ^{0} C or ^{o} K, dx = thickness of body in the direction of flow, m.

Where: R=resistance to heat flow Hi and ho = inner and outer convective heat transfer coefficient A= cross sectional area la, lb and lc= thickness of materials a, b, c Ka, kb and kc = conductive heat transfer co-efficient for materials a, b, c,

Qcond total=QcondBF+QcondTF=12589.992watt

Heat Loss to Baking Space

The heat loss to baking space were the heat conducted from both fire chambers and convective and radiated heat that circulates inside baking chamber that was found to be 16,281.672watt.

Qlbs=Qcond+Qconv+Qrad

Heat loss to the environment

The heat losses to the environment were the heat conducted via chimney and doors. It is the un-controllable heat loss that was emitted to the environment via nature and calculated as follows.it was found to be 4265.31watt

Thus, Qloss=Qrad.chmney+Qrad.door

Volume of the baking chamber

The baking oven chamber is the enclosed chamber where the baking takes place and the volume was calculated using Eq as described by (Clements et al., 2001).

$$V = BCL \times BCW \times BCH$$

Where, V= is the volume of the baking chamber (mm^3), BCL is the baking chamber length, BCW= is the baking chamber width and BCH= is the baking chamber height. Therefore, the volume of the baking chamber (V) is equivalent to 0.285 m3, given the values of 1000mm, 810mm and 260mm for BCL, BCW and BCH respectively.

The capacity of the oven

The capacity of the oven is directly proportional to the number of bread loaves/batch and baking pan dimensions (size of the baking pan and the dough weight). The average weight of bread for bread dough of 100g,500g and 2000g(small, medium and large loaf of bread) after baked were 84.133g, 468.825g and 1872.344g respectively as design basis, having volume of $2.614*10^{-4}$ m^3, $2.92*10^{-3}$ m^3 and $1.082*10^{-2}$ m^3 respectively. Whereas, bread average surface area for each bread type were $3.049*10^{-3}m^2$, $2.842*10^{-2}m^2$ and $3.32*10^{-1}m^2$ respectively. The surface area occupied by 160, 32 and 8 loaves of bread for each bread weight of 100g, 500g and 2000g per batch of = $0.39m^2$,$0.03\ m^2$ and $0.0628m^2$ respectively. Two baking compartments dimensions are then established as follows:

The Surface area of baking bread for each compartment = $0.\ 81m^2$

The oven has total area and volume of $0.84m^2$ and $0.23085m^3$ respectively.

• The vertical height of the baking compartment proposed = 0.285m

Therefore, Capacity of the oven = $0.23085m^3$

$$CO = \frac{Sizeoftray}{Sizeofbread}$$

Therefore, CO for small, medium and large bread dough weight and size trays were=160, 32 and 8 pieces of bread per batch for 10kg of flour which is 16.41kg of dough and320- 480,64-96 and 16-24 pieces of bread per hour for 20-30kg of flour which is32.82- 49.23Kg of dough respectivelly.it operates two to three times per hour.

Baking capacity

Baking capacity: the number of pieces of the bread dough in each baking compartment depends on the arrangement of the food samples in the baking chamber. The baking capacity of the oven was determined by putting into consideration the size of the baking pan and the dough weight.

The wood powered/fired bread baking oven has two baking compartments, in each compartment, a total of 160, 32 and 8 pieces of bread dough was baked per batch in baking pans/tray size of 985 mm × 390 mm × 60 mm, 300mm*100mm*100mm and Ø400mm*100mm for small, medium and large loaf of bread respectively was attained. The baking chamber of the fabricated wood powered/fired bread baking oven (WPBBO) has a volume of $2.614*10^{-4}\ m^3$, $2.92*10^{-3}\ m^3$ and $1.082*10^{-2}\ m^3$ respectively at an average baking time of 20minute (15-25) minutes. Therefore, the WPBBO has maximum baking capacity of 30-50 kg/hr at producing at baked bread of 480, 96 and 24 pieces per hour for each dough masses of 100g, 500g and 2000g per batch of operation respectively.

$$BC = \frac{MD}{BT}$$

Where, BC= is baking capacity, MD= is mass of dough (kg) and BT= is baking time (hr)

Baking efficiency

The baking efficiency of the oven is calculated as the output energy per input energy of the baking oven (B.S. Kosemani, *et al*, 2021)**.** The baking efficiencies increased relatively with increase in the baking temperatures.

The baking efficiency of the WPBBO was determined by using the ratio of the designed baking time to the actual baking time required to bake a batch of dough to its desired taste, colour and texture in the rotary oven as calculated in (Okafor et al., 2014).

$$BE = \frac{DBT}{ABT}$$

Where, DBT=designed baking time and ABT=actual baking time

Weight loss in the food samples: this is the weight losses encountered during the operation of oven. The weight loss in the food samples (bread dough) was calculated by subtracting the weight of the food sample after heating from the initial weight of the food sample (B.S. Kosemani, *et al*, 2021).

Weight loss in the food samples (baked bread)

The weight loss in the food samples (bread dough) was calculated by subtracting the weight of the food sample after baking (heating) from the initial weight of the food sample. The percentage of moisture loss was obtained using Equation follows;

$$Weightloss = (Initialweight) - (Finalweight)$$

$$\%Moistureloss = \frac{Initialweight - Finalweight}{Initialweight} * 100$$

The moisture loss in baked bread is minimal. Therefore the average weight losses or moisture for each three different weight of bread dough of 100g, 500g and 2000g were 15.867%, 6.24% and 6.3828% respectively.

Heat loss in the oven

The heat loss from the oven to the environment was estimated as negligible because the WPB-BO wall was totally insulated by high thermal insulation material of aluminum reinforced Fiber-glas and assumed an adiabatically insulated boundary condition except via chimney and air ventilation hole provided on fire door which was of minimal and Natural type and uncontrollable.

Biomass fuel energy efficiency and moisture content

Parameters of the biomass fuel selection for fire wood when woods were alive and fresh it consists primarily of water, i.e. most of the weight was actually water. After being cut to length and stacked for a year or two the average moisture content generally drops to approximately 20% *(*Engineering ToolBox, 2003).

In the combustion process water is evaporated and the temperature is raised to fuel gas temperature. Dry wood has approximate combustion values of 16300kj/kg and 3890kcal/kg. For 20% air dry wood it has a Usable Energy of 97% by Volume and 81% energy per weight. Accordingly we have gote the combustion value of 17,447.98watt.

The moisture content, ash and heat values of the four different species of wood were determined by the following equations. However, Eucalyptus grandis wood type was selected which were more energy efficient than others and long-lasting of firing time with high thermal efficiency.

$$MCwb = \frac{Wi - Wf}{Wi} * 100 \quad \text{and} \quad MCdb = \frac{Wi - Wf}{Wf} * 100$$

Where, MC_{wb} = Moisture content wet basis (%), MC_{db} = Moisture content dry basis (%),

W_i = Initial weight and W_f = Final weight

Weight loss during drying

During drying, paddy wood loses its weight due to loss of moisture:

$$Wf = Wi * \frac{100 - MCi}{100 - MCf}$$

Where, W_I = Initial weight (g) and W_f = Final weight (g)

The moisture content for four different locally available biomasses were found by weighing each sample before and after they were placed in the oven for a 72hr at 65°C.

The ash content were determined to obtained their moisture by examining four different wood species in the weight of the samples after combustion in a wood powered bread oven for 3-4 hr. The densities were based on the volume and weight measurements of the samples. The volume was determined using a known amount of wood used during evaluation. The amount of wood used was determined by weighing sample individually per replication.

Energy generated by the heat source (fire wood)

The energy generated by fuel wood for oven heating is given by the Eq (Mayilsamy K., Rudra-moorthy R.,2006)

$$Hg = Hp + Hc + Hm$$

Where Hg = the quantity of heat produced by the wood burned; Hp = the quantity of heat gained by food product (Bread dough); Hc= the quantity of heat radiated to the heating chamber; Hm= the quantity of heat conducted through lateral walls (stainless steel sheet of 2mm thickness) (Mayilsamy K., Rudramoorthy R., 2006). Hence the total heat energy generated by the wood for heating the oven chamber was 40.531MJ by neglecting the heat escaping through lateral walls (Hm)since the oven was thermally insulated by aluminum reinforced fiberglass.

$$Hp = MpCp\Delta T$$

Where Mp= Mass of food product; Cp= Specific heat capacity of food product (wheat Bread dough = 2890J/kgK) (Zheleva I., Kambourova V.,2005) ΔTp= Change in temperature. Baking of the dough at an average time 20, 25 minutes with 160,32 and 8 bread dough pieces at a time, while the an average dough weight is 100g,500g and 2000g for single bread dough weight respectively, hence total weight of dough is 16.410 kg, Hence, Hp = 23.083MJ.

Energy radiated

The quantum of energy radiated was calculated by using the following Equation (Mayilsamy K., Rudramoorthy R.,2006).

$$Hc = \delta A\left(T1^4 - T2^4\right)$$

Where δ = The constant of Stefan-Boltzmann (5.669×10-8 W/m2 K4); T1= Initial temperature of surrounding air(20.2^{o}c),T2= Final temperature of surrounding air(35.1^{o}c); Hc =17,447.98watt.

