Regional Review Workshop on Completed Research Activities

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Preface

Agricultural production can be increased by using direct inputs of improved seeds and fertilizers, and/or by bringing more land under production. Nonetheless, these alone cannot affect sustained increase in production and productivity. One of the other important technological interventions is Agricultural Engineering Science and Technology. Agricultural Engineering is generally defined as the application of engineering knowledge and skills to solve problems of agriculture. Based on these principles, currently, the Agricultural Engineering Research Directorate of the Oromia Agricultural Research Institute is doing unreserved efforts through its research centers in generating, modifying and adapting improved agricultural engineering technologies, with the objectives of increasing labor productivity, decreasing post-harvest loses, conserving soil and water, increasing water use efficiency, decreasing deforestation and indoor air pollution.

The present research teams of the directorate are; Agricultural machineries and power, soil and water engineering, agricultural postharvest and product processing engineering and Renewable energy technologies.

The technologies comprise tillage implements and machineries, animal and mechanical power utilization for farm purposes, irrigation and efficient water resources utilization technologies drainage systems, and soil conservation measures, postharvest product processing, storage and handling facilities, animal confinements, processing of the products for value addition of food and feed as well as for the agricultural based renewable energy sources utilization technologies.

Though unlimited efforts have been made by the IQQO to progress in availing and making the regional farmers beneficial out of these technologies, however, there are huge research gaps identified to be addressed with in the short, medium and long term strategic approaches of the directorate in order to meet the dynamically changing technology demanding of the region. Some of the identified gaps are low efficiency of the developed technologies, piece and bit technology generation approaches, in adequate types of generation and prototype multiplication, etc. Thus the current and the future research directions of the directorate and the centers will be focused on the reduction of these gaps and making benefit of the farmers out of the utilization of the technologies in improving their farming practices and livelihoods, mainly by generating and or adapting powered and multipurpose mechanical farming technologies and information.

Aims and Scope of the Proceeding

The main aim of the Proceeding of the Agricultural Engineering Research Directorate's Completed Research Activities Review Workshop, is to provide a medium for dissemination of Technical and Scientific information emanating from research on Engineering for Agriculture. This, it is hoped will encourage researchers in the area to continue to develop appropriate and improved technologies for solving the numerous engineering problems facing agriculture in Oromia in particular and Ethiopia in general.

Contents

Performance Evaluation of Dharti Seed cum Fertilizer Drill Wheat Crop Planter

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ABSTRACT

This study was undertaken to evaluate the performance of imported animal drawn row planter for wheat seeds at predetermined spacing and depths. Physical properties of seeds involved in the study were investigated to select metering roller and exposure scale number for desired seed rate. The evaluated row seeder have overall dimension of 1600 mm x 1000 mm x 1240 mm, height of hopper from ground level was 900 mm and total weight of the machine was 70 kg. Calibration of planter for wheat seeds and granular fertilizer (DAP) was carried out. The average seed rate under laboratory testing of evaluated row planter for wheat (Shorima variety) and fertilizer (DAP) were found to be 116.18 and 99.38 kg/ha respectively. The desired opening exposure scale was identified 4 and 5 with metering roller number 5 and 3 respectively for wheat and fertilizer. The performances of row planter were evaluated in terms of seed rate of the seed, depth of planting, plant count/population, field capacity and field efficiency. Percent of visible mechanical seed damaged by the planter was found null. The mean speed of operation, field capacity and field efficiency were found to be 1.75 km/h, 0.15 ha/h (7.7 h/ha) and 82.08% respectively. Time to complete a hectare of land was 5.75 hr/ha. Based on the performance evaluation results, it was concluded that the row planter can be efficiently and effectively used by the majority of farmers.

***Keywords** – Row planter, Seed rate, Animal drawn, Wheat*

1. INTRODUCTION

Agricultural work in Ethiopia is carried out by using manual, animal and mechanical power sources. Animal power contribution in the total power used in agriculture and draught animals are used for crop production and transportation purposes. Sixty nine per cent of farmers have less than or equal to 1 ha of land (CSA, 2012). Therefore tractor ownership is not economically viable for these farmers leaving draught animal power as the only source.

In Ethiopia wheat is the most important food crop and accordingly the crop is grown on 1.63 million hectare annually. The annual production was estimated to 3.43 million tons which is 17% of total cereal crops production. According to (CSA, 2014) the average national productivity is 2.01 tons per hectare which is one of the least productivity in the world compared to world average wheat productivity per hectare which is 4 tons (Jelle B., 2009).

These low production and productivity of the crop are all attributed to low use of improved farm inputs (both biological, and mechanical), dependency on traditional farming system and rainfall. Taking all these issues into account, the Ethiopian agricultural research system and extension system tried to give awareness on improved agronomic practices, mainly on row planting. Despite all the efforts of the government and the farmers to adopt the practices, unavailability of row planting technologies was a great challenge that faced the process.

The basic objective of sowing operation is to put the seed and fertilizer in rows at desired depth and seed to seed spacing, cover the seeds with soil and provide proper compaction over the seed. The recommended row to row spacing, seed rate, seed to seed spacing and depth of seed placement vary from crop to crop and for different agro-climatic conditions to achieve optimum yields. Seed sowing devices plays a wide role in agriculture field.

Under intensive cropping, timeliness of operations is one of the most important factors which can only be achieved if appropriate use of agricultural machines is advocated. Manual method of seed planting, results in low seed placement, low spacing efficiencies and serious back ache for the farmer which limits the size of field that can be seeding.

Wheat is one of the major staple food crops in many parts of Ethiopia covering about 11% of total land cultivated and production share of 17% of total cereals. However, land productivity is found to be among the lowest in the country from the world which is about 2.01 tons/ha (CSA, 2014).

To increase this lowest productivity, among all others, good agronomic practices is the most important and to facilitate this practice row planting is the one major action to be taken by farmers.

But even though farmers were convinced to practice row planting, absence of appropriate technology was the most bottlenecks for development. To overcome the problem considerable researchers and individuals were engaged to development and adaptation of wheat row planters.

Following the advocacy, recently demand was growing for row planting implements and methods as farmers' awareness for row planting is developing. Many attempts for wheat and teff row planting are emerging as farmers in many places are trying out with un designed items like 'masti/cans' (designed for baking injera) and various bottles and other containers. With such traditional and unverified methods of row planting, dramatic increase in yield and reduction of the quantity of seed required has been reported by farmers, DAs and experts. The research study done by (Tolesa, et al, 2014) in highlands and lowlands of Arsi zone also reported that there is significant yield difference between row planted and broadcasted wheat farm (13.9%) in highlands but with low significant difference in lowland areas. But using the local material for row planting has encountered a number of problems like absence of accuracy, labor intensiveness and tediousness of the work.

The government also import some number of row planter. However, before the mass import and wider dissemination of the technologies, technical viability of the technologies was found to be crucial activity.

Therefore, this research activity was initiated to verify technical viability of the technologies for wheat row planting and recommend for further import and demonstration.

2. Materials and Methods

2.1. Experimental Machine Details

The planter hopper capacity for seed was 9 kg and 11 kg for fertilizer. The experimental machine of seed cum fertilizer row crop planter is shown in figure 1 and the specification of planter is given in table 1 below.

Figure 1. a. Dharti seed cum fertilizer row plant at field b. seed metering roller

Table 1. Specification of dharti seed cum fertilizer row planter

No	Part description	Theoretical details
1	Planter Metering mechanism	peripheral seed metering mechanism
2	Planter number of rows	Five
3	Row spacing	20 cm
4	Seed cum fertilizer box (L x B x h) cm	(42.5 x 19.5 x 28) cm
5	Power transmission system to planter	Ground wheel & chain, sprocket assembly
6	Width of furrow	4 cm
7	Depth of furrow	5-7 cm
8	Weight	70 kg

2.2. Physical Properties of Seed

The physical properties of seed are important factors for the design of seed drill machine. The performance of seed metering mechanism in terms of picking, metering and dropping was influenced by the physical properties of seeds. Therefore, seed properties relevant to select the seed metering roller size. Wheat varieties of Hidase, Shorima, Ogolcho seeds were selected for the study to determine the geometrical size of the seed based on their physical properties. Parameters like thousand grain mass was considered.

2.2.1. Thousand grain mass

The thousand grain mass (1000) were selected randomly and then weighed on the digital electronic weighting balance to obtain the thousand grain mass in gram. The number of sample of each variety was weighed and mean thousand grain mass of each variety was determined.

2.2.2. Calibration of seed metering of wheat row planter

Calibration of the machine was conducted in the laboratory for metering the desired quantity of wheat seeds and fertilizer. It was calibrated in the laboratory for metering desired quantity of wheat seed and fertilizer. The following parameters were observed during a test.

Width of area covered by planter

$W = N\,x\,D = 5\,x\,0.20 = 1m$

Where: - D = Spacing between two furrow openers
D = 20 cm = 0.20 m
N = Number of rows

Circumference of driving wheel

$L = \pi\,x\,D_e = 3.14\ x\ 0.50 = 1.57m$

Where *De* = effective diameter of seed metering ground wheel
De = 0.5 m

Area covered by seed metering ground wheel by one revolution

$A = W\,x\,L = 1\ x\ 1.57 = 1.57m^2$

Number of revolution of seed metering driving wheel for one hectare

$$R = \frac{10000}{A} = \frac{10000}{1.57} = 6369$$

Number of revolutions actually required to cover one hectare

$M = R\,x\,0.9 = 6369\ x\ 0.9 = 5732$

(Assuming 10% slippage during operations)

Seed rate (Q) to be sown per hectare

Wheat seeds delivered in 10 revolution (n=10) of metering ground wheel = 187 g = 0.187 kg
Seed rate (Q) to be sown per hectare.

$$Q = \frac{q\,x10000}{\pi\,x\,D_e\,x\,n\,xW} = \frac{0.187x\,10000}{3.14x0.5x10x1} = \frac{1870}{15.7} = 119.11kg/ha$$

2.2.3. Effect of seed quantity in hopper on seed rate

Seed and fertilizer box was completely filled by seed and the seed rate was checked. The process was repeated by filling the hopper for 3/4, 1/2, 1/4 capacity and the corresponding seed rate were measured for comparison.

2.2.4. Mechanical seed damage by metering mechanism

During calibration, the seeds were collected from furrow putting a bag below the furrow openers and visually broken seeds were counted. The broken seeds were weighed and percentage of damaged seeds was determined, using given formula.

2.3. Field Performance Test of the Drill Machine

In this section, the methods and procedure for measurement of various parameters associated with evaluation of the machine under field condition have been presented. The test plot preparation of tillage operation was conducted with local plough and one pass of harrowing. After test plot preparation sowing was done with the five row animal drawn row planter.

The planter was operated with the draught animal at mean operating speed of 1.75 ± 0.1 km/h. The field performance was conducted in order to obtain actual data for overall machine performance, operating accuracy, work capacity and field efficiency.

2.3.1. Measurement of time

The five row animal drawn wheat row planter was operated length wise from one end to other. Time required to travel and turning at headland was recorded. The time loss in h/ha was also computed.

2.3.2. Operating speed

The speed of operation of planter was determined in test plots by putting two marks 40 m apart (A & B). The time was recorded with the help of stop watch to travel the distance of 40 m. The speed of operation was calculated in km/h as given below (Hunt, 1995).

$$S = \frac{D}{T}$$

Where, S = Speed of operation (km/h)

D = Distance (m)

T = time needed to cover 40 m distance (sec)

2.3.3. Width and depth of sowing

The depth of sowing was measured at different locations with the help of ruler scale by putting a tip of depth ruler scale in ploughed furrow and average was taken, the width of operation was calculated by dividing the total width of plot by the number of passes.

2.3.4. Theoretical field capacity

It is the rate of field coverage of the implement, based on hundred per cent of time at the rated speed and covering of hundred per cent of its rated width. It was determined as per the following formula given by (Hunt, 1995).

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

Where, TFC = Theoretical Field capacity (ha/h)

W = Effective width of implement (m) and

S = Speed of operation (km/h).

2.3.5. Actual field capacity

Actual field capacity was measured by taking an area of 40 x 20 m^2 i.e. 0.08 ha and measuring the time in actual field condition. It includes turning loss, filling time and obstacle down time also. There was continuously operated in the field for 0.08 ha to assess its actual coverage. The time required for complete operation was recorded and effective field capacity was calculated by (Hunt, 1995).

$$AFC\left(ha/h\right) = \frac{A}{T}$$

Where, AFC = Actual Field capacity (ha/h)

A = Actual area covered (ha)

T = Time required to cover the area (h)

2.3.6. Field efficiency

Field efficiency is the ratio of effective field capacity to theoretical field capacity. It was determined by the following formula given by (Hunt, 1995):-

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

Where, FE= Field efficiency (%)

AFC=Actual field capacity (ha/h) and TFC=Theoretical field capacity (ha/h).

The data were recorded for all three planting methods of row planter, local row planting (hand metering method) and broad casting under actual field conditions and also compared. The yield data also was taken and compared.

2.3.7. Plant population

The average plant population was determined by count of the number of plants per square meter at six random places and the mean value was determined to represent the average plant population.

2.3.8. Distribution uniformity

Distribution uniformity indicates variation in delivery between openers. The coefficient of variation (CV) is a mathematical term used to describe distribution uniformity. The interpretation of coefficient of variation is as characterized by PAMI (Prairie Agricultural Machinery Institute), 1979)

$$CV = (stdev\,sample)\; x \; \frac{100}{Average\,sample}$$

Where: - CV- is Coefficient of Variation
Stdev - is standard deviation of sample data and
Average sample- is arithmetic average of the sample data taken.

The interpretation of coefficient of variation is as characterized by PAMI (Prairie Agricultural Machinery Institute. It is Canadian Company working on machinery research) has accepted the following scale as its basis for rating distribution uniformity of seeding implements for wheat crop: CV greater than 15% -- unacceptable, CV between 10 and 15% -- acceptable, CV less than 10% -- very good and CV less than 5% -- excellent.

2.4.Experimental Design and Data Analysis

The randomized complete block design was adopted in experimental field with two treatments and six replications. Data were analyzed using GenStat 16th edition statistical software by least significant difference (LSD) at 5% level of significance.

RESULTS AND DISCUSSION

This chapter deals with the results of experiments in order to full fill the objectives of the activity. The experiments were conducted for five row animal drawn wheat row planter at station as well as in the field. The performance of this machine was evaluated at selected sites of farmers, considering seed rate, effective field capacity and field efficiency. The physical properties of seeds and soil condition were measured under laboratory.

2.5. Physical Properties of Seeds

The physical properties of seeds are among the most important factors to be considered for selecting a suitable metering mechanism and size for its better performance. The attempt was made to study the physical properties of wheat seeds purchased from Ethiopian Seed Enterprise Asella branch. The wheat varieties selected by farmers among number of varieties were Shorima, Ogolicho and Hidase. The physical properties of these wheat varieties such as thousand grain mass was considered for this study.

2.5.1. Thousand grain mass of the seed

The thousand grain mass (TGM) of different wheat variety was found as ranges from 29.15 to 34.82 gm. The thousand grain weight is an important parameter which affects the seed rate, so it is very necessary to calculate the thousand grain weight for row sowing. The mean thousand grain weight of wheat was observed as 32.41g, which is a similar result was observed with (Navneet, 2016 and Solomon A, 2017).

Table: 2. Average of Thousand Grain Mass

S/N	Wheat Variety	TGW,gm
1	Shorima	29.15 ± 0.64
2	Hidase	34.82 ± 0.73
3	Ogolicho	32.25 ± 0.65

2.5.2. Calibration and Selection of metering roller

From pre assessment and looking to the observed values of seed size and cup size of metering roller, roller no.5 was selected for calibration of the row planter for wheat. Table 3 shows the calibration result of wheat seed with metering roller 5 and different metering exposure scale from 7 to 1. Data revealed that with metering roller no.5 and scale exposure of 4 gave nearest values of seed rate in the range of 113 - 118 kg/ha. Average value of 116.18 kg/ha was obtained which is closer to seed rate of 111.4 kg/ha obtained by (Tamrat et al, 2017) and similar seed rate of 115.68 kg/ha was obtained by (Dhruwe et al, 2018). Therefore, the calibrated seed rate of evaluated animal drawn wheat seeder was lies in the recommended range.

Table 3: Calibration seed rate (kg/ha) of planter for selection of metering roller for sowing of wheat seeds for different furrow openers

Scale exposure No	Seed rate kg/ha							
	Metering roller 5							
	F1	F2	F3	F4	F5	Mean	SD	CV
1	96.6	99.88	98.24	95.70	97.64	97.61	1.6	1.64
2	100.38	101.08	102.04	98.65	99.22	100.27	1.37	1.37
3	108.65	112	111.28	110.56	107.62	110.02	1.83	1.66
4	118.62	117.49	116.51	114.62	113.68	116.18	2.03	1.75
5	121.26	123.40	122.68	119.95	124.26	122.31	1.72	1.41
6	131.28	129.61	134.61	132.76	130.29	131.71	2.01	1.53
7	142.83	143.68	140.25	139.97	144.71	132.29	2.10	1.59

2.5.3. Effect of hopper filling capacity on seed rate

Table 4 indicates the seed rate of wheat for different exposure scale varied with the hopper filling (Full, 3/4th and half). It was observed that the entire sample collected for same exposure scale were nearly same and there was very little deviation among the sample i.e. (<2.0). The CV was also very less about in range of 0.96 - 1.71on average.

Table 4:- Effect of hopper filling on seed rate (kg/ha) of wheat crop with different exposure scale at selected roller no. 5

Scale exposure no.	Seed rate kg/ha					
	full	3/4th	half	Mean	SD	CV
7	99.74	98.91	102.20	100.28	1.71	1.71
6	102.30	101.39	99.90	101.20	1.21	1.19

5	106.88	107.89	108.99	107.92	1.06	0.98
4	114.79	115.25	113.05	114.36	1.16	1.01
3	122.68	121.95	124.26	122.96	1.18	0.96
2	134.61	132.76	131.98	133.12	1.35	1.01
1	140.25	139.97	142.71	140.98	1.51	1.07

The planting machine was calibrated in the laboratory for the desired seed rate by adjusting the exposed length of the opening. Wide ranges of quantity of seeds dropped through the opening exposure were collected during the calibration of the planter. The data presented in Table 4 shows that, the highest seed rate of 142.71 kg/ha was found with 1 opening exposure length and half-filled hopper whereas, the minimum seed rate 98.91 kg/ha was observed with 7 opening exposures scale and three-fourth hopper filled.

The optimum seed rate close to the mean of recommended seed rate was found 113.05 kg/ha (for line sowing) when the planter was half filled and opening exposure scale were 4. From Fig. 2 it was also revealed that, for all the capacities of hopper, half, three fourth and full with 4 opening exposure scale of the seed rate was close to mean value of recommended seed rate.

The observed seed rates for 4 opening exposure scale were 114.79 kg/ha, 115.25 kg/ha and 113.05 kg/ha, for full, three fourth and half hopper capacity respectively.

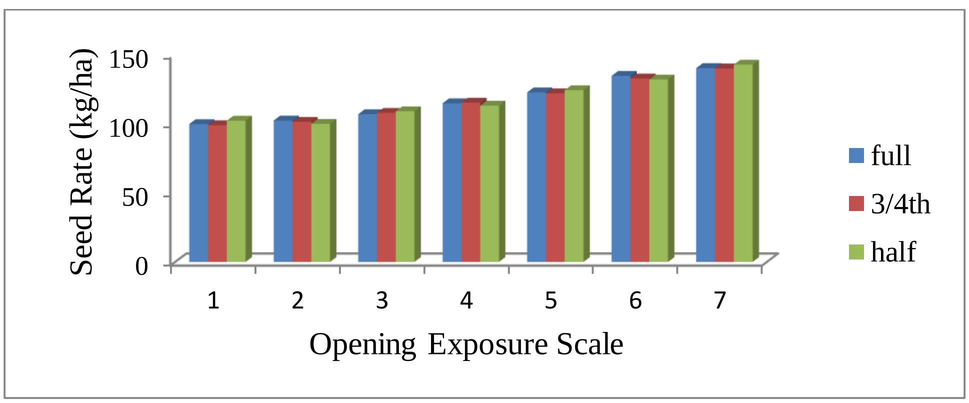

Fig 2: Effect of variation of opening exposure scale on seed rate of wheat

2.5.4. Mechanical damage to seed by metering mechanism

Visual observations for mechanical damage due to metering mechanism were recorded and it was found that there was no visual damage to the seeds of wheat.

2.5.5. Calibration and selection of metering unit for fertilizer

The planter was calibrated with 3 available fertilizer metering rollers and the optimum application rate (99.38 kg/ha) was found with roller number 3 at exposure scale 5. Table 5 indicates the observed fertilizer application rate of seeds among the rows (Furrow openers). It was observed that the entire samples collected for same exposure scale were nearly same and there was little deviation among the rows i.e. (0.29 - 1.44). The CV was about in the range of (0.27-1.31). (Exposure scale 5 is best suited for the recommended fertilizer application rate of DAP for wheat 100 kg/ha (EIAR, 2007)).

Table 5: Fertilizer application rate (kg/ha) for wheat crops for different furrow openers

Scale exposure No	Fertilizer rate (kg/ha)							
	Roller no. 3							
	F1	F2	F3	F4	F5	Mean	SD	CV
7	81.05	82	80.97	79.67	80.73	80.88	0.83	1.03
6	91.08	90.75	89.81	90.57	91.03	90.65	0.51	0.56
5	100.07	98.92	100.19	99.74	97.99	99.38	0.92	0.93
4	106.48	108.01	105.82	107.08	107.84	107.05	0.92	0.86
3	109.14	108.51	109.01	109.05	108.59	108.86	0.29	0.27
2	110.07	111.89	109.19	110.83	108.15	110.03	1.44	1.31
1	116.98	118.92	119.78	118.52	120.01	118.84	1.21	1.02

2.5.6. Effect of hopper filling on fertilization application rate

Table 6 indicates the fertilizer application rate of DAP for different exposure scale varied with the hopper filling (Full, 3/4th and half). It was observed that the entire sample collected for same exposure scale were nearly same and there was very little deviation among the sample i.e. (<2.0). The CV was also very less about in range of 0.50 - 1.29 on average.

Table 6: Effect of hopper filling on fertilization application rate (kg/ha) of DAP with different exposure scale at selected roller no. 5

Scale exposure no.	Fertilizer application rate kg/ha					
	full	3/4th	half	Mean	SD	CV
7	84.74	86.91	86.20	85.95	1.11	1.29
6	96.30	97.39	96.90	96.86	0.55	0.57
5	102.88	103.89	103.19	103.32	0.52	0.50

The planting machine was calibrated in the laboratory for the desired fertilizer application rate by adjusting the exposed length of the opening. Wide ranges of quantity of fertilizer dropped through the opening exposure were collected during the calibration of the planter. The optimum fertilizer application rate close to the recommended rate was found 103.89 kg/ha (for line sowing) when the planter was three fourth filled and opening exposure scale were 5.

From Fig. 3 it was also revealed that, for all the capacities of hopper, half, three fourth and full with 5 opening exposure scale of the fertilizer application rate was close to the recommended application rate of fertilizer. The observed fertilizer application rates for 5 opening exposure scale were 102.88 kg/ha, 103.89 kg/ha and 103.19 kg/ha, for full, three fourth and half hopper capacity respectively.

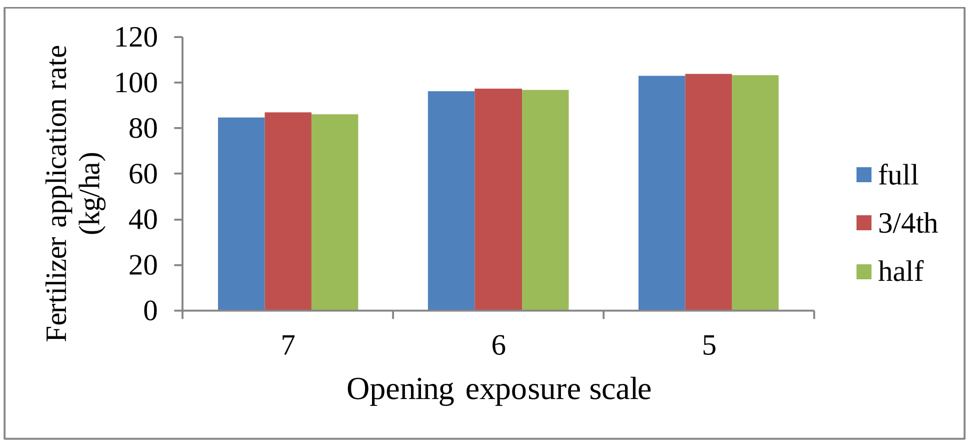

Fig 3: Effect of variation of opening exposure scale on application rate of fertilizer.

2.6. Field performance evaluation result

The planter was evaluated on field for its mechanical and functional performances in farmers' field area of 40 x 20 m^2 at Gadeb Asasa and Hetosa woreda of Oromia region of Ethiopia during rainy season. The soil type obtained at Gadeb Asasa was sandy loam while that of Hetosa was clay loam. The sowing of crops in field was done with 20 cm row to row spacing.

2.6.1. Depth of seed placement

The average depth of seed placement achieved in the field was 4.73 cm. The depth of placement of seeds was adjusted by angle of supporting wheel of five row animal drawn row crop planters.

Table 7: Depth of seed placement

S/N	Depth of seed placement				
	F1	F2	F3	F4	F5
1	5.2	4.5	4.8	4.7	4.4
2	4.8	4.3	5.3	4.9	4.6
3	4.6	4.7	4.4	4.3	4.7
4	4.7	4.9	4.8	4.5	4.8
5	4.5	5.1	4.6	5.2	4.9
Mean value	4.76	4.7	4.78	4.72	4.68
SD	0.27	0.32	0.33	0.35	0.19
CV	5.67	6.81	6.90	7.42	4.06

2.6.2. Speed of operation

The speed of operation was found to vary from 1.71 to 1.77 km/h (Table 9).The average speed of operation of the planter for sowing of wheat seeds was found to be 1.75 km/h, for a distance of 40m. The planter takes 5.75 hr/ha to complete a hectare of land. Similar findings (5.88 hr/ha) was obtained by (Ayalew, 2017)

Table 8: Speed of operation

S. No.	Distance (m)	Time (s)	Speed (km/h)
1	40	81	1.77
2	40	82	1.75
3	40	84	1.71
4	40	82	1.75
5	40	83	1.73
6	40	81	1.77
Average			1.75

2.6.3. Field efficiency

The field capacity and field efficiency was calculated for planter using standard procedure described earlier and results are presented in Table 10. The theoretical field capacity was determined as 0.18 ha/h, whereas the actual field capacity of planter was found to be 0.15 ha/h. From the actual and theoretical field capacity the field efficiency of the light weight animal drawn multi crop planter was found to be 82.08%.

Table 9: Field efficiency of five row animal drawn row planters

Operating speed (km/h)	TFC (ha/h)	AFC (ha/h)	Field efficiency (%)
1.75	0.18	0.15	82.08

2.6.4. Germination count and distribution uniformity Analysis

The number of germination count per meter square at random places were counted and the mean value was determined to represent the average germination in all test sites.

Fig. Germination Counting

2.6.4.1. Germination Count

The analysis of variance (ANOVA) revealed that the planting method had significant effect ($p < 0.05$) on germination count, as well as test site and the interaction of planting method and test site had significant effect ($p < 0.05$) on germination count. Table 10 show the effect of planting methods, test site and the combined effect of planting methods and test sites on mean percent of germination count. The highest germination count was recorded for BC (491) and the lowest was recorded for LRP (370).

Table 10 showing Effects of Test site and Planting methods on Germination Count (GC)

Parameter	Source of variation				Measure of differences	
	Test Site	Planting Methods				
		RP	LRP	BC	LSD (5%)	SE(M)
Germination Count	Site 1	458^{a}	370^{b}	491^{a}	112.4	35.7
	Site 2	424^{ab}	439^{a}	390^{b}		

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

2.6.4.2.Distribution Uniformity

Distribution uniformity indicates variation in delivery between openers. The standard deviation and coefficient of variation for Dharti row planter was shown in table below.

Table 11 Coefficient of variation (CV) for six sites

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
StDEV	4.04	8.25	2.9	4.04	7.11	5.77
Sample mean	54.6	58.8	60.2	54.6	59	53.4
CV (%)	7.4	14.03	4.82	7.4	12.05	10.81

From the table above, the CV of dharti row planter according to PAMI (CV less than 15%) distribution uniformity of the planter is in the range of accepted uniformity.

2.6.5. Potential yield of harvested crop

The analysis of variance (ANOVA) revealed that the planting method had significant effect ($p < 0.05$) on potential yield, whereas test site and the interaction of planting method and test site had no significant effect ($p > 0.05$) on potential yield. Table 12, show the effect of planting methods, test site and the combined effect of planting methods and test sites on mean percent of potential yield. The highest potential yield was recorded for RP (79.1 qunt/ha) and the lowest was recorded for BC (67.5 qunt/ha).

Table12, Effects of Test site and Planting methods on Potential Yield (PY)

Parameter	Source of variation				Measure of differences	
	Test Site	Planting Methods				
		RP	LRP	BC	LSD (5%)	SE(M)
Potential Yield (qunt/ha)	Site 1	79.1^{a}	74.1^{b}	73.5^{b}	9.34	2.96
	Site 2	77.1^{a}	75.4^{ab}	67.5^{c}		

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

2.7. Cost Analysis

The total cost of planting was obtained from all planter operation and labor cost for planting whereas in Local row planting and broadcasting, the total cost of operation is just related to labor cost. Annually coverage area was determined by multiplication of the effective field capacity and annual hours of operation. Table 13 shows that only operational cost of planting in wheat crop for one hectare. The lowest planting method cost was associated with Row Planter (162.50 Birr/ha). The planting cost of planter was reduced by 87.4 and 80.6 %, respectively as compared to Local row planting and broadcast methods. These studies showed that selection of a method for planting has significant role in the reduction of cost. The Local row planting method is not economical, because of costly planting, difficulty of performance and limitation of labour.

Table 13, Planting cost in different planting methods

Planting methods	**Labour input (Man-h/ha)**	**Total operational cost(birr /ha)**	**Saving in cost of Planting (%)**
Broadcast	67	837.50	80.6
Local Row Plant	69	862.50	87.4
Row Plant	13	162.50	-

2.8. Summary and Conclusion

2.8.1. Summary

The machine consists of power transmission system, seed and fertilizer hopper stand, metering mechanism for seed as well as fertilizer, delivery tubes and furrow opener. Power was transmitted from ground wheel through chain-sprocket drive system to the gear box and finally to the metering roller mechanism. The row seeder have overall dimension of 1600 mm x 1000 mm x 1240 mm, height of hopper from ground level was 900 mm and total weight of the machine was recorded as 70 kg. The hopper capacity is 9 kg for wheat and 11 kg for fertilizer.

Due to fragmented and small land holdings and variable farmer typology, it is neither affordable not advisable to purchase tractor drawn row planting machines. Daharti seed cum fertilizer animal drawn row seeder is providing simple solution to this. In addition, the planter have precise seed metering system using cup feed type seed metering roller with variable grove number and size for different seed rate and fertilizer application rate. The planter has the provision of drilling both seed and fertilizer in one pass.

Dharti seed cum fertilizer animal drawn row seeder was tested for its lab and field performances. Based on the investigation conducted the following results were obtained.

The observed average values of seed rate of wheat and fertilizers. Desired seed rate of wheat was obtained as *116.18* kg/ha with exposure scale 4 and roller no 5. Required fertilizer rate was obtained as 99.38 kg/ha with exposure scale 5 and roller no. 3. The speed of operation, actual field capacity and field efficiency were recorded as 1.75 km/h, 0.15ha/h and 82.08% for the evaluated seeder machine with five furrow openers at 20cm row spacing.

3.4.2. Conclusion

As per concerned of the objectives of the present study and results obtained, the following conclusion and recommendation could be drawn.

The developed five row animal drawn multi crop planter worked satisfactory in actual field condition for planting of wheat seeds.

The dharti seed cum fertilizer of five row animal drawn row seeder suggested to redesigned and modified in order to reduce the weight of the planter and increasing comfort level of both operator and animal and their safety.

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Development and Evaluation of Manually Operated Row Wheat Weeder

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ABSTRACT

Weed control is one of the most difficult tasks on an agricultural farm. Three methods of weed control are commonly known in agriculture. These are mechanical, chemical and biological control. Mechanical weed control is easily adopted by farmers once they get convinced of its advantages. Various types of mechanical weeders have been developed. This project work involved the design and construction of mechanical weeder, after discovering that tools such as cutlass and hoes require high drudgery, time consuming and high labour force. As a solution to these problems, mechanical weeder was designed and constructed. The mechanical weeder was made of two implements attachment i.e. the primary cutting edge which is in front to loose soil above and the secondary cutting edge which is behind to do cutting and lifting of weeds. The developed row weeder was tested in the row sown wheat crop (variety Ogolcho) and the relevant data were collected and statistically analyzed. The weeding efficiency plant damage percentage of the weeder was 84.67 and 81.67% respectively for sandy loam and clay loam soil types. The plant damage percentage of the weeder was 1.413 and 1.853% respectively for sandy loam and clay loam soil types. The weeder field efficiency was 82.79 and 81.72% at field capacity of 0.185 and 0.182 ha/day respectively at sandy loam and clay loam soils. The cost of operation was found 1,087.50, 1,762.50 and 1,712.5birr per hectare for weeder, hoe and hand weeding methods respectively. The weeding cost of mechanical weeder was reduced by 38.30 and 36.50%, respectively as compared to hoe and hand weeding methods. Thus the research work was carried out according to the pre decided objectives and the developed weeder was found to work satisfactorily requiring some further improvements as given in the suggestions for future research work.