Heat energy requirement

The heat energy required to bake bread was obtained from fire wood collected from local area where the prototype constructed and experimental evaluation also done..

Average baking (oven) temperature =**229.15^{o}c**

$$QH = Md * Cb * TRM$$

Where, Md = Mass of of dough, =---, Cb = Specific heat capacity of bread (wheat), 2890J/kgK (Vogel, 2005) TRM = Oven room temperature was 25.325oc and the amount of heat energy required for baking bread was QH=14.148MJ. But the heat energy utilized by the heat sources were much more than heat required which was 16.9MJ high excess.

Wood thermal (Energy) Efficiency

The system thermal efficiency is the ratio of net useful energy utilized to the gross energy supply

$$Woodthermalefficiency = \frac{Usefullenergyutilized}{Gros \sin\ putenergyrequired} \Rightarrow \eta_{wood} = \frac{Eusefull}{Einput}$$

Thus, E usefull=16,855.302J, Gross E required= 17,447.98J

Therefore, thermal efficiency of used woods were 96.6% at 12.562%

for approximately 20% air dry wood it has a Usable Energy of 97% by Volume and 81% energy per weight (Engineering Toolbox, 2003).

Baking chamber (compartment)

The oven has two baking compartments where baking tray is suspended.

The doors (fire and bread)

Both inner and outer walls of the fire door were made of mild steel sheet metal of 2mm. The dimensions of both of the door is 995 mm*173 mm*10mm;

whereas the bread door inner and outer walls were made of stainless steel and mild steel sheet metal of 2mm and having dimensions of 840mm* 285mm*15mm respectively. It was hinged to the frame of the fire door of the oven at two points to enhance adequate suspension whereas the bread door was of the sliding type to prevent heat losses via leaking hot gases. The door was lagged with Aluminum reinforced Fiberglas to prevent heat loss to the environment and bakery operators.

The supporting frame

There were four legs (skeletal) that suspended down below the baking oven vertically. They were made of mildsteel square pipe of 40mm×40mm×4mm.

Fig1. View of the portable wood powered bread baking oven components

Hint; 1, Bread door 2, oven body 3,steam/proofer chamber 4, Transportation wheel

5, Ventilation hole 6, support frame 7, Ash chimney 8, Water Tankers and their connector pipes with gate valves 9, Fire chimney and 10, Fire door

Experimental set up

Tests were conducted using four different local biomass fuel such as: Eucalyptus (local name bargamo), wadessa, Gatira and Gravilia with a 50cm length and having different diameter and weight individually, but equal weight for each per batch and splited into usable size for ease ignition ways. Real-time temperature data was acquired by type K thermocouples installed into both top and bottom chamber, and bread chamber. The test includes measurement of fuel-wood consumed for each tests were pre-weighed and the quantities of the same weight of fuel-wood for both fire chamber (5 by5kg of fuel wood) and 10kg of flour were put a side for every experiments conducted. A batch of firewood and flour was set aside and weighed before for each test of process

Thermocouple

Three K-type thermocouples were installed in to the top and bottom fire chamber and baking chamber compartments for measuring the temperature values during baking operation.

Dough preparation

The bread dough was prepared by mixing 10 kg of flour, 100 g of salt, 70g of dry yeast, 6litre of water, 70g of magemakes, 70g of baking powder and 100g of sugar. The dough was mixed manual by finger infringement into mixing bowl or vessel for 10 to15 min until consistent dough character was achieved. The dough was then placed on flat table and divided into required weight and kneaded into a ball shape. The kneaded dough was divided and weighed on digital mass balance into 100, 500, and 2000 (g) as one set. Three sets were made in four replication, then moulded and placed inside clean and oiled baking pans of four different sizes to develop moist surface and their physical dimension were measured and recorded as average diameter , length, width and height. A set of three different sizes of moulded dough was placed inside a proofer for 30min to 1hr. at $25^{o}c$ to $40^{o}c$. During the proofing process, alcohol is produced with carbon dioxide due to fermentation of sugar content by the yeast. This resulted to dough rising to almost a doubling height. After the proofing process, they were transferred and properly arranged on the baking tray then loaded inside oven and baked for 20 to 25 min at different temperature because .These procedures were repeated and the changes were observed for other sets of molded dough at baking temperature consecutively. The temperature was recorded at an interval of 5 min interval for bread chamber in order to see effective backing time average temperature required to bake the dough and avoid over cooking which leads to bread burning and 10min interval for both fire chambers to see oven temperature rise and drop.

Fig 2. Dough and Bread preparation profile with 3 different bread trays

Bread

Bread is composed of crust and crumb, the proportions of which depend on the conditions in the oven. Crumb has a porous structure; it consists of a monomolecular lipid with a few, polymerised, protein units of high molecular weight dispersed within it. The walls of the pores are composed of dried gelatinised starch (Therdthai et al., 2004). The curvature of pores has three functional aspects that affect: 1. The structure of the bread. 2. The mechanism of heat transfer, particularly the evaporation and condensation of water vapour through/within the pore system. 3. The adsorption of the flavour compounds formed during baking. The volume of each bread were significantly d/t due to their expansion and space coverage.

Fuel Materials

Tests were conducted using four different local biomass fuel such as Eucalyptus grandi, Wadessa, Gatira and Gravilia with a 50cm length and having different diameter and weight individually, but equal length. Equal weight of wood was set aside for each per batch and splited into usable size for ease ignition.

The test includes measurement of fuel-wood consumed for each tests were pre-weighed and the quantities of the same weight of fuel-wood for both fire chamber (5 by 5 kg of fuel wood) and 10 kg of flour were put a side for every experiments conducted. A batch of firewood and flour was set aside and weighed before for each test of process.

Temperature

The baking temperature dominates the quality of the product during baking. The increased temperature creates a pressure gradient in the product; causing the lattice of the gluten threads to dilate from the center of the loaf outwards, i.e. towards the surface. Real-time temperature data was acquired by type K thermocouples installed into both top and bottom chamber and bread chamber.

Insulations

The main objective of insulation is to reduce the amount of heat escaping from the oven to atmosphere. In order to work effectively, the insulation material must have a low thermal conductivity. Insulations are used to decrease heat flow and surface temperatures.

Data Collected

The data collected during experimental evaluation were: Temperature, and time taken for baking bread, fuel wood moisture content, weight of bread before and after baked, weight of biomass before and after oven dry, heat loss and gained during operation,…etc.

Data Analysis

All the collected data were analyzed using Stat.8 SAS Statistical software version –and R-Software (Rx64 4.1.0). The treatments were subjected to Randomized Complete Block Design for their significance using calculated least significant difference (LSD) values at 5% level of probability.

Results and Discussion

A prototype of Wood powered bread baking oven was fabricated and constructed for baking purpose. The Wood powered bread baking oven is a compact type of oven that uses the three modes of heat transfer (conduction, convection and radiation) to bake food products.

During the baking process, the initial bread dough of white colour changed to varying degrees of brownness as baking temperature increased. The final product had an outer layer that is semi-rigid less fragile structure called the crust layer while the inner part of the dough had a crumb texture.

Heat and mass transfers to the bread chamber and bread through several mechanisms such as: convection, radiation, conduction from heat sources to the baking chamber and evaporation and condensation of steam occurred in the baking compartments.

Performance Evaluation

Performance evaluation was carried out to determine the functionality and performance characteristics of the wood powered or wood fired bread baking oven. The performance evaluation characteristics were carried out to establish the optimum baking capacity and baking efficiency. The performance of a wood-fired bakery oven (WFBO) depends, to a large extent, upon the efficiency of the way in which energy is converted. Such a system includes the conversion of chemical energy in the fuel to thermal energy, and the efficiency with which the thermal energy is transferred to the baking chamber. The system for transporting combustion products through a WFBO and the types of material used in the construction of the oven are important parameters that impact its overall performance.

Baking capacity

The wood powered/fired bread baking oven has two baking compartments, in each compartment, a total of 160, 32 and 8 pieces of bread dough was baked per batch in baking pans of size 985 mm × 390 mm × 60 mm, 300mm*100mm*100mm and Ø400mm*100mm for small, medium and large loaf of bread respectively was attained. The baking chamber of the fabricated wood powered/fired bread baking oven (WPBBO) has a volume of $2.614*10^{-4}$ m^3, $2.92*10^{-3}$ m^3 and $1.082*10^{-2}$ m^3 respectively. Therefore, the WPBBO has maximum baking capacity of 30 kg/hr at producing at baked bread of 480, 96 and 24 pieces per hour for each dough masses of 100g, 500g and 2000g per batch of operation respectively.

Baking efficiency

Show the baking efficiency for wood-fired and gas-fired at the three selected temperature levels. It was observed that baking efficiencies increased as the baking temperature increases. The optimum baking efficiency of the oven occurred at the 229˚C baking temperature. Most especially when the weight of dough was increased to 2000g. This may be due to the increased in the surface area of the bread dough to absorb maximum thermal energy dissipated from the heat exchangers. The baking efficiencies increased relatively with increase in the baking temperatures.