1. INTRODUCTION

In Ethiopia, wheat is sown by different methods, broadcasting and row seeding depending upon the type of soil, topography of land and labours. In order to increase the productivity, efforts have been made through row sowing systems. With the advent of row seeding and the adoption of high yielding varieties interest in row seeding is seen among the farmers, which is not only maintain plant population but also offers additive advantages, such as intercultural operations and proper weed control.

Weeding is one of the most important farm operations in crop production system. Weed growth is a major problem for wet land crops particularly in cereal crops like rice and wheat, causing a considerable lower yield (Rangasamy *et al*, 1993). In Ethiopia, this operation is mostly performed manually that requires higher labor input and also time consuming process. Moreover, the labor requirement for weeding depends on weed flora, weed intensity, time of weeding and soil moisture at the time of weeding and efficiency of worker. Often several weeding are necessary to keep the crop weed free. Weed interference is one of the most important, but less understood factors, contributing to lowering the yields of wheat (Hassan and Marwat, 2001). Reduction in yield due to weed alone is estimated as 16-42% depending on crop and location and involves one third of the cost of cultivation (Rangasamy *et al*, 1993).

The weed control operations are mainly done by three methods such as hand weeding, hoe weeding and herbicides application. In hoe weeding, weeds are removed by using an indigenous tool, which is more effective but it is expensive, labour intensive as well as time consuming. Moreover, the labour requirement for weeding depends on weed flora, weed intensity, time of weeding, and soil moisture at the time of weeding and efficiency of worker (Attanda, M. L.,*et. al.*, 2013). Nowadays herbicide usage is increasing. In view point of labour shortage circumstances; it is preferred as a quick and effective weed control method without damaging the plants. But, it has adverse effects on human health and environment.

Today the agricultural sector requires non-chemical weed control that ensures food safety. Consumers demand high quality food products and pay special attention to food safety. Through the technical development of mechanisms for physical weed control, it might be possible to control weeds in a way that meets consumer and environmental demands (Olukunle and Oguntunde (2006). Mechanical weed control reduces the chemical application involved in weeds control. Moreover mechanical weeder besides killing the weeds loosen the soil between rows thus increasing air and water intake capacity. But this method of weed control has received much less scientific attention compared to the other methods. As a result traditional tools, implements and methods are still used by majority of the farmers for weed control. Nkakini et al. (2010) stated that the problems usually associated with traditional methods of weeding practices are low efficiency and farmer bending over resulting in tremendous loss of energy.

Mechanical weed control is very effective as it helps to reduce drudgery involved in manual weeding, it kills the weeds and also keeps the soil surface soft and loose ensuring soil aeration and water intake capacity thereby contribute significantly to safe food production (Pullen and Cowell, 1997). This study therefore, carried out performance evaluation tests on a locally developed hand push-pull mechanical weeder to determine its field performance and also compare the performance with that of traditional method of hand hoe weeding.

Materials and Methods

1.1. Description of the Developed Weeder

The developed mechanical weeder is manually pushed and pulled which consist of a frame made from hallow square pipes (Figure 1). The weeder has two cutting blades mounted in horizontal with staggered orientation. It has a smooth L- shaped and V- shaped blades mounted alternately on the frame that uproots the weeds because the weeder create intercultural operations on the top 3-5 cm of soil. The weeder weeds in a single forward pass with a push pull movement. Its main feature includes; frame, handle, cutting blade and drive wheel assembly.

Fig. 1. The developed row crop weeder

1.1.1. Frame

The frame is the most important part of the weeder which all other parts were mounted on it. The frame was constructed from hollow square pipes steel of 40 mm. Two angle iron steel of 40mm was bolted to the frame which the blades were mounted.

1.1.2. Handle

The handle grip was made from hollow circular steel pipe of 25 mm diameter and length of 400 mm. The angle between the main frame and handle was 30^0. The square bar was cut in required size, and then one side of it was welded with handle grip and the other side with the main frame at 45º angle (Fig.1). The weeder is operated by the action of push and pulls which causes the soil working part to penetrate and cut or uproot the weeds in between the rows.

1.1.3. Cutting Blades

There are two sets of the cutting blades made up of mild steel are mounted on the frame. The L - shaped blades used to loosen the soil at the front while V- shaped blade is used for weeding operation. The cutting edge of the L - shaped blades was well sharped to minimize the effort required in cutting the soil. The V- shaped blade performs the cutting, uprooting of the weeds, besides stirring the soil.

1.2. Experimental Field Layout and Procedure

The field experiment was conducted at farmer's field where wheat was sown. Row to row distance was 20 cm. The trail was carried out when the crop was 20 days old and the field was infested with weeds. Two experimental plots of the same dimensions of 270 m^2 each were used for both the sandy loam soil (SLS) and clay loam soil (CLS) for the field test on which wheat seeds were sown in row. Both sites were subjected to the same land preparation and cultural operations. The main field was divided into 9 sub plots each of size 10 m x 3 m.

1.3. Methods of Evaluation

In order to determine the performance of push pull type manually operated weeder different data were taken randomly from test area of 1 m x 1 m for each replication from spot for evaluation. Experimental areas were marked through measuring the area with steel tape. The number of weeds was counted in the experimental field. After that the weeder was pushed in the forward direction to cut the weed in the wheat field. This procedure was repeated until the selected area was completed. The operating time of the weeder was measured and recorded by using stop watch. After complete the operation, the number of remove and un-remove weed was counted from the spot. This information was used to calculate the weeding efficiency of the weeder. On the other hand, actual time was recorded for predefined area of weeding.

1.4. Performance Evaluation Index

The following parameters were the indices of the performance evaluated in the field experiment:-

1.4.1. Operation Speed

The operating speed was measured in the test plots for weeder. For determining the operating speed a distance of 10 meter in between the crop rows were marked in all the plots and the weeder was then used in between the straight rows. As the weeder traversed in between the crop rows, time taken to cover 10 meter distance was recorded with the help of stop watch. A minimum of such five readings were recorded for calculating the average operating speed of the weeder in the respective field plots.

$$Speed(km/h) = \frac{Dis\tan ce(m)}{Time\,(s)} x 3.6 \qquad 1$$

1.4.2. Theoretical Field Capacity

Theoretical field capacity of the weeder is the rate of field coverage that would be obtained if the weeder was performing its function 100% of the time at the rated forward speed and cover 100% of its rated width. It is expressed as hectare per hour and determined as follows (Kepner *et al.*, 1978)

$$Theoretical\ field\,capacity(km/h) = \frac{S\,xW}{10} \qquad 2$$

Where, S = speed, km/h
W = theoretical width, m

1.4.3. Actual Field Capacity

The weeder was continuously operated in the field for the specific time period. Actual field capacity is the actual average rate of work coverage by the weeder, based upon the total field time. It is a function of the rated width of the machine, the percentage of rated width actually utilized, speed of the travel and the amount of field time lost during the operation. Actual field capacity is usually expressed as hectare per hour (Kepner *et al.*, 1978).

$$Actual\ field\ capacity(ha/h) = \frac{A}{T_P + T_n} \qquad 3$$

Where,

A = area covered, ha
Tp = productive time, h
T_n = nonproductive time, h

1.4.4. Field Efficiency

It is the ratio of actual field capacity to theoretical field capacity, expressed as percent. It includes the effect of time lost in the field and the failure to utilize the full width of machine. It was calculated by using the following formula.

$$\text{Field efficiency} = \frac{Actual\ Field\ Capacity}{Theoretical\ Field\ Capacity}\ x100 \qquad 4$$

1.4.5. Plant Damage

The implement may cause damage to the crop during weeding. The percentage of damaged plants indicates the quality of work done. Plant damage was calculated by counting the number of plants in 10 m row length before weeding and number of the plant damaged in 10 m row length after weeding. The plant damage was calculated by following expression (Yadav and Pund, 2007).

$$q = \left[1 - \left(\frac{Q}{P}\right)\right] x100 \qquad 5$$

Where: - q = plant damage per cent
Q = number of plants in a 10 m row length after weeding
p = number of plants in a 10 m row length before weeding.

Weeding efficiency

To determine weeding efficiency in each plot randomly, four patches of 1m × 1m size was taken and the number of weeds were counted before and after weeding operation and the average values were used for calculating the weeding efficiency. The weeding efficiency was computed by using the following expression:

$$W_E = \frac{w_r}{w_r + w_u} x100 \qquad 6$$

Where, W_E = Weeding efficiency (%),
w_r = Number of weeds removed by the weeder/m^2
w_u = Number of weeds left in the field after weeding operation/m^2

Cost Estimation

Estimation of annual and hourly operational costs of the weeder were based on capital cost of the weeder, interest on capital, cost of repairs and maintenance, labor cost, and depreciation. Cost of weeding operation performed for weeder was worked out on the basis of the prevailing input and fabrication price of the implements, machinery and rental wages of operator and labors required. The cost of operation of the weeder is divided into two heads known as fixed cost and variable cost. Fixed cost is independent of operational use while variable cost varies proportionally with the amount of use. (Kamboj *et al*, 2012).

The fixed cost of the weeder includes mainly depreciation and interest on the capital costs. Variable cost of the weeder mainly includes, repair and maintenances cost and wages. Cost of weeding operation for the weeder was calculated as Birr/ha. Operation cost of the weeder was calculated as follows:-

Fixed cost

Depreciation

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

$$D = \frac{C - S}{L\,x\,H} \qquad 7$$

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

Interest

Interest is calculated on the average investment of the machine taking into consideration the value of the machine in the first and last year. These are usually calculated on yearly basis. The annual interest on the investment can be calculated as follows (Kepner *et al.* (2005) :-

$$I = \left(\frac{C+S}{2}\right) \times \left(\frac{i}{H}\right) \qquad 8$$

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 weeder was taken as 2.5% of the cost of the weeder (Kepner *et al*., 2005 and Kamboj *et al.*,2012).

$$RM = \frac{C \times 2.5\%}{H} \qquad 9$$

Where:- RM = Repair and maintenance cost per hour
H = Annual working hours of the weeder

Wages of operator

Wages are calculated based on actual wages of workers per day or hour.

Total cost of weeding per hour

The total cost of weeding per hour of the weeder 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

The operational cost of using the hoe and hand weeding was estimated and compared with the operational cost of the weeder. The operational cost components only.

Wages are calculated based on actual wages of workers per day or hour.

Experimental Design and Data Analysis

The experiment was laid out in randomized complete block design and three replications of each type of soil and weeding methods. Data were analyzed using GenStat 16th edition statistical software by least significant difference (LSD) at 5% level of significance.

RESULTS AND DISCUSSIONS

The study was undertaken to determine technical performance of push pull type manually operated weeder in selected wheat field. Weeding efficiency, percent of breakage and field capacity were calculated and operating cost of the weeder compared with hoe weeding and manually hand weeding operation.

The field performance evaluation results obtained with both the developed weeder and the traditional hand hoe and comparative operation speed for both implements are shown in Tables 1. Table 1 shows the mean working speed of developed weeder to be 0.102 m/s and 0.101m/s while that of hand hoe was 0.014m/s and 0.013 m/s respectively at sandy loam and clay loam soil. The mean test showed that the means of the forward speed of the developed weeder are not significantly different while that of the traditional hoe showed clear significant difference at 5%. This suggest that the developed weeder's working speed is uniform which is an impetus to field efficiency of an implement as against the traditional hoe with inconsistence in working speed, probably due to fatigue and drudgery of the human nature. At these working speeds of the implements the mean actual field capacity of the developed weeder is significantly higher than mean actual field capacity of the hand hoe of area of the same size weeded.

Table 1: Comparative field performance evaluation

Furrow Number	Length of Furrow (m)	Sandy loam soil				Clay loam soil			
		Forward speed (m/s)		Actual Field Capacity (ha/hr)		Forward speed (m/s)		Actual Field Capacity (ha/hr)	
		Hoe	Weeder	Hoe	Weeder	Hoe	Weeder	Hoe	Weeder
1	10	0.012	0.102	0.0068	0.0281	0.012	0.101	0.0063	0.0235
2	10	0.016	0.101	0.0064	0.0225	0.016	0.099	0.0064	0.0229
3	10	0.01	0.102	0.0058	0.0214	0.011	0.102	0.0058	0.0230
4	10	0.018	0.101	0.0066	0.0231	0.01	0.101	0.0066	0.0228
5	10	0.013	0.103	0.0069	0.0216	0.013	0.103	0.0065	0.0227
6	10	0.017	0.102	0.0066	0.0219	0.017	0.103	0.0064	0.0227
Mean	10	0.014	0.102	0.0065	0.0231	0.013	0.101	0.0063	0.0228

Actual Field Capacity

The field capacity of developed weeder was calculated by selecting a respective three plots of size 10 × 10 m for each soil types. The weeder was operated in these plots and the different observations were recorded. The analysis of variance (ANOVA) revealed that the weeding method had significant effect ($p < 0.05$) on field capacity, whereas soil type and the interaction of weeding method and soil type had no significant effect ($p > 0.05$) on field capacity. Table 2 show the effect of weeding methods, soil type and the combined effect of weeding methods and soil type on mean actual field capacity. The maximum field capacity (0.023067 ha/h) was obtained with weeder followed by hand weeding which gave field capacity of (0.007533 ha/h), and the minimum field capacity obtained in case of hoe weeding, however, the hoe weeding methods besides killing the weeds loosen the soil between rows thus increasing air and water intake capacity. Similar finding were reported by Shiru (2011) at rice field.

Table 2. Effects of soil type and weeding methods on Actual Field Capacity (AFC)

Parameter	Source of variation				Measure of differences	
	Soil Type	Weeding Methods				
		Hoe	Hand	Weeder	LSD (5%)	SE(M)
Actual Field capacity	SLS	0.007400[c]	0.007533[c]	0.023067[a]	0.0004821	0.0001530
	CLS	0.007133[d]	0.007333[e]	0.022800[b]		

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

Field Efficiency

Table 3. Field efficiency

Weeding methods	Actual field capacity (hah^{-1})		Theoretical field capacity	Field Efficiency (%)	
	Sandy loam soil	Clay loam soil		Sandy loam soil	Clay loam soil
Weeder	0.0231	0.0228	0.0279	82.79	81.72
Hoe weeding	0.0074	0.0071	Nd	nd	nd
Hand weeding	0.0075	0.0073	Nd	nd	nd

nd- no data

The field efficiency of the weeder is the ratio of useful working to the total working time. The mean values of field efficiency of the weeder were 82.79 and 81.72 % at sandy loam and clay loam soil respectively. The data in Table 3, revealed that the weeder has the highest field efficiency (82.79%) at sandy loam soil followed by clay loam soil (81.72%), this means the weeder can work very effective on the sandy loam soil. Clay loam soil has the least percentage because of the fertility of the soil which allow deep root of the soil, making some weeds to bend and which do not allow the cutting edge to cut them. In sandy soil, the soil is loose and the roots of the weeds are not so deep for the cutting edge to lift them. Similar finding were reported by Quadri A., 2010.

Weeding efficiency

The analysis of variance (ANOVA) revealed that the weeding method had significant effect ($p < 0.05$) on weeding efficiency, whereas soil type and the interaction of weeding method and soil type had no significant effect ($p > 0.05$) on weeding efficiency. Table 4 shows the effect of weeding methods, soil type and the combined effect of weeding methods and soil type on mean percent of weeding efficiency. The highest weeding efficiency was recorded for hand weeding (98.00%), but it was not economical because of more labour intensive and time consuming. The lowest weeding efficiency was recorded for the weeder (81.67%), however, besides uprooting the weeds loosen the soil between rows thus increasing air and water intake capacity. Similar finding were reported by Ramesan *et. al.,* (2007) and Quadri A., 2010.

Table 4. Effects of soil type and weeding methods on weeding efficiency (WE)

Parameter	Source of variation				Measure of differences	
	Soil Type	Weeding Methods				
		Hoe	Hand	Weeder	LSD (5%)	SE(M)
Weeding Efficiency (%)	SLS	87.67^{b}	97.67^{a}	84.67^{c}	6.472	2.054
	CLS	86.00^{b}	98.00^{a}	81.67^{d}		

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

Damaged plants

The analysis of variance (ANOVA) revealed that the weeding method had significant effect ($p < 0.05$) on percentage of plant damage, whereas soil type and the interaction of weeding method and soil type had no significant effect ($p > 0.05$) on percentage of plant damage. Table 5 show the effect of weeding methods, soil type and the combined effect of weeding methods and soil type on mean percentage of plant damage. The minimum percentage of plants damaged was (0.250%) in hand weeding, while the maximum percentage of plant damaged (1.853 %) respectively by weeder. The higher damaged of plant in case of the weeder as compared to hoe and hand weeding methods may be due to higher travel speed. These results are in agreement with finding of Alizadeh M.R. (2011).

Table 5. Effects of soil type and weeding methods on plant damage (Pd)

Parameter	Source of variation				Measure of differences	
	Soil Type	Weeding Methods				
		Hoe	Hand	Weeder	LSD (5%)	SE(M)
Plant Damage	SLS	0.413^{c}	0.357^{c}	1.413^{b}	0.3769	0.1196
	CLS	0.483^{c}	0.250^{cd}	1.853^{a}		

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

Labour requirement in different weeding methods

Results in table 6 shows the labour required for different weeding methods and labour saving per hectare as compared to hoe and hand weeding method.

Table 6. Labour required in different weeding methods (man-hha^{-1}) at different soil types

Weeding methods	Labour requirement (man-h/ha)	Man (Birr/ h)	Labour cost (Birr/ha)	Labour saving (%)
Weeder	87	12.50	1087.50	-
Hoe weeding	141	12.50	1762.50	38.30
Hand weeding	137	12.50	1712.50	36.50

Table 6 revealed that the minimum time for controlling weeds was (87 man-h/ha) for mechanical weeder and maximum time for controlling weeds was (141 man-h/ha) for hoe weeding. Khan and Diesto (1987) reported that, manual weeding of rice in one hectare requires on an average of 120 man-h/ha. Saving in time for weeding operation mechanical weeder were 38.30 and 36.50% as compared to hoe and hand weeding method respectively. In case of hoe weeding the labour requirement was almost similar to hand weeding methods. Hoe and hand weeding methods are costly and labour intensive. These involve considerable time and labours. Limitation of labour at the time of weeding is becoming day to day a major constraint; therefore mechanical weeder could be selected to save time as well as labour.

Potential Yield

Potential yield was determined from 1 m^2 area. Five random observations were taken from each plot and the seeds were thoroughly separated from straw and the weight of seeds were recorded and expressed in kg ha^{-1}. The analysis of variance (ANOVA) revealed that the soil had significant effect ($p < 0.05$) on potential, whereas weeding method and the interaction of weeding method and soil type had no significant effect ($p > 0.05$) on potential yield. Table 7 show the effect of weeding methods, soil type and the combined effect of weeding methods and soil type on mean potential yield.

Table 7. Effects of soil type and weeding methods on potential yield (PY)

Parameter	Source of variation				Measure of differences	
	Soil Type	Weeding Methods				
		Hoe	Hand	Weeder	LSD (5%)	SE(M)
Potential yield(Qtl/ha)	SLS	91.0^a	80.1^b	92.5^a	11.16	3.54
	CLS	73.1^c	65.3^d	70.1^c		

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

Cost Analysis

The cost of weeder operation is the sum of fixed and variable cost. The total cost of weeding was obtained from all weeder operation and labor cost for weeding whereas in hoe and hand weeding the total cost of operation is just related to labor cost. Annual operation of the weeder was considered as 160 hour based on 20 days actual annual use in wheat field and daily 8 hour useful operation. Annually coverage area was determined by multiplication of the effective field capacity and annual hours of operation. In hoe and hand weeding, the total cost of operation is only related to the labour cost. The initial cost of mechanical weeder is high by which more fixed cost was associated with weeder than the other weeding methods. The unit cost of the developed mechanical weeder was determined by calculating the cost of different components and their fabrication cost as given in Appendix table B1, B2 and B3. Table 8 shows that only operational cost of weeding in wheat crop for one hectare. The lowest weeding cost was associated with mechanical weeder (1087.50 Birr/ha). The weeding cost of mechanical weeder was reduced by 38.30 and 36.50%, respectively as compared to hoe and hand weeding methods. Similar findings were also reported by Goel *et al*. (2008); Remesan *et al*. (2007); Tajuddin, (2009) and Parida (2002). These studies showed that selection of a method for controlling weed has significant role in the reduction of cost. The hand weeding method is not economical, because of costly weeding, difficulty of performance and limitation of labour at the proper time.

Table 8. Weeding cost in different weed control methods.

Weeding methods	**Labour input (Man-h/ha)**	**Total operational cost(birr /ha)**	**Saving in cost of Weeding (%)**
Hand weeding	137	1,712.50	36.50
Hoe weeding	141	1,762.50	38.30
Mechanical weeder	87	1,087.50	-

Summery and Recommendations

Summery

The weeding methods included were hand weeding, Hoe weeding and weeder. The performance of the weeder was compared with the hand and hoe weeding. Different performance parameters such as field capacity, field efficiency, travel speed, labour required, damaged plant, weeding efficiency, potential yield and cost of operation were observed. Based on the results of various experiments conducted the following summaries were drawn.

It was imagined that mechanizing the manual weeding operation could displace labour force and which could be used in other productive activities that could lead to increased productivity and can solve labourer scarcity to a large extent.

The damaged plant percentages was found to be maximum in weeder (1.853%) due to higher speed of operation, and damaged plant percentages was found to be minimum in hand weeding (0.250%) .

The weeding efficiency was found highest (98%) in hand weeding, but it is not economical due to high labour requirement and cost of operation. The lowest (81.67%) weeding efficiency was found in weeder.

The field capacity was found to be maximum (0.0231 ha/h) in weeder and minimum (0.0071ha/h) in hoe weeding.

Field efficiency of the weeder was found to be maximum (82.79%) at sandy loam soil and minimum (81.72%) at clay loam soil.

The minimum time required for controlling weeds was related to the weeder (87 man-h/ha) and maximum time required for controlling weeds was in hand weeding (141 man-h/ha) and weeding time saving in weeder was reduced by 38.30 and 36.50%, respectively as compared to hoe and hand weeding method .

The operational cost of weeding in wheat crop was maximum in hoe weeding (1762.50 Birr ha^{-1}) whiles the minimum was in weeder (1087.50 Birr ha^{-1}).

Recommendations

Through observation, this project work was good for local farmers and small scale agro-base industries that need a better treatment and operations carried out on farms. The following conclusion can be drawn:-

The developed hand-pushed weeder should be adapted due to its higher forward speed and effective actual field capacity which is more than that of the traditional hand-held hoe.

This evaluation was conducted under rainfall planting season; the evaluation of the weeder could be investigated under irrigation farming.

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Adaptation and Evaluation of Manual Hay Baller

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Abstract

The aim of hay baler is to store feed for later on-farm use. Traditional hay making practice in has many problems. This activity is, therefore, intended to evaluate and adapt manual hay baler so as to assist users in hay making and baling practice. Three hay baler models, vertical and horizontal metal and wood body hay balers, were collected from Amio engineering, selam technical and vocation school and Bako Agricultural Engineering Center respectively. All manual hay balers were tested and evaluated for their capacity and also compared their advantage over the traditional hay making using their bale weight and area. Tests were conducted in three sites with three replications a total of nine replications using single hay bale. The required area and weight of baled and hay were determined. The test result has shown that, the average baling rate and baling time of vertical hay baler was 87 kg /h and 5.83 min per bale.

Key words: hay baler, baling rate, baling density, baling time, traditional.

1. Introduction

The Ethiopian economy is highly dependent on agriculture. Agriculture is the basis of Ethiopia's economy. In Ethiopia, the agricultural sector is a corner stone of the economic and social life of the people. The sector employs 80-85 percent of the population and contributes 40 percent to the total GDP (Aleme and Lemma, 2015). According to the livestock census of CSA, (2016/7), Oromia Region has about 24,144,361 million cattle, 9,866,172 million sheep, 8,129,784 million goats, 1,296,520 horses, 140,114 mules, 3,446,746 donkeys, 299,422 camels, 20,408,299 million poultry and 2,993,147 beehives constituting about 35.7 percent of the national livestock population.

Grazing lands are the main source of livelihood to many farmers and pastoralists providing year-round feed supporting livestock. As green plants availability is seasonally in most area, the provision of feed for deficit seasons has always been the major concern in many livestock production system. Therefore, Hay is the most important conserved fodder used for this purpose. Many small-scale farmers in the Region by their own method make hay and store crop residues to carry livestock through periods of feed shortage. It can be prepared at house hold level using simple machines and techniques.

In Ethiopia, teff, barley and wheat are cultivated about 3.023, 1 and 1.7 million ha with a production of 5.3, 2.1 and 4.6 Million tons respectively, Where as in Oromia 1.4, 0.5 and 0.9 million ha with production of 2.6, 1.1 and 2.7 million tons respectively during 2017-18 (CSA, 2017/18). About 1 to 1.77 kg of paddy straw is produced per kg of grain harvested (Thirunavukkarasu, 2011) and thus, approximately 12 and 6 million tons of straw is estimated to be produced annually in Ethiopia and Oromia respectively.

The major barrier against the use of these bulky residues as feedstock was due to their collection, handling, transportation and storage. Baling is a process of reducing the material volume to achieve a defined package which facilitates handling and preserves material quality for future use.

Hay making is traditional in most parts of Ethiopia, Especially in Oromia region there is no wide practice of making or storing hay and straw in bale, rather most farmers and small-scale dairy holders store hay traditionally by making heap. However, the conventional method of haymaking has some drawbacks, such as feed loss; maintain low nutrient content, not convenient in transporting and storing. These drawbacks confirm that farmer's lacks knowledge about forage conservation, improvement of low quality feed and using of proper technology for haymaking and storing residue. There are different types of haymaking machines in the market. Mechanical presser is one of an important implement. These machines have three level of operation, i.e., human, animal, and mechanical powered. Hay production is dominant in those areas of the world where good drying conditions prevail. Studies indicate that, baling of hay by pressing helps to feed animals with little or no wastage, conserve its nutrient for a long time, simplifies the transport and storage condition and preparation of feed rations.

Therefore, to alleviate problems associated with hay baling it was felt appropriate to adapt manual baler that can solve the problem raised above. Hence, this study was aimed to adopt and evaluate the performances of manually operated hay baler in local conditions

2. Materials and methods

In this particular activity, attempt has been made to evaluate manual hay balers. Based on extensive review, attempt on different existing manual hay baler of three models i.e. vertical, horizontal metal and wood body manual hay balers were selected. But, these balers are not used in the Region by farmers due to unavailability of manual hay baler in the market and poor awareness of farmers on the technologies. It was also intended to render recommendation on the merits and demerits of the technologies. These technologies were horizontal metal body baler, horizontal wood body baler and vertical baler.

2.1. Technology description

The Horizontal baler metal body piston (figure 1) obtained from Selam technical and vocational school has a 282 x 51 x 72 cm (LxWxH) dimension whose body is made from sheet metals, angle iron, round bar, galvanized pipe, and U-channeled cross section metals. Its empty weight is 88 and 95 kg with and without wheel respectively.

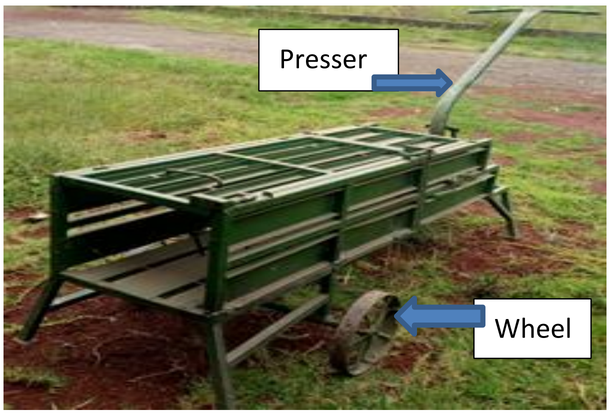

Figure1. Horizontal Baler (metal body)

The vertical hay press screw type (Figure 2) obtained from Amio engineering whose parts are manufactured from sheet metals, angle iron, rectangular pipe, ball bearing and water pipe has the overall dimension of the machine (LxWxH) in centimeter is 74 x 86 x 186. Its weight is 94 and 87 kg with and without wheel respectively.

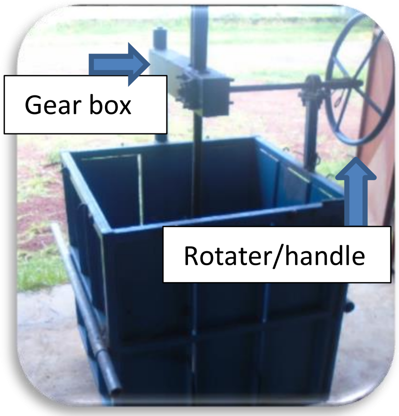

Figure 2. Vertical baler and Horizontal baler(wood body)

The Horizontal baler wood body piston type (Figure 3) Obtained from Bako Agricultural Engineering Research Center has a 200 x 52 x 100 cm (LxWxH) dimension whose body is made from hardwood (eucalyptuses tree). Part other than the main body was made from available angle iron, round bar, galvanized pipe. Its empty weight is 85.5 kg.

2.2. **Site Selection**

After collected the balers, experience on preparation of animal feed, awareness about the improved technology, and potential forage production, participant and farmers were selected from Arsi Zone, Hetosa, D/Tijo and L/Bilbilo Woredas. In each selected woredas, all manual hay balers with full accessories were delivered for participants. Selected farmers were trained on operation and handling of manual hay balers.

2.3. **Modification of parts**

Based on test result and farmers comment modification was made on some parts of Horizontal metal body and vertical balers. Horizontal MB, before it opened one side only, these make difficulties to remove straw now capable to open two sides so the straw is easily removed after operation. Vertical bale Gear changed from bevel to helical gear and changed one bearing to four bearing. So piston is move simply to press the hay in the rectangular channel. After modification, all hay baler were tested and evaluated for their capacity and also compared their advantage over the traditional at site.

2.4. **Measuring Devices and Instruments**

Baling time was measured by stopwatch and defined as the total time required from start of preparation of tightening rope, bale formation, till the end of double tightening of the pressed square bale. All bales were wrapped using plastic rope twine. The length, width, and height of all bales were measured using tape meter to the nearest of 1 cm to allow calculation of bale area, volume and density. Each bale was weighed to the nearest 0.5 kg on a 50 kg capacity spring balance scale.

2.5. **Performance evaluation**

All manual hay balers were tested and evaluated for their capacity and also compared their advantage over the traditional hay making using their bale weight and area. Tests were conducted in three sites with three replications a total of nine replications using single hay bale with a single operator. The required area and weight of baled and hay were determined. Generally performance evaluation of all manual balers were made on the basis of the following parameters; density, mass, pressing rate and time required.

2.6. **Statistical Analysis**

Data were subjected to analysis of variance following a procedure appropriate to the design of the experiment as recommended by Gomez and Gomez (1984). Analysis was made using Statistix 8 statistical software. The treatment means that were different at 5% levels of significance were separated using LSDT. Level of significance (P) for these relations was obtained by F- test based on analysis of variance.

3. Result and discussion

3.1. Performance of baler on wheat straw

The average baling time, bale density and baling rate (output) of the vertical manual baler was 5.83 min per bale, 26.8 kg/m^3 and 87 kg/hr respectively on wheat straw. Likewise similar parameters for horizontal wood body and horizontal metal body balers were 12.8 and 6.23 min per bale, 29.72 and 39 kg/m^3, 39.6 and 75 kg/hr respectively. These results indicate that the vertical hay press performed better with less baling time and higher output and followed with horizontal metal body hay baler. But regarding to bale density it is favor with horizontal metal body hay baler Figure 4

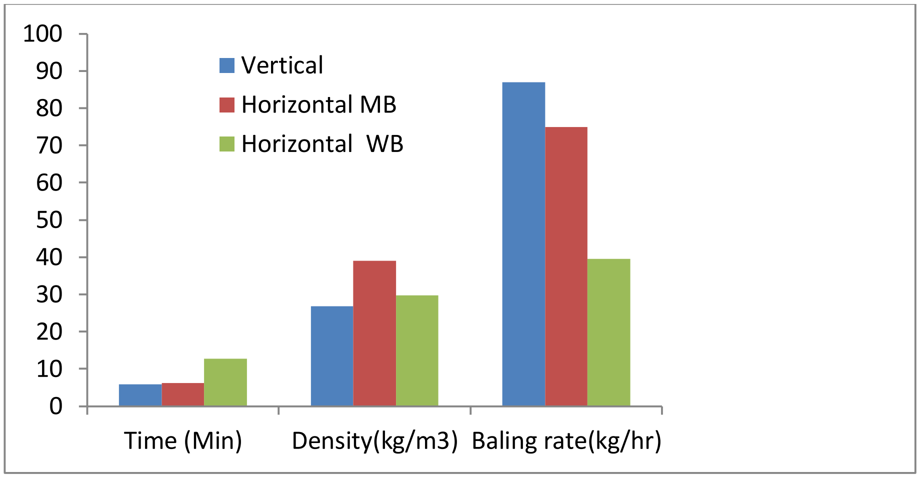

Figure3. Mean performance parameters for vertical, horizontal MB and horizontal WB Manual hay baler on wheat straw

There were differences between the hay balers regarding baling time, pressing rate in favor of the vertical hay baler. The reason is that the vertical hay baler the piston unit is freely moved up and down with the use of ball bearing with help of beveled gear, so that the construction allows the operator to use his/her hand force to rotate the handle easily with minimum friction. Therefore, this condition assists to reduce energy and facilitate easiness of operation. A similar relationship of bale density with compression force was reported by Abu *et al.* (2012). But the horizontal one requires more energy than the vertical one because of the pusher pad which slides over sheet metals and timber wood producing high frictional force and thus reducing operator's efficiency and speed. Regarding density in favor of horizontal metal body hay baler this is due to compressed well and minimized the size when compared to others even if it needs high energy (Figure 4.).