The baking efficiency of the WPBBO was determined by using the ratio of the designed baking time to the actual baking time required to bake a batch of dough to its desired taste, colour and texture in the rotary oven as calculated in (Okafor et al., 2014).

Heat loss in the oven

The heat loss from the oven to the environment was estimated as negligible because the WPBBO wall was totally insulated by high thermal insulation material of aluminum reinforced Fiberglas and assumed an adiabatically insulated boundary condition except via chimney and air ventilation hole provided on fire door which was of minimal and natural type and uncontrollable.

Weight loss in the baked bread

The weight loss in the food samples (bread dough) was calculated by subtracting the weight of the food sample after baking (heating) from the initial weight of the food sample.

The moisture loss in baked bread is minimal. Therefore the average weight losses or moisture for each three different weight of bread dough of 100g, 500g and 2000g were 15.867%, 6.24% and 6.3828% respectively.

Table 1: physical properties of un baked dough for different dough weight (gm)

Bread	weight of Un-baked Dough (g)	Surface Area (cm^2)	Volume (cm^3)	Density (g/cm^3)	Specific Volume (cm^3/g)
Small	100^c	4.54^c	16.25^c	6.1939^a	0.1625^c
medium	500^b	156.475^b	707.043^b	0.7323^c	1.4141^a
Large	2000^a	4897.007^a	1913.984^a	1.0791^b	0.957^b
Mean	866.6667	2040.168	879.0919	2.668419	4.517556
LSd	5.352241^{e-13}	1277.147	245.8837	0.3451783	3.429359
Cv	5.921161^{e-14}	60.02	26.81753	12.4026	72.78346

Note: means with the same letters in the same column are non-significant whereas the others are highly significant, Lsd=list significant difference, Cv = critical value for comparison.

Table 2: physical properties of baked dough (baked bread) and the experimental weight losses of bread during the baking.

Bread	baked Dough (g)	Surface Area (cm^2)	Volume (cm^3)	Density (g/cm^3)	Specific Volume(cm^3/g)	MCwb	MCdb	%rise
Small	85.875^c	27.34^b	132.0821^b	0.6638^a	1.541^a	14.125^a	16.52^a	74.29^a
medium	472.875^b	284.16^b	2798.98^b	0.1691^b	5.92^b	5.425^b	5.745^b	45.667^b
Large	1869.875^a	5809.00^a	11363.486^a	0.2192^b	6.0926^a	6.50625^b	6.692^b	28.07^c
Mean	9.0125	879.092	0.350667	0.845	8.68542	9.742097	9.742097	49.34435
lSd	0.07161	245.884	0.07598	0.20835	1.42723	1.958048	1.958048	6.750833
Cv	0.7618	26.8175	20.77665	23.655	15.7552	19.27056	19.27056	13.11726

Note: means with the same letters in the same column are non-significant whereas the others are highly significant, Lsd=list significant difference, Cv = critical value for comparison, MCwb =wet base moisture content of baked bread, MCdb= dry base moisture content of baked bread and %rise= percentage of baked bread rise in volume.

The table 1 and 2 showed that the wood powered bread baking oven was significant difference for $p<0.05$ and there moisture and weight dropped by 12.06%, 9.74g which was a minimal moisture and weight loss according to (Afolabi T.M. *et al*, 2017) 12.2% and 12.5g respectively for gas fired oven. This result showed that the oven was very effective and efficient relatively. The baked bread surface area, volume and specific volume were increased where as their density decrease after baked and result showed that the wood powered bread baking oven constructed was effective and performs well.

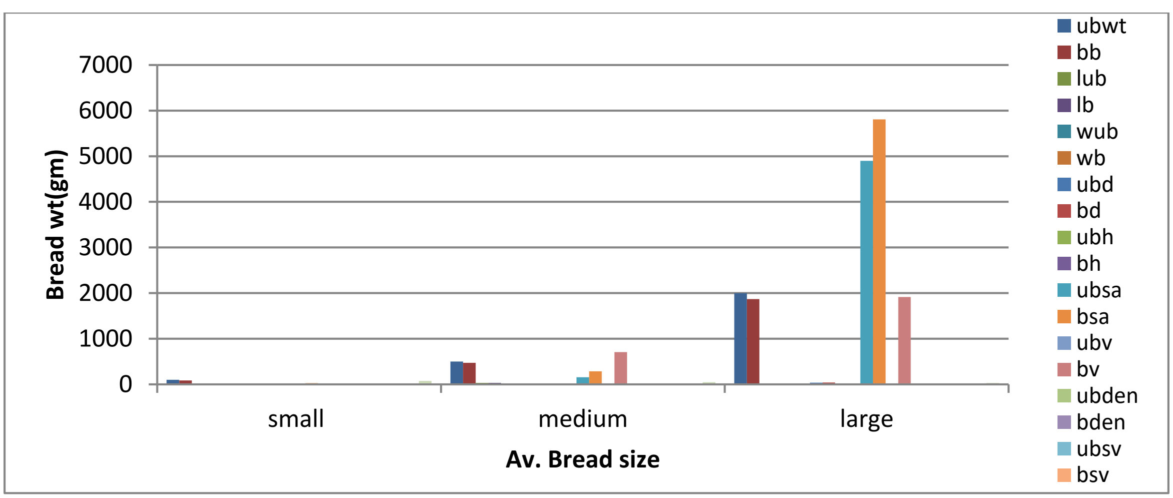

Figure 3: graph of physical properties of un baked dough and baked bread

The graph of graph of physical properties of unbaked dough and baked bread showed that there was significant difference between unbaked and baked bread in terms of its weight and size or volume.

Biomass fuel energy efficiency and moisture content

Parameter of the biomass fuel selection for fire wood when wood was alive and fresh it consists primarily of water, i.e. most of the weight was actually water. After being cut to length and stacked for a year or two the average moisture content generally drops to approximately 20% *(*Engineering ToolBox, 2003).

In the combustion process water is evaporated and the temperature is raised to fuel gas temperature. Dry wood has approximate combustion values of 16300kj/kg and 3890kcal/kg. for 20% air dry wood it has a Usable Energy of 97% by Volume and 81% energy per weight. Accordingly we have got the combustion value of 17,447.98watt

Weight loss during drying

During drying, paddy wood loses its weight due to loss of moisture. The moisture contents for four different locally available biomasses were found by weighing each sample before and after they were placed in the oven for a 72 h period at 65°C. The ash content were determined to obtained their moisture by examining four difference in the weight of the samples after combustion in a wood powered bread oven for 3-4 h. The densities were based on the volume and weight measurements of the samples. The volume was determined using a known amount of fine sand. The amount of wood used was determined by weight.

Wood thermal Efficiency

The system thermal efficiency was the ratio of net useful energy utilized to the gross energy supply and found to be 96.6% at 12.652% average air dry based weight according *(*Engineering Tool Box, 2012) 97% for 20% air dried tree wood. The experimental results (table 3 below) showed that locally available biomasses used such as eucalyptus and wadessa has good thermal efficiency than gatira and gravilia. However, gatira and gravilia has high air and oven dry weight than eucalyptus and wadessa, and their thermal efficiencies and heating time were lower than eucalyptus and wadessa which lasted up to 4:30-5:00 and 4:00-4:30 with the same weight of wood sample loaded for each batch of baking operation respectively. However, wadesa was not recommendable for fire wood since it was too cost because it was needed for other purpose than firing and therefore eucalyptus was the best fuel wood since it was also being cultivated as cash crop tree next to jima(chat) and can be easily affordable everywhere at any time at no or low cost at community level. It was sold by batch even on rod side, sub-urban and in urban too.

Table 3: Weight of fire wood different biomasses for fuel sources

woodtype	Air dry wt(g)	Oven dry wt(g)	MCwb(%)	MCdb(%)
Eucalyptus	428.60[b]	370.40[b]	13.699[a]	16.08[a]
Gatira	514.70[a]	449.2[a]	12.718[a]	14.724[a]
Wadessa	316.50[c]	279.80[c]	11.562[a]	13.082[a]
Gravilia	449.20[ab]	391.30[ab]	12.627[a]	14.705[a]
Mean	427.25	372.68	12.652	14.632
Lsd	79.126	68.604	2.9686	3.8831
cv	20.18	20.06	25.57	28.92

Note: means with the same letters in the same column are non-significant whereas the others are highly significant, Lsd=list significant difference Cv=critical value for comparison, MCwb =wet base moisture content of fire wood, MCdb= dry base moisture content of fire wood, and wt= weight in (g) of fire wood biomasses weighed air dry before taking laboratory for oven dry moisture content determination and after for 72hrs at65^{o}c.