Table 1. LSD All-Pairwise Comparisons Test of performance of all Balers on wheat straw

Parameters	TIME	MASS	DENSITY	PRESING RATE
HWB	12.783a	8.4667 a	30.063 b	0.6700 b
VB	5.833b	8.5667 a	26.923 b	1.4733 a
HMB	6.217b	7.8000 a	39.000 a	1.2533 a
CV %	8.98	8.58	12.17	10.39
Alpha = 0.05				

The same letter in column no significant difference at alpha 5%

As shown in table 1 there are no significant pairwise differences among the means of mass in all balers. Regarding to time, density and pressing rate there is significant difference at probability level of 5%. Pressing rate and time has no significance difference in Vertical and horizontal metal body balers. In vertical and horizontal wood body balers the density is no significantly difference at probability level of 5%.

3.2. Performance of balers on barley straw

The average baling time, bale density and baling rate (output) of the vertical manual baler was 9.833 min per bale, 27.7 kg/m^3 and 148 kg/hr respectively on barley straw. Likewise similar parameters for horizontal wood body and horizontal metal body balers were 13.37 and 10.97 min per bale, 60.29 and 67.75 kg/m^3, 120 and 121.8 kg/hr respectively. These results indicate that the vertical hay press performed better with less baling time and higher output and followed with horizontal metal body hay baler. But regarding to bale density it is favor with horizontal metal body hay baler (Figure 5)

Similar trend was obtained on the performance of all hay manual balers on barley straw as wheat straw. As shown in figure 5 baling time, pressing rate in favor of the vertical hay baler. Regarding density in favor of horizontal metal body hay bale, generally all manual hay balers show better result on barley straw than wheat straw. This may be barley straw pressed easily than wheat straw but it takes higher time per bale.

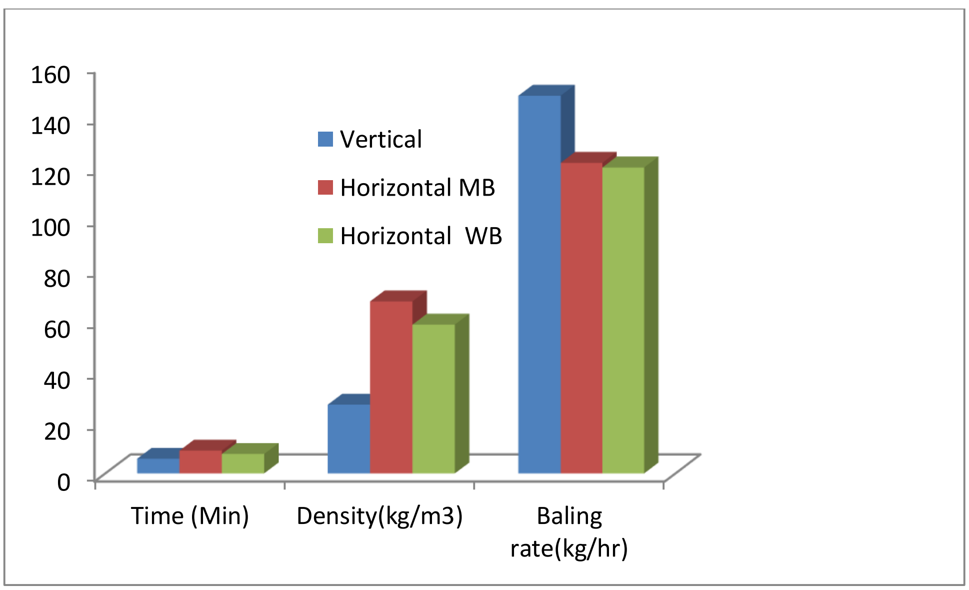

Figure 4. Mean performance parameters for vertical, horizontal MB and horizontal WB Manual hay baler on barley straw

Table 2. LSD All-Pairwise Comparisons Test of performance of all Balers on Barley straw

Parameters	TIME	MASS	DENSITY	PRESING RATE
HWB	13.367 b	14.500 a	60.293 a	2.0350 a
VB	9.833 a	14.233 a	27.100 b	2.4800 b
HMB	10.967 a	13.467 a	67.747 a	2.0300 a
CV %	**11.11**	**10.18**	**11.00**	**8.44**
Alpha = 0.05				

The same letter in column no significant difference at alpha 5%

As shown in table 2 there are no significant pairwise differences among the means of mass in all balers on barley straw. Regarding to time, density and pressing rate there is significant difference among baler to baler at probability level of 5%. In Pressing rate and density have no significance difference in both horizontal balers. But the vertical has significance with other balers in density and pressing rate. Whereas vertical and horizontal metal body have no significance difference with time at probability level of 5%.

4. Conclusion

Based on the performance evaluation made and results obtained, the following conclusions can be drawn:

- ✓ Vertical hay baler has better performance in baling rate than the others manual hay balers
- ✓ Regarding to density it favors to horizontal metal body hay baler
- ✓ All manual hay balers have better result on barley straw than wheat straw
- ✓ All manual have no significance difference on mass in both wheat and barley straw.

5. Recommendation

Based on the farmers comment and findings obtained, the following recommendation was made:

- Since all the balers were operated manually, so it was difficult address medium and large scale farmers hence an automatic or semi-automatic baler must be developed and used.

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Adaptation and Evaluation of Powered Termite Mound Driller

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Abstract

Termites are one of the major threats to agricultural crops, forestry, rangelands and the entire environments in western part of Oromia. Farmers in the termite problematic areas used queen removal, flooding and smoking as cultural control practices, which are also blamed as tiresome and ineffective by farmers in the area. Therefore, this activity was done with the objectives of adapting and evaluating of manually operated, powered termite mound driller with poisoning mechanisms as an improved termite control methods. Hence, the driller was evaluated in terms of mean penetration rate (cm/sec) and percentage of mound destruction (%). Test results revealed that, two operators can drill a big mound of sand clay soil, in three directions within 1.59 and 3.09 minutes in wet and dry soil conditions, respectively. It also takes 2.58 and 2.79 minutes with two operators for clay soil type during wet and dry soil conditions, respectively. In comparison with the powered machine, manual drilling method, takes 17.4 and 17.25 minutes with two operators for clay and sandy clay soil types respectively, in wet conditions. Thus, the powered drilling machine is recommended as better method for saving time of operating when compared with manual mound drilling machine.

Keywords: Adaptation, Evaluation, Drilling, Mound

1. Introduction

Termites are abundant and widely distributed throughout tropical and sub-tropical regions of Ethiopia. Some species cause serious damage to certain crops, young forestry plantations and wooden buildings. In these areas, termites are one of the major threats to agricultural crops, forestry seedlings, rangelands and wooden structures. The problem is severe in the western part of the country including Wollega area (Abdulahi *et al.*, 2010).

In the past, several attempts were made to reduce damage caused by termites, including extensive termite mound poisoning campaigns. Farmers also employed several cultural practices to reduce the damage caused by termites. These control measures includes queen removal, flooding and smoking. The damage can occur from seedling to harvest and usually occurs every year, as termites form more or less stable populations and foraging by various combinations of several species occurring throughout the year.

The gradual increase in human and livestock populations, depletion of natural resource bases, lack of agricultural technology and information support system and poor land management, among other factors, in the Western Oromia region have resulted in a gradual increase in termite population over decades (Sileshi, 2005).

Farmers differentiated two types of termites. The local names given to the two types of termites are '*Weerrartuu' (*meaning *'invaders' in* Afan Oromo*)* and '*Marimartu'* (meaning '*common to the area'* in Afan Oromo*)*. The *Marimartu* have mounds and stay in some places whereas, the *Werrartu* are non-mound forming and migratory type (Abdulahi, 2010).

Control measures (queen removal, flooding and smoking) are cultural practices which are not effective so far to control termites. Perhaps this could be due to the development of substitute queens because certain termite species are known to produce substitute queens under favorable conditions when the primary queen is lost (Harris, 1971; Schmutterer, 1969). According to Abdulahi (1990), queen removal took four local farmers about 20.15 minutes on average to dig a mound and remove the queen. In addition to these control measures chemicals were used by the agricultural office of the districts in areas where the severity was very high. But, the mechanism to apply chemicals, limited access and capacity to use chemicals affect the action of termite pesticide application.

Due to the fact that mechanism to apply chemicals to termite mound is a problem, appropriate drilling technology did not exist. Drilling of any slabs that butt up next to the home, business centers or inside the garage is the vital part of termite treatment in developed countries (need citation).

The reason for drilling these holes is to put the pesticide under the slab where the termites can come into contact with the finished product. Bako agricultural engineering research center) has modified manual operated termite mound driller which is much better than traditional way of mound breaking. But it was tiresome that to break a termite mound, it takes 17.4 and 17.25 minutes with two operators for clay and sandy clay soil type respectively during wet season. Therefore, by bearing in mind these facts, this activity has been done to adapt and evaluate hand drilling machine for termite mound driller.

2. Material and Methods

Experimental Site

Modification of the machine was done at Bako Agricultural Engineering Research Center (BAERC), While, the evaluation of the prototype was done at Najo (Ebawakoya kebele), Jarso and Mana sibu (Gonfi kebele) districts of West Wellega Zone of Oromia.

Materials

Important materials like hand drilling machine (1000W), diesel generator (2.8KW), electric cable with extensions, hard steel shaft (Ø16mm), termite killer chemical (pesticides), water pipe with Ø½, and 3 inch, etc.

Methods

After all the necessary materials are availed hand drilling machine was adapted for BAERC manual termite mound drillers basically the driller and power transmission parts. Power transmission system is the very important point where, how to mesh electric hand drill and driller.

Driller

Manual mound driller has auger of 40 cm at one end and 60 cm length, three fourth inch water pipe and totally one meter length. The modified has two coupled driller with bolt and nut. The first has auger of 30 cm at one end and 18 cm three fourth inch water pipe. The second has 60 cm length with three fourth inch water pipe and 10 cm length half inch water pipe was welded at both ends to insert to the first water pipe and power transmission was produced. On water pipe curled flat metal (10x1.5mm) was welded on it in the form of auger to make it pull the soil out during drilling.

Power transmission

It was produced, in order to transmit power from electric hand drill to driller, from 3.5cm length hard steel shaft of Ø16mm welded on 8cm length three fourth inch water pipe.

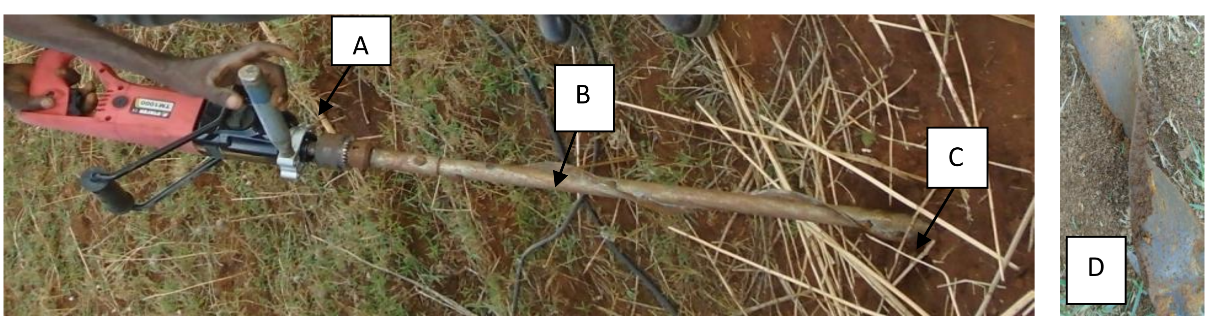

Figure 1. Basic parts of the power driven termite mound driller, A-hand drill, B-power transmission, C-mound driller and D-tip auger

Evaluation of the prototype

It was evaluated in terms of mean penetration rate (cm/sec) and percentage of mound destruction (%). For small and medium mounds 70 ml and 90 ml diazinon 40% EC with 20 lit of water was applied respectively, while for large mound 110 ml with 30lit of water was applied. The trial was conducted in a factorial experiment with the following factors.

1. Mound type: small, medium and big size, according to Daniel Getahun (2014) based on basal diameters, the mounds was drilled in three direction; vertically, inclined in west and east from farmers experience.
2. Drilling season: wet and dry seasons
3. Soil type: Clay and sandy clay

All treatments were replicated three times for each soil type and drilling seasons.

For insecticide treatment the top portion of termite mounds were drilled in vertically and two diagonal directions up to sensing of easily penetrating. The treatments were carried out only on live mounds after checking the presence of live termites in the nest. The amount of insecticides required for each mound was measured and mixed with 20 and 30 liters of water for small and medium and big mounds respectively. The solution was poured into the nest through those drilled holes. These were immediately covered with soil and tramped on foot to prevent evaporation of the insecticides and to reduce the risk of birds being poisoned by eating dead termites.

Statistical Analysis

Analysis of variance was made using Statistix 8 statistical software. Significantly differnet pairs of treatment means were separated using the Least Significant Difference Test at 5% level of significance (LSD 5%).

3. Results and Discussion

Penetrating Rate of the Prototype

In general, penetration rate (cm/sec) was decreased while we drill from small to big mound for each soil type. This confirms us that it was due to their basal diameter and height. From the table we can poison the mounds during wet and dry season by driller. But the minimum penetration rate was recorded at dry season, big mound and sandy clay soil type.

Table 1 Effect of mound types on penetration rate (cm/sec) at different soil type and seasons

Source of variation				
Mound types	Penetration rate (cm/sec), Clay soil		Penetration rate (cm/sec), sandy clay soil	
	Wet season	Dry season	Wet season	Dry season
Small	3.900 [ab]	3.137 [a]	5.918 [a]	2.476 [a]
Medium	3.991 [a]	2.175 [a]	3.962 [a]	2.189 [a]
Big	2.319 [b]	2.16 [a]	3.790 [a]	1.951 [a]
SE (M)	0.752	0.629	1.193	0.342
LSD (5%)	1.594	1.334	2.530	0.725

Means followed by the same letter within columns do not differ significantly by Least Significant Difference Test (LSD) at 5% of probability

It was found that, the prototype can penetrate the termite mound up to 120cm that is the deepest depth and the maximum drilling time 0.53 and 1.03minutes was recorded at big mound for sand clay soil type during wet and dry seasons respectively. While, 0.86 and 0.93 minutes was recorded at big mound for clay soil type during wet and dry seasons respectively. This means, to drill a big mound at three directions, it takes 1.59 and 3.09 minutes with two operators for sandy clay soil type during wet and dry seasons respectively. It takes 2.58 and 2.79 minutes with two operators for clay soil type during wet and dry seasons respectively. Manual drilling, takes 17.4 and 17.25 minutes with two operators for clay and sandy clay soil type respectively during wet seasons (Mekibab A and Merga W, 2015). Generally, when we compare power driven with manual drilling machine, the power driven saves more operating time. Additionally, it reduces the operating severity which is the basic one.

Fig2. Field testing of the driller

Evaluation of Mound Destruction

The effectiveness of mound poisoning was assessed in terms of destruction of poisoned mound/ appearance of new mounds on it after two to three months. Nine mounds were treated with diazinon 40% EC for dry and wet seasons, respectively at each district. From the assessment every visible mounds were destroyed, except one mound at Manasibu district of dry season treated. This shows us using the driller in order to destruct the mound by application of the chemicals was effective.

4. Conclusion and Recommendation

Removal of the queen from the nest was not an effective method of killing Macrotermes colonies. Mound treatment with diazinon 40% was effective by drilling; however, the effect of long-term mound poisoning in crop damage and grain yield needs further investigation. It is better to poison mounds in mass rather than individual farmers and the access of the technology provide through weredas agriculture sector.

Since the effect of mound poisoning on crop yield is not known, an assessment of the method is quite important.

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Estimation of Spatially Distributed Groundwater recharge in Modjo River Catchment, Awash Basin, Oromia, Central Ethiopia

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Abstract

Recharge is an important factor in evaluating groundwater resources but difficult to quantify. Hence estimation of groundwater recharge requires modeling of the interaction between all the important processes in the hydrological cycle. In this study the long term seasonal and annual groundwater recharge of Modjo river catchment (2,202 km^2) was estimated and recharge map were developed through a grid based physically distributed model, WetSpass. Long term average hydro-meteorological data and spatial pattern of watershed physical grid maps were used as main inputs for the model. All input maps for the model were prepared using ArcGIS 10.2 spatial analysis tool. Soil, land use and runoff coefficient parameters in data base files, season independent gridded base map of topography, slope, and soil were used in the model; whereas precipitation, potential evapotranspiration, temperature, wind speed, groundwater depth and land use map were prepared and employed by the model, in ASCII grid format of 120m cell size with 647 numbers of row and 425 numbers of columns for both winter and summer seasons. From the result, it is found that the long-term temporal and spatial average annual rainfall of 933 mm was distributed as: surface runoff of 164 mm (17.6%), evapotranspiration of 686 mm (73.5%), and recharge of 83 mm (8.9%). Thus an average of 183Mm^3 of groundwater will be recharged per year or 5,802 liter/second from the catchment area. Flood control dams (artificial recharge) practice was recommended in this study area to harvest the excess water (simulated annual surface runoff of 361Mm^3) which is helpful in one way to reduce soil erosion and in the other way to enhance more recharge to groundwater.

1. INTRODUCTION

Groundwater is a critical source of fresh water throughout the world. It has become an important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries (Todd, 2005). Comprehensive statistics on groundwater abstraction and use are not available, but it is estimated that more than 1.5 billion people worldwide rely on groundwater for potable water (Clarke *et al*., 1996). Other than water stored in icecaps and glaciers, groundwater accounts for approximately 97% of fresh water on Earth (Shiklomanov and Rodda, 2003). As the world population continues to grow, more people will come to rely on groundwater sources, particularly in arid and semiarid areas (Simmers, 1990). Long-term availability of groundwater supplies for burgeoning populations can be ensured only if effective management schemes are developed and put into practice. Hence, knowledge of groundwater resource potential is important for its management and sustainable use, because the optimal exploitation of the groundwater requires a previous knowledge on the aquifers potential (Benjamin *et al*., 2007).

Groundwater potential is directly dependent on recharge. For efficient and sustainable management of the groundwater resource, understanding and quantification of groundwater recharge have paramount importance (Obuobie *et al*., 2008). Recharge can be defined as the entry into the saturated zone of water made available at the water table surface. It is the process by which water percolates down the soil and reaches the water table either by natural or artificial methods to replenish the aquifer with water from the land surface. Generally, quantification of natural rates of groundwater recharge (i.e. the rates at which aquifer waters are replenished) is imperative for efficient groundwater resource management (Simmers, 1990).

Even though recharge is an important factor in evaluating groundwater resource, it is found difficult to quantify (Alley *et al*., 2002). Therefore, groundwater models have been used as tools for investigating groundwater system dynamics (Anderson and Woessner,1992). Hence, WetSpass was built as a physically based methodology for estimation of the long-term average, spatially varying, water balance components: surface runoff, actual evapotranspiration and groundwater recharge (Batelaan and Smedt, 2001 and 2007). It is an acronym for water and energy transfer between soil, plants and atmosphere under quasi-steady state that was built upon the foundations of the time dependent spatially distributed water balance model (Batelaan and Smedt, 2001 and 2007). In this study geographical information system GIS and WetSpass (Batelaan and Smedt, 2007) model, were used for groundwater recharge estimation.

Studies on groundwater potential of Ethiopia show erroneous results of 2.5 BCM by WAPCOS, to 185 BCM by Ayenew and Alemayehu, (2001, as cited in Moges, 2012). Best guesses in this respect ranges between 12-30 BCM or even more if all aquifers in the lowlands are assessed (MoWIE, 2011). This ambiguity is an indication of how much detailed study and survey is needed to estimate the countries resources with a better precision; because such uncertainty can have a hindering effect on the countries pursuit to utilize its water resources potential to the limit.

To formulate technically-sound groundwater resources management policies, decision makers always ask questions like: How long can an aquifer maintain the current rate of groundwater abstraction? What is the safety yield that the aquifer can sustain the continuous abstraction? What is the capture zone of a water supply well field?

The analysis of estimating groundwater recharge will assist scientific community, policy makers, donors, non-governmental organizations and other development practitioners to deliver right policy and programs in required areas on time. As a result, this study provides valuable data and baseline information in formulating technically sound groundwater resources management policies for the response of declining groundwater tables in the study area. Therefore, this study was carried out with general objective of estimating groundwater recharge in the Modjo river catchment. Hence, the study had focused on developing groundwater recharge map and estimating the average recharge amount of Modjo river catchment.

2. MATERIAL AND METHODS

2.1 Description of Study Area

This study was conducted at Modjo river catchment, which is located at upper Awash Basin. The sub-basin covers about 2201.98 km^2 area and is bounded within 8°75'N-9°05'N latitude and 38°56'E -39°17'E longitude. The average elevation in the catchment ranges between (1591 to 3060) meter above mean sea level. The area has a bi-modal rainfall with a short rainy season from March to May and with a long rainy season from June to September. The mean annual temperature of the sub-basin is 19.91°C and the mean annual rainfall is 933mm. The relief of the study area is generally flatland with an undulation of some ridges and mountains like eastern part of Yerer and the catchment generally shows an eastward decrease in elevation above mean sea level. The water units found in the study area are Modjo and Gale Wemecha rivers. As to the geological set up, the area belongs to the Quaternary rocks of Pleistocene and Holocene which is 70% quaternary volcanic rock and 30% unconsolidated sediment. According to (WSP, 2006) those rocks are highly fractured rocks and resulted a favorable situation for groundwater recharge and occurrence and are very important hydro-geological formation that are used as good source of groundwater in Ethiopia.

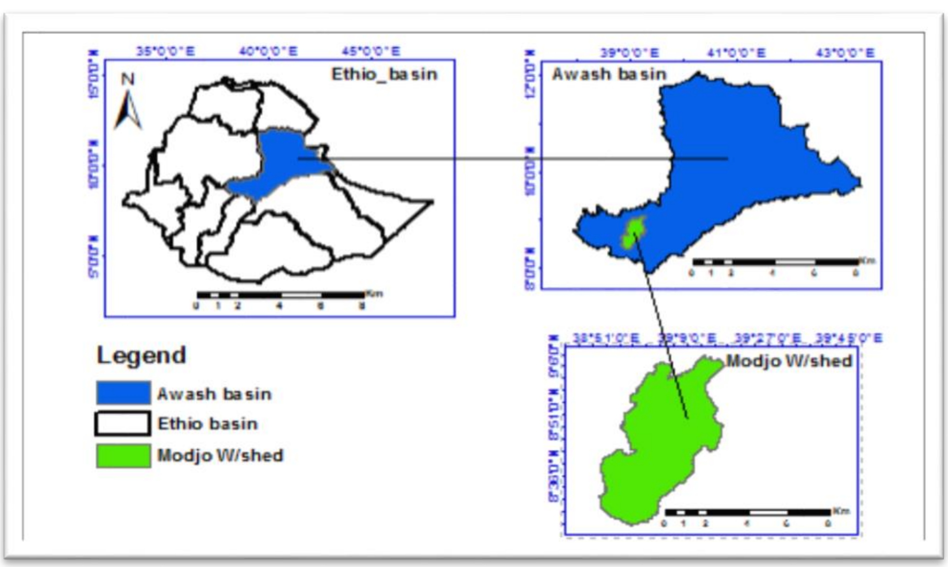

Figure 1.Location map of Modjo Sub-basin

2.2 Data and software used

ArcGIS10.2 were used for all data processing, data management and data preparation of the model required, and WetSpass model to estimate the long-term average spatially varying water balance components of the area.

Twenty eight years (1987-2014) climatic data were collected for all station from Ethiopian National Meteorological Services, and the reference evapotranspiration (ETo) was computed using FAO-Penman-Monteith equation. Forty-one static water level data for groundwater depth estimation in the sub-basin was collected from MoWIE and finally all the data were processed and grid map of each data was prepared using ArcGIS 10.2

The watershed delineation was carried out with Ethiopian digital elevation model obtained from SRTM (Shuttle radar topographic mission), topographic map and slope map of the study area were also developed from this DEM (digital elevation model). In addition Enhanced Thematic Mapper Plus (ETM+) satellite imagery was used to develop land use classification of the study area; and the soil map of the study area were prepared from soil map data-base of the Northeastern African.

2.3 Climatic data

The study area is located within the main Ethiopian rift and mostly affected by the southerly and easterly Indian Ocean air currents, as a result the air currents supply rain with bimodal characteristics. There are two main seasons in the study area, namely summer and winter also locally called as Kiremt, Bega respectively. The main rainfall season is summer season ends only for four months from June to September. During this period the region receives more than 70% of the total annual rainfall.

Twenty eight years (1987-2014) climatic data was used for six metrological stations selected for this study (see Table 1) and the spatial areal rainfall distribution of each station is computed with Thiessen polygon using ArcGIS 10.2

Table 1.Rain gauge stations in Modjo river catchment

S.No	Gauge Station	Elevation (m)	Location		Period of data
			X(m)	Y(m)	
1	Chefedonsa	2392	512765	990959	1987-2014
2	Debrazeyit	1943	496335	985639	1987-2014
3	Modjo	1870	510904	950795	1987-2014
4	Koka	1597	516196	936243	1987-2014
5	Hombole	1670	484503	925367	1987-2014
6	Ejere	2233	531128	969873	1987-2014

Debrazeyit, Modjo, Koka and Hombole are class one metrological stations which include rainfall, max and min temperature, relative humidity, wind speed and sunshine hour whereas stations Chefedonsa and Ejere are class two metrological stations which contain rainfall, max, min temperature and wind speed. Other parameters like relative humidity and sunshine hour were filled for missed period of those two stations by normal ratio-method which is recommended to estimate missing data in the sub-basin where annual rainfall among stations differ by more than 10% (Dingman, 2002), for this study the variation among station shows 12%. The homogeneity of annual rainfall data for each station was tested using XLSTAT 2017 software by means of SNHT test (Standard Normal Homogeneity Test) and double mass curve method was used to check and correct consistency of recording data.

2.4 Wet Spass application

The total water balance for a raster cell (Figure 2) is split into independent water balances for the vegetated, bare-soil, open-water and impervious parts of each cell. This allows one to account for the non-uniformity of the land-use per cell, which is dependent on the resolution of the raster cell. The processes in each part of a cell are set in a cascading way. This means that an order of occurrence of the processes, after the precipitation event, is assumed. Defining such an order is a prerequisite for the seasonal timescale with which the processes will be quantified. The quantity determined for each process is consequently limited by a number of constraints.

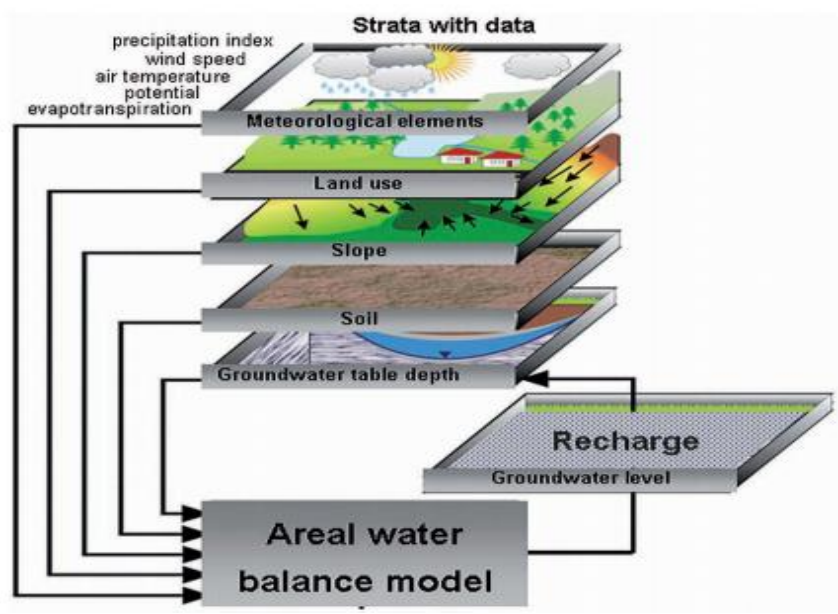

Figure 2. Schematization and integration of data for a hypothetical raster cell in the WetSpass water balance model, after Batelaan and Smedt (2001).

Water balance calculation

The water balance components of vegetated, bare-soil, open-water, and impervious surfaces are used to calculate the total water balance of a raster cell as follows:

$$ET_{raster} = avETv + asEs + aoEo + aiEi \quad (1)$$

$$S_{raster} = avSv + asSs + aoSo + aiSi \quad (2)$$

$$R_{raster} = avRv + asRs + aoRo + aiRi \quad (3)$$

where ET_{raster}, S_{raster}, R_{raster} are the total Evapotranspiration, Surface runoff, and Groundwater recharge of a raster cell respectively, each having a vegetated, bare-soil, open-water and impervious area component denoted by av, as, ao, and ai, respectively. Precipitation is taken as the starting point for the computation of the water balance of each of the above mentioned components of a raster cell, the rest of the processes (interception, runoff, evapotranspiration, and recharge) follow in an orderly manner.

2.5 WetSpass adjustment

WetSpass is originally developed for conditions in the temperate regions; there should be some adjustment to use it for the case of Ethiopia. Summer and winter land-use, soil and runoff coefficient parameters are the four parameters tables used by WetSpass and be adjusted according to different area. They are connected to the model as attribute tables. The land-use attribute table includes parameters such as land-use type, rooting depth, leaf area index and vegetation height. The soil parameter table contains soil parameters such as textural soil class, and plant available water contents. The runoff coefficient attribute tables contain parameters for runoff classes of various land-uses, slope and runoff coefficient. These attributes tables allow for easy definition of new land-use and soil type as well as changes to each parameter value.

The original land use parameter tables for the model was developed based on land use types and characteristics from temperate regions, Europe in particular. Thus an attempt has been made, in this study, to modify the land use parameter table as the case in Ethiopia is different than what someone can find in Europe. Basic modification has been done on the land use parameters such as leaf area index, crop height, interception and percentage. In this regard, the vegetative area, bare land area, impervious area, and open water area proportions of each land use class in Modjo sub-basin has been defined based on the knowledge about the natural characteristics of the different land use types in the sub-basin; some of the seasonal land uses parameter values were readjusted as it has been used by (Tesfamichael *et al.*, 2010) for Ethiopia case. In addition, the parameters tables were adjusted by try and error through WetSpass watershed simulation repeatedly; this was done depending on the estimated groundwater recharge from well data and adjusting WetSpass recharge simulation value to the known ground truth spatial groundwater recharge obtained from the well data.

2.6 Model Input Data Preparation

WetSpass is a steady state models and therefore, needs long-term average climatic data (precipitation, reference evapotranspiration, temperature and wind speed), and catchment configuration data (groundwater depth, slope, elevation, and land use), soil data and boundary conditions (extent of area to be modeled). All input data must be in ASCII grid file format. Thus as a first step, a mask map was prepared from the delineated catchment based on the DEM and Modjo sub-basin with a total area of 2202 km² was delineated and this mask map has been used to develop all other grid-map inputs for the model

3. Result and discussion

3.1 Spatial Data for Model Input

3.1.1 Soil map

The sub-basin is covered with four different soil textural classes, 54% of silty clay, 34% of silty loam, 8% of clay and 4% of loam soil. The soil map of sub-basin used in watershed simulation is shown in Figure 3 below

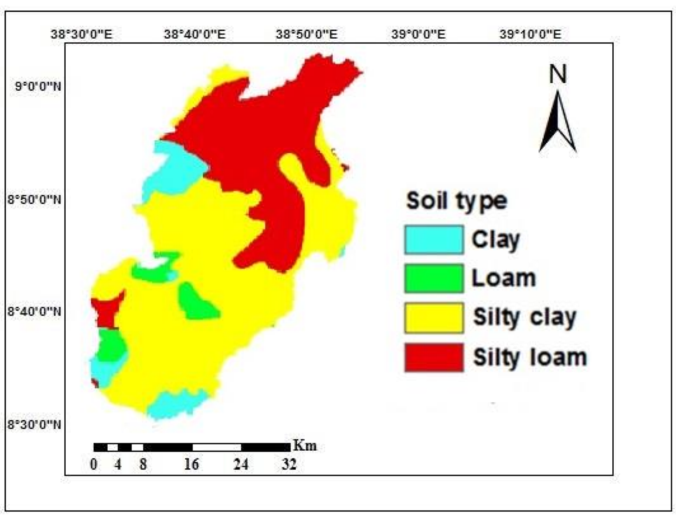

Figure 3. Dominant soil textural class of Modjo sub-basin

3.1.2 Topography

Altitude in the basin increases from south to north and from west to east. The lowest point in the basin is located in the western edge and the highest in the north. The mean elevation of the basin is 2030 m with a standard deviation of about 273 m. This considerably large standard deviation explains the fact that the topography is rugged. Figure 4 below is the topographic grid map of study area used in the watershed simulation.

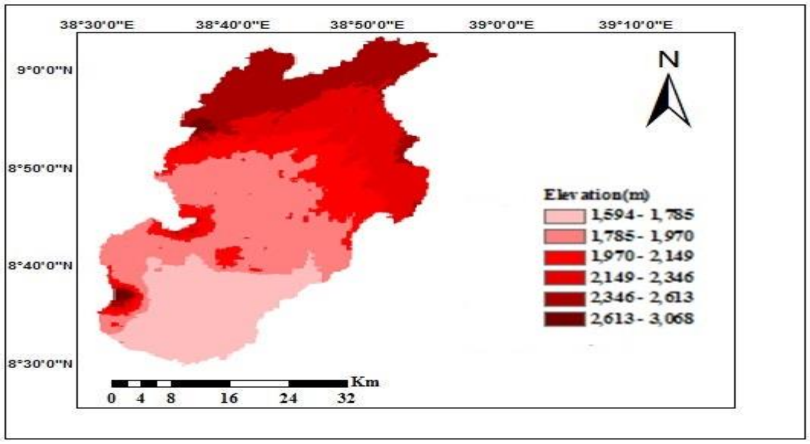

Figure 4.Topographic map of Modjo sub-basin

3.1.3 Slope

The slope ranges from 0 to 52%, with 3% mean and standard deviation of 4%. Most of the agricultural area lies within the slope of 3-10%.

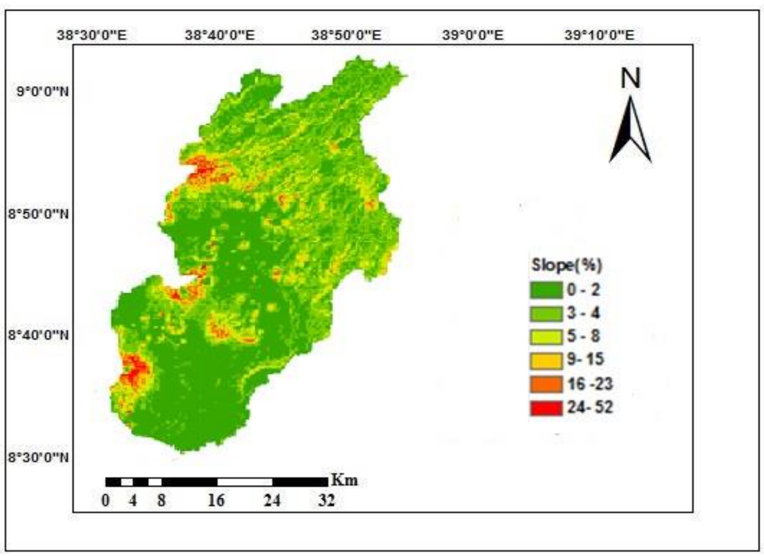

Figure 5.Slope map of Modjo sub-basin

3.1.4 Land Use Classification

The land use classification of the study area were developed from landsat image and the identity of each class is determined by a combination of experience and ground truth (i.e. visiting the study area and observing the actual cover types) and the land use/cover type obtained accuracy estimation were justified by error (confusion) matrix. Accordingly, in

Modjo sub-basin agricultural land being the dominant which comprises 49.3% of the total sub-basin area, grassland 16.5%, Tree & Shrub 15% and Water body 7%, Settlement 11% were the prominent types of land use type.

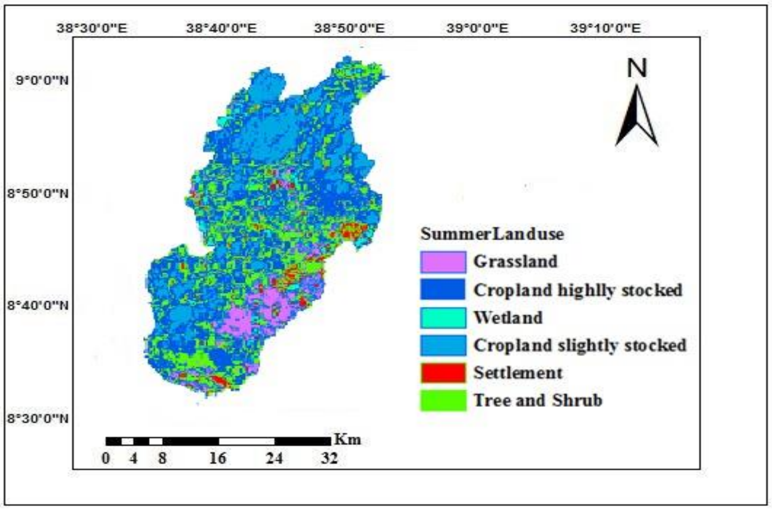

Figure 6. Summer land use map of Modjo subbasin

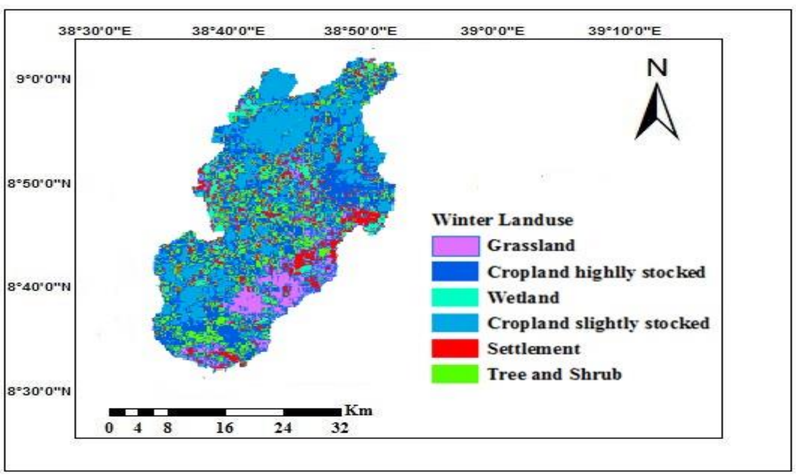

Figure 7.Winter land use map of Modjo sub-basin (source: own analysis)

3.1.5 Adjusted land use parameter table

The land use parameter table was modified and land use parameter tables for Modjo sub-basin summer and winter seasons was developed. The modified summer and winter land use parameter tables have been used to run WetSpass for the subbasin modeling processes. The highlighted portion on Table 3 and 4 below indicates the amended parameter table values for the study area.

Table 2. Soil parameter table for Modjo sub-basin

Code	SOIL	FIED CAPA	WILTIG PNT	PAW	RESIDU AL WC	A1	EVAPOD EPTH	TENSIO NHH	P_FRAC _SU	P_FAC_ W	Teta
12	clay	0.46	0.33	0.13	0.09	0.21	0.05	0.37	0.95	0.85	0.852
5	loam	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02	0.333
11	silty clay	0.43	0.27	0.16	0.056	0.23	0.05	0.34	0.84	0.75	0.754
4	Silty loam	0.29	0.1	0.19	0.015	0.4	0.05	0.21	0.26	0.07	0.408

Table 3.Summer land-use parameter table for Modjo sub-basin

NUMBER	LUS_TYPE	RUNOFF_VEG	NUM_ VEG_R O	NUM_I MP _RO	VEG_A REA	BARE_A REA	IMP_ARE A	OPENW _AREA	ROOT_D EPTH	LAI	MIN_STO M	INTERC _PER	VEG_HEI GHT
1	City center	grass	2	0	0.7	0	0.3	0	0.3	2	100	10	0.2
21	Crop land	crop	1	0	0.9000	0.0000	0.2000	0.0000	0.4000	2.00	180.00	35.00	0.7000
23	Grass land	grass	2	0	0.7000	0.0000	0.2000	0.0000	0.3000	2.00	100.00	10.00	0.2000
33	Forest	forest	3	0	0.8000	0.0000	0.2000	0.0000	2.5000	7.50	375.00	50.00	10.0000
36	Shrub land	grass	2	0	0.8000	0.0000	0.2000	0.0000	0.6000	6.00	110.00	42.00	2.5000
52	lake	open water	0	0	0.001	0.000	0.05	1	0.05	0.00	110	5.00	0.001

Table 4.Winter land-use parameter table for Modjo sub-basin

NUMBER	LUS_TYPE	RUNOFF_VEG	NUM_ VEG_R O	NUM_I MP _RO	VEG_A REA	BARE_A REA	IMP_ARE A	OPENW _AREA	ROOT_D EPTH	LAI	MIN_STO M	INTERC _PER	VEG_HEI GHT
1	City center	grass	2	0	0.4	0.2	0.05	0	0.3	2	170	20	0.2000
21	Crop land	crop	1	0	0.2000	0.4000	0.4000	0.0000	0.3500	2.00	180.00	20.00	0.6000
23	Grass land	grass	2	0	0.3000	0.2000	0.0500	0.0000	0.3000	2.00	170.00	20.00	0.2000
33	Forest	forest	3	0	0.8000	0.1000	0.1000	0.0000	2.0000	4.50	350.00	38.00	10.0000
36	Shrub land	grass	2	0	0.2000	0.8000	0.0000	0.0000	0.6000	0.00	110.00	30.00	2.0000
52	lake	open water	0	0	0.001	0.000	0.05	1	0.05	0.0	110	5.00	0.001

3.2 Climatic Data for Model Input

3.2.1 Areal rainfall distribution

To compute spatial areal rainfall, Theissen polygon method was used in ArcGIS environments and the gauge weights developed for sub-catchments are presented in Table 5.

Table 5. Theissen gauge weights for Modjo sub-basin

S.No.	Rainfall stations	Area weight (km^2)	Gauge weight (%)
1	Chefedonsa	450	20
2	Debrazeyit	694	32
3	Modjo	510	23
4	Koka	173	8
5	Hombole	142	6.4
6	Ejere	233	10.6

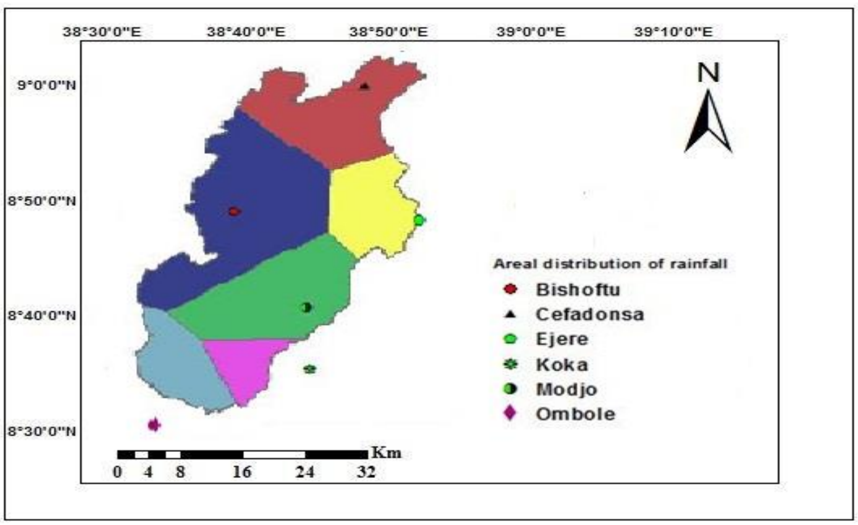

Figure 8.Theissen polygon developed for Modjo sub-basin

3.2.1 Precipitation

The mean annual precipitation value calculated for the sub-basin is 933mm and its grid map used in the model for watershed simulation is shown on Figure 9 below.

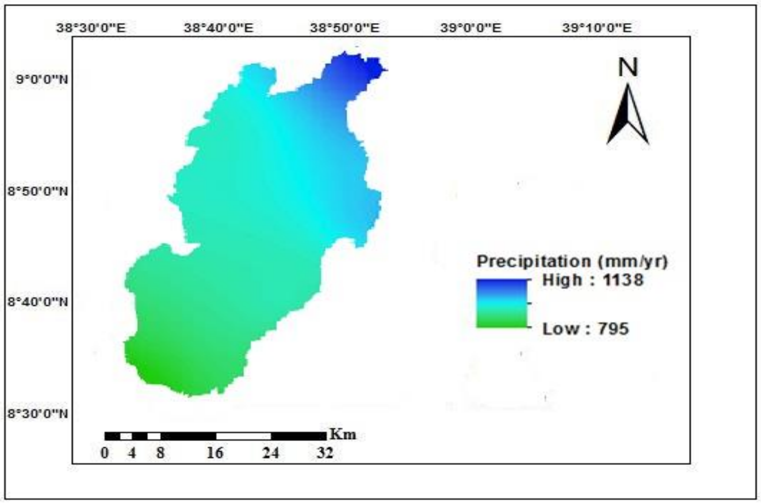

Figure 9.Average annual precipitation of Modjo sub-basin

3.2.3 Temperature

The study area has an average temperature of 19.91°C with a minimum temperature of 11.6°C and a maximum temperature of 29.2°C. Maximum temperature values were obtained in the months of May and minimum temperature was recorded in the month of August and it has generally been observed that the average annual temperature decreases with an increase in altitude.

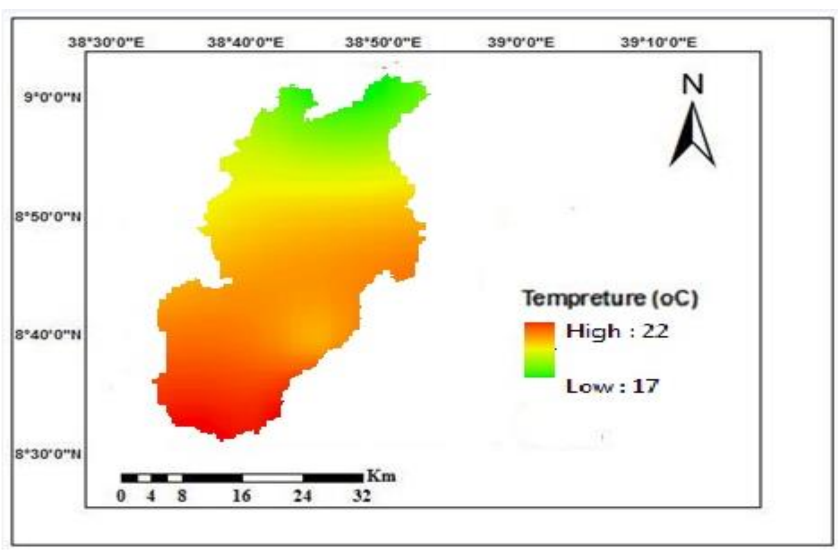

Figure 10. Average annual temperature of Modjo sub-basin

3.2.4 Evapotranspiration

Often a value for the potential evapotranspiration is calculated at a nearby climate station on a reference surface, conventionally short grass. This value is called the reference evapotranspiration (ETo) which is equal to PET. For this simulation PET grid map shown on Figure 11 is used as input for the model.

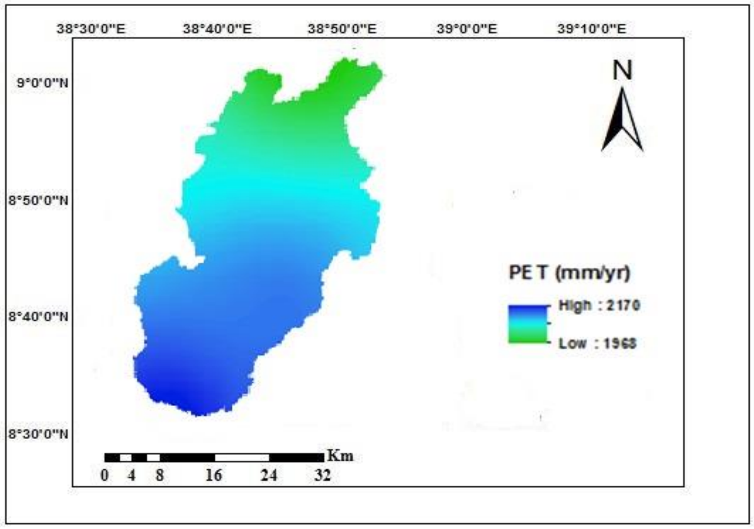

Figure 11. Average annual PET of Modjo sub-basin

3.2.5 Wind speed

The mean monthly wind speed of the area measured at two meters above the ground varies from 1.6 to 2.6m/s. with maximum values observed in the months between February to May and minimum values in the months of August and September.

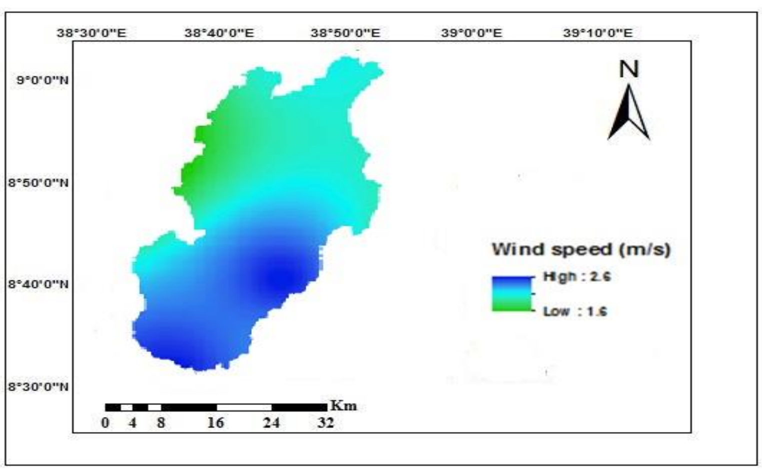

Figure 12. Average annual wind speed of Modjo sub-basin

3.2.6 Groundwater depth

In this study, an average value of groundwater level was used for all station from data collected and assumed as the groundwater depth for both summer and winter seasons

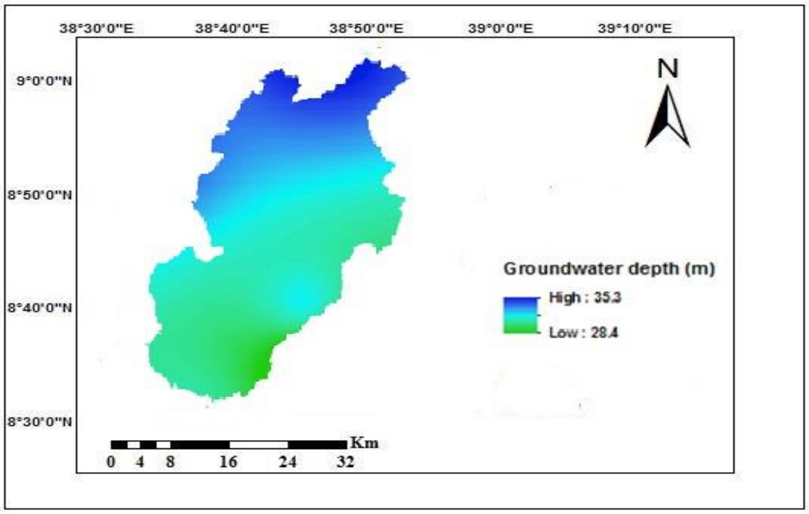

Figure 13.Average groundwater depth of Modjo sub-basin

3.3 Water Balance Analysis

Water balance represents the hydrological gains and losses of a given system. For this study WetSpass modeling was applied and total water balance of a raster cell computations were calculated depending on the following equation in the model and all water balance were carried out from the model output.

$$Rv = P - Sv - ETv - Es - I \quad (4)$$

Where; Rv is recharge, P is precipitation, Sv is surface runoff, ETv is Evapotranspiration, Es is evaporation from bare soil and I is Interception of a raster cell.

3.3.1 Evapotranspiration

The WetSpass model calculates the total actual evapotranspiration as a sum of the evaporation of water intercepted by vegetation, the transpiration of the vegetative cover and the evaporation from the bare soil between the vegetation. The simulated average minimum and maximum annual evapotranspiration of the catchment are 359 mm and 952 mm respectively, with 686 mm mean and standard deviation of 141 mm distribution.

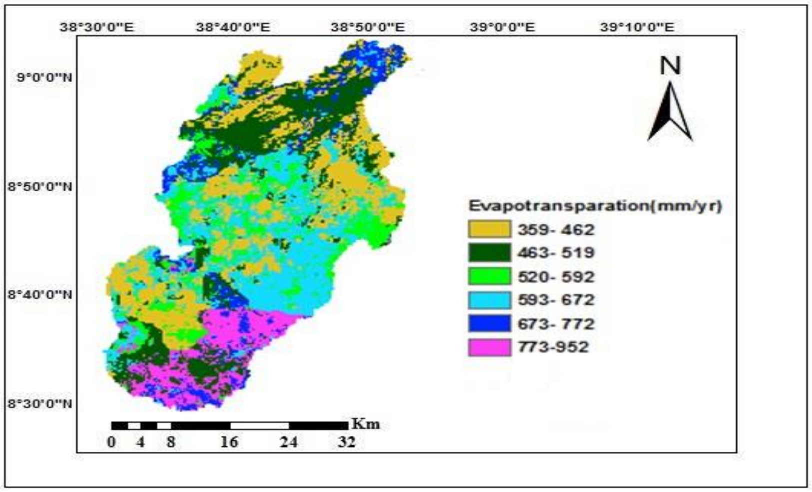

Figure 14 Simulated annual evapotranspiration with the WetSpass model for Modjo subbasin

The average evapotranspiration accounts more than 73.5% of the total annual rainfall. This shows that evapotranspiration is the main processes by which water is lost in the catchment. This is attributed to the high rates of radiation and the persistence of strong dry Westerly winds coming from the Awash depression. The evapotranspiration is largely determined by the solar radiation, which is fairly constant between years. As a result evapotranspiration varies little from year to year, especially in the dry season. About 77% of the total annual evapotranspiration is lost during summer season while the rest 23% is released in the winter season. This variation occurs due to difference in precipitation within the two seasons.

According to Behailu (2007), the average annual actual evapotranspiration of Modjo river catchment is about 650.33 and 789.47 mm with Thornthwaite and Turc method respectively. Getachaw (2007), reports similar results for the nearest watershed Welanchiti area, annual actual evapotranspiration, from Turc method gives value of 697 mm. Thus 952 mm maximum and 686 mm average annual evapotranspiration, simulated by WetSpass for Modjo river catchment, is reasonable.

WetSpass has also simulated constituents of evapotranspiration, i.e. interception, soil evaporation and transpiration. Interception is the part of the rainfall that is intercepted by the earth's surface and subsequently evaporated. It can take place by vegetal cover and depression storage in puddles and in land formation such as rills and furrows. Interception can amount up to 15-50% of precipitation, which is significant part of the water balance. For this subbasin 260 mm and 15 mm interception was simulated by WetSpass as maximum and minimum respectively and the mean was 177 mm which accounts about 25% of the mean evapo- transpiration. WetSpass also simulate 447 mm and 52 mm maximum and minimum transpiration with 290 mm mean value, soil evaporation of 375 mm maximum and 12 mm minimum with mean of 220 mm was simulated for the sub-basin. See the map of three constitute of evapotranspiration on Figure (15-17)

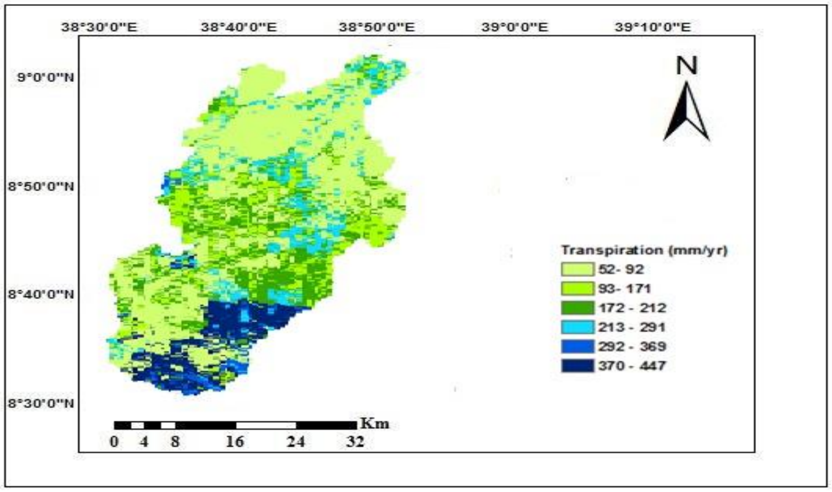

Figure 15. Simulated annual transpiration with WetSpass model for Modjo subbasin

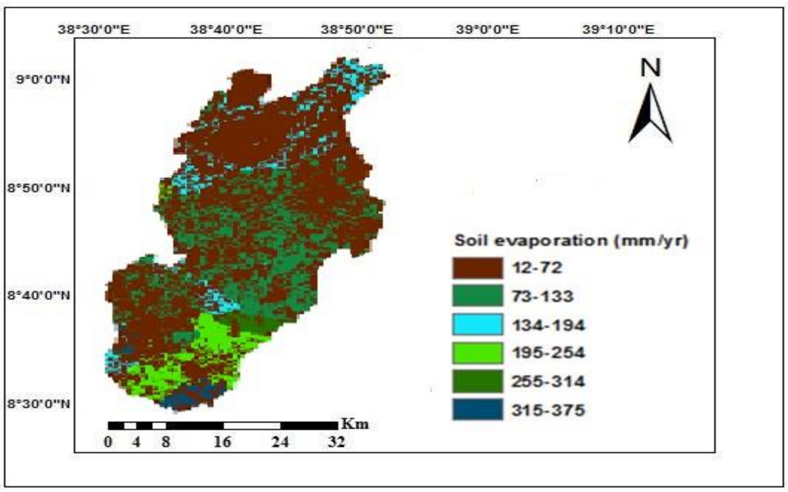

Figure 16. Simulated annual soil evaporation with WetSpass model for Modjo subbasin

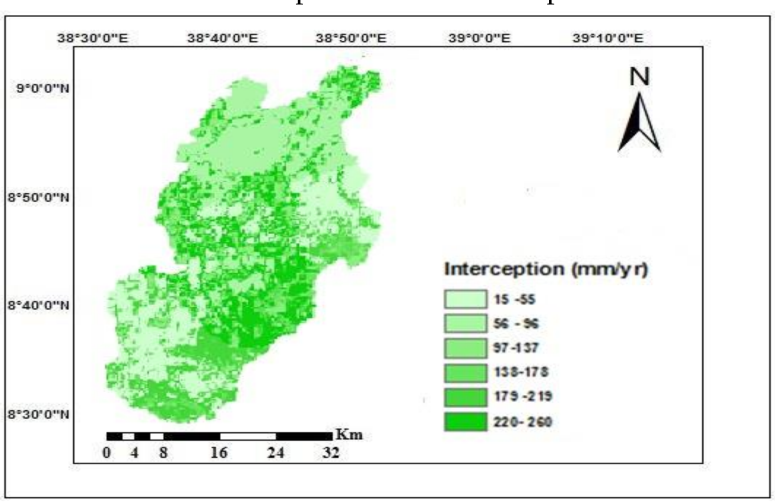

Figure 17. Simulated annual interception with WetSpass model for Modjo subbasin

The relation between transpiration and soil evaporation depends strongly on the density of the plant cover, expressed by the leaf area index (LAI). In general, soil evaporation decreases rapidly with increasing LAI while the opposite is true for transpiration (Merta *et al*., 2008). Since WetSpass determines the total evapotranspiration as the sum of the evaporation from soil, intercepted water and transpiration, it is obvious that the evapotranspiration varies spatially according to the land use class and soil types.

Since the catchment is located in one of the sub-humid regions of Ethiopia, soil evaporation is less important than transpiration. The simulated result also supports this fact that, as can be understood; evapotranspiration in the catchment is mostly in the form of transpiration and hence it is less dependent on the soil type.

3.3.2 Surface runoff

According to Batelaan (2007), surface runoff is dependent on the availability of vegetation, soil type and slope of the sub-basin. Hence the surface runoff of Modjo river catchment varies spatially with topography and other catchment characteristics. Rugged topography and silty clay, silty loam soil dominated the lands and gave the largest amount of runoff in the catchment. This is due to a lower concentration time of overland flow for rugged topographic surface and the lesser infiltration capacity of the soil type.

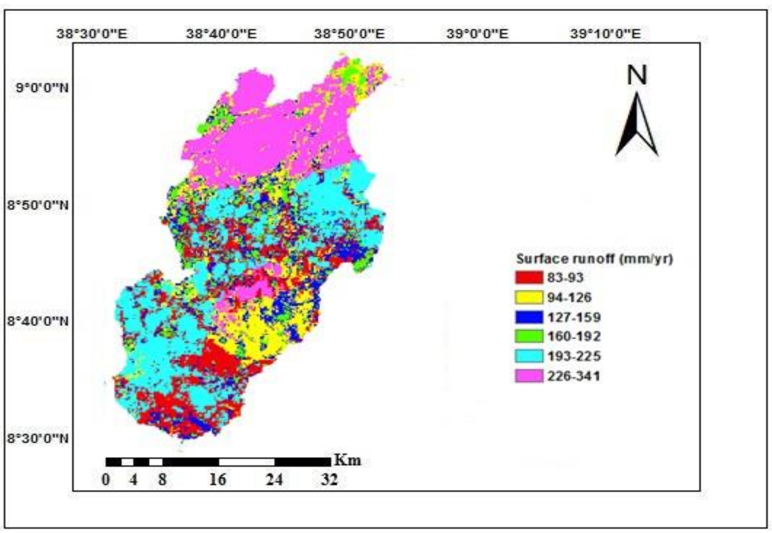

Figure 18.Simulated annual surface runoff with the WetSpass model for Modjo sub-basin

The simulated annual runoff varies from 83 mm to a maximum of 341 mm with a mean and standard deviation of 164 mm and 66.89 mm respectively. This accounts about 17.6% of the total annual precipitation. Considering the (2202 km^2) area of Modjo river catchment, average annual surface runoff will be 361Mm^3. The rainfall exceeds the infiltration capacity of the soil during the wet season, this leads to high surface runoff. Equivalently about 81% of the surface runoff occurs during the wet months (June to September) while the remaining 19% occurs during the dry months (October to May) from the catchment. Behailu (2007), applied runoff coefficient method and revealed that the annual surface runoff of Modjo river catchment of area of 2202 km^2 is 130 mm, also the research conducted in the nearest watershed Welanchiti area by Getachaw (2007) reveals the annual surface water out flow, estimated using runoff coefficient methods from an area of 780 km^2 resulted 129.5 Mm^3. Thus 83 mm minimum and 341 mm maximum annual surface runoff, simulated by WetSpass for Modjo river catchment, is reasonable.

3.3.3 Groundwater recharge

Recharge is promoted by natural vegetation cover, flat topography, permeable soils, a deep water table and the absence of confining beds. The WetSpass model determines the long term average spatially distributed recharge as a spatial variable dependent on the soil texture, landuse, slope and meteorological conditions.