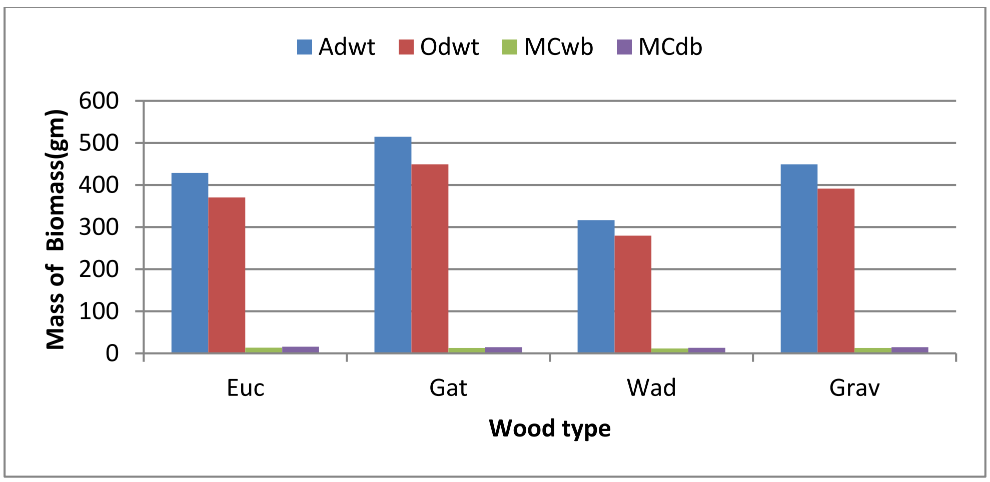

Figure 4: different biomass fuel wood weight for combustion and their moisture content determination.

Tests were conducted using four different local biomass fuel such as Eucalyptus grandi, Wadessa, Gatira and Gravilia with a 50cm length and having different diameter and weight individually, but equal weight for each per batch and splited into usable size for ease ignition.

Real-time temperature data was acquired by type K thermocouples installed into both top and bottom chamber and bread chamber.

The test includes measurement of fuel-wood consumed for each tests were pre-weighed and the quantities of the same weight of fuel-wood for both fire chamber (5 by 5 kg of fuel wood) and 10 kg of flour were put a side for every experiments conducted. A batch of firewood and flour was set aside and weighed before for each test of process.

Baking Process Temperature Profile

The oven baking process temperature profile is another important indicator about the energy consumption behavior of the equipment (bread dough). The temperature profile of the bread oven (WPBBO) showed that as baking temperature increased, baking time decreased. This result shows that oven performs well above 140^{o}c but more efficient at an average baking temperature of 229^{o}c .

Table 4: Average temperature recorded at an interval of 10minute difference

Trt(time.min)	TF(^{o}C)	BF(^{o}C)	BC(^{o}C)	Ch(^{o}C)	DR(^{o}C)	ET(^{o}C)	ERH(%)
0	26.40^b	26.77^e	28.9^c	29.925^b	30.650^c	25.325^a	36.50^a
10	345.22^a	347.80^d	262.63^{ab}	67.225^a	60.225^b	29.85^a	36.0^a
20	381.50^a	393.50^{cd}	272.18^{ab}	74.80^a	65.675^b	35.825^a	36.0^a
30	440.90^a	479.50^{ab}	288.05^a	81.70^a	77.30^a	38.075^a	35.50^a
40	463.65^a	495.73^a	256.92^{ab}	79.0^a	75.325^a	37.15^a	37.0^a
50	463.10^a	438.27^{abc}	251.72^{ab}	76.075^a	81.0^a	36.35^a	37.50^a
60	427.80^a	403.23^{bcd}	243.63^b	73.125^a	76.70^a	35.30^a	37.50^a
Mean	364.08	369.26	229.15	68.836	66.696	33.982	36.571
Lsd(5%)	119.69	81.039	39.586	16.901	9.0766	14.022	3.4764
Cv(%)	22.12	14.77	11.63	16.53	9.16	27.78	6.40

Note: means with the same letters in the same column are non-significant whereas the others are significant and highly significant respectively, Lsd= list significant difference, Cv=critical value for comparison, TF=top fire chamber temperature, BF= bottom fire chamber temperature, BC= bread chamber temperature, CH= chimney temperature, DR= doors temperature, ET= environmental temperature, ERH= environmental relative humidity and it was determined in two conditions: with no load and with full load conditions.

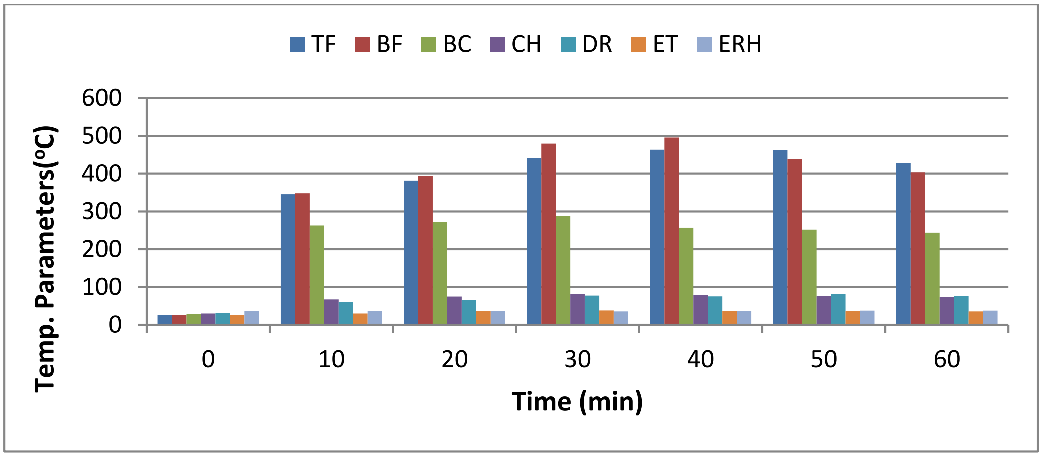

Figure 5. Baked bread Temperature profile for three different dough weights

Conclusions

The portable Wood powered bread baking oven was designed, constructed and evaluated using three different weight of bread dough of the same recipe. The dough was baked at an average temperature 229.15^{o}c. It was observed that during this experiment that baking temperature and baking period influence the rate of weight loss during baking process.

It was amazing to discover such an efficient and highly economical oven. With a very small quantity of wood, bread can be baked in a short time. What is even more interesting is that it does not depend on electricity and other fuel for heat supply. The wood provides the heat supply and it is readily available at a cheap rate. The performance evaluation of the oven showed that the oven is efficient, with a baking efficiency and baking capacity of 86.9%, and 96.6% respectively at baking period of 15-25 minutes that is 20-30 kg h-1 and for small, medium, and large bread baked respectively.

Recommendation

This oven is a very important piece for small scale farmers, governmentally organized youth, and small-scale business. The oven has a combination of efficiency and availability of raw materials for construction as well as evaluation. The oven can be used all in rural, per-urban and urban settlements. This oven has a largely advantages because of electricity power instability and shortage over large area of our rural society in Ethiopia and oromia too and it operates for a longer time with a minimum of biomass for fuel and operate with any type of air dried biomasses as fuel sources. The Federal and State Government should assist in the mass production of this oven to the end users. Improves bakeries and reduces their wood use, which in turn improves the situation for bakery owners. Reduces wood use that reduces deforestations and therefore also reduces CO_2 emissions. Reduces local air pollution because of reduced wood use and better combustion efficiency which is eco-friendly.

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Adaptation of Polyhouse Type Solar Drier Technology for hot pepper, groundnut and coffee bean drying

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Abstract

In this study two polyhouse type solar prototypes were prepared for test and performance check-up was carried out for series of days with conventional way of drying as standard check. The dryer was investigated with no load and fully loaded test. Performance evaluation of solar dryers were conducted with collector efficiency, drying efficiency and overall efficiency and average drying rate when hot pepper, coffee bean and groundnut pod was fully loaded. Average maximum and minimum temperature rating of polyhouse type solar dryer was registered to be 61.4 0c at 10-11-2020 for two consecutive hours and 23.4 0c at 03-01-2021 at commencing of drying processes respectively with no load test. With full load test, while hot pepper loaded in polyhouse type solar dryer maximum attainable temperature inside the dryer become 58.2 ^{0}C.Accordingly at end of hot pepper drying collector, drying and overall efficiency become 0.396664, 0.198753 and 0.078838 respectively; collector, drying and overall efficiency of dyer while coffee bean become 0.1521563, 0.759157 and 0.1535543 respectively whereas collector drying and overall efficiency become 0.3022587, 0.4308603 and 0.130231respectively. In polyhouse type solar dryer, with load and fully load test averaged maximum temperature rating of above 55 degrees Celsius was attained which is better temperature for drying of various food stuff with short time.

Key words: *solar dryer, hot pepper, coffee bean and groundnut pod*

Introduction

Solar drying of agricultural product is essential and most viable solution to reduce considerable loss, which occurs due to various reasons such as lack of suitable technology, improper cultivation and fertilization, lack of marketing channels, improper transportation, high post-harvest losses, etc., causing a food loss from 10 to 40%. The food preservation by solar drying is the only method to reduce the food loss that is being adopted since many centuries [1]. Various types of solar dryers had been designed to overcome these all problems. The type of dryer depends on the produce and the drying process required for that particular type of agricultural product.

Basically, the drying process involves the migration of water from the interior of the product to be dried on to the surface for its evaporation and therefore it is a heat and mass transfer phenomenon [2]**.** The convective heat transfer coefficient is an important parameter which determines the heat and mass transfer. The convective heat transfer coefficient varies from crop to crop and the mode of drying. In case of red pepper, the convective heat transfer coefficient becomes 1.31 W/m^2K [3]**.**The basic essence of drying is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time. Drying is a dual process of heat transfer to the product from the heating source. And mass transfer of moisture from the interior of the product to its surface and from the surface to the surrounding air [4]**.**

Solar dryer employed for the drying of agricultural produce can be broadly classified as *direct, indirect*, *mixed mode* and *hybrid solar dryers*. In *direct solar dryers*, solar radiation is transmitted through the transparent cover and absorbed on blackened interior surface. Due to *accumulation of energy*, heat builds up within the dryer from the direct sun and also due to the *greenhouse effect*. These types of solar dryer are suitable for small scalecrops, fruits and vegetables drying. The polyhouse dryer belongs to the greenhouse type of dryers. *In indirect solar dryers*, a separate solar collector is used to heat the air entering into the cabinet. The heat required for the drying operation in *mixed mode solar dryer* is produced by the combined action of solar radiation incident on the produce and the preheated air in the solar collector. Performance of the above driers depends on the variations in insulation, ambient temperature and relative humidity. *Hybrid solar driers* partly depend on solar. They utilize solar energy, electrical energy or fossil fuel-based heating systems [5].

Solar driers are more effective than sun drying, with lower operating costs than mechanized driers.Direct sunlight for drying allows foods to be dried immediately after harvest at low capital, low operating costs and with requirement of a little expertise. However, considerable losses may occur during natural sun drying due to various influences such as rodents, birds, insects, theft, slow or intermittent drying and no protection from rain or dew that wets the product. The quality of dried products may also be lowered significantly due to over or under drying and contamination by dust and insect infestation are typical for natural sun drying. Moreover, since sun drying depends on uncontrolled factors, production of uniform and standard products is not expected.

An extensive study has been conducted on different types of direct solar dryers such as box/cabinet-type, tent type, and polyhouse solar dryers for drying of agricultural produce. Poly-house dryers are now being increasingly used because they are more efficient option of direct solar driers [6]. It is a unique and cost efficient method of drying agricultural products on small as well as commercial scale. It consists of a drying chamber, an exhaust chimney. The roof and the wall of a PHD are made by transparent plastic films that are mounted on a metal frame. The sheet has a transitivity of approximately 92% for visible radiation which traps the solar energy during the day and maintains optimum temperature for drying of produce. UV stabilized films play an important role in polyhouse dryers. The sheet allows only short wavelength which is converted into long wavelength when it strikes on the surface of product or a black body.

Based on the mode of heat transfer, polyhouse solar dryer is classified into passive and active polyhouse dryer. The passive mode dryer works on the principle of thermosiphon effect i.e., the moist air gets ventilated through the outlet provided at the roof or through the chimney of the dryer. For active polyhouse dryer, there are two energy sources namely the air saturation deficit and the incident global solar radiation. Both natural and forced convection methods circulate the hot air to agricultural products or crops.

In traditional method of drying agricultural products, crops are spread in open sun-light on the ground, floors or on roofs of houses and stirred once or twice day. The thickness of such a spread may vary from 10 to 15 cm depending on the product types [7]**.** The crops are heaped in the evening and covered with thin layer mat and are spread again the next day morning till they are completely dried upby being exposed to the sun and wind in an open environment.Therefore, to void such loss and drudgery, solar dryer with natural convection solar air heater will be applied for drying of agricultural products. This type solar dryer is financial profitability and more applicable in tropical and subtropical zones.

For hot pepper, the maximum permissible temperature inside the dryer is 65°C with initial and final moisture content is 80% & 5% respectively[8]**.** The temperature of dryers should never exceed above 70°C, otherwise the product set to be dried will tend to be cooked rather than dry[9]**.** Drying temperature above 65°C has to be avoided in order to prevent color changes induced by high temperature [10] suggested that the optimum temperature for drying of hot pepper should be 60°c.

Because of the advantages of polyhouse solar dryer over other small-scale driers, the initiation of this work is to develop and evaluate passive mode polyhouse type solar drier for hot pepper, groundnut and coffee drying purpose to increase their quality.The purpose of this research project was toevaluate the feasibility of employing solar dryingtechnology to dry freshly-harvested hot pepper, coffee bean and peanuts and itsimpact on seed quality.

Materials and Methods

Description of study area

West Shoa and East Wellega zones of Oromia region have large production potential of hot pepper, coffee and groundnut. However significant amount of these product got lost their quality due to insufficient drying process and marketing difficulties. Drying these products could help to increase the quality and solve problem associated with losses. Ethiopia has great potential for the use of solar energy. The average solar irradiation is more than 600wh/square meter for more than 8 months a year *(https://www.reeep.org/ethiopia-2014, accessed on 24, January 2017)*[11]. Harvesting this potential and using for small scale product processing is essential in transforming agriculture.

Design Preparation and Materials Selection

Conceptual design and material selection for construction of polyhouse solar dryer had been consecutively executed. Based on the specifications, the required materialslikepolyethylene sheet, angle iron, plywood, water pipe, upper vent and mesh wire for chamber were prepared and the prototype was produced.

Design Features of the Dryer

The poly house type Dryer was used for this experimental work. It consisted of base frame, rectangular drying chamber, solar collector, absorber and air distribution system with chimney. The required dimensions of the solar dryer were determined based on physical properties of agricultural products employed for drying purpose and specific design prepared for them. Consequently, the dryer had overall dimensions of 3mx3mx2.5mandhas trays that have capacity to hold about 4, 3, 3quntal of raw hot pepper, groundnut and coffee respectively.Exhaust vents were suited over upper part of solar collector so as to remove humid air.The vents have sliding covers which control air inflow and outflow.

Construction of the Dryer

Prototype of polyhouse type solar dryer was constructed in Bako Agricultural Engineering Research Center workshop as follow independently. Solar collector chamber standing and lateral frame that supported whole or entire body of solar dryer get allied and build up to make completed dryer.Consequently, the stand and frame parts were formed from half and three-fourth inch of water pipe. Polyethylene sheet type solar plastic was used to cover whole the dryer chamber. Solar plastic material was covered over the roof and all lateral side parts in order to generate and conserve considerable of amount heat for drying purpose. Exhaust vents were suited over upper part drying chamber so as to remove humid air. In order to increase amount humid air from dryer, four vents were employed. Finally, five trays which had different carrying capacity were prepared from 5mm and 2mm diameter of mesh wire to store and well ventilating the agricultural products. The mish wire gave important contact of air and the product as well played great role in moisture reduction.Eventually, all units were get assembled to give complete solar drying equipment and prepared for experimental testing.

Figure 1. Prototype of polyhouse solar drier seems this when constructed

Performance Evaluation

After prototype construction of polyhouse type solar dryer get accomplished, performance evaluation and testing of the dryer was carried out with No Load and Full load test as follow.

No Load Test

Here performance of the prototype was evaluated under no load condition. The highest and lowest temperature absorbed on the drying chamber by the drier was recorded for sun shine hours of the study area. The average temperature inside the polyhouse type solar drier was compared with the average ambient temperature. This temperature was compared with quick dehydration temperature of hot pepper, coffee and groundnut. The maximum relative humidity attained inside the dryer under no load condition was also be compared with recommendation.

Full Load Test

For case ofinitial test, samples of hot pepper, coffee and groundnut were spread uniformly in layer thickness of 10mm on tray prepared in the drying chamber. However, for normal experimental test, the dryer was loaded to its full capacity based on recommendation from literature. Before experimental test was conducted or carried out, moisture content of each raw agricultural products was estimated using standard method. As result, moisture content of the three of the items were tried to estimate employing over electrical oven drier before storage get employed.Each agricultural product was set over electrical oven drier for 72 hours at specific temperature of 55 0C to estimate moisture content of employed crops.

In order to make data reliable, various samples of each three agricultural products (raw hot pepper, groundnut, and coffee bean) were taken by repeating three times and average data were used. Moisture content of each agricultural product was estimated using standard formula below:

$$Mc = \frac{W_{ws} - W_{ds}}{W_{ds}} x100$$

Where as W_{ws}- weight of wet sample and W_{ds}-weight of dried. Moisture content of these agricultutal products were computed using this forumula employing standard insturments. During the drying operation, the temperature (ambient air, inside the dryer and at exhaust), relative humidity (ambient and inside the dryer), solar radiation and air velocity were recorded each day of experiment.

Figure 2. When three agricultural products get fully loaded in the drier chamber

Nutritional Value Analysis

Most of the time, in developing countries, agricultural products are usually dried with an open sun method. This method of drying process is economical and does not require well qualified skilled human for operation. Now a day, there are different types of solar drying technology were developed and employed for drying agricultural products. Polyhouse type solar dryer is one of technology applied for drying hot pepper, groundnut and coffee bean. Here, we need to see drying the products with technology can affect their nutritional value or not. Thus, their initial chemical composition before drying and after drying were identified employing standard laboratory analysis.