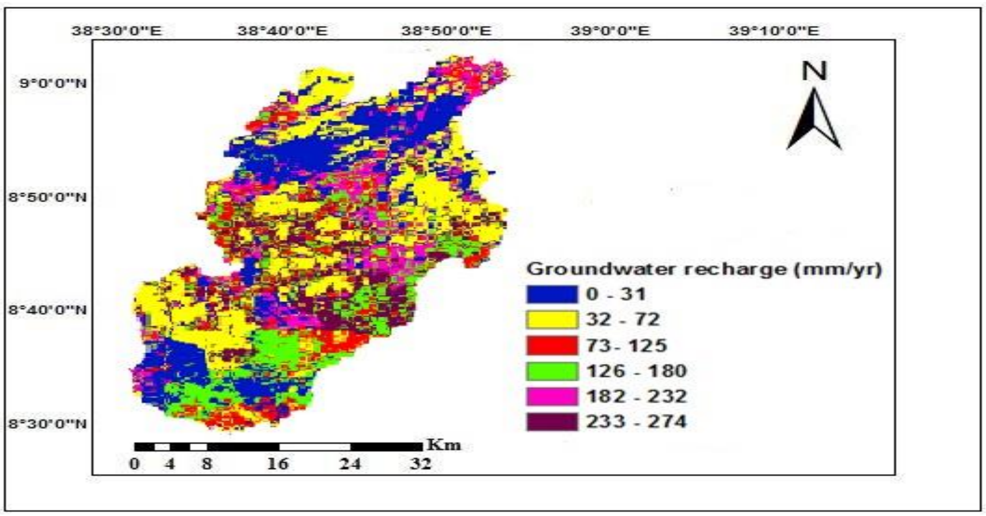

Figure 19.Simulated annual groundwater recharge with the WetSpass model for Modjo sub-basin

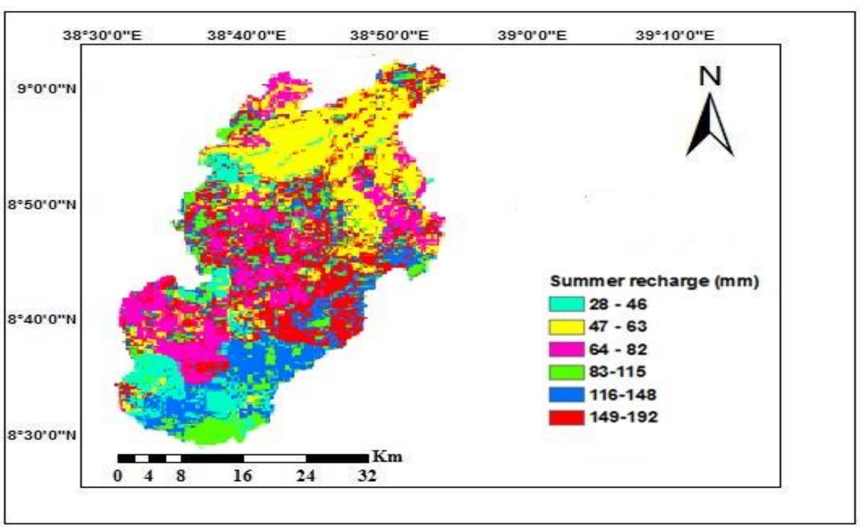

Figure 20. Simulated summer groundwater recharge with WetSpass model for Modjo sub-basin

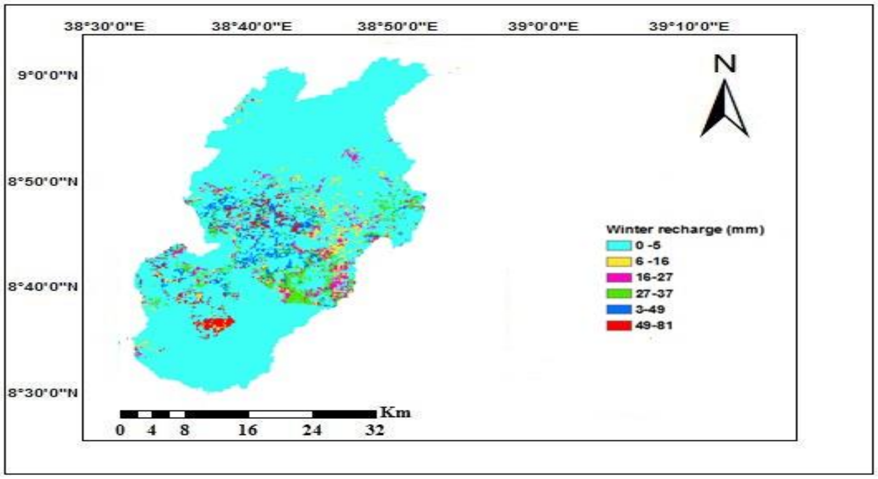

Figure 21.Simulated winter groundwater recharge with the WetSpass model for Modjo subbasin

The resulting groundwater recharge from WetSpass for the present land use ranges from about 274 mm/yr to zero, with an average value of 83 mm/yr, which is about 8.9% of the mean annual precipitation, and standard deviation of about 32 mm. About 70% of the annual ground water recharge of the sub-basin occurs during the wet season (summer), and the remaining 30% in dry season (winter) specially (April and May).Thus an average of 183 Mm^3 of ground water will be recharged per year for total catchment area. For the study conducted on groundwater potential of Ada'a Becho plain, annual groundwater recharge contributed from Modjo river to Ada'a Becho plain is 85 mm and 153 Mm^3 (Semu, 2012), which is almost comparable with WetSpass result. Similarly (WAPCOS, 1990) report 7% of annual groundwater recharge for Awash basin for the mean annual rainfall of 850 mm. Therefore the result simulated by WetSpass for the Modjo river catchment is within the previous study range and was found reasonable.

3.4 Seasonal Result Analysis

The potential evapotranspiration in the catchment is larger in winter (66.5%) than in summer (33.5%). This is apparently associated with longer sunshine hour and larger wind speed values in winter than in summer. However, the simulated actual evapotranspiration in winter is lower for most of the land use types than for summer. This is due to the lower rate of soil evaporation, transpiration and interception in winter due to insufficient rainfall to meet the potential demands. During summer the evapotranspiration is so excessive that it causes negative recharge in some parts of the catchment, in winter since the rainfall is not excessive to create too much runoff and also due to the fact that the soil is dry the groundwater recharge has found to be larger than summer. However, the total recharge in the catchment is larger in summer due to the fact that high rainfall in this season.

Table 6. Mean seasonal & annual WetSpass hydrologic output for Modjo river catchment

Parameters (mm)	Summer (mm)	Winter (mm)	Annual (mm)
Precipitation	717	216	933
Runoff	133	31	164
Evapotranspiration	526	160	686
Interception	157	24	181
Transpiration	249	33	282
Soil evaporation	120	103	223
Recharge	**58**	**25**	**83**

3.5 Water Balance Analysis by Land Use and Soil Type

Since WetSpass determines the total evapotranspiration as the sum of the evaporation from soil, intercepted water and transpiration, it is automatic that the evapotranspiration varies spatially according to the land use class and soil types. Water bodies (936 mm) and trees and shrub (756 mm) land use is the land cover types where the simulated evapotranspiration is the highest followed by grassland (675 mm) due to high evaporation from open water surface and transpiration rates from vegetation respectively, while highland areas of the cropland and settlement with lower evaporation and transpiration, because large areas of this land use is found to be hilly stone covered impervious surfaces and relatively low temperature areas.

The WetSpass model uses the runoff coefficient method for the estimation of surface runoff, whereas this parameter is a function of vegetation type, soil texture and slope. Similarly, the highest runoff rate occurs from the agricultural lands (290 mm) and settlement (233 mm) due to disturbed soil and impervious surfaces in these land-use classes respectively. Plain areas, more silty loam and silty clay soil covers, and areas with vegetation cover have relatively lower runoff rates in the catchment.

Groundwater recharge is generally found to be much higher in non vegetated land-uses than in vegetated land-uses (Gee *et al.*,1974) and is greater in areas of annual crops and grasses than in areas of trees and shrubs (Prych,1989). In this simulation, from WetSpass water balance of the catchment high recharge occurs from grassland on the plain areas (155 mm). This land-use unit has lower runoff and evapotranspiration compared to the cultivated land and tree and shrubs; secondly the groundwater recharge was high on agricultural land (143 mm), because this land unit is bare and the soil is dry at the beginning of the rainy season having low transpiration; and drying up of soil favors more water infiltration contributing to recharge.

Table 7. Average water balance in land use difference

Land use group	Average water balance component (mm)			
	Precipitation	Evapo-transpiration	Runoff	Recharge
Grass land	923	675	93	155
Cropland highly stocked	943	555	245	143
Cropland slightly stocked	913	550	290	73
Tree and Shrub	956	756	120	80
Settlement	923	642	233	48
Water bodies	936	936	0	0

The evapotranspiration seems not to show a clear pattern with soil texture in general, it is less dependent on the soil type in the sub-basin. The highest runoff is generated from silty loam and clay soil located in the high slope and high rainfall area. This is due to high rainfall and rugged topographic nature of the area. The runoff rate decreases as the soil gets lighter loam and silty clay; however, the runoff difference in this simulation is more affected by rainfall amount and topographic effect than soil type. High values of groundwater recharge are observed in the grassland and cropland with silty loam, silty clay and loam soils. This is due to relatively good permeability of the soils and gentle slope. Areas where clay soil is dominant yield the lowest rate of recharge (36 mm). However, the variation of recharge with land use type is more pronounced than its variation with soil type.

In general, the annual results analysis reveals that evapotranspiration is the most important hydrologic process in the basin, by which most of the precipitation is lost, than surface runoff and recharge.

Table 8.Average water balance in soil type difference

Soil texture group	Average water balance component (mm)			
	Precipitation	Evapo transpiration	Runoff	Recharge
Silty clay	939	743	105	91
Silty loam	967	628	208	131
Clay	932	698	198	36
Loam	893	675	145	73

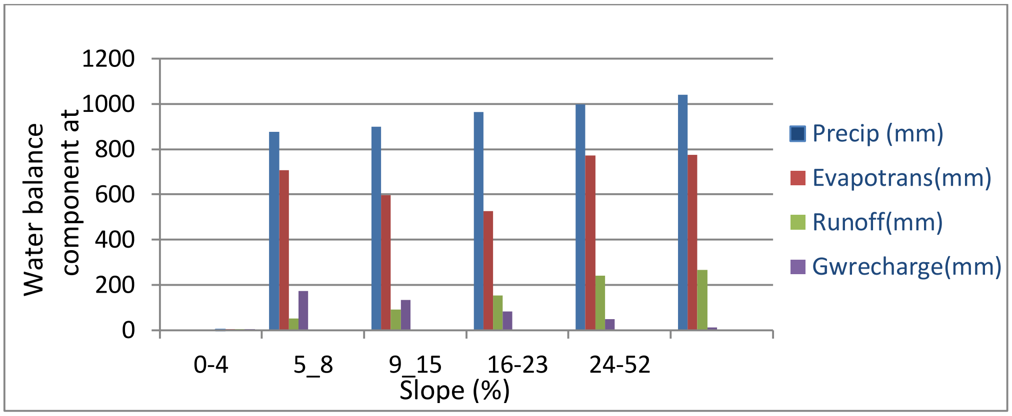

Figure 22.WetSpass simulation for average runoff, actual evapotranspiration, and recharge for different slop classes in Modjo subbasin

4. *Conclusion and recommendations*

In this study the long term seasonal groundwater recharge of Modjo river catchment (2,202 km^2) was estimated and the recharge zone is mapped through use of a grid based physically distributed model, WetSpass. The model applies up to date physical and empirical relationships of the subbasin for its efficiently running processes. Obviously, long term average hydro meteorological data and spatial patterns of watershed physical grid maps are used as main inputs for the model.

Seventeen model parameter variables are used as an input for the WetSpass model in ASCII grid map and data base file formats. Season independent gridded base maps of soil, slope, and topography; and soil, land use and runoff coefficient parameters in data base files are used in the model. Precipitation, potential evapotranspiration, temperature, wind speed and groundwater depth and land use map are also prepared and employed by the model, in ASCII grid format for both winter and summer seasons. GIS and remote sensing techniques have been applied to develop the land use map of the sub-basin and ArcGIS 10.2 to prepare the data per model required.

Finally annual and seasonal values and ASCII grid map of runoff, Evapotranspiration, interception, transpiration, soil evaporation and finally recharge of the subbasin are obtained as model output results.

From the results of this study, the following recommendations are made:

- The water balance results obtained from this modeling can be used as base for future groundwater resources development and improvement of the catchment in particular, for soil and water conservation work in general.

- The largest amount of evapotranspiration simulated for the catchment, relative to the groundwater recharge and the surface runoff, indicates that much effort is needed to change the environmental conditions of the catchment by applying some soil and water conservation practices.
- An average 5,802 l/s recharge is calculated for the catchment, for further groundwater resource development plans of sustainable use, the abstraction rate both for irrigation and domestic water supply from the sub-basin should be maintained under consideration of this rate.
- Well drilling requires huge amount of investment cost, however it is common to have problem in exploitation of groundwater in that unsuccessful rate of well production encounter, hence, using WetSpass output groundwater recharge map with consideration of geologic properties of the aquifer is recommended to reduce this problem in site selection for water abstraction point.
- The simulated annual surface runoff is 361Mm^3. Therefore, to harvest this excess water, it could be advantageous to practice flood control dams (artificial recharge). This is helpful in one way to reduce soil erosion and in the other way to enhance more recharge to groundwater.
- This study depends only on the hydro metrological data and spatial pattern of the sub-basin to understand spatial and temporal groundwater recharge, further study should be investigated including aquifer property for more understanding of groundwater dynamics in the catchment for better groundwater resource development and management.

Acknowledge. The authors would like to thank Ethiopian National Meteorological Agency for providing the necessary data. We also acknowledge USGS Earth Resources Observation portal for providing ASTER DEM data and Prof. O. Batelaan for the provision of WetSpass program. This research work was funded by Oromia Agricultural Research Institute.

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Evaluation of In-Situ Moisture Conservation Structures on Soil Moisture, Yield and Yield Components of Sorghum in Moisture Deficit Areas of Daro Lebu and Boke Districts

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Abstract

The study was conducted to evaluate the effect of in-situ soil moisture conservation structures on soil moisture, yield and yield components of sorghum in Daro Lebu and Boke districts of western Hararghe zone where highly affected by moisture stress. The in-situ moisture conservation structures used as treatments were open ridges with double and single rows of sorghum in furrow, tied ridges with double and single rows of sorghum in furrow, circular pit moisture conservation structure and flat (farmers practice) used as control. The treatments were laid out in RCBD with three replications on two locations. The data on soil moisture content, plant height, panicle length, head weight, head number, stand count at harvest and grain yield were collected. From in-situ water harvesting practices four structures shown better performance in improving soil moisture stored within the root zone as well as yield and yield components at both locations under rain-fed condition. These structures were; tied ridges with single rows of sorghum in furrow (TS), Open ridges with single rows of sorghum in furrow (OS), Tied ridges with double rows of sorghum in furrow (TD) and Open ridges with double rows of sorghum in furrow (OS). It's advisable and appropriate to use these structures for sorghum production as well as for improving soil moisture of the root zone of crop in the test areas and similar agro ecologies.

Key words: In-situ moisture conservation, ridges, soil moisture, yield

1. Introduction

Sorghum (*Sorghum bicolor* (L.) (Moench) is the fifth most important cereal crop in the world (FAO, 2005). It is cultivated in wide geographic areas in America, Africa, Asia and the Pacific. According to African Agricultural Technology Foundation (AATF) report (2011), sorghum is a viable food grain for many of the world's most food insecure people who live in marginal areas and erratic rains. In Ethiopia, sorghum is the third most important crop after *teff* and maize in terms of area coverage and the second most important cereal crop in total production next to maize (CSA, 2018). Sorghum production is estimated to be 27.25 Qt/ha (CSA, 2018). It accounts for 14.96% out of the total area allocated to cereals crops and it also accounts for 16.89% of the grain production (CSA, 2018). Sorghum is the most dominant cereal crop in western Hararghe zone, but its production is hampered both by biotic and abiotic stresses. Out of these abiotic stresses, drought is the most pronounced problem in the study area (Fuad *et al.*, 2017).

Rain fed agriculture in semi-arid areas of Ethiopia is suffering from moisture stress (Temesgen, 2007), which is a major limiting factor for successful crop production. Rainfall variability, dry spells, soil moisture stress and drought are the main challenges for rain fed agriculture production and productivity; particularly in the midland and lowland parts of the Western Hararghe zone (priority problem raised in REFLAC-Research Extension Farmers Linkage Advisory Council meeting). The main causes of moisture stress are low and erratic rainfall, runoff losses due to poor water retention. Extreme dry spells and recurrent drought is usual. Late start, early finish and little in amount are the main characteristics of rainfall in the study areas. Due to this crops fail at vegetative stages before seed setting, livestock lost in the absence of feed and watering. As a result, the population living in the zone is food insecure and is under aid by Safety Net programs, United Nations World Food Program and other Non-governmental Organizations.

To cope with prevailing moisture stress so that ensure food security of the area, promoting and evaluating different in-situ moisture conservation technologies is necessary. In-situ moisture conservation techniques increase the amount of water stored in the soil profile by trapping or holding rainwater where it falls; it involves small movements of rainwater as surface runoff, in order to concentrate the water where it is required in the root zone of the crop (Mudatenguha *et* *al*., 2014). In-situ moisture conservation techniques such as pot-holing, ridging, pit planting and mulch ripping reduce runoff and hold water long enough to allow most of it infiltrate into the soil. The benefits of *in-situ* moisture conservation are reduction in runoff and erosion and increased infiltration and storage of water in the soil profile which delay the onset and occurrence of severe water stress thereby improving the crop against damage caused by water deficits during dry periods (Nyamadzawo *et al*., 2013). So, uses of in-situ moisture conservation practices play a vital role for successful and sustainable sorghum crop production in drought prone areas. Therefore; this study was initiated with the objective of evaluating the effect of in-situ moisture conservation practices on soil moisture, yield and yield components of sorghum that leads to better soil moisture conservation in moisture stress area of Western Hararghe zone.

2. MATERIALS AND METHODS

2.1 Description of the study area

The study was conducted at Daro Lebu and Boke districts, western Hararghe zone where highly affected by moisture stress in 2016-2017 cropping season. Milkaye FTC (farmers' training center) from Daro Lebu district and Keyu PA (Cabbi FTC) from Boke district were selected and in-situ moisture conservation structures were constructed. Milkaye PA (peasant association) lies to the east of Finfinne on 474 km and south of Chiro town, the capital of the zone, at a distance of 150 km. The area has bimodal type of rain fall distribution of short rainy season '*Belg*' that lasts from mid-February to April whereas the long rainy season '*kiremt*' is from June to September with annual rainfall ranging from 900-1300mm (average annual rainfall of 1094mm) and ambient temperature of the district varies from 14 to 26ºC with an average of 20ºC (Climate data obtained from Mechara Metrological Station). The nature of rain fall is very erratic and unpredictable causing tremendous erosion. The major soil textural class of the study area at Daro Labu district Milkaye PA is clay and sandy clay loam at Boke district which is reddish in color.

Boke is one of districts of West Hararghe zone known for coffee production. It is located at 391 km East of Finfinne and about 69 km south of Chiro, capital town of the zone. The district receives an average annual rainfall of 850 mm and the average temperature is 20°C. It shares borders with Chiro district in the west and north, Oda Bultum district in the south and Mesala district in the East. The district is found within 1300 to 2400 m.a.s.l.

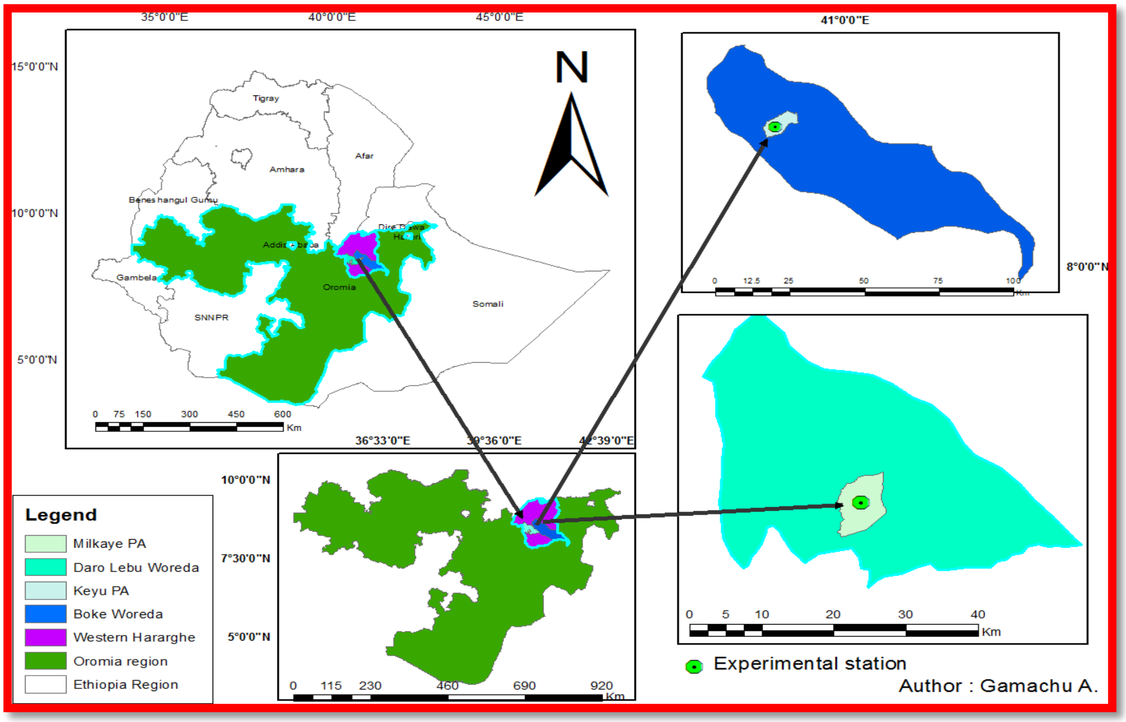


Figure1. Map of study area

2.2. Treatments and experimental design

In-situ moisture conservation structures open ridge and tied ridge with two patterns of sorghum planting (single and double rows in furrow), circular pit and flat (farmers practice used as control) were arranged in RCBD design in three replications. Grana-1 sorghum variety with spacing of 0.75m between rows and 0.25m between plants was used for the study. The recommended fertilizer rate of Urea 100kg/ha and DAP 100kg/ha was applied.

The structures were constructed on plot areas of 6.75m*6m and 1m distance between plots and blocks. The ridges constructed by 0.3m width and 0.3m height for both open and tied ridges. The distance between ridges were 1.20m (furrow width) for double rows of sorghum in a furrow and 0.45m distance between ridges for a single row sorghum sown in a furrow. The tied ridge was constructed with small earth tie at every 2m along contours. While the planting pits with dimensions of 0.25m width, 0.25m of length and 0.15m of depth and 0.25m distance between a pit constructed in a staggered rows perpendicularly to the slope to harvest runoff water from external catchments upslope and slows the flow of water over the surface. The slope of the land considered was between 1-5%. Finally, continuous inspection and repair was done for all structures.

2.3. Data collection, analysis and presentation

Agronomic data, soil data and yield of sorghum were collected. The growth parameters such as plant height, stand count at harvest, panicle length and diameter, head weight per plot, number of head per plot, 1000 seed weight, and grain yield were collected. Plant height was recorded by using meter tape measured from the ground up to apical. Stand count at harvest was recorded by counting number of plant per plot. Panicle length and diameter were measured by meter tape, head length and head diameter (cm) as well as head weight was measured in gram. Grain yield was measured using kilogram and adjusted yield calculated using seed moisture percentage as given in formula below for sorghum crop (eq 1). Then, the adjusted yield (kg/plot) was changed to Quintal per hectare (Qt/ha, as a Qt is equivalent to 100 kg).

$$\textbf{Adjusted Yield} = \frac{\boldsymbol{Yld\ kg/plot(100 - \%\ moisture)}}{\boldsymbol{(100 - 12.5\%)}} \qquad 1$$

Where; yld kg/plot = yield in kilogram per plot, % moisture = grain moisture content in percentage.

The data recorded throughout the growing periods were averaged over every harvest in the growing seasons for data analysis and computation. Soil samples at a depth of 0-20cm and 20-40cm were collected and analyzed for moisture content using gravimetric method at vegetative stage, pH (using H_2O 1:2.5), texture, C/N, CEC (using Ammonium Acetate Method) and organic carbon (using Walkely and Black method). The weight of the wet soil samples were measured and put in an oven at 105°C for 24 hours and then the weight of dry samples were measured. The following formula was used for calculating the soil moisture content.

$$SMC = \frac{(Ww - Wd)}{(Wd)} * 100 \qquad 2$$

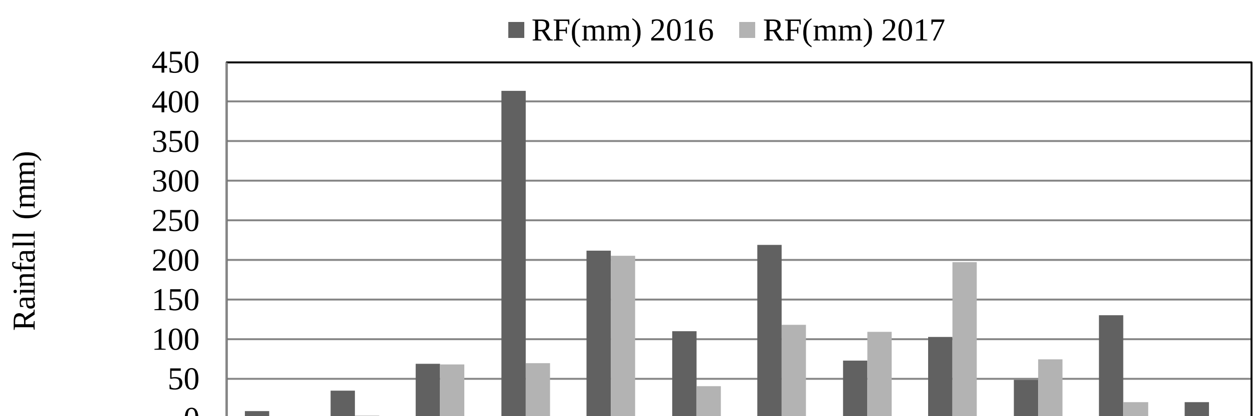
Where; SMC = Soil moisture content (%), Ww = Weight of the wet soil (gm), Wd= Weight of the dry soil (gm).

Finally, the collected data were subjected to analysis of variance (ANOVA) using SAS 9.1 version statistical software and the means of treatment effects were separated using least significant difference (LSD at 5%) test.

3. RESULTS AND DISCUSSION

3.1. Seasonal rainfall distribution

The annual rainfall during both cropping season at Daro Lebu district, Milkaye PA were 1444.6 and 907.5 mm in 2016 and 2017 (Mechara research center metrology station which is found at about 40 kms away and relatively have similar agro ecology) (Figure 2). The total amount of rainfall seems like high but it was erratic which cause dry spells during critical crop growth stages and as a result reduces production. During first season, the rainfall was high as well as high soil moisture retained in the in-situ moisture conservation structures while during the second season low rainfall as well as low soil moisture was retained on clay soil at Milkaye PA of Daro Lebu district. The poor distribution of rainfall rather than absolute water scarcity, more often leads to crop failure due to low cumulative annual rainfall (Daniel, 2007). Unfortunately, most dry spells occur during critical crop growth stages under rain-fed agriculture. As cited in Beshir *et al.* (2012) the crop growth conditions may further be hampered by a number of climatic factors, such as low and erratic rainfall, low humidity levels and high temperature during growing season.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RF(mm) 2016	9.2	34.9	68.5	414	212	110	219	73	103	48.3	130	20.2
RF(mm) 2017	0	3.2	68.3	69.7	205	40.4	118	109	197	74.8	20.1	0

Figure 2. Monthly rain fall distribution of Mechara metrological station in 2016 and 2017

3.2. Soil physicochemical properties

The soil of Mikaye PA is characterized by soil physicochemical analysis (Table 1), while soil samples taken from Boke district were analyzed for moisture content determination only. The soil physicochemical analysis result indicated that the soil textural class of Milkaye PA at Daro Lebu distrct is clay; and total nitrogen (TN), available phosphorus (Avail. P) and electrical conductivity (EC) are found low. But other chemical properties of the soil like organic carbon (OC), cation exchange capacity (CEC) and available potassium (Avail. K) are found moderate to high.

Table1: Soil physicochemical properties at Milkaye PA

Parameters	Results	Unit	Method of analysis	Optimum range	Interpretation
PH-H_2O	6.73	-	-	5.50 - 7.00	sufficient
OC	1.42	%	Walkely and Black	1.00 - 3.00	moderate
TN	0.10	%	Kjeldahl Method	0.12 - 0.25	low
C:N	14.56	-	-	-	-
Avail. P	12.90	mg/kg of soil	Olsens Method	20 - 30	low
CEC	26.21	Meq/100g soil	Ammonium Acetate Method	15-25	high
Texture	Sand (37) Clay(50) Silt(13)	%	Hydrometer Method	-	Clay
EC	0.03	mS/cm	-	0.40 - 0.80	low
Avail. K	265.20	mg/kg of soil	Ammonium Acetate Method	150 - 250	high

3.3. Effect of moisture conservation structures on soil moisture content

The effects of in-situ moisture conservation on soil moisture content are shown in Figure 3 at Daro Lebu district during first and second seasons. The in-situ moisture conservation showed that relatively higher soil moisture content were recorded from pits and TS with mean values of 34.35 and 33.07% while low soil moisture were recorded from OS and flat planting with mean value of 30.95% each at 0-20cm soil profile. In similar manner, higher soil moisture content were recorded from pits and TS with mean values of 37.55 and 34.19% while low soil moisture were recorded from OS and flat planting with mean values of 33.07 and 30.95% at 20-40cm soil profile in the first season (2016). During the second season (2017), there was observed high erratic rainfall which resulted in dry spell. Hence, the soil moisture content recorded was very low compared to that of first season.

The soil moisture content recorded at Boke district is lower as compared to that obtained at Daro Lebu district in 2016 (Figure 4). Higher soil moisture content were recorded from TD and TS which equals 19.6% each, while low soil moisture were recorded from OS and flat which equals to 17.05% each at 0-20cm soil profile respectively. Similarly, higher soil moisture content was recorded from Pit (20.49%) and TS (20.45%) at 20-40cm soil profile. Highest soil moisture was recorded at 20-40cm soil depth under all moisture conservation structures. This shows there is recharge due to these structures. This result is in agreement with Bashir *et al.*, (2012**)** and Mudatenguha *et al.*, (2014) that in-situ moisture conservation can improve soil moisture storage, prolong the period of moisture availability, and enhance the growth of crops and economic yield (Figures 3 & 4).

Generally, the highest overall soil moisture content was recorded from Pit and tied ridges with single and double rows of sorghum at both locations during two years of practice. This was due to tied ridges has better performance in storing high amount of water and high water retention capacity which is available for crop. The result is in agreement with Gebreyesus (2004) and Stroosnijder (2010) as tied ridges and mulch was beneficial in increasing crop yields in seasons with below-normal rainfall in semi-arid environments. Dagnaw *et al.* (2018) also found that tied ridges was found harvest more water than flat bed.

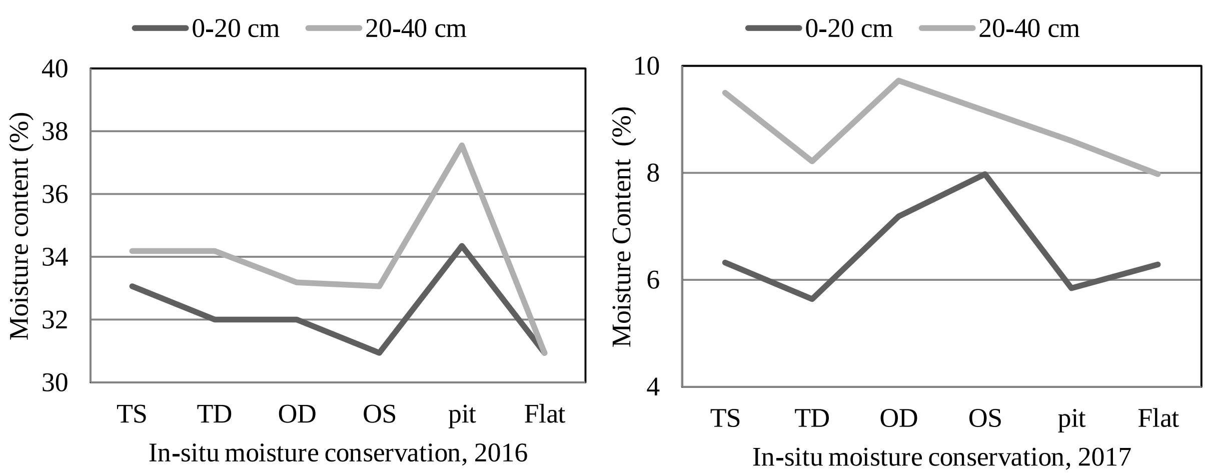


Figure 3: Effect of in-situ moisture conservation structures on soil moisture at Daro Lebu district, 2016 and 2017

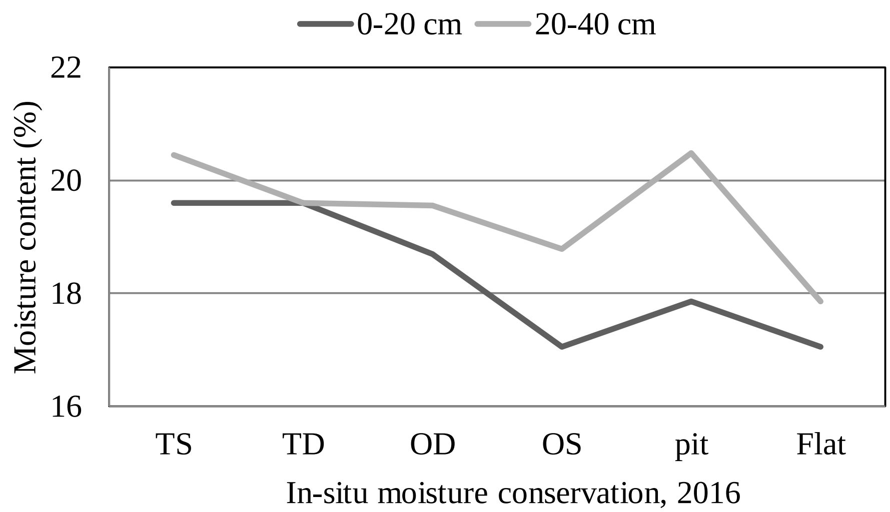


Figure 4: Effect of in situ moisture conservation on soil moisture at Boke district, 2016

where; TD=Tied ridges double rows of sorghum in furrow, OD=Open ridges double rows of sorghum in furrow, TS=Tied ridges single rows of sorghum in furrow, OS=Open ridges single rows of sorghum in furrow.