Parameters considered during evaluation

Performance evaluation of the solar dryers was done on the basis of operational parameters that significantly influence the performance of a dryer. These are drying air characteristics (such as drying air temperature, humidity and airflow rate);product variables (product Throughput, initial and final moisture contents, product size and size distribution) anddimensional variables (width, length, height or diameter of the dryer, number of passes and dryer configuration). And based on these parameters the following performance indicators was computed.

Data collection and analyzing method

Drying air characteristics such as drying air temperature, humidity and airflow rate; product variables that is initial and final moisture contents, product size and size distribution and dimensional variables (width, length, height or diameter of the dryer and dryer configuration) were collected by measurement. The collected data was arranged and analyzed by using simple descriptive analytical method.

Collected Data

Recorded data of temperature of drier, temperature at vent exit, ambient temperature, sky and black body temperature on 10 December, 2020 while row*hot pepper* was loaded in polyhouse solar drier.

Time (s)	Temp of dryer (c^0)	Temp of air (c^0)	Temp @ vent exit ($c^{0)}$	Sky temp (c^0)	Black Body (c^0)	Solar radiation (w/m^2)
10	32.6	21.4	30.6	-10	46.0	395.4
60	42.4	21.5	33.4	-4	55.0	468.0
120	49.2	30.9	34.6	-7.4	59.2	473.8
180	52.8	31.6	33.9	9.4	65.8	598.8
240	55.8	32.1	33.9	-5.8	70.4	626.5
300	55.2	32.4	33.6	-16	70.6	678.3
360	53.6	30.2	32.5	-21	67.4	600.4
420	47.8	28.4	29.6	-7.2	44.8	313.9

Table 1. Measurement of above stated parameter when row hot pepper fully loaded in the drier

Recorded data of temperature of drier, temperature at vent exit, ambient temperature, sky and black body temperature on 03 January, 2020 while *coffee* was set in polyhouse type solar drier.

Table 2. Measurement of above stated parameter when row coffee bean fully loaded in the drier

Time (s)	Temp of dryer (c^0)	Temp of air (c^0)	Temp @ vent exit (c^0)	Sky temp (c^0)	Black Body (c^0)	Solar radiation (w/m^2)
10	28.5	26.5	30.7	-6.0	52.6	3489.1
60	49.1	27.9	31.1	-16	68.5	523.8
120	52.3	32.4	33.5	-14	69.0	520.5
180	54.6	33.2	34.0	-14	67.8	509.7
240	53.9	32.4	32.2	-14	65.4	488.4
300	57.6	30.0	32.9	-10	60.8	448.8
360	46.4	29.4	30.5	-19	56.4	431.5
420	42.3	27.3	29.6	-19	52.3	398.9

Recorded data of temperature of drier, temperature at vent exit, ambient temperature, sky and black body temperature on 04December, 2020 while *groundnut* was set in polyhouse type solar drier.

Table 3. Measurement of above stated parameter when row groundnut fully loaded in the drier

Time (s)	Temp of dry-er (c^0)	Temp of air (c^0)	Temp at vent exit	Sky temp (c^0)	Black Body (c^0)	Solar Radiation (w/m^2)
10	43.5	30.9	32.2	-35	54.8	472.7
60	45.2	33.9	31.1	-26	67.8	553.8
120	53.9	32.6	33.6	-25	76.6	632.5
180	56.8	31.3	33.9	-26	83.8	707.9
240	58.2	32.2	31.7	-24	77.6	638.7
300	43.9	33.1	34.3	2.6	67.0	430.4
360	48.2	32.4	32.5	-12	59.2	427.4
420	46.2	28.6	29.5	-12	48.4	340.4

Collector Efficiency

Collector efficiency is defined as the ratio of energy output of the collector to energy input to the collector. Solar energy input on the collector was computed as:

$$I_{Ac} = 10^{-3} A_c S_r T$$

Where, I_{AC} - Input to the collector, kJ, A_c - Area of solar Collector, m2, S_r – Solar radiations W/m2, T - Time, s. The output of the collector in terms of energy is the amount of heat generated inside the dryer.

$$O_{Ac} = \left(m_s C_p \Delta t\right) + m_a (H_2 - H_1)$$

Where; O_{AC} -Output of the collector, kJ, m_s - Mass of the sample material, kg, C_p - Specific heat of material, kJ/kg/0C (3.954 kJ/kg/ 0C), m_a - mass of air, kg, H_2 - Enthalpy of air at exhaust conditions, kJ/kg, H_1 - Enthalpy of air at ambient conditions, kJ/kg.

Therefore, collector efficiency was computed as follow:

$$\eta_c = \frac{O_{AC}}{I_{Ac}}$$

Where: ηc - Collector efficiency, %.

Drying Efficiency

The drying efficiency is defined as the ratio of energy output of the drying section to energy input to the drying section. The output of the dryer in terms of energy is amount of heat required to remove moisture from material, considering sensible heating of the sample is very small in comparison with latent heat.

$$O_d = m_r L_v$$

Where: O_d - Output of the dryer, kJ, m_r - Moisture removed, kg, L_v - latent heat of vaporization of moisture, kJ/kg. The amount of moisture to be removed from the product, m_r, in kg was calculated using the following equation:

$$m_r = \frac{m_p(m_i - m_f)}{100 - m_f}$$

Where m_p is the initial mass of product to be dried, m_i is the initial moisture content, % wet basis and m_f is the final moisture content, % wet basis.

Average drying rate, d_r [kg/hr], will be determined from the mass of moisture (m_r) to be removed by solar heat and drying time (t_d) by the following equation

$$d_r = \frac{m_r}{t_d}$$

Thus, efficiency of the dryer is:

$$\eta_d = \frac{O_d}{I_{AC}}$$

Where, η_d - Drying efficiency, %

Overall Efficiency of Dryer

The overall efficiency of dryer is defined as the ratio of energy output of the dryer to total energy input. Thus, overall efficiency of the system is,

$$\eta_o = \frac{m_r L_v}{I_{AC}} * \eta c$$

Where, ηo - Overall efficiency of dryer, %

Result and Discussion

As stated before, hot pepper, coffee and groundnut agricultural products were kept in solar drying chamber to increase quality of product post drying. Polyhouse type of solar drying was entirely constructed from materials locally available and the construction was seriously made in order to preserve solar energy propagated into solar collector. From previous analysis done so far, it was concluded that solar drier need to be modified particular on size, drier material, arrangement and type of tray used require special attention. As result trays of the dryer were changed from ply wood to mesh wire and also its arrangement was changed from overlap to parallel in order to avoid over shadows. Another determining parameter was thickness of crop over layer. So, amount of thickness of crop used is another important factor and lesser denser get short drying time than denser. The closer tray to upper roof got faster in drying than the lower far from roof and arrangement of tray affect drying rate and time too.

Before drying begin, prior data particularly on solar dryers were collected and recorded. Temperature and relative humidity of surrounding environment and drying chamber were collected at day time to characterize their daily status. As a whole,ambient temperature and humidity as well as temperature and humidity of dryer were among those important treatment collected to determine number of days the product required to be dried without losses occurred. Collector important parameters like collector and drying efficiencies were calculated in order to determine the performance of polyhouse type solar dryer.

Moisture Content of the product

Evaluation of solar drier was accomplished over the required parameters and all necessary data were collected.Conventional or traditional way of drying system was used as standard check. Normally local farmers were usually dried hot pepper, groundnut and coffee bean by employing traditional methods such as spreading on the ground floor and over the roof corrugated iron sheet. It exposes the product to many challenges. This traditional way of drying agricultural products approximately requires drying time interval of 10-15 days.

According to Singh, 2013 [7] thickness of crops spread over ground, floors or on roofs of houses vary from 10 to 15 cm depending on product types. Drying time of the product can be influenced with thickness of layer of the product, size and arrangement of drying units. Lesser denser in thickness get shorter drying time than denser.The more closed tray to upper roof gets faster in drying than the lower far from roof so that arrangement of tray affect drying rate and time. In order to solve the problem,dryer tray was constructed from mesh wire and also its arrangement was changed from overlap to parallel in order to avoid over shadows.The trays have carrying capacity of 400, 300 and 300 of raw hot pepper, groundnut, and coffee respectively.

Moisture content of hot pepper, coffee bean and ground were estimated at three stages. Initial moisture content of hot pepper, coffee bean and groundnut were measured during beginning of drying process. Intermediate moisture measurement was done four days after drying started. Final moisture contents were estimated at the end of drying day of 7days for hot pepper ,6 days for coffee bean and 6 days for groundnut.

Table 4. Moisture content of agricultural products

No	Name of item	Initial Moisture (%)	Intermediate (%)	Final Moisture (%)
1	Hot pepper	76.15	16.41	11.89
2	Coffee Bean	74.7	9.27	8.22
3	Groundnut	43.88	5.58	5.51

Analysis of Nutritional Value

In developing countries, agricultural products are usually dried with an open sun method.Solar drying is also an old, however re-emergingtechnology which is economical and affordable andmay avoid some of the problems associated withopen sun drying[12].At recent, there are many types of solar drying technologies were developed and employed for drying agricultural products.

However, Sunning is the earliest and most simple processing method of traditional coffee beans, hot pepper and groundnut pod. Because it does not involve the fermentation process, pectin is preserved and dried, and the sweetness is relatively high[13]. In addition,tray drying (TD) and sun drying (SD) did not affect the caffeine content, but influenced levels of some amino acids [14]. However, for the case of data limitation here mineral contents of hot pepper, coffee bean and groundnut pod before drying and after drying were analyzed employing PTSD and conventional.

Table 5. Mineral content of hot pepper, coffee bean & groundnut pod while inside dryer and outside dryer

SN	Name of Item	Inside dryer				Outside dryer			
		Mineral @ AASS		Mineral @dry basis		Mineral @ AASS		Mineral @ dry basis	
		Fe(ppm)	Zn(ppm)	Fe(ppm)	Zn(ppm)	Fe(ppm)	Zn(ppm)	Fe(ppm)	Zn(ppm)
1	Hot pepper								
1.1	Initial Sample	34.72	19.8	39.4	18.7	29.3	16.9	33.05	18.26
1.2	Intermediate	64.10	15.35	76.68	18.37				
1.3	Final sample	102.32	22.99	116.13	26.10	74.17	21.75	83.66	24.54
2	Coffee Bean								
2.1	Initial Sample	39.56	10.99	39.56	10.99	674.75	8.44	674.75	8.44
2.2	Intermediate	90.98	12.19	90.98	12.19	33.46	7.35	33.46	7.35
2.3	Final sample	41.75	10.81	45.49	11.78	54.06	10.6	59.59	11.69
3	Groundnut								
3.1	Initial Sample								
3.2	Intermediate	707.52	26.73	749.34	28.31				
3.3	Final sample	22.37	23.81	23.67	25.21	25.46	23.23	26.83	24.48

Performance Test

Performance evaluation and testing of polyhouse type solar dryer was carried out with no load and full load test. In both test procedures temperature of the dryers and environmental temperature was collected and compared with recommendation given by related literature done so far.

Temperature distributionwhen no load Test

In this stage, the highest and lowest temperature absorbed by drier with no load action was recorded for sun shine hours of the study area. Comparison of average temperature inside the polyhouse type solar drier and ambient temperature was done. This temperature was compared with quick dehydration temperature of hot pepper, coffee and groundnut. The maximum relative humidity attained inside the dryer under no load condition was also be compared with recommendation.

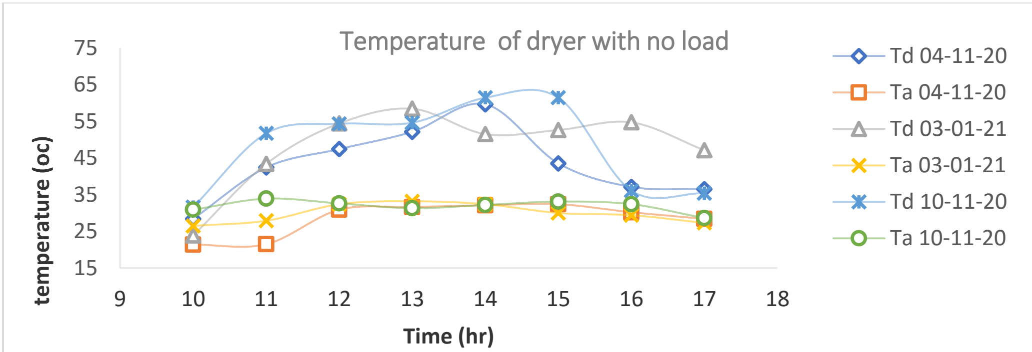

Figure 3. Temperature dryer and ambient temperature distribution with no load operation

Average maximum temperature rating of polyhouse type solar dryer was registered to be 61.4 0c at 10-11-2020 for two consecutive hours whereas average minimum temperature was recorded to become 23.4 0c at 03-01-2021 at commencing of drying processes. Average maximum ambient temperature was 33.4 0c at 03-010-2021 and minimum was registered to be 21.4 at 04-11-2020.

Temperature Distribution when full load Test

In this stage, the dryer was loaded to its full capacity based on recommendation from literature. Here in the dryer employed of hot pepper, coffee and groundnut were spread uniformly in layer thickness of 10mm on tray prepared in the drying chamber. Before experimental test was conducted or carried out, moisture content of each raw agricultural products was estimated. Average temperature in the dryer and environmental temperature during drying process of hot pepper, coffee bean and groundnut collected and compared as follow.

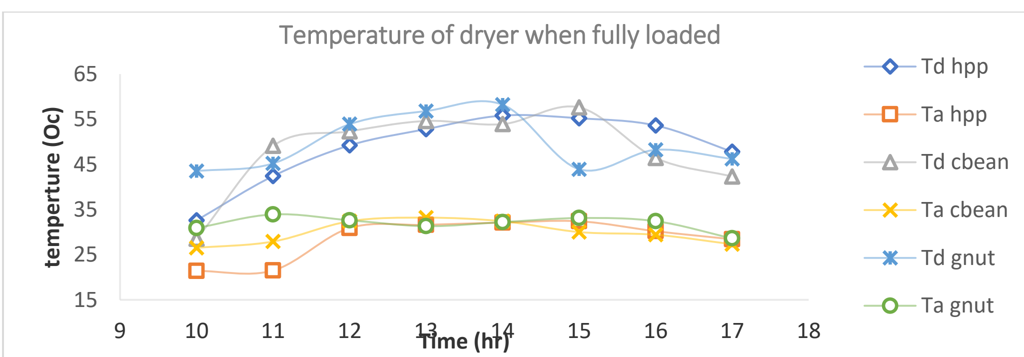

Figure 4. Temperature dryer and ambient temperature distribution

According to Spagna, 1993[8] for hot pepper maximum permissible temperature inside the dryer is 65 °C with initial and final moisture content is 80% and 5% respectively. The temperature of dryers above 70°C turn the product to cook rather than dry**.**

However, Ramesh, 2001[10] suggested that drying temperature above 65°C has to be avoided in order to prevent color changes induced by high temperature· He suggested that the optimum temperature for drying of red pepper should be 60°c.

According to our experimental test, polyhouse type solar dryer while loaded with hot pepper attained maximum temperature inside the dryer become 58.2 ^{0}C with initial & final moisture content is 76.15 and 11.89 %.This result was measured at the end of seven consecutive drying periods. The temperature and moisture recorded was still far below recommendation suggested for different solar dryer.For the case of coffee bean, average maximum temperature inside the dryer was 55.80c with initial & final moisture content is 74.7 and 8.22 % where as in groundnut pod drying, maximum temperature inside the dryer was 55.60c with initial & final moisture content is 43.88 % & 5.51%.

Solar Radiation

An average solar radiation of the when hot pepper, coffee bean and groundnut pod were kept in the dryer until withdrawal of the product. Normally hot pepper kept in the dryer for seven consecutive days where as coffee bean and groundnut pod were kept for six days a lonely. The data here were recorded during the specific days.

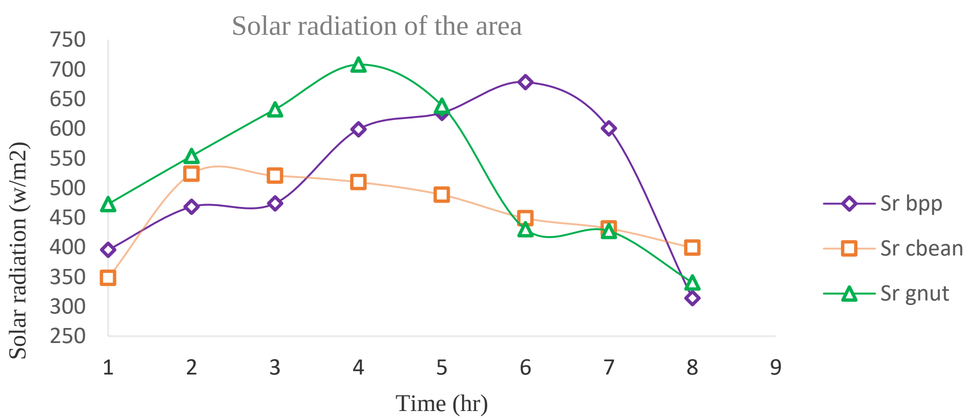

Figure 5. Solar radiation pattern when hot pepper, coffee bean and groundnut get loaded

Average maximum and minimum solar radiation attained while drying hot pepper become 678.3 and 395.4 w/m^2 respectively. For the case coffee bean drying operation, average maximum and minimum solar radiation of 523.8 and 348.1 w/m^{2}was attainable respectively. Whereas for groundnut drying process, average maximum and minimum solar radiation of 707.9 and 427.7 w/m^{2}were registered respectively. These all measured solar radiation attainable were far below recommendation and influenced moisture removement process of drying chamber.

Parameters which were important to estimate performance of polyhouse type solar dryercalculated and characterized in table 5 below. Consequently, average solar radiation, input energy and heat generated and whole efficiency of the dryer were determined while 80 kg of row hot pepper when employed for drying or admitted into dryer.