3.4. Yield and yield components of sorghum

The analysis of variance (ANOVA) reveals that there was a significant difference ($P<0.05$) among treatments on plant height, panicle length, panicle width, head number per plant, plant density, 1000 seed weight and yield among in-situ moisture conservation practices during 2016 cropping season at both locations. However, the results of ANOVA showed non-significant differences among the in-situ moisture conservation for head weight (Table 2 & 3). According to the finding, maximum plant height, panicle width, 1000 seed weight and grain yield was recorded from tied ridges with single rows of sorghum than other moisture conservation structures and also tied ridges with double rows of sorghum sown in furrow gave maximum panicle length, head weight, head number and plant density due to their relatively high efficiency in soil moisture retention capacity than others during both season. While minimum plant height, panicle length, panicle width, head weight, 1000 seed weights and grain yield were recorded from farmers practice (flat planting without moisture conservation) and also minimum head number and plant density were recorded from planting pits at Daro Lebu district during 2016 cropping season (Table 3).

During the second year, the established experiment at Boke district was totally failed due to due extreme drought that occurred in the area, but some results were recorded at Daro Lebu district. As indicated in Table 4, none of in-situ moisture conservation techniques affected yield and yield components of sorghum crop except on head number per hectare and on plant density.

Table 2. Effect of in-situ moisture conservation on growth, yield and yield component parameters of sorghum at Boke district, 2016

Trt	PH (cm)	PL(cm)	PW (cm)	HWP(gm)	HN/ha	PD/ha	1000 seed wt (g)	Yield (Qt/ha)
TS	137.0^{a}	19.5^{a}	5.6^{a}	45.9^{a}	42305^{a}	44362^{a}	33.8^{a}	9.9^{a}
TD	135.4^{a}	20^{a}	5.4^{a}	40.7^{a}	39506^{a}	44444^{a}	32.0^{ab}	9.3^{ab}
OD	134.2^{ab}	18.5^{ab}	5.3^{ab}	38.7^{a}	39177^{a}	42058^{a}	29.7^{bc}	6.6^{abc}
OS	127.9^{bc}	18.8^{a}	4.7^{c}	33.2^{a}	36626^{ab}	40165^{ab}	29.5^{bc}	5.6^{c}
Pit	127.9^{bc}	16.8^{b}	5.2^{ab}	34.6^{a}	28971^{b}	33086^{bc}	28.6^{bc}	4.2^{c}
flat	126.7^{c}	16.7^{b}	4.9^{bc}	32.8^{ab}	29465^{b}	31605^{c}	27.8^{c}	5.4^{c}
mean	131.5	18.3	5.1	37.6	36008.3	39286.7	30.2	6.8
$LSD_{0.05}$	7.4	1.9	0.4	14.3	7891.6	7782.4	3.8	3.3
CV(%)	3	5.7	4.4	20.9	12	10.9	6.8	26.4

Means with the same letters within the columns are not significantly different at $P < 0.05$.
Where; LSD=Least significant difference, CV=Coefficient of variation, PH=Plant height, PL=Panicle length, PW=Panicle width, HWP=Head weight per plant, HNPha=Head number per hectare, PD/ha=plant density per hectare, 1000 seed wt=1000 seed weight.

Table 3. Effect of in-situ moisture conservation on growth parameters, yield and yield components of sorghum at Daro Lebu district, 2016

Trt	PH(cm)	PL(cm)	Pw (cm)	HWP (gm)	HNPha	PD/ha	1000 seed wt(gm)	Yield (Qt/ha)
TS	155.1^{a}	26.2^{a}	12.8^{a}	96.6^{a}	51358^{a}	52428^{a}	34.5^{a}	36.7^{a}
TD	154.7^{a}	26.6^{a}	11.7^{ab}	97.9^{a}	51523^{a}	52840^{a}	34.0^{a}	34.5^{a}
OD	151.7^{ab}	26.2^{a}	9.4^{dc}	77.7^{b}	46584^{ab}	48066^{a}	32.3^{bc}	31.7^{ab}

OS	148.0^{cab}	25.6^{a}	10.7^{bc}	81.4^{ab}	51276^{a}	52263^{a}	32.2^{bc}	32.0^{ab}
Pit	146.0^{bc}	23.1^{b}	10.3^{bc}	77.6^{b}	30947^{c}	32428^{b}	33.3^{ab}	26.8^{b}
flat	144.3^{c}	21.4^{b}	8.3^{d}	74.8^{b}	38519^{bc}	47984^{a}	31.8^{c}	26.4^{b}
Mean	149.9	24.8	10.5	84.3	45034.5	47668	33	31.4
$LSD_{0.05}$	7.1	2.8	1.9	16.8	12342	13152	1.5	6.0
CV(%)	2.6	6.4	9.9	10.9	15.0	15.1	2.5	10.6

Means with the same letters within the columns are not significantly different at $P < 0.05$

Table 4. Effect of in-situ moisture conservation on growth parameters, yield and yield components of sorghum at Daro Lebu district, 2017

Trt	PH (cm)	PL(cm)	Pw (cm)	HWP (g)	HNPha	PD/ha	Yield (Qt/ha)
TS	157.5^{a}	23.3^{a}	9.5^{a}	9.62^{a}	32839.5^{a}	31852^{ab}	19.0^{a}
TD	156.6^{a}	22.1^{a}	8.4^{ab}	6.95^{ab}	27407.4^{ab}	41564^{a}	13.7^{a}
OD	158.7^{a}	23.5^{a}	10.0^{a}	8.40^{a}	27728.4^{ab}	28477^{b}	17.4^{a}
OS	154.9^{a}	23.6^{a}	9.6^{a}	9.89^{a}	29703.7^{a}	30123^{bc}	19.8^{a}
Pit	147.3^{a}	20.8^{a}	8.2^{ab}	5.14^{ab}	18271.6^{b}	32016^{ab}	10.2^{a}
flat	157.9^{a}	22.3^{a}	9.4^{a}	9.79^{a}	30123.4^{a}	26420^{c}	19.9^{a}
Mean	155.5	22.6	9.2	8.29	27679	156.6	16.7
$LSD_{0.05}$	20.6	2.8	1.9	6.6	12342	10719	13.9
CV(%)	7.3	7.0	9.9	6.8	30.5	18.6	7.7

Table 5. Over years mean growth parameters, yield and yield components of sorghum at Daro Lebu district

Trt	PH(cm)	PL(cm)	Pw(cm)	HWPha (g)	HNPha	PD/ha	Yield (Q/ha)
TS	156.3^{a}	24.8^{a}	11.1^{a}	2771^{a}	42099^{a}	42139.9^{a}	29.3^{a}
TD	155.6^{a}	24.4^{a}	10.1^{a}	2637^{b}	39465^{a}	47201.6^{a}	27.8^{a}
OD	155.2^{a}	24.9^{a}	10.4^{a}	2952^{a}	37160^{a}	38271.6^{ab}	26.2^{a}
OS	151.4^{a}	24.6^{a}	9.5^{a}	3306^{a}	40494^{a}	41193.4^{ab}	25.2^{a}
Pit	146.6^{a}	22^{bc}	9.3^{a}	2608^{bc}	24609^{b}	32222.2^{b}	18.4^{bc}
flat	151.1^{a}	21.9^{c}	8.9^{b}	3277^{a}	34321^{a}	37201.6^{ab}	17.4^{c}
Mean	152.7	23.8	9.9	2925	36358	39705.1	24
$LSD_{0.05}$	10.7	2.2	2.08	662.7	9296.7	9659.9	5.4
CV(%)	3.9	5.1	11.6	12.5	14.1	13.4	12.4

3.4.1. Effect on plant height

The highest mean plant height was recorded from TS and TD with mean values of 156.3 and 155.6 cm, respectively while the lowest was recorded from Flat planting and Pit with values of 151.1 and 146.6 cm respectively at Daro Lebu district in both cropping season (Table 5) while at Boke district during 2016, TS and TD with mean values of 137.0 and 135.4cm while lowest from Flat and Pit with mean values of 127.9 and 126.7cm, respectively (Table 2). This was in agreement with the findings of Takle and Wedajo (2015) who reported that the highest and the lowest plant height were obtained from tied ridges and farmers practice respectively.

3.4.2. Effect on panicle length, panicle width and head weight per plant

From analysis of variance the mean of panicle length, panicle width and head weight per plant were not shown significant difference on different in-situ moisture conservation structures (Table 4). However, higher mean panicle length, head weight per plant and panicle width were observed on open ridges with single row platting pattern and the lowest was obtained on Pit plating. These results were supported by Takle and Wedajo (2015) indicating that the highest panicle length was recorded from tied ridges than without in-situ moisture conservation due to its relatively high efficiency in soil moisture retention capacity. Generally, in this study it was observed that in-situ moisture conservation practices had brought improvements on most studied growth and yield attributing parameters compared to farmers' practice.

3.4.3. Effect on plant density

There was observed significant difference between in-situ moisture conservation techniques on plant density parameter (Tables 3-5). Even though the observed plant density is significantly higher under moisture conservation structures compared to flat planting, the grain yield recorded for flat planting is relatively higher during 2017 at Daro Labu district (Table 4). This is due to the structures stored high moisture at sowing which negatively affected germination. Structures other than flat planting are affected by this problem and after germination made many tillers which couldn't bear head and thus affected yields (Table 4). The plant density recorded for pit was less than other in-situ moisture conservation structures that it gave low yield at Daro Lebu district (Table 5). This result shows disagreement with the findings of Beshir *et al.* (2012) that sorghum plant density was not significantly affected by in-situ moisture conservation structures.

This was due to early cessation of rainfall during germination and caused sparse population of plant on moisture conservation structures. In addition, the area is known by producing beef cattle, thus the straw of sorghum could be used for animal feed.

3.4.4. Grain yield

The highest mean grain yield was recorded from tied ridges with single rows of sorghum and tied ridges with double rows with values of 29.3 and 27.8 Qt/ha while the lowest mean yield was recorded from pit and flat structures with value of 18.4 and 17.4 Qt/ha respectively at Daro Lebu district (Table 5). Sorghum grain yield was increased by 83.3, 72.2, and 22.2% compared to flat planting in the tied ridging with single row of sorghum in furrow, tied ridging with double rows of sorghum in furrow and open ridging with double rows of sorghum in furrow treatments at Boke district in 2016. Similarly, yield increments of 39, 30.7 and 20% compared to flat planting for TS, TD and OD treatments respectively at Daro Lebu district during the same year.

The yield increments on these structures were due to the effect of in-situ moisture conservation practices that harvest moisture within a root zone of the crop. This result is in agreement with the previous findings of Heluf and Yohannes (2002), who reported that tied ridges, has resulted in yield increments of 15 to 50% for maize and 15 to 38% for sorghum on different soil types of eastern Ethiopia. Similarly, Tekle (2014b) reported that the grain yield advantage of 12.5% was obtained from tied ridges over the farmers' practice for pearl millet. He also reported that tied ridges had resulted in grain yield advantage of 26% over farmers' practice for cowpea (Tekle, 2014a). However, during 2017 at Daro Lebu district there was no difference between flat and other in-situ moisture conservation structures except pit which was the lowest compared to others due to extreme dry spell that occurred in the area.

4. CONCLUSION AND RECOMMENDATION

Integrating in-situ moisture conservation structures to crop production could make an important contribution to improve agricultural production and productivity where there is high moisture stress. In-situ moisture conservation techniques improved soil moisture stored within the root zone as compared to the farmers' practice resulting in higher yield and yield components of sorghum. From in-situ moisture conservation practices four structures shown better performance in improving soil moisture stored within the root zone as well as yield and yield components in moisture stress areas tested on two locations under rain-fed crop production.

These in-situ moisture conservation structures found increased grain yield of sorghum from 20 to 83.3% in the study areas. In addition, these structures are beneficial in reducing runoff, slowing runoff velocity and improve soil characteristics to resist erosion. Therefore, it can be concluded that Tied ridges with single rows of sorghum in furrow, Open ridges with single rows of sorghum in furrow, Tied ridges with double rows of sorghum in furrow and Open ridges with double rows of sorghum in furrow are advisable and could be appropriate to be used for sorghum production by integrating with other technology packages in the moisture stress areas of Western Hararghe zone and similar agro-ecologies.

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Effect of Alternate, Fixed and Every Furrow Irrigation Systems on Water Use Efficiency and Yield of Onion at Adami Tulu Research Center of Oromia Region, Ethiopia

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Abstract

Alternate furrow irrigation was believed to improve water use efficiency and save labor without a significant tradeoff in yield. An experiment was conducted to evaluate alternate furrow irrigation versus every furrow and fixed furrow irrigation systems at Adami Tulu Agricultural Research Center for onion production. The field experiment was designed as a two factor factorial experiment in RCBD, replicated three times. The two factors were three furrow irrigation systems combined with two irrigation intervals. Irrigation was applied to furrows using parshal flume from head ditch with similar inflow rate. Results obtained revealed that alternate furrow irrigation method produced total yield of 25,203kg/ha which was not significantly different with that obtained under every furrow irrigation (26,469kg/ha). Total yield harvested from fixed furrow irrigation was 24,024kg/ha, which showed insignificant difference between the three methods. High marketable yield of 26,053kg/ha was recorded from every furrow irrigation and it was 24, 601 kg/ha for alternate furrow irrigation which was not found significantly different. Water productivity of 7.6, 7.3 and 5.9 kg/m3 was determined under alternate, fixed and every furrow irrigation methods respectively. It was found that alternate and fixed furrow irrigation methods saved 26.61 and 26.81% of irrigation water respectively as compared to every furrow irrigation method. Alternate furrow irrigation method with three days irrigation interval is thus found suitable for onion production in semi-arid areas where soil is dominated by loam soil and water is a liming factor.

Key words: Alternate Furrow Irrigation, Irrigation Interval, Water Use Efficiency

1. Introduction

Water plays a critical role in food production. It is estimated that 80% of the additional production required to meet the demands of the future will have to come from intensification and yield increase. Improved moisture control and irrigation are essential to achieve these. As reported by Burt and Styles (1999), the major agricultural use of water is used for irrigation, which is affected by decreased supply. Hence, innovations are needed that increase the efficient use of available water. Better management of agricultural water for increased productivity and efficiency are of vital importance.

Agricultural water management will be the key to maintain food security and income generation for the rural poor. FAO (2003), suggests that the key principle for improving water productivity at field, farm and basin level, which apply regardless of whether the crop is grown under rain-fed or irrigated conditions are:(1) increase the marketable yield of the crops for each unit of water transpired by the plants; (2) reduce all outflows (e.g. drainage, seepage and percolation), including evaporative outflows other than the crop stomata transpiration; and (3) increase the effective use of rainfall, stored water and water of marginal quality.

Inappropriate irrigation system design and management and the use of traditional irrigation methods have been reported to cause large water losses in agricultural fields (Howell, 2001). Upgrading irrigation systems and replacement with efficient methods mitigate water shortages or lead to increased irrigated area to cope with rapid population growth (Rijsberman, 2006).

Furrow irrigation water application system is most popular of surface irrigation, as it requires a smaller initial investment compared to other types of irrigation water application systems. This type of irrigation method is the most widely used in our country in almost all-large and small irrigation schemes. It has been reported by FAO (2001) that 97.8% of irrigation in Ethiopia is done by surface methods of irrigation especially by furrow system in farmer's fields and majority of the commercial farms. Furrow irrigation method is best suited to deep, moderately permeable soils with uniform relatively flat slopes and for crops that are cultivated in rows (vegetables, maize, cotton and potatoes, etc). Furrows are particularly well adapted to irrigating crops, which are susceptible to fungal root rot since water ponding and contact with plant parts can be avoided (Michael, 1997).

Nowadays, there are different furrow irrigation systems developed to improve water application. Alternate furrow irrigation (AFI) is one such irrigation management strategy in which one out of two adjacent furrows is irrigated alternatively. By facilitating horizontal (lateral) water movement, AFI has potential to reduce water losses via deep percolation and runoff. A number of researchers have reported that using AFI reduces irrigation water use, often decreases crop yield, and results in an increase in water productivity (Kang *et al.*, 2000a; Horst *et al.*, 2007; Slatni *et al.*, 2011). These traits make alternate furrow irrigation convenient and economical in arid and semi-arid regions.

According to Karajeh *et al*. (2000), under AFI system, 56.7-72% of the water supply has been used to replenish soil moisture, 12-21.1% for infiltration within the temporary irrigation network and 11.3-17.8% for surface runoff. Working conditions of labors carrying out the irrigation process were improved as this technology allowed moving on the dry furrows while irrigating. Experiment on AFI in Arys-Turksitana region of Kazakstan for two years indicated that the new system of AFI, combined with the use of shallow ground water, is much more effective than traditional methods. Less water was applied, less was lost due to surface runoff, resulting in a net saving of water, and enhanced productivity, with a higher yield of cotton per volume of water applied. In addition, AFI has the potential to maintain soil quality and to sustain production over the longer term (ICARDA, 2000).

Alternate furrow irrigation (AFI) is considered to be one of the most effective tools to minimize water application and irrigation costs and produce a higher crop yield. It is a way to save irrigation water, improve irrigation efficiency and thus leads to higher WUE (Kashiani *et al*., 2011). This system saves quite good amount of water and is very useful and crucial in areas of water scarcity and where there exists salt problem (Majumdar, 2002).

Fixed furrow irrigation (FFI) system supplies water to one side of each furrow ridge. Usually, this technique applies water to more area in a given amount of time than does irrigating conventional furrow irrigation. Benefit of irrigating every other furrow is the ability to store rainfall in a recently irrigated soil. FFI should not be used on steep slopes or on soils with low intake rates. On steep slopes, the water flowing down the furrow is in contact with only a limited amount of soil surface causing low intake rates. Research indicates that every other furrow irrigation method results in comparable yield to that achieved when irrigated with every furrow method. Irrigation water application may be reduced 20 to 30 percent by implementing every other furrow irrigation method (Yonts *et al*., 2003).

Under conventional furrow irrigation (CFI), significant quantities of irrigation water lost by infiltration and surface runoff (i.e., about 40% of total water supply), reduced water supply to the irrigated lands and decreased the efficiency of agricultural production as well as the reliability of drainage systems. This irrigation system has speed up the processes of decomposition and removal of organic elements and mobile forms of nutrients in the root zone that eventually, led to soil fertility losses (Karajeh *et al*., 2000).

It is necessary to develop efficient, reliable and economically viable irrigation management strategies for effective use of existing limited water resources. Improper irrigation management practices do not only waste scarce and expensive water resources but also decrease marketable yield and economic return. According to FAO (2001b), the high seasonal and annual variability of water for agriculture, coupled with the requirement for higher agricultural productivity, means that the world has no option but to improve the water use efficiency. This has to include an efficient utilization of rainwater, which otherwise would be lost as evaporation or runoff. The productive use of water for agricultural production and rural development will need to improve continuously in order to meet targets for food production, economic growth, and the environment (Boers, 1994). Therefore, the objective of this research study was to evaluate effect of alternate furrow irrigation with two irrigation intervals (5day and 3day intervals) on crop yield and water productivity of onion in semi-arid areas of Ethiopia.

2. Materials and Methods

2.1. Description of the study area

The experiment was conducted at the experimental site of Adami Tulu Agricultural Research Centre (ATARC) during irrigation time of 2015, 2016 and 2017 for three consecutive years. The area is found at 7° 9'N latitude and 38° 7'E longitude and altitude of about 1650 meters above sea level. The rainfall is bimodal and unevenly distributed with average annual rainfall of 760 mm. The small and main rainfall periods are from February to April and July to September, respectively.

2.2. Materials used

Materials used for the experiment were meteorological data, Cropwat software, Parshall flume, soil augers, core samplers and double ring Infiltrometer. About 0.25 hectare of land for the experimental was prepared and tilled using animal drawn implements. Onion (*Allium cepa*), Bombay red variety was used as test crop.

2.3. Methodology

The seedlings were transplanted on well prepared experimental plots on both sides of furrow ridge at row and plant spacing of 20cm and 10cm, respectively. Single fertilization with DAP at transplanting and split application of urea at transplanting and 10 days after transplanting was done at a rate of 200kg/ha and 100kg/ha, respectively (Olani and Fikre, 2010).

2.3.1. Crop agronomy

CROPWAT model was used to determine water requirement of onion. Input data for the model were obtained from meteorological station at ATARC. Onion Bombe red having growing period of 125 days, was planted in the last week of October 2014/15 on nursery and transplanted to experimental plot on the third week of November 2014/15. All cultural practices other than treatment variables which are recommended for the area were used. Weed and insect controls were managed according to standard management practices. Onions were harvested by hand from the two center ridges of all plots.

2.3.2. Treatments and experimental design

The treatments considered for the experiment were two factors; namely, three irrigation systems and two irrigation intervals. The three irrigation systems are EFI (every/conventional furrow irrigation), AFI (alternate furrow irrigation), and FFI (fixed furrow irrigation) and the two irrigation intervals are three (3) and five (5) days. These irrigation intervals are adopted from previous onion crop water requirement determination study at ATARC at different growth stages (Aschalew and Zelalem, 2012 unpublished research document). Based on this we proposed to use the minimum 3 days and maximum 5 days irrigation interval for this experiment for on-station. Thus, the treatment combinations are 1) Every/conventional irrigation method, irrigated at 3 and 5-days intervals; 2) Alternate furrow irrigation: only selective watering of every other furrow, that is, each bed receives water only on one side and alternating sides/furrow at 3 and 5-days intervals and odd furrows (1, 3, 5, etc.) were irrigated first followed by even furrows (2, 4, 6, etc.); and 3) Fixed furrow irrigation: means that, irrigation was fixed to one of the two neighboring furrows at 3 and 5-days intervals giving a total of 6 treatment combinations. The treatments were arranged in a randomized complete block design (RCBD) with three replications. Furrow was prepared on plot size of 5 m by 3 m and 0.1% slope along the advance that accommodates five furrows. There is 30 cm free space between plots and 1m wide road between replications.

The determined amount of irrigation water was applied using Parshall flume. Water productivity was determined by dividing grain yield by total applied irrigation water and is expressed as follows (Ali *et al*., 2007).

$$WP = GY/Wa, \qquad (1)$$

Where GY is grain yield (kg ha^{-1}) and Wa is irrigation applied water (m^3 ha^{-1}).

2.3.3. Irrigation water management

Irrigation water was conveyed to the experimental plots through Parshall Flume of three inches. The amount of water for each experimental plot was added until reaching 95% of run length of the average of irrigated furrows. This is in accordance with local farmer practices in the area. Irrigation time was recorded with a stopwatch to estimate the amount of water applied to each plot. Furrows subjected to irrigation were open-ended; however, water does not exceed the edge of the plot because it flows through the parallel furrows, whereas other furrows not subjected to irrigation were closed-ended. The depth of applied water was calculated by using the following formula:

$$t = 10Ad/Q*60 \qquad (2)$$

Where d is depth (cm); Q is discharge (L/s); t is time (min), and A is plot area (m^2). The depth of applied water varied according to the time for each irrigation treatment. Total depth of applied water (Wa) was the sum of the amounts of water added at each irrigation event during the entire growing season.

2.3.4. Irrigation water requirement of onion

The water requirement of onion was computed for the growing season of 95 days using the CROPWAT computer program with climate, soil and crop input data from the experimental area. The onion crop coefficient, root depth, length and growing stages used as inputs for CROPWAT program computation were taken from Allen *et al.* (1998). The net irrigation requirement was calculated using the CROPWAT computer program based on Allen *et al.* (1998). The gross irrigation requirement of the onion was calculated with the assumed application efficiencies of 60%.

2.3.5. Data Collected

Important data for the experiment like daily meteorological data, in-situ and laboratory analysis data on soil physical and chemical properties and data on crop development relevant to assess the response of the crop to irrigation treatments were collected.

Climate data

Long term climatic data and daily records of climatic factors such as rainfall, maximum and minimum temperature records, wind speed, relative humidity, and sunshine duration for 20 years (1996-2014) were collected for the experimental period from meteorological station at ATARC.

Soil analysis

The soil was characterized in terms of its physical and chemical properties. The soil properties analyzed include, texture, organic carbon, bulk density, water retention at FC and PWP and pH. The samples were taken from three points along the diagonal of the experimental plot and from two depths (0-20cm and 20-40cm). Soil texture was determined using pipette method. Organic carbon content was determined by titration method using chromic acid (potassium dichromate + H2SO4) digestion according to Sahlemedhin and Taye (2000) method.

Moisture contents at field capacity and permanent wilting point were measured using a pressure plate apparatus at National Soil Laboratory by applying pressures at 0.33 and 15 bars, respectively. The moisture content of the soil samples on volume basis were determined by multiplying the gravimetric water content on weight basis by the bulk density. pH was measured in 1:1 soil: water mixture by using a pH meter. Distilled water was used as a liquid in the mixture. Ten gram air dried < 2 mm soil was weighed into 100 ml beakers and 10 ml distilled water was added to 1:1 soil/water suspension and transferred to an automatic stirrer, to be stirred for 30 minutes and pH on the upper part of the suspension was measured.

The soil bulk density is defined as the oven dry weight of soil in a given volume, as it occurs in the field. It was determined by core method. Soil bulk-density data was taken as cores of 100cm^3 volumes in the field at two depths 0-20cm, and 20-40cm oven dried for 24 hrs at 105 ^{0}c and weighed for dry density using the following formula.

$$\rho b = \frac{Wd}{Vc} \qquad (3)$$

Where

ρ_b= soil bulk-density (g/cm^3)

Wd = weight of dry soil (g)

Vc = volume of core (cm^3)

Double ring infiltrometer was used to measure basic infiltration rate of the soil. The test was done at location in the experimental plot, randomly selected.

Yield collection

Since individual treatment had five furrows, yield was collected from the central two furrow of each treatment. During yield collection, each treatment furrow divided into four parts along the furrow length. In order to see the yield difference along the furrow, onion yields were collected from the four quarters and weighed separately whereas for the analysis purpose it was summed. The harvested yield graded into marketable and non-marketable categories according to the size and degree of damage. Onion bulbs with less than 2 cm diameter were categorized under non-marketable (Lemma and Shimels, 2003).

Water use efficiency

The water use efficiency was calculated by dividing harvested yield in kg per unit volume of water (kg/m^3). Two kinds of water use efficiencies, namely total water use efficiency (CWUE) and net irrigation water use efficiency (FWUE) were calculated.

Crop water use efficiency: The crop water use efficiency is the yield harvested per ha-mm of total water used.

$$CWUE = \frac{Y}{ET_c} \qquad (4)$$

Where: CWUE = crop water use efficiency (kg/ha-mm)

Y = grain 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.

$$FWUE = \frac{Y}{I_g} \qquad (5)$$

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

Y= grain yield in (kg/ha)

I_g= gross irrigation is in (mm)

Benefit-Cost Ratio (BCR) and Net Return (NR)

The total cost mainly includes labor, input, chemical and fuel costs. Labor cost included costs for land preparation, weeding and watering and estimated based on the study area. Input costs included costs for purchasing of seed and fertilizer. The farmers in the study area do not pay for water for their farms. Therefore, they only bear the costs of labor for land preparation, weeding and watering (estimated the man-day labor cost of 100 Ethiopian Birr) as well as the price of seed, fertilizer and fuel to run a pump to withdraw water from the channel. Therefore, labor cost, input cost, chemical and fuel costs of the three irrigation method were estimated at plot level based on the observed costs and converted to hectare.

In the study area majority of the farmers are using pumps to convey water from the river channels to their farm land. Based on this fact fuel cost was estimated at plot level and converted to hectare. Gross revenue had been calculated by multiplying marketable yield in kg ha^{-1} and onion market price per kilogram. The farm-gate price for onion in this study was 10 Ethiopian Birr per kilogram (local price). Net return (NR) and benefit-cost ratio (BCR) due to irrigation were calculated as follows:

$$NR = GR - TC \qquad (6)$$

$$BCR = NR/\text{Total costs} \qquad (7)$$

Where: NR Net return (ETB), GR Gross revenue (ETB), TC Total costs (ETB) and BCR Benefit-Cost ratio.

2.3.6. Data managements and analysis

The data was handled and documented appropriately. Frequent monitoring and evaluation technique was employed to control reliability of the data. The data collected during the field studies were compared using statistical analysis, ANOVA. When the treatment effects are found significant, LSD test was used to see the significant difference among the mean values of the treatments.

3. Result and Discussions

3.1. Soil characterization

The results of textural analysis using Hydrometer method of the soil from the experimental site showed that the composition of sand, silt and clay percentage were 30.26, 47.03 and 20.13%, respectively. Thus as per the USDA texture triangle classification, the soil was classified as loam soil. The volumetric soil moisture content at the field capacity and permanent wilting point of the soil were determined to be 36.65 and 20.96 percent, respectively. The infiltration rate determined from ring infltrometer data was 34.0 mm/hr. The above information showed that the soil was categorized under loam soil with good water holding capacity (i.e., total available water of 156.95 mm/m) with appreciable infiltration rate. The laboratory results of the soil physical and chemical characteristics for (0-20 cm) and (20-40 cm) are as indicated in Table 2.

Table 9. The physical and chemical characteristics of the soil at ATARC

Soil property		Soil depth (cm)		
		(0-20)	(20-40)	Average
Particle size distribution	Sand (%)	31.05	29.47	30.26
	Silt (%)	47.19	46.86	47.03
	Clay (%)	18.56	21.70	20.13
Textural class		Loam	Loam	Loam
Bulk density (g/cm^3)		1.02	1.06	1.04
pH		7.15	7.17	7.16
EC(ds/m)		1.3	1.5	1.4
FC (Vol %)		38.08	35.22	36.65
PWP (Vol %)		19.91	22.00	20.96
TAW (mm/m)		181.70	132.20	156.95

3.2. Rain fall distribution of study area

The average Twenty years rainfall data was collected from Adami Tulu Metrological Station. The effective rain fall was computed by the CROPWAT program for the monthly total rainfalls. The average total rain falls were 755.9mm and the total effective rain were 383.5.

Table 3 The average total rain fall of the study area

Months	Total rain fall (mm)	Effective rain (mm)
January	9.4	0.0
February	18.3	1.0
March	57.3	24.4
April	69.6	31.8
May	86.1	44.9
June	84.3	43.4
July	164.2	107.4
August	119.6	71.7
September	78.9	39.1
October	49.8	19.9
November	11.9	0.0
December	6.5	0.0
Total	755.9	383.5

3.3. Referance evapotranspiration (ETo)

The reference evapotranspiration of the study area was computed and the result is presented in table below. The average reference evapotranspiration (ET_o) of the site was found to be 4.57 mm/day.

Table 4: the reference evapotranspiration of the study area

Months	Max. temp (^{0}c)	Min. temp (^{0}c)	RH (%)	WS (km/day)	Sunshine hour (hrs)	ET_O (mm/day)
January	28.6	10.2	52	143	8.9	4.53
February	30.1	11.1	47	146	9.3	5.11
March	30.5	12.8	51	136	8.6	5.13
April	30.0	14.1	54	139	8.2	5.04
May	29.4	15.2	59	149	8.0	4.83
June	28.2	15.1	62	197	7.5	4.74
July	25.3	14.8	70	185	5.8	3.90
August	25.4	14.6	71	147	6.3	3.92
September	26.6	13.7	68	117	6.6	4.04
October	28.0	11.4	57	113	8.0	4.39
November	28.3	10.1	52	147	9.3	4.69
December	27.7	9.1	50	143	9.4	4.47
Mean	28.2	12.7	57.8	146.8	8.0	4.6

3.4. Crop water requirement of onion

The crop water requirement of the test crop calculated by multiplying the reference ETo with crop coefficient (Kc). The onion crop water requirement and irrigation water requirement is presented in table below.

Table 5 crop water requirement and irrigation water requirement of onion

Date	Crop Kc	CWR (ETm) (mm/day)	CWR (ETm) (mm/period)	Effe rain (mm/period)	Irrigation requirement (mm/period)
20/11/15	0.7	3.28	19.7	0.0	19.7
30/11/15	0.7	3.23	32.3	0.0	32.3
10/12/15	0.72	3.29	32.9	0.0	32.9
20/12/15	0.83	3.73	37.3	0.0	37.3
31/12/15	0.96	4.30	47.3	0.0	47.3
10/01/15	1.05	4.72	47.2	0.0	47.2
20/01/16	1.05	4.75	47.5	0.0	47.5
31/01/16	1.05	4.96	54.5	0.1	54.5
10/02/16	1.03	5.04	50.4	0.0	50.4
18/02/16	0.97	4.95	34.7	0.0	34.7
Total			**403.9**	**0.1**	**403.9**

3.5. Applied irrigation water

The amounts of applied water for each treatment throughout the growing season of the crop were summarized in the table below.

Table 6: The amounts of applied water in mm/season for each treatment

Year	Treatments					
	AFI3	AFI5	EFI3	EFI5	FFI3	FFI5
2015	389	265	471	429	381	278
2016	395	272	475	435	385	270
2017	387	278	461	433	379	285
Mean	390.3	271.7	469	432.3	381.7	277.7

Each treatment with the same irrigation interval has the same number of irrigation events. The seasonal amount of Wa (applied irrigation water) for each treatment is the sum of Wa applied at each irrigation events. The overall mean study indicates that fixed furrow irrigation treatments saved more water than both alternate and every furrow irrigation system. The mean high amount of seasonal water applied (469 mm/seasonal) was recorded under every furrow irrigation at three day intervals (EFI3), while the low (271.7 mm/seasonal) was recorded under alternate furrow irrigation at five day intervals (AFI5). When we compared seasonal water applied for similar irrigation interval for each treatment, high amount (469mm/season) of water was applied for EFI3 while low amount (381.7 mm/season) was applied for FFI3. Similarly high amount (432.3) of seasonal water was applied under EFI than both AFI (271.7) and FFI (277.7) at five days of irrigation interval. This might be due to the great reduction of wetted surface in AFI and FFI than EFI at both irrigation intervals. Almost half of the soil surface is wetted in AFI and FFI as compared with EFI. This result supports the outcome obtained by Graterol *et al*. (1993),who found that AFI methods can supply water in a way that greatly reduce the amount of wetted surface, which leads to less evapotranspiration and less deep percolation. The amount of Wa with AFI at 3 days interval was greater than at 5 days interval. This can be attributed to more frequent irrigation under the AFI3 treatment by Abdel-Maksoud *et al*. (2002). Reduced irrigation water due to the AFI system was reported by El-Sharkawy *et al*. (2006) for potato; Sepaskah and Hosseini (2008) for wheat; Ibrahim and Emara (2010) for sugar beet.

3.6. Effects of furrow irrigation systems on yield and yield components of onion

3.6.1. Effect on Bulb Size and Bulb Diameter

Irrigation Interval: The irrigation interval were significantly different from each other in Bulb size and bulb diameter at ($P <0.05$). Significantly higher, bulb diameter (5.05 cm) and bulb size (4.21 cm) were recorded by three days of irrigation interval respectively. On the other hand the lowest size of bulb of 4.01 cm and 4.76 cm of bulb diameter were observed in five days of irrigation interval, respectively.

Table 7: Effect of irrigation method and irrigation interval on stand count, bulb size and bulb diameter

Treatments		Bulb size (cm)	Bulb diameter (cm)
Irrigation Method	AFI	4.18a	4.86ab
	EFI	4.22a	5.03a
	FFI	3.92b	4.83b
	LSD 0.05	0.21	0.19
	Days		
Irrigation Interval	3	4.21a	5.05a
	5	4.01b	4.76b
	LSD 0.05	0.17	0.15

Irrigation Method: Fixed Furrow Irrigation was found different from others; it is significantly different on bulb size. Significantly higher bulb size (4.22cm) and (4.18cm) were recorded under EFI and AFI systems respectively. Significantly lower bulb size (3.92cm) was recorded on FFI method. Significantly higher bulb diameter (5.03cm) was recorded at EFI and significantly lower (4.83cm) was observed at FFI. There is no significant difference on bulb diameter between AFI and EFI, and also between FFI and AFI.

Table 8: combination effects of furrow systems on bulb size and bulb diameter

Furrow system	Irrigation Interval	Bulb size (cm)	Bulb diameter (cm)
AFI	3	4.29a	4.99ab
	5	4.08ab	4.73bc
EFI	3	4.31a	5.19a
	5	4.13a	4.87bc
FFI	3	4.02ab	4.97ab
	5	3.81b	4.68c
	LSD 0.05	0.29	0.27
	CV	7.56	5.73

The combination effect showed significant difference on bulb size. Significantly higher bulb size of (4.31cm) was recorded in combination treatment of Every Furrow Irrigation with irrigation scheduling of three days interval. Similarly onion bulb size of 4.29cm and 4.13cm were recorded in treatment combination of AFI3 and EFI5 respectively. But the combination effect of FFI with five days irrigation interval of applied water were highly significantly different with that of AFI3, EFI3 and EFI5 respectively. However, there is no significant different between the combination treatment of when AFI with three and five days interval, EFI with three and five days interval, and FFI with three days of interval of water were applied.

On the other hand the combination effect of irrigation method with irrigation interval showed that there was significant difference on bulb diameter. There were highly significant difference in combination effects of treatments between FFI with five days interval (FFI5) and EFI with three days interval (EFI3), AFI with three days interval and FFI with three days interval respectively. But there is no significant in combination between treatments of EFI3, AFI3 and FFI3. Similarly no significance deference observed between AFI3, AFI5, EFI5 and FFI3, and also b/n treatments of AFI5, EFI5 and FFI5. Significantly higher bulb diameter of 5.19cm was recorded on treatment combination of EFI with three days irrigation interval (AFI3) of irrigation water applied. AFI3 of 0.46cm, 0.32cm, 0.51cm greater than the treatment combination of AFI with three days interval, EFI with five days interval and FFI with five days interval of irrigation scheduled respectively.

3.6.2. Effect on bulb weight, under and oversized bulb

Irrigation Method: The irrigation methods were not significantly different from each other in bulb weight at (P >0.05). But, the effect of irrigation methods on undersized and oversized bulb was found significantly different (P<0.05). Significantly higher (5.64 and 3.91 Qt/ha) undersized bulb were recorded for AFI and FFI respectively. Significantly lower (1.47 Qt/ha) was found for EFI. On the other hand, significantly higher oversized bulb (9.32 Qt/ha) was recorded on FFI and lower lower (0.78 Qt/ha) was observed for AFI.

Table 9: the effect of irrigation method and irrigation interval on bulb weight, under and oversized bulb in three years

Treatment		Bulb weight (gm)	Undersized (Qt/ha)	Oversized (Qt/ha)
Irrigation Method	AFI	76.44a	5.64a	0.78b
	EFI	84.67a	1.47b	3.19b
	FFI	76.64a	3.91ab	9.32a
	LSD 0.05	8.29	2.66	5.01
	Days			
Irrigation Interval	3	84.41a	3.17a	7.21a
	5	74.09b	4.18a	1.65b
	LSD 0.05	6.77	2.17	4.09

Irrigation Interval: Significantly higher bulb weight (84.41 gm) and 7.21Qt/ha oversized bulb were observed at three days of irrigation interval. Whereas significantly lower bulb weight (74.09 gm) and oversized bulb (1.65 Qt/ha) were recorded at five days irrigation interval. Irrigation interval has no effect on undersized bulb. Higher undersized bulb of 4.18 Qt/ha was recorded in five days irrigation interval while lower (3.17 Qt/ha) was observed in three days irrigation interval. Value of bulb weight was decreased by 13.93% when the onion crop was irrigated every five days.

Table 10: Combination effects on bulb weight, under and oversized bulb

Furrow system	Irrigation Interval	Bulb weight (gm)	Undersized (Qt/ha)	Oversized (Qt/ha)
AFI	3	81.33ab	6.17a	0.83b
	5	71.56b	5.12ab	0.72b
EFI	3	91.78a	1.10c	6.39b
	5	77.56b	1.84bc	0.00b
FFI	3	80.11ab	2.24bc	14.41a
	5	73.17b	5.58ab	4.23b
	LSD 0.05	11.72	3.76	7.08
	CV	15.56	10.70	16.81

Irrigation furrow methods showed significant effect in combination with irrigation interval on bulb weight and oversized bulb at ($P<0.05$) (Table 10). Every Furrow Irrigation system produced 77.56 gm bulb weight with five days irrigation interval, which increased to 91.78 gm with three days irrigation interval. Values of average single bulb weight were increased by 18.33, 13.65 and 9.48% at three days irrigation interval when compared with five days irrigation interval for EFI, AFI and FFI respectively. Relatively higher undersized bulb of 6.17 Qt/ha was recorded in treatment combination of AFI with three days of irrigation interval and the lowest (1.1 Qt/ha) was observed when EFI interact with three days of irrigation interval. It was also observed that significantly higher oversized bulb (14.41Qt/ha) was recorded on FFI with three days irrigation interval (Table 10).

3.6.3. Effect on marketable yield

Table 11 shows that there was significant difference ($P<0.05$) between the marketable yields obtained under EFI and FFI irrigation methods. But there was no significant difference between EFI and AFI irrigation systems even though reduction in the volume of water applied in case of AFI method is observed. Significantly higher marketable yield of 260.53 Qt/ha was recorded by EFI system followed by AFI (246.01Qt/ha) and FFI (228.18Qt/ha) respectively. And significantly higher marketable yield was recorded at irrigation interval of three days and its yield advantage is 16.14% more than that of five days irrigation interval. The results obtained are in consistent with the significant loss of water that has been associated with CFI (Graterol *et al.*, 1993); physiological response associated with AFI (Franandez, 1994; Kang *et al.*, 2000; Zhang *et al.*, 2000) and minimized evapotranspiration associated with AFI (Stone *et al.*, 1979).

The combined effect of irrigation method with irrigation interval showed significance difference on marketable yield at ($P<0.05$). Significantly higher (296.62 Qt/ha) marketable yield was recorded on AFI with three days of irrigation interval with yield advantage of 12.16 and 18.41% as compared to EFI and FFI method respectively. A treatment combination of AFI with three days irrigation interval significantly differed from treatment combination of AFI with five days irrigation interval, FFI with three and five days of irrigation interval, but there is no significant difference with treatment combination of EFI with three and five days of irrigation interval. Even if they have no significant different, AFI with three days irrigation interval gave 12.16 and 12.18% more marketable yield than EFI at three and five days irrigation interval respectively. This may be attributed to the better availability of soil moisture during the irrigation cycle under AFI. The same trend of water saving advantage was observed in AFI with three days interval of 16.78 and 9.72% amount of water saved than EFI at three and five days interval respectively (Table 14).

It was shown that the soil moisture contents between the two neighboring furrows in AFI remained different until the next irrigation, with higher water content in the previously irrigated furrow. This pattern of soil moisture distribution in the crop root zone should allow part of the root system to be always exposed to a drying soil, consequently, the uniformity of soil moisture distribution in the AFI treatments didn't change noticeably when irrigation amounts was reduced (Kang *et al.*, 2000a).

Table 11: Effect of irrigation method and irrigation interval on marketable yield and total yield

Treatment		Marketable yield	Total yield
Irrigation Method	AFI	246.01ab	252.03a
	EFI	260.53a	264.69a
	FFI	228.18b	240.24a
	LSD 0.05	30.41	30.84
	Days		
Irrigation Interval	3	266.40a	275.78a
	5	223.41b	228.87b
	LSD 0.05	24.83	25.18

Total Yield

Irrigation methods showed no significance difference over total yield at ($P>0.05$). The maximum total yield observed was 264.69 Qt/ha (EFI) which is not significantly different from AFI (252.03 Qt/ha). The lower total yield (240.24 Qt/ha) was recorded on FFI method. Even though, no significance difference was observed in total yield between irrigation methods, EFI gave yield advantage of 4.78 and 9.24% for AFI and FFI methods respectively. But significantly higher (275.78 Qt/ha) total yield was recorded at three days irrigation interval than at five days interval. The combination effect of irrigation method with irrigation interval had a significant effect on total yield ($P<0.05$). Significantly higher yield was recorded on treatment combination of AFI with three days irrigation interval which was not significantly different from EFI with three and five days interval. A higher total yield (303.62 Qt/ha) was recorded on AFI with three days of irrigation interval whereas lower total yield (200.44 Qt/ha) was observed in AFI with five days irrigation interval (Tables 11 & 12).

The treatment combination of AFI with three days irrigation interval had shown a better total yield (12.05% and 13.6% yield advantage) as compared to EFI with three and five days of irrigation interval respectively. Similarly, AFI with three days irrigation interval gave 33.98%, 15.46% and 26.28% more total yield than AFI with five days irrigation interval, FFI with three and five days of irrigation interval respectively.

Table 12: Combination effect on marketable yield and total yield

Furrow system	Irrigation Interval	Marketable yield (Qt/ha)	Total yield (Qt/ha)
AFI	3	296.62a	303.62a
	5	195.39d	200.44c
EFI	3	260.56ab	267.04ab
	5	260.50ab	262.34ab
FFI	3	242.02bc	256.67b
	5	214.34cd	223.82bc
	LSD 0.05	43.01	43.61
	CV	18.48	18.19

3.6.4. Effect on water use efficiency

As can be noted from Table 13, there was found significant difference ($P<0.05$) between furrow irrigation methods and intervals on crop as well as irrigation water use efficiencies. One can clearly see that AFI was better in improving water use efficiencies than EFI and FFI methods. Similarly, irrigation interval at three days gave higher crop water use efficiency.

Table 13 effect irrigation method and interval on crop and irrigation water use efficiencies

Furrow system	Total yield (Qt/ha)	CWR (mm)	Applied water (mm)	CWUE	IWUE
AFI	252.03	197.05	331	1.28a	0.76a
EFI	264.69	394.1	451	0.67b	0.59b
FFI	240.24	197.05	330	1.22a	0.73a
Irrigation interval					
3	275.78	394.1	414	0.70a	0.67b
5	228.87	394.1	327	0.58b	0.70a

This finding agreed with result obtained by Ibrahim and Emara (2010) that there was inverse relationship between amount of water applied and water use efficiencies. The applied water was used more efficiently in the alternate furrow irrigation treatment in which the lower amount of water applied produces higher water productivity (Zhang *et al*., 2000). Table 13 also shows that the difference observed in water productivity between AFI and FFI was not statistically significant ($P>0.05$). The same amount of irrigation water was applied for AFI and FFI techniques. However, alternative drying of root zone under AFI method showed higher water productivity than fixed drying of root zone under FFI method. This is due to relatively uniform water distribution between ridges in AFI than FFI methods that enhanced root growth and improved nutrient uptake which eventually leads to increased crop yield.

The highest water use efficiencies were observed under AFI and FFI with three days of irrigation interval which attributed to the more often application of water in small quantities led to the efficient water utilization of onion crop. The highest IWUE value under limited water supply (i.e.8.1 kg/m^3 and 7.8 kg/m^3), was observed when FFI and AFI irrigation method with five and three days intervals were used. These results are in accordance with Bakker *et al*. (1997), EL-Sherbeny *et al*. (1997) and Abdel-Maksoud *et al*. (2002) who concluded that AFI improved crop water utilization efficiency for the crop under study.

Table 14: Combined effect on crop and irrigation water use efficiencies

Furrow system	Irrigation Interval	Total yield (Qt/ha)	CWR (mm)	Applied water (mm)	CWUE (kg/m^3)	IWUE (kg/m^3)
AFI	3	303.62	197.05	390.3	15.4a	7.8a
	5	200.44	197.05	271.7	10.2b	7.4ab
EFI	3	267.04	394.1	469	6.8c	5.7d
	5	262.34	394.1	432.3	6.7c	6.1cd
FFI	3	256.67	197.05	381.7	13.0ab	6.7bc
	5	223.82	197.05	277.7	11.4b	8.1a

3.7. Irrigation water saved and additional area of land irrigated

Table 15 indicated that amount of water saved under each irrigation methods comparing with each other. This table also indicated additional area that can be irrigated by amount of water saved under each irrigation methods. AFI3 and AFI5, FFI3 and FFI5 and EFI5 saved 78.7mm and 197.3mm, 87.3mm and 191.3mm and 36.7mm more water than of water applied under EFI3 respectively. The amount of water saved can be utilized to irrigate another additional land of the same crop. Thus, amount of water saved can be used to irrigate 0.2ha and 0.73ha, 0.23ha and 0.69ha and 0.08ha of extra land using irrigation systems of AFI3 and AFI5, FFI3 and FFI5 and EFI5 when compared to EFI3 for onion production respectively (Table 15). Similarly, AFI3 and AFI5, FFI3 and FFI5 saved 42mm and 160.6mm, 50.6mm and 154.6mm of water applied under EFI5 which can be used to irrigate 0.11ha and 0.59ha, 0.13ha and 0.56ha of extra land using the irrigation system of AFI3 and AFI5, FFI3 and FFI5 when compared to EFI5 for onion production respectively. AFI5, FFI3 and FFI5 saved more water 118.6mm, 8.6mm and 112.6mm than of water applied under AFI3 which can be used to irrigate 0.44ha, 0.02ha and 0.41ha of additional land using the irrigation system of AFI5, FFI3 and FFI5 when compared to AFI3 for onion production respectively (Table 15).

In the same manner AFI5 and FFI5 saved more water of 110mm and 104mm than the amount of water applied under FFI3 which can be used to irrigate extra 0.4ha and 0.37ha of additional land using the irrigation system of AFI5 and FFI5 when compared to FFI3 for onion production respectively (Table 15).

Table 10 Irrigation water saved and additional area irrigated under each treatments

Treatment		Irrig. Water used (mm)	Irrig. Water saved comparing with EFI3 (mm)	Extra land that can be irrigated (ha)	Irrig. Water saved comparing EFI5 (mm)	Extra land that can be irrigated (ha)	Irrig. Water saved comparing with AFI3 (mm)	Extra land that can be irrigated (ha)	Irrigation water saved comparing with FFI3 (mm)	Extra land that can be irrigated (ha)	Irrig. Water saved comparing with FFI5 (mm)	Extra land that can be irrigated (ha)
Methods	Interval											
AFI	3	390.3	78.7	0.20	42	0.11	0	0	-	-	-	-
	5	271.7	197.3	0.73	160.6	0.59	118.6	0.44	110	0.40	6	0.02
EFI	3	469	0	0	-	-	-	-	-	-	-	-
	5	432.3	36.7	0.08	0	0	-	-	-	-	-	-
FFI	3	381.7	87.3	0.23	50.6	0.13	8.6	0.02	0	0	-	-
	5	277.7	191.3	0.69	154.6	0.56	112.6	0.41	104	0.37	0	0

EFI3 and EFI5=every furrow irrigation at three and five days irrigation interval, FFI3 & FFI5= fixed furrow irrigation at three and five days irrigation interval, AFI3 & AFI5= alternate furrow irrigation at three and five days irrigation interval

3.8. Benefit-Cost Ratio (BCR) and Net Return (NR)

Table 16: Expenses involved in the implementation of irrigation methods

Treatments		Labor cost (ETB)		Input cost (ETB)		Chemical cost (ETB)	Fuel cost (ETB)	Total cost (ETB)
Furrow system	Irrigation Interval	Land preparation &Weeding	Watering	Fertilizer	Seed			
AFI	3	25000	9000	6400	10000	25000	5500	80900
	5	19000	6000	6400	10000	25000	2750	69150
EFI	3	33000	24000	6400	10000	25000	11000	109400
	5	27000	12000	6400	10000	25000	5500	85900
FFI	3	25000	9000	6400	10000	25000	5500	80900
	5	19000	6000	6400	10000	25000	2750	69150

Table 17: Revenues gained from the implementation of irrigation treatments

Treatments		Marketable yield $kgha^{-1}$	Unit price (per kg)	Total price
Furrow system	Irrigation Interval			
AFI	3	29662	10	296620
	5	19539	10	195390
EFI	3	26056	10	260560
	5	26050	10	260500
FFI	3	24202	10	242020
	5	21434	10	214340

Estimation of cost and revenue earned was done based on the expenses involved to produce onion around study area and revenues can be gained from production onion in the study area. Estimated benefit-cost ratio (BCR) and net return (NR) were affected by the irrigation techniques. Maximum benefit-cost ratio (BCR) was 2.67 obtained from AFI with three days of irrigation interval followed by 2.1 from FFI with five days of irrigation interval and 2.03 from EFI technique with five days of irrigation interval, whereas minimum benefit-cost ratio of 1.38 was observed from EFI technique with five days of irrigation interval. However, net revenue gained from AFI with five days interval was low due to low marketable yield collected. AFI with three days of irrigation interval was the best method to improve water productivity, water use efficiency and economic return from onion production (Table 18).

Table 18. Benefit-cost ratio (BCR) and net return (NR) associated with the adopted irrigation treatments

Treatments		Applied water (m^3ha^{-1})	Labor cost (ETB ha^{-1})	Input cost (ETB ha^{-1})	Chem. cost (ETB)	Fuel cost (ETB)	Total cost (ETB)	Marketable yield (kgha-^{1})	Gross Revenue (ETB)	Net revenue (ETB)	Benefit-cost ratio
Furrow system	Irrigation Interval										
AFI	3	3903	34000	16400	25000	5500	80900	29662	296620	215720	2.67
	5	2717	25000	16400	25000	2750	69150	19539	195390	126240	1.83
EFI	3	4690	57000	16400	25000	11000	109400	26056	260560	151160	1.38
	5	4323	39000	16400	25000	5500	85900	26050	260500	174600	2.03
FFI	3	3817	34000	16400	25000	5500	80900	24202	242020	161120	1.99
	5	2777	25000	16400	25000	2750	69150	21434	214340	145190	2.10

4. Summary and Conclusion

In this study, an attempt was made to evaluate the effect of Alternate, Every and Fixed furrow irrigation systems and two irrigation intervals in order to identify the best irrigation management strategies which could contribute for water saving, increase water productivity and water use efficiency with no or minimum yield reduction in the mid rift valley particularly east Shoa zone of Oromia region in Adami Tulu Agricultural Research Center for onion production.

Alternate furrow irrigation system, was considered as improved irrigation technology and its performance was evaluated in comparison with fixed furrow and every furrow irrigation systems. From the study the highest total yield was observed under every furrow irrigation method which showed little difference as compared with alternate furrow irrigation. The yield reduction under alternate furrow irrigation is less than 5% as compared with every furrow irrigation method, which has no significant impact on total yield of onion crop. The highest marketable yield (26,053 kg ha^{-1}) was obtained from every furrow irrigation, whereas the lowest marketable yield (22,818 $kgha^{-1}$) was obtained from fixed furrow irrigation method.

Comparing the results of the irrigation methods from the point of crop water productivity, it clearly confirmed that, alternate furrow irrigation method had more beneficial use of water followed by fixed furrow irrigation and every furrow irrigation methods respectively. The highest water productivity (WP) value (7.6 kg m^{-3}) was obtained under alternate furrow irrigation whereas the lowest value (5.9kg m^{-3}) was obtained by every furrow irrigation. Alternate furrow and fixed furrow irrigation methods saved 26.61% and 26.83% of water applied as compared to every furrow irrigation method respectively.

Result obtained from this study show that alternate furrow irrigation system lead to lesser water input yet was still able to generate comparable onion yield to every furrow irrigation. Alternate furrow and fixed furrow irrigation methods were also saved labor by 50% since in every furrow; four furrows irrigated at same time while in AFI and FFI only two furrows out of four furrows. Therefore, time and labor reduced by half and improves working conditions as technology allows irrigator moving on the dry furrows.

Therefore applying alternate-furrow irrigation with appropriate irrigation intervals is efficient method in the study area and where water is a limiting factor for crop production. It can be concluded that using alternate irrigation is a good water management technique to save irrigation water without significantly reducing the yield of onion. The preference between alternate furrow irrigation method and other methods depends on the value of water in relation to crop returns. This water application technique is much important for semi-arid areas of Ethiopia where limited amount of water is available for irrigation and irrigation water management is very poor.

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Effect of furrow dimensions on yield and water productivity of maize in Sibu Sire district, Eastern Wollega, Ethiopia

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Abstract

A field experiment was conducted during the dry season of 2017/2018 at the Sibu Sire district East Wollega zone of Oromia Regional State to evaluate the impact of furrow dimensions on yield and water productivity of maize. Climatic, plant and soil factors were used for the calculation of monthly crop water and irrigation requirements and results compared with actual performance of the irrigation systems. The experiment was laid out in a randomized complete block design with three treatments replicated four times. The experimental treatments including farmer practice or T1 (furrow with top width of 21cm, bottom width of 13cm and depth of 10cm without determined flow rate), T2 (furrow with top width of 25cm, bottom width of 14cm and depth of 15cm with determined flow rate) and T3 (furrow with top width of 18cm, bottom width of 8cm and depth of 12cm with determined flow rate) having a plot size of 6mx8m with spacing of 0.5m and 1m between plots and blocks respectively. The application efficiency in the treatment T2 was distinctly much higher (78.791%) in comparison to other treatments. The lowest (58.149%) application efficiency was found in T1 (i.e. farmer practice). Distribution efficiency and water productivity were also highest (89.5% and 1.4855 kg/m^3) in treatment T2 and lowest (81.75% and 1.232 kg/m^3) in treatment T1 respectively. The best treatment towards the yield of maize was T2 which produced mean yield of 7964.4 kg/ha while treatment T1 produced the lowest yield of 5629.8 kg/ha. Some maize growth related parameters were also investigated. There were significant differences in maize cob diameter, cob length, number of cob per plants between some treatments while no significant differences occurred in plant height and stand count at harvest among all treatments at significance level of 5%. Hence T2 is recommended to be used for better irrigation efficiencies, water productivity and maize yields in the study area and similar agro-ecologies. It is recommended that further research covering major soil types and for major irrigated crops replicated over years should be conducted.

***Keywords**:* Furrow irrigation, furrow dimension, irrigation efficiency, water productivity

1. Introduction

Irrigation plays an important role in food production, self-sufficiency and security but potential increase in irrigation water and land resources are limited. Despite the higher risks in rain-fed agriculture, it is widely accepted that the bulk of the world's food will continue to come from this systems (Oweis, 2012). Therefore, accelerated and sustainable development in agriculture sector needs transformation of rain-fed agriculture to irrigated agriculture. Furrow irrigation is the most extensively used means of irrigating crops in many developing countries. It is especially recommended for growing row crops on medium to heavy textured soils and is preferred over other surface irrigation methods due to its simplicity and low capital cost (Crevoisier et al., 2008).This method of irrigation as compared with sprinkler or trickle methods is inexpensive. Therefore, more attention is being paid to improve the efficiency of this method of irrigation. Irrigation water management like how much to irrigate, how often to irrigate and when to irrigate has vital impact on the sustainability of water resources, soil and crop production. If not appropriately managed, it will be resulted in complete or partial loss to their production, soil loss and irrigation water loss. Over irrigating will result not only in water loss but also production loss, and under irrigation result in yield loss.

In the study area, the existing furrow dimensions have been made on the trial and error basis. The incoming flow rate in to the field has been used for irrigation without measurement and furrow dimension design. The use of high flow rate overflows the furrow section and takes off the soil resources as surface runoff which in turn reduces the nutrient of the soil. This phenomenon is occurred if the furrow dimensions do not coincide with the incoming flow rate depending on the soil type of the area. The problem leads to erosion and frequent need of furrow construction. In other hand, application of very low flow rate results in deep percolation at furrow head while, other part of the furrow become under irrigated. Consequently, these practices are known to produce greater chance of water logging, tail water losses, salinity hazards, high yield loss and lower economical profit (Walker, 2003). Problems of irrigation water management leads to shortage of water and competitions among different agricultural and non- agricultural demands. The need of suitable water resource management is, therefore, serious concern for enhanced water use among different sectors. Proper use of furrow widths, depth, and length is one of the practices in irrigated agriculture to maximize irrigation efficiencies and enhanced crop yield as well as the water use efficiency. In addition, it can make capable the users to conserve soil and water resources. This study will provide indicative information on the response of irrigation performance indicators, yield and water use efficiency of maize due to the proper furrow dimensions.

Maize (Zea mays) is one of the most important cereals broadly adapted worldwide (Christian et al., 2012). In Ethiopia, maize grows from moisture stress areas to high rainfall areas and from lowlands to the highlands. In Ethiopia maize is produced for food, especially in major maize producing regions mainly for low-income groups. The total annual production and productivity of maize in Ethiopia exceeds all other cereals (23.24% of 13.7 Million tons), and is second after Teff (Eragrostis tef) in area coverage (16.12% of the 8.7 Million ha) (Mosisa et al., 2007). It is an important field crop in terms of area coverage, production and utilization for food and feed purposes. Maize is widely produced in the study area under rain-fed and also occasionally under furrow irrigation system. However, the farmers have no idea about the design of furrow which can affect the application efficiency, distribution uniformity and yield of the crop. The yield of crop is decreasing from year to year as a result of poor preparation of furrow dimensions. In addition to this, large amount of irrigation water has been lost in form of surface runoff and deep percolation which in turn decreases the productivity of irrigation water. Therefore, it is required to specify appropriate furrow dimension which is suitable based on predetermined soil type. Hence, the main objective of this study was to investigate the effect of different furrow dimensions on yield and water productivity of maize.

2. Materials and Methods

2.1 Experimental site description

The study was conducted in Sibu Sire district, East Wollega Zone of Oromia Regional State, Western Ethiopia, from 2017-2018, At east Wollega Zone, 281 kms from Addis Ababa and 50 kms East from Nekemte. It lies between 8°56'- 9°23'N latitudes and 36°35'- 36°56' E longitudes. The altitude of the district ranges between 1360 m a.s.l to 2500 m a.s.l. There are three agro-ecological zones represented in this district. The majority (74.3%) of the district is classified as mid-land with lowland (18.27%) and only 7.53% is considered as highland. The minimum, maximum and mean temperatures of the study area were 14.09 ºC, 27.30 ºC, and 22.55 ºC respectively. The highest temperature occurs in February and March. The lowest temperature occurs in July and August. The annual average rainfall of the district is 1295mm (RLEPOSSD, 2013).

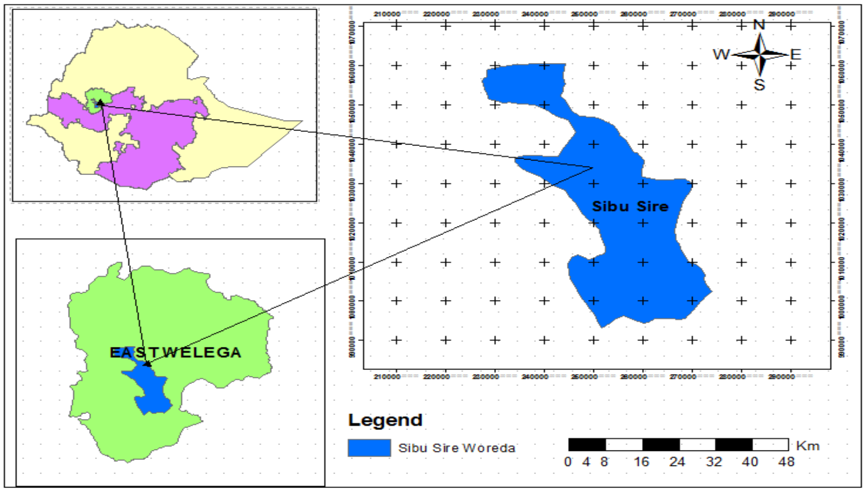

Figure1. Map of study area

2.2 Design of experiment and treatments

The experiment was laid out in Randomized Complete Block Design (RCBD) with four replications consisting of three treatments. The treatments were composed of T1 or farmer practice (furrow with top width of 21cm, bottom width of 13cm and depth of 10cm without determined flow rate), T2 (furrow with top width of 25cm, bottom width of 14cm and depth of 15cm with determined flow rate) and T3 (furrow with top width of 18cm, bottom width of 8cm and depth of 12cm with determined flow rate). The experiment was conducted on plot size of 6 m x 8 m and pacing of 0.5m and 1m between plots and blocks respectively. Furrows of T2 and T3 were closed end and the applied water was slowly infiltrated into the root zone. But furrows under farmers' practice were open ended and the water was lost as surface runoff at the tail. The experimental crop used was maize (Limmu variety) and planted with 75 cm x 30 cm spacing between rows and plants respectively.

Figure 2. Sibu Sire experimental site

2.3 Determination of crop water requirements

Crop water requirements (CWR) refer to the amount of water required to compensate the evapotranspiration losses from a cropped field during a specified period of time. It is the product of crop factor and reference evapotranspiration. Reference evapotranspiration is calculated by Cropwat 8.0 software from climate data.

$$ETc = ETo x Kc \qquad (1)$$

Where, ETc: crop evaporation or crop water need (mm/day), Kc: Crop factor, ETo: Reference evapotranspiration (mm/day).

2.3.1. Irrigation requirement

Irrigation water requirements can be defined as the quantity, or depth, of irrigation water in addition to precipitation required to produce the desired crop yield and quality and to maintain an acceptable salt balance in the root zone. It can be calculated by the following equation.

$IR_n = (\theta_{fc} - \theta_{pwp}) \times p \times D_b \times Z_r$ (2)

Where, θ_{fc} = field capacity (mm/m)

θ_{pwp}= permanent wilting point (mm/m)

p= depletion fraction (%)

Zr= root depth of crop (m)

D_b= bulk density (g/cm^3)

2.4. Data collection

2.4.1. Irrigation performance parameters

Water application efficiency is a measurement of how effective the irrigation system is in storing water in the crop root zone. It is expressed as the percentage of the total volume of water delivered to the field that is stored in the root zone to meet crop evapotranspiration (ET) needs.

$$Ea = \frac{Ws}{Wf} * 100 \quad (3)$$

Where, Ea is water application efficiency (%), W_s is water stored in crop root zone (cm), W_f is water delivered at the head end of the furrows, cm.