Table 5. Collector efficiency, drying efficiency and overall efficiency of polyhouse type solar dryer for hot pepper drying

S_r (w/m^2)	**Time (s)**	**I_{ac}**	**O_{ac}**	**η_c**	**O_d**	**η_d**	**η_0**
395.4	0	0	258465.8803	0	23572.12	0	0
468	3600	40435.2	481960.0764	0.0838974	23348.59	0.577432	0.048445
473.8	7200	81872.64	422298.9299	0.1938737	23193.49	0.283287	0.054922
598.8	10800	155208.96	489068.8536	0.3173561	23111.38	0.148905	0.047256
626.5	14400	216518.4	546655.1937	0.3960786	23042.95	0.106425	0.042153
678.3	18000	293025.6	525921.7583	0.5571658	23056.64	0.078685	0.04384
600.4	21600	311247.36	539642.6064	0.5767657	23093.13	0.074195	0.042793
313.9	25200	189846.72	447379.1466	0.4243531	23225.42	0.122338	0.051914
519.39	25200	184022.1257	463924.0557	0.3966643	23205.47	0.198753	0.078838
Mean Value							

Initial mass of hot pepper was 80 kg and specific heat capacity of hot pepper become 287.73 kJ/kg0c. Total area of the collector is 24 m^2. The amount of moisture gets removed from the hot pepper when calculated become ($m_{r\ hpp}$) 58.3453 kg and mass of hot pepper at exit of dryer became 21.655kg. Amount of mass air that was required to drive out the stated moisture from the hot pepper ($m_{a\ hpp}$) 2.1618 kg of dry air. Average drying rate ($d_{r\ hpp}$) become 1.3892 kg/hr. This was determined from the mass of moisture to be removed by solar heat and drying time. An average solar radiation become 519.39 w/m^2 it is relative so small when compared with other literature [12].

Average solar collector efficiency, drying efficiency and overall efficiency of polyhouse type solar dryer for drying 80 kg of row hot pepper become 0.396664, 0.198753 and 0.078838 respectively. However, few literatures predict out that collector efficiency (η_c) of solar dryer usually rang from 30 to 50 % [12,13].

Therefore, according to these authors, our collector efficiency in the safe range. However, drying efficiency become higher in starting time and become lower while drying operation take place. This is because the temperature difference or in gradient become decreasing as time of drying increasing. In other way temperature of dryer become little bite equal with average environmental temperature.

Parameters which were important to estimate performance of polyhouse type solar dryercalculated and characterized in table 6 below. Consequently, average solar radiation, input energy and heat generated and whole efficiency of the dryer were determined while 50 kg of row coffee bean when employed for drying or admitted into dryer.

Table 6. Collector efficiency, drying efficiency and overall efficiency of polyhouse type solar dryer for coffee bean drying

S_r (w/m^2)	**Time (s)**	**I_{ac}**	**O_{ac}**	η_c	**O_d**	η_d	η_0
348.1	0	0	2029.840869	0	87977.24	0	0
523.8	3600	45256.32	13643.24229	0.301466	87942.62	1.943212	0.5858123
520.5	7200	89942.4	19212.69152	0.2136111	87734.88	0.975456	0.2083682
509.7	10800	132114.24	20652.81028	0.1563254	87691.6	0.663756	0.1037619
488.4	14400	168791.04	20748.21762	0.1229225	87847.4	0.520451	0.0639751
448.8	18000	193881.6	26600.72171	0.1372009	87786.81	0.452786	0.0621226
431.5	21600	223689.6	16427.43905	0.0734385	87994.55	0.393378	0.0288891
398.9	25200	241254.72	14506.55343	0.0601296	88072.45	0.36506	0.0219509
458.72	25200	156418.56	16727.6896	0.1521563	87880.94	0.759157	0.1535543
Mean Value							

Initial mass of coffee bean used was 50 kg and specific heat capacity of coffee bean becomes 1.918 kJ/kg0c. Total area of the collector is 10 m^2. The amount of moisture gets removed from the coffee bean when calculated become ($m_{r\ cbean}$) 36.2171 kg and mass of coffee bean at time of exit from dryer became 13.7829 kg. Amount of mass air that was required to drive out the stated moisture from the hot pepper ($m_{a\ cbean}$) 1.2919 kg of dry air. Average drying rate ($d_{r\ cbean}$) become 0.8623 kg/hr. This was determined from the mass of moisture to be removed by solar heat and drying time. An average solar radiation become 458.72w/m^2 it is relative so small when compared with other literature [12].

Average solar collector efficiency, drying efficiency and overall efficiency of polyhouse type solar dryer for drying 50 kg of row coffee bean become 0.1521563,0.759157 and 0.1535543 respectively.Drying efficiency become greater than solar collector efficiency due to size of agricultural product is so smaller as compared with previous item. Since the surface area of coffee bean so small, hot air get high chance to contact many surfaces. Many parts of the product are exposed to air for contact so that can easily react to take high heat transfer activity. Because of this more moisture can easily be removed from the product and drying time may be shorter. As the result coffee bean was dried to final moisture of 8.22 % within six consecutive days.

Drying efficiency become higher in starting time and become lowering while drying operation going on. This is because the temperature difference or in gradient become decreasing as time of drying increasing. In other way temperature of dryer become little bite equal with average environmental temperature.

Parameters which were important to estimate performance of polyhouse type solar dryercalculated and characterized in table 7 below. Consequently, average solar radiation, input energy and heat generated and whole efficiency of the dryer were determined while 60 kg of row groundnut when employed for drying or admitted into dryer.

Table 7. Collector efficiency, drying efficiency and overall efficiency of polyhouse type solar dryer for groundnut drying

S_r (w/m^2)	T (second)	I_{ac}	O_{ac}	η_c	O_d	η_d	η_0
472.7	0	0	33793.70775	0	63270.3464	0	0
553.8	3600	47848.32	30332.68438	0.6339342	63165.161	0.9201124	0.836864
632.5	7200	109296	57000.47652	0.5215239	62626.8592	0.5730023	0.298834
707.9	10800	183487.68	68199.40723	0.3716838	62447.4253	0.3403358	0.126497
638.7	14400	220734.72	69534.77033	0.3150151	62360.802	0.2825147	0.088996
430.4	18000	185932.8	28997.52578	0.155957	63245.5969	0.340153	0.053049
427.4	21600	221564.16	42331.3196	0.1910567	62979.5397	0.2842497	0.054308
340.4	25200	205873.92	47124.22945	0.2288985	63103.2872	0.3065142	0.070161
525.48	25200	167819.6571	47164.26513	0.3022587	62899.8772	0.4308603	0.130231
Mean Value							

Initial mass of groundnut pod was 60 kg and specific heat capacity of coffee bean becomes 1.918 kJ/kg0c. Total area of the collector is 10 m^2. The amount of moisture gets removed from the hot pepper when calculated become ($m_{r\ cbean}$) 36.2171 kg and mass of groundnut pod at time of exit from dryer became 23.7829 kg. Amount of mass air that was required to drive out the stated moisture from the hot pepper ($m_{a\ cbean}$) 1.2919 kg of dry air. Average drying rate ($d_{r\ cbean}$) become 0.8623 kg/hr. This was determined from the mass of moisture to be removed by solar heat and drying time. An average solar radiation become 525.48 w/m^2 it is relative so small when compared with other literature [12].

Average solar collector efficiency, drying efficiency and overall efficiency of polyhouse type solar dryer for drying 60 kg of row groundnut pod or peanuts pod became 0.3022587, 0.4308603 and 0.130231respectively.

Solar collector efficiency is lower than drying efficiency of polyhouse type solar dryer when groundnut pod was fully loaded in the dryer. Product size of groundnut pod is bigger than coffee bean and the pod is stronger. Groundnut pod that was loaded in the solar dryer had initial moisture content of 43.88 % which is less than coffee bean. When it was subjected to solar dryer with average solar radiation of 525.48 w/m^2, considerable amount of moisture was removed quickly and drying rate or efficiency become well than other.

Conclusion and Recommendation

The study was conducted to investigate performance of polyhouse type of solar dryer when hot pepper, coffee bean and groundnut pod was loaded fully for drying purpose under solar insolation. Normally, two prototypes were prepared and series of experimental test was carried out under the same and different environmental condition. While the test was conducted, it was observed that various parameters were engaged to identify and determine status of the dryer.Collector efficiency of, dryer efficiency, overall efficiency and drying rate of hot pepper, coffee bean and groundnut pod when fully loaded was calculated and comparison were done.

Therefore, average maximum temperature of the dryer while hot pepper, coffee bean and groundnut pod were loaded become 58.2, 55.8 and 55.6 ^{0}C respectively. Average maximum temperature of 61.4 ^{0}C was attainable with no load test. In case of collector efficiency, maximum value was gained while hot pepper was loaded. Maximum drying efficiency were calculated while coffee bean was fully loaded. From the experimental result obtained, it can be concluded that solar drier need to be modified particular on size and shape, drier material, arrangement and size of tray required special attention. Dryer materials is not durable and has short life span. On drying rate and time, amount of thickness of crop used had big factor and influences the performance of the dryer. Furthermore, the closer tray to upper roof gets faster in drying than the lower far from roof. Therefore, appropriate arrangement and position must be allocated the problem associated with drying uniformity to remove irregularity.

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