Water distribution efficiency is defined as the percentage of difference from unity of the ratio between the average numerical deviations from the average depth stored during the irrigation. It was determined using the following formula:

$$Ed = \left(1 - \frac{y}{d}\right) * 100 \quad (4)$$

Where, Ed=Water distribution efficiency, % d=Average depth of water stored in root zone along the furrow after irrigation, cm and y=Average numerical deviation from d, cm

Crop water productivity (CWP) is defined as the relationship between the amounts of crop produced or the economic value of the produce and the volume of water associated with crop production (Playan and Mateos, 2005). There are three dimensions of water productivity: physical productivity, expressed in kg per unit of water consumed; combined physical and economic productivity expressed in terms of net income returns from unit of water consumed, and economic productivity expressed in terms of net income returns from a given amount of water consumed against the opportunity cost of using the same amount of water (Kumar *et al.*, 2005). The CWP considered in this study is physical productivity defined as: Mass of produce (kg) per volume of water supplied (m^3) expressed as (Playan and Mateos, 2005):

$$CWP = \frac{Y}{WR} \quad (5)$$

Where, CWP = Crop water productivity (kg/ m^3), Y= Yield of the crop, (kg/ha), WR=Water requirement of the crop, (m^3/ha).

2.5 Laboratory analysis of soil samples

About 0-60cm depth of disturbed (composite) and undisturbed soil samples were collected from different points by using soil auger and core sampler respectively for the analysis of physical and chemical properties. The Composite sample (after being well mixed in a bucket) of about 2 kg of the mixed sub samples (composite sample) was properly bagged, labeled and transported to the laboratory for analysis of soil chemical properties.

The soil pH was measured potentiometrically with a digital pH meter in the supernatant suspension of 1:2.5 soils to water ratio. The soil electrical conductivity measurement was done using a conductivity meter at 25ºc using its standard procedures.

Soil available P was extracted by the Bray-II method (Bray and Kurtz, 1945) and quantified using spectrophotometer (Wave length of 880ηm) colorimetrically using vanadomolybedate acid as an indicator. Exchangeable basic (Ca, Mg, K and Na) ions were extracted using 1 M ammonium acetate (NH4OAc) solution at pH 7. The extracts of Ca and Mg ions were determined using atomic absorption spectrophotometry (AAS) while K and Na were determined by flame photometer. To determine the cation exchange capacity (CEC), the soil samples were first leached with 1 M NH4OAc, washed with ethanol and the adsorbed ammonium was replaced by Na.

The CEC was then measured titrimetrically by distillation of ammonia that was displaced by Na following the micro-Kjeldahl procedure. Field capacity (FC) and permanent wilting Point (PWP) of sampled soil were determined using pressure plate apparatus at 1/3 and 15 bar, respectively. The soil texture was measured from samples collected at different depths using hydrometer method. The textural class of the soil profile was determined using USDA textural triangle.

Soil samples for field capacity and bulk density were taken from pits 0.6 m deep dug at the center of each experimental block. The samples were taken using core samplers of known volume (98.2 cm3) from depths 0-20 cm, 20-40 cm and 40-60cm. The samples were then sealed in containers to avoid moisture loss before being sent to the laboratory for analysis. Field capacity was determined as the moisture content at pF 2.4 (0.3 bar) using pressure plate apparatus.

Soil samples for field capacity determination were also used to determine the permanent wilting point of the soil. Measurements of permanent wilting point were made from disturbed soil samples on a pressure plate apparatus in the laboratory. Wilting point was determined as the moisture content at pF 4.2 (15 bar).

The core soil samples were dried in oven dry apparatus at 105 °C for 24 hours and the bulk density was calculated using equation:

$$Pb = \frac{Ms}{Vc} \quad (6)$$

Where,

ρb = soil bulk density (g/cm^3),
Ms = weight of dried soil (g), and
Vc = volume of core sampler (cm^3)

2.6. Data management and analysis

All relevant data were recorded periodically and stored and managed in Microsoft excel .The collected data were arranged and organized for the suitability of statistical analysis and finally analysis of variance (ANOVA) was performed using statistix 8 software. Lest significant difference (LSD) at 5% level significance was used to make mean separation.

3. Results and Discussion

3.1. Soil chemical properties

Many soil chemical and biological reactions are controlled by the pH of the soil solution in equilibrium with the soil particle surfaces. In the present study, results of standard measurement of soil pH using H_2O, CaCl2 and KCl are presented in (Table 1). The pH in H_2O under this study area is ranged in optimum value which is slightly acidic as recommended by Jones (2003). An electric conductivity of 0.035 ms/cm lies in the range which is <3 ms/cm, hence the soil samples are non- saline soils. Plants growing in this area do not have the problem of absorbing water because of the lower osmotic effect of dissolved salt contents. The total nitrogen of study area as suggested by Tekalign (1991) rated as high percent which is suitable for plant growth. Since the plant obtains phosphorus (P) from the soil solution through its roots or root symbionts, available P is composed of solution P plus P that enters the solution during the period used to define availability. As per the rating suggested by Jones (2003), the available P of soil of experimental field of the studied area was classified as low value. As per the ratings recommended by Hazelton and Murphy (2007), the CEC value of the agricultural land of the present study area was within the recommended range. Normally it is satisfactory for agriculture if realizers are used. The value of exchangeable Ca was low and Mg was medium whereas that of K was high as suggested by Matsumoto et al. (2013). The organic matter of this study area was found to be medium which is suitable for crop growth.

Table 1.Chemical composition of the soil at Sibu Sire experimental field

Chemical properties	Value
Organic carbon (%)	2.979
Available phosphorus (ppm)	10.666
pH in H2O	6.17
pH in 0.01 m CaCl2	5.07
pH in 1M KCL	4.56
Total nitrogen (%)	0.257
electrical conductivity (ms/cm)	0.066
Organic matter (%)	5.136
Exchangeable cations (meq/100 g soil)	
Ca	2.138
Mg	2.138
K	0.736
Na	0.325
CEC	30.290

3.2. Soil physical properties

As depicted from laboratory analysis, particle size distribution indicated that the soil is sandy clay loam in textural class throughout the soil depth with an average particle size distribution of 29.3.6% sand, 23% silt and 47.7% clay whereas the average gravimetric moisture content at field capacity and permanent wilting point were 32.6 and 24.1%, respectively. The value of bulk densities (1.3gcm^{-3}) were obtained by considering the average of the 0 - 60 cm depth. Since the value of bulk density has to be <1.6, this value has no problem with the crop growth. Moreover, the average available water under this depth was found to be 109.1mm.

Table 2: Physical properties of soils at various depths at Sibu Sire experimental field

Sample number	Depth of soil (cm)	Size proportion			Textural class	Bulk density (g/cm^3)	FC (%Vol)	PWP (%Vol)	TAW (mm/m of soil depth)
		Clay (%)	Silt (%)	Sand (%)					
1	0-20	47	23	30	SCL	1.319	27.375	21.9675	71.3
2	20-40	44	25	31	SCL	1.224	31.5975	22.465	111.8
3	40-60	52	21	27	SC L	1.331	38.7475	27.92	144.1

Key: FC=Field capacity, PWP=Permanent wilting point, SCL=Sandy clay loam, TAW=total available water

3.3. Irrigation efficiencies and water productivity

Statistical analysis revealed that there were significant differences among some treatments as shown in Table 3. Significant differences in water application efficiencies were observed between T1 and the rest two treatments ($p \leq 0.05$). However, there were no significant variations between T2 and T3 ($P > 0.05$), but there was observed slight difference among them numerically. The highest (78.79%) application efficiency was resulted from T2 while the lowest (58.149) was recorded under treatment T1. Similar result was reported by Manisha *et al.* (2016) in that furrow irrigation application efficiencies ranging in between 65.26 and 81.96% was found. Similar to water application efficiency, significant differences was observed between Treatments T1 andT2. Significantly lowest (81.75%) water distribution efficiency was recorded from T1 while the highest (89.5%) was obtained under T2. This result is in agreement with Manisha *et al.* (2016) who reported the closest result in water distribution efficiency.

Significant difference between T1 and other treatments were observed in water productivity whereas no statistical variation recorded between T2 and T3. The highest (1.4855 kg/m^3) in water productivity was resulted from T2 while the lowest (1.2320 kg/m^3) was obtained under T1. These all variations between treatment T1 and the rest two treatments are due to the all furrows of treatment T2 and T3 were closed at the end of their length and no water was lost by run off. Even if treatment T2 had no significant statistical difference with T3, it revealed numerical variation with it. Hence treatment T2 showed better efficiencies and productivity advantage than the rests of treatments.

Table 3.Irrigation efficiencies and water productivity in different treatments

Treatments	**Application efficiency (%)**	**Distribution efficiency (%)**	**Water productivity (kg/m^3)**
T1	58.15b	81.75b	1.23b
T2	78.79a	89.50a	1.50a
T3	73.27a	85.25ab	1.32b
LSD 0.05	5.10	3.01	0.10
CV%	8.87	12.84	9.68

Key: Means with the same letter in a column are not significantly different, Ns =Not significant

3.4. Yield and growth related parameters of maize

As statistical analysis depicted in Table 4, there were significant differences in maize cob diameter, cob length, number of cob per plants and maize grain yield between some treatments while no significant differences occurred in percentage of stand count and plant height among all treatments at significance level of 5%.There were significant differences in cob diameter between treatments T1 and T2. The highest (5.1cm) cob diameter was recorded in treatment T2 and the lowest (4.875cm) was obtained from T1. Similarly, Sharifai et al. (2012) reported cob diameter range of 5-6cm. Significant differences were recorded between treatments T1 (farmer practice) and T2 (designed furrow), however there was no variation between treatments T2 and

T3 in cob length. An average of 24.64cm and 21.42cm cob length were resulted from treatments T2 and T1 respectively. Grain yield of T2 also revealed better advantage as compared to T1 statistically and T3 numerically. It also amounted 7964.4 kg/ha and 5629.8 kg/ha for T2 and T1 respectively. In line with results of this study, Legesu (2017) reported that yield of Limmu maize variety was 8271 kg/ha which is closer to each other. Also from the local experience, the yield of Limmu maize variety in this study area was 3000 kg/ha-6500 kg/ha, hence T2 revealed better yield advantage than the local practice. This was due to the designed furrow was blocked at the end and the delivered water was infiltrated directly to crop root zone.

Table 4.Maize yields and growth related parameters of all treatments

Treatments	**Stand count (%)**	**Number of Cob per plant**	**Plant height (m)**	**Cob diameter (cm)**	**Cob length (cm)**	**Grain Yield (kg/ha)**
T1	85.915a	1.40b	2.6565a	4.875b	21.42b	5629.8b
T2	86.388a	1.90a	2.7845a	5.10a	24.64a	7964.4a
T3	85.800a	1.60ab	2.691a	5.01ab	23.28ab	6696.0ab
LSD 0.05	Ns	0.383	Ns	1.381	1.999	1275.10
CV%	0.56	13.54	6.21	1.60	5.00	10.9

Key: Means with the same letter in a column are not significantly different, Ns =Not significant

4. Conclusions and Recommendation

From the study, T2 (furrow with top width of 25cm, bottom width of 14cm and depth of 15cm with determined flow rate) revealed superiority in water application efficiency, water distribution efficiency and water productivity over other treatments, whereas T1 (furrow with top width of 21cm, bottom width of 13cm and depth of 10cm without determined flow rate) showed lowest results as compared to others. Moreover, yield and growth related parameters of T1 (farmer practice) were found to be the lowest as compared to T2 and T3. Generally T2 indicated better performance in both application and distribution efficiencies, water productivity as well as yield and growth related parameters. Hence T2 is recommended to be used for better irrigation efficiencies, water productivity and maize yields in the study area and similar agro-ecologies. It is recommended that further research covering major soil types and for major irrigated crops replicated over years should be conducted.

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Effect of Furrow Dimensions on Yield and Water Productivity of Onion at Ilu Gelan District, Western Shoa, Ethiopia

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Abstract

This study was conducted to evaluate the impact of furrow dimensions on yield and water productivity of onion. Climatic, plant and soil factors were used for the calculation of monthly crop water and irrigation requirements and results compared with actual performance of each furrow irrigation systems. The experiment was laid out in a randomized complete block design with three treatments replicated four times. The experimental treatments including farmer practice or T1 (furrow with top width of 23 cm, bottom width of 13 cm and depth of 11cm without determined flow rate), T2 (furrow with top width of 45 cm, bottom width of 20 cm and depth of 12 cm with determined flow rate) and T3 (furrow with top width of 35 cm, bottom width of 14 cm and depth of 10 cm with determined flow rate) having a plot size of 8mx5m with spacing of 0.5m and 1m between plots and blocks respectively. The application efficiency in the treatment T2 was highest (75.87%) in comparison to other treatments. The lowest (56.17%) application efficiency was found in T1 (i.e. farmer practice). Distribution efficiency was highest (89%) in treatment T2 and lowest (81%) in treatment T1. There was observed significance difference in plant height of onion among all treatments ($P<0.05$). The highest (41.525cm) was recorded from T2 and the lowest (39.275cm) was obtained from T1. The best treatment in terms of water productivity and yield of onion was T2 which were 5.2 kg/m^3 and 19,520 kg/ha respectively. Whereas, the lowest water productivity (3.11 kg/m^3) and yield of onion (15,088 kg/ha) was obtained from T1. It is recommended that further research covering major soil types and crops with replications over years should be conducted.

***Keywords**:* Furrow irrigation; furrow dimension; irrigation efficiency; water productivity

1. Introduction

Irrigation plays an important role in food production, self-sufficiency and security but potential increase in irrigation water and land resources are limited. Despite the higher risks in rain-fed agriculture, it is widely accepted that the bulk of the world's food will continue to come from this systems (Oweis, 2012). Therefore, accelerated and sustainable development in agriculture sector needs transformation of rain-fed agriculture to irrigated agriculture. Furrow irrigation is the most extensively used means of irrigating crops in many developing countries. It is especially recommended for growing row crops on medium to heavy textured soils and is preferred over other surface irrigation methods due to its simplicity and low capital cost (Crevoisier et al., 2008).This method of irrigation as compared with sprinkler or trickle methods is inexpensive. Therefore, more attention is being paid to improve the efficiency of this method of irrigation. Irrigation water management like how much to irrigate, how often to irrigate and when to irrigate has vital impact on the sustainability of water resources, soil and crop production. If not appropriately managed, it will be resulted in complete or partial loss to their production, soil loss and irrigation water loss. Over irrigating will result not only in water loss but also production loss, and under irrigation result in yield loss.

In the study area, the existing furrow dimensions have been made on the trial and error basis. The incoming flow rate in to the field has been used for irrigation without measurement and furrow dimension design. The use of high flow rate overflows the furrow section and takes off the soil resources as surface runoff which in turn reduces the nutrient of the soil. This phenomenon is occurred if the furrow dimensions do not coincide with the incoming flow rate depending on the soil type of the area. The problem leads to erosion and frequent need of furrow construction. In other hand, application of very low flow rate results in deep percolation at furrow head while, other part of the furrow become under irrigated. Consequently, these practices are known to produce greater chance of water logging, tail water losses, salinity hazards, high yield loss and lower economical profit (Walker, 2003). Problems of irrigation water management leads to shortage of water and competitions among different agricultural and non- agricultural demands. The need of suitable water resource management is, therefore, serious concern for enhanced water use among different sectors. Proper use of furrow widths, depth, and length is one of the practices in irrigated agriculture to maximize irrigation efficiencies and enhanced crop yield as well as the water use efficiency. In addition, it can make capable the users to conserve soil and water resources. This study will provide indicative information on the response of irrigation performance indicators, yield and water use efficiency of onion due to the proper furrow dimensions.

At present, following tomatoes, onion (*Allium cepa L*) is one of the most popular vegetables in the world. It is a recently introduced bulb crop in the agriculture community of Ethiopia and it is rapidly becoming a popular vegetable among producers and consumers. The crop is produced as a cash crop by small farmers and commercial growers especially under irrigated conditions compared to the traditional bulb crops, shallot and garlic, which are rain fed. Ethiopia has a great potential to produce onion throughout the year both for local consumption and for export. It is popular among producers because of the advantage of high yield potential, availability of desirable cultivars for various uses, ease of propagation by seed, high domestic (bulb and seed) and export (bulb, cut flowers) markets in fresh and processed forms. As a result, in the last few years, the demands for onion production have shown a significant increase in the country.

This indicates that Ethiopia has high potential to benefit from onion crop, with the growing small-scale irrigation scheme in the country. Onion crop was widely produced around the study area under furrow irrigation. However farmers or producers have no idea about the design of furrow which can affect the application efficiency, distribution uniformity and yield of the crop. The yield of the crop is decreasing from year to year as a result of poor preparation of furrow dimensions. In addition to this, large amount of irrigation water was lost in form of surface runoff and deep percolation which in turn decreases the productivity of irrigation water. Therefore, it is mandatory work to specify appropriate furrow dimensions which is suitable for predetermined soil type. Generally, the main objective of this study was to investigate the effect of different furrow dimensions on yield and water productivity of onion.

2. Materials and methods

2.1. Experimental site description

The experiment was conducted in West Shewa zone of Oromia regional state, in Ilu Gelan district, Jato Derke kebele, Ethiopia, at about 200 kms from Addis Ababa to the West. The experimental site is located at 08°59'51''N latitude and 37°19'49''E longitude with an elevation of 1812 meters above sea level. The district receives mean annual rainfall of 1351mm with mean maximum temperature of 28.1 °C and the mean minimum temperature was 13.8 °C.

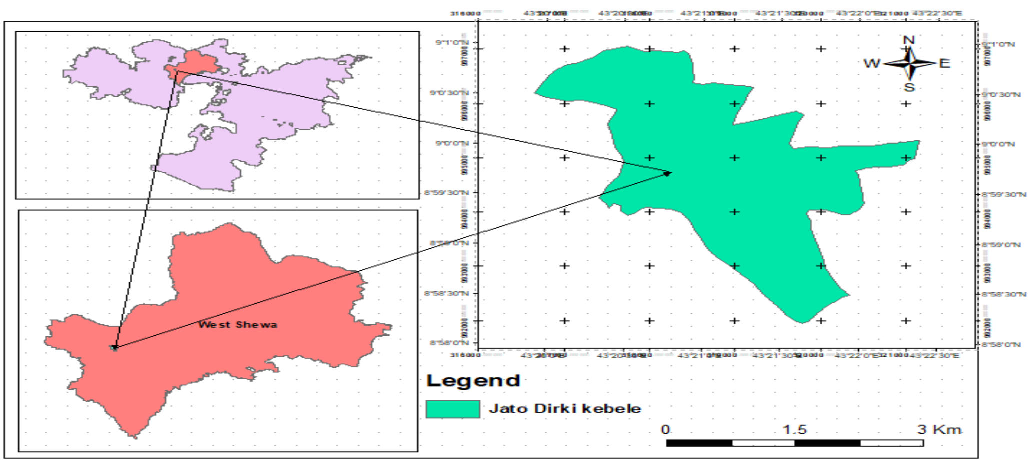

Figure 1. Map of the study area

2.2. Design of experiment and treatments

The experiment was laid out in Randomized Complete Block Design (RCBD) with four replications consisting of three treatments. The treatments were composed of T1 or farmer practice (furrow dimension of top width 23cm, bottom width of 13cm and depth of 11cm without determined flow rate), T2 (furrow dimension of top width 45cm, bottom width 20cm and depth 12cm with determined flow rate) and T3 (furrow dimension with top width 35cm, bottom width of 14cm and depth of 10cm with determined flow rate). The experiment was conducted on plot size of 8 m x 5 m sand pacing of 0.5m and 1m between plots and blocks respectively. Furrows of T2 and T3 were closed end and the applied water was slowly infiltrated into the root zone. But furrows under farmers' practice were open ended and the water was lost as surface runoff at the tail. The experimental crop was red bombe onion variety and transplanted with 40 cm x 20 cm spacing between rows and plants respectively.

Figure 2. Ilu Gelan experimental site

2.3. Determination of crop water requirements

Crop water requirements (CWR) refer to the amount of water required to compensate the evapotranspiration losses from a cropped field during a specified period of time. It is the product of crop factor and reference evapotranspiration. Reference evapotranspiration is calculated by Cropwat 8.0 software from climate data.

$$ETc = ETo \times Kc \qquad 1$$

Where, ETc: crop evaporation or crop water need (mm/day), Kc: Crop factor, ETo: Reference evapotranspiration (mm/day).

2.3.1. Irrigation requirement

Irrigation water requirements can be defined as the quantity, or depth, of irrigation water in addition to precipitation required to produce the desired crop yield and quality and to maintain an acceptable salt balance in the root zone. It can be calculated by the following equation.

$$IR_n = (\theta_{fc} - \theta_{pwp}) \times p \times D_b \times Z_r \qquad 2$$

Where, θ_{fc} = field capacity (mm/m)

θ_{pwp}= permanent wilting point (mm/m)

p= depletion fraction (%)

Zr= root depth of crop (m)

D_b= bulk density (g/cm^3)

2.4. Data collection

2.4.1. Irrigation performance parameters

Water application efficiency is a measurement of how effective the irrigation system is in storing water in the crop root zone. It is expressed as the percentage of the total volume of water delivered to the field that is stored in the root zone to meet crop evapotranspiration (ET) needs.

$$Ea = \frac{Ws}{Wf} * 100 \qquad (3)$$

Where, Ea is water application efficiency (%), W_s is water stored in crop root zone (cm), W_f is water delivered at the head end of the furrows, cm.

Water distribution efficiency is defined as the percentage of difference from unity of the ratio between the average numerical deviations from the average depth stored during the irrigation. It was determined using the following formula:

$$Ed = \left(1 - \frac{y}{d}\right) * 100 \qquad (4)$$

Where, Ed=Water distribution efficiency, % d=Average depth of water stored in root zone along the furrow after irrigation, cm and y=Average numerical deviation from d, cm

Crop water productivity (CWP) is defined as the relationship between the amounts of crop produced or the economic value of the produce and the volume of water associated with crop production (Playan and Mateos, 2005). There are three dimensions of water productivity: physical productivity, expressed in kg per unit of water consumed; combined physical and economic productivity expressed in terms of net income returns from unit of water consumed, and economic productivity expressed in terms of net income returns from a given amount of water consumed against the opportunity cost of using the same amount of water (Kumar *et al*., 2005). The CWP considered in this study is physical productivity defined as: Mass of produce (kg) per volume of water supplied (m^3) expressed as (Playan and Mateos, 2005):

$$\mathrm{CWP} = \frac{\mathrm{Y}}{\mathrm{WR}} \qquad (5)$$

Where, CWP = Crop water productivity (kg/ m^3), Y= Yield of the crop, (kg/ha), WR=Water requirement of the crop, (m^3/ha).

2.4.2. Growth and yield parameters

Stand count at harvest (percentage: plants that successfully established in the central rows were counted at harvest and expressed as percentage.

Plant height (cm): This was measured from the ground to the tip of the leaves from 10 randomly selected plants at maturity.

Marketable bulb yield (t ha^{-1}): This referred to the weight of healthy and marketable bulbs that range from 20 g to 160 g in weight. Bulbs below 20 g in weight were considered too small to be marketed whereas those above 160 g were considered oversized according to Lemma and Shimeles (2003). This parameter was determined from the net plot at final harvest and expressed as t ha^{-1}.

2.4.3. Laboratory analysis of soil samples

About 0-60cm depth of disturbed (composite) and undisturbed soil samples were collected from different points by using soil auger and core sampler respectively for the analysis of physical and chemical properties. The Composite sample (after being well mixed in a bucket) of about 2 kg of the mixed sub samples (composite sample) was properly bagged, labeled and transported to the laboratory for analysis of soil chemical properties.

The soil pH was measured potentiometrically with digital pH meter in the supernatant suspension of 1:2.5 soils to water ratio (Baruah and Barthakur, 1997). The soil electrical conductivity measurement was done using a conductivity meter at 25ºc using its standard procedures.

Soil available P was extracted by Bray-II method (Bray and Kurtz, 1945) and quantified using spectrophotometer (Wave length of 880ηm) colorimetrically using vanadomolybedate acid as an indicator. Exchangeable bases (Ca, Mg, K and Na) were extracted using 1 M ammonium acetate (NH4OAc) solution at pH 7. The extracts of Ca and Mg ions were determined using AAS while K and Na were determined by flame photometer. To determine the cation exchange capacity (CEC), the soil samples were first leached with 1 M NH4OAc, washed with ethanol and the adsorbed ammonium was replaced by Na (Chapman, 1965). The CEC was then measured titrimetrically by distillation of ammonia that was displaced by Na following the micro-Kjeldahl procedure.

Soil samples for field capacity and bulk density were taken from pits 0.4 m deep dug at the center of each experimental block. The samples were taken using core samplers of known volume (98.2 cm3) from depths 0-20 cm and 20-40 cm. The samples were then sealed in containers to avoid moisture loss before being sent to the laboratory for analysis.

Field capacity was determined as the moisture content at pF 2.4 (0.3 bar) using pressure plate apparatus. Soil samples for field capacity determination were also used to determine the permanent wilting point of the soil. Measurements of permanent wilting point were made from disturbed soil samples on a pressure plate apparatus in the laboratory. Wilting point was determined as the moisture content at pF 4.2 (15 bar). The soil texture was measured from samples collected at different depths using hydrometer method. The textural class of the soil profile was determined using USDA textural triangle.

The core soil samples were dried in oven dry apparatus at 105°C for 24 hours and the bulk density was calculated using equation:

$$Pb = \frac{Ms}{Vc} \tag{6}$$

Where, ρb = soil bulk density (g/cm^3), Ms = weight of dried soil (g), and Vc = volume of core sampler (cm^3)

2.5. Data management and analysis

All relevant data were recorded periodically and stored and managed in Microsoft excel .The collected data were arranged and organized for the suitability of statistical analysis and finally analysis of variance (ANOVA) was performed using statistix 8 statistical software. Lest significant difference (LSD) at 5% level of significance was used for mean separation among treatments.

3. Results and Discussion

3.1. Physico-chemical analysis result of soils at Ilu Gelan district

Soil pH is one of the most common and important measurements in standard soil analyses. Many soil chemical and biological reactions are controlled by the pH of the soil solution in equilibrium with the soil particle surfaces. In the present study, result of standard measurement of soil pH using H_2O was presented in (Table 1). The pH in H_2O under this study area is ranged in optimum value as suggested by Jones (2003). An electric conductivity of 0.035 ms/cm lies at lower limit of saline soils, hence the soil samples are non-saline soils. Plants growing in this area do not have the problem of absorbing water because of the lower osmotic effect of dissolved salt contents. The total nitrogen of study area as suggested by Tekalign (1991) rated as high percent which is suitable for plant growth. Since the plant obtains phosphorus (P) from the soil solution through its roots or root symbionts, available P is composed of solution P plus P that enters the solution during the period used to define availability. As per the rating suggested by Jones (2003), the available P of soil of experimental field of the studied area was qualified as low. As per the ratings recommended by Hazelton and Murphy (2007), the CEC value of the agricultural land of the present study area classified as high value range. The high CEC value recorded may be attributed to the fact that soils which recorded high CEC accumulate high percent OC and has greater capacity to hold cations thereby resulted in greater potential fertility in the soil. The value of available Ca and Mg were below the optimum range whereas that of K was within the recommended optimum range as suggested by Matsumoto et al. (2013). The organic matter was rated as medium which is suitable for crop growth.

Table 1.Chemical properties of soil at Ilu Gelan district

Chemical properties	Value
Organic carbon (%)	2.786
Available phosphorus (ppm)	6.546
pH in H2O	6.21
pH in 0.01 m CaCl2	5.11
pH in 1M KCL	4.65
Total nitrogen (%)	0.240
Electrical conductivity (ms/cm)	0.035
Organic matter (%)	4.803
Exchangeable cations (meq/100 g soil)	
Ca	2.553
Mg	1.200
K	0.656
Na	0.261
CEC	35.283

As laboratory analysis of particle size distribution indicated that the soil is clay in textural class throughout the soil depth with an average particle size distribution of 34% sand, 21% silt and 45% clay whereas the average gravimetric moisture content at field capacity and permanent wilting point were 33.02 and 24.8%, respectively. The value of bulk densities (1.303 gcm^{-3}) were obtained by considering the average of the 0-40cm depth. This value is in the recommended range for crop production. The average total available water was found to be 106.8mm/m.

Table 2.physical properties of soils at various depths at Ilu Gelan experimental field

Sample number	Depth of soil (cm)	Particle size proportion			Textural class	Bulk density (g/cm3)	FC (%Vol)	PWP (%Vol)	TAW (mm/m of soil depth)
		Clay (%)	Silt (%)	Sand (%)					
1	0-20	46	19	35	Clay	1.269	31.28	22.6275	109.8
2	20-40	44	23	33	Clay	1.337	34.7475	26.9825	103.8

Key: FC=Field capacity, PWP=Permanent wilting point, TAW=total available water

3.2. Irrigation efficiencies and water productivity

Analysis of variance revealed significant difference for some parameters among treatments. Significant variation in water application efficiency was observed between T2 and other treatments at 5% level of confidence. Its value ranged from 56.17% under T1 to 75.87% under T2. Similarly, significantly higher water distribution efficiency was found in T2 (90.5%) and lowest was recorded in T1 (81%). However, no significant variation was recorded between treatments T2 and T3. There was found significant differences in productivity among all treatment means. A water productivity of 5.20 kg/m3 was resulted from treatment T2 and 3.11 kg/m3 was obtained from treatment T1. Kang *et al*. (2000) also observed nearly the same result in water productivity of furrow irrigation system.

Table 3.Irrigation efficiencies and water productivity of onion

Treatments	**Application efficiency (%)**	**Water distribution efficiency (%)**	**Water productivity (kg/m^3)**
T1	56.17c	81.00b	3.11c
T2	75.87a	90.50a	5.20a
T3	69.48b	89.00a	4.36b
LSD0.05	5.6817	8.3	0.6126
CV%	12.89	10.31	8.38

Key: Means with the same letter in a column are not significantly different.

3.3. Yield and growth related parameters of onion

Analysis of variance showed that, there were significant differences among the means of plant height and grain yield. There were significant differences between treatments T2 and other two treatments in plant height. However no significant variation was recorded between treatments T1 and T3. Plant height ranged from 39.28cm to 41.53cm under T1 and T2 respectively. Significant difference was obtained among all means of treatments under grain yield. The highest grain yield (19520kg/ha) was gained from T2 when compared with the lowest (15088kg/ha) observed by T1. This was due to blockage of designed furrow at the end of its length and the required crop water requirement was satisfied. In the end blocked furrow, the water only infiltrates to the crop root zone and runoff is reduced. This increases appropriate utilization of delivered irrigation water such as irrigation efficiencies, water productivity and crop yield. About 13000kg/ha to 160kg/ha was found to be produced under local experience. Similarly, previous research findings reported by Guesh (2015), was found to be closer to this result for the same crop. There were no significant differences in percentage of stand count of onion among all treatments as shown in Table 4.

Table 4.Yield and growth related parameters of onion

Treatments	Stand count (%)	Plant height (cm)	Grain Yield (kg/ha)
T1	97.713a	39.275b	15088c
T2	97.278a	41.525a	19520a
T3	97.282a	39.800b	18009b
LSD 0.05	NS	1.4898	1224.6
CV%	1.35	7.14	14.04

Key: Means with the same letter in a column are not significantly different.

4. Conclusions and Recommendations

As the study showed, T2 revealed superiority in water application efficiency over other treatments. The highest Water distribution efficiencies also recorded in T2 as compared to the rest treatments. Moreover T2 indicated better advantage in water productivity over other treatments. Yield and growth related parameters of farmer practice were found to be the lowest as compared to T2 and T3. Generally T2 indicated better performance in both efficiencies and water productivity as well as yield and growth related parameters. Hence T2 is recommended for better irrigation efficiencies, water productivity and crop yields.

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Abdulahi Umar was "a Friend" to many of us!

Messages of Condolence from Colleagues

It was with deep sadness and profound regret that members of the AERD - IQQO learned the recent Car Accident that inflicted illness and untimely death of our beloved staff and colleague, Abdulahi Umar at the age of 45 years.

It is indeed a great loss for all of us, a loss of senior staff, a researcher, personally known to many of us in IQQO over many years. Many of us have also lost a beloved brother, a dear colleague, a personal friend.

'Qurxe', as he was fondly called, had the rare ability to communicate, articulate and inspiring. Those of us who knew Abdulahi found him to be one of life's positive individuals; bright, cheerful and a wonderfully optimistic and encouraging presence.

Abdulahi was one of the few senior researchers, a dedicated researcher, a long-standing and leading figure in the Agricultural Engineering Research Directorate (AERD) as well as in his center, the Fadis Agricultural Research Center, where he was served as the researcher, team leader and process owner, from September 1988 to November 2018.

In these journeys of life, many of us have all went together through a pile of research and training workshops, seminars, countless reviews and in other multiple responsibilities; such as training of farmers and agricultural experts, being a member of strategy planning team, BPR designing team and BPR recalibration team, to name a few. Thus, we can be a witness as he was a frontier without border determined to improve agricultural engineering research and making benefit of the farmers out of the utilization of the technologies in improving their living standard.

While he was focused on getting things done and worked hard, he was also great fun to be with, in which, we have got so many nice memories from his knowledgeable approach, wisdom, his kindness and heartbreaking smile that made him an adorable person. Indeed he had all of those qualities of profession and friendship in abundance - but above all, he was a really nice guy!

Remembering his nice beauty of friendly and many unforgettable events in our journeys, we promise, we will never forget him, and on behalf of the entire IQQO staff, we extend our deepest sympathies to his wife, his daughters, to his extended family and to all who knew, worked with and loved Abdulahi.

May the Almighty, grant him the highest Janna (heaven)!