The Productivity of Shallow Wells Groundwater in Agriculture and Interacting Systems: A Case Study at Debre Kidane Watershed, Eastern Tigray, Northern Ethiopia

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ABSTRACT

Productivity of Water in Agriculture (PWA) is a means of saving water by which farmers can produce more crops per drop of water. This paper assesses current levels of PWA in rain fed and irrigated agriculture, the different water users and their corresponding demands and constraints in the irrigation schemes related to PWA in Debre Kidane watershed, which is located in northern Ethiopia. Data for the study were obtained from a formal household questionnaire survey, focus group discussion and direct observations on farmer's field. Field experiment was also carried out to know the productivity of water in tomato irrigation. SPSS version 10 was used to analyze the socio economic data. In the watershed rainfall water productivity was highest for mixed crops (0.37 kg/m^3) followed by wheat (0.30 kg/m^3) and barley (0.25 kg/m^3). Under existing irrigation practices, the highest diverted water productivity was for maize (0.24 kg/m^3) and the lowest was for green pepper (0.07 kg/m^3). On the controlled plots high water productivity was obtained for tomato in sandy soil (0.1.34 kg/m^3) followed by clay loam soil (0.39 kg/m^3) and silty loam soil (0.28 kg/m^3) whereas on the farmers plot diverted water productivity was highest for tomato in silty loam soil (0.08 kg/m^3) followed by sandy and clay loam soils equally (0.06 kg/m^3). The diverted water productivity of tomato in sandy soil was 4.474% of the diverted water productivity in controlled plots, 28.95% in silty loam soil and 15..23% in clay loam soil, respectively. Though the productivity of water in the controlled plot was higher than the farmer's plot it is by far less than the potential water productivity of tomato in the area. The highest economic water productivity under rain fed condition was obtained for teff (0.229 Euro/m^3) and the minimum was for maize (0.041 Euro/m^3). On the other hand, the economic water productivity of tomato was 0.011 Euro/m^3 (silty loam soil), 0.009 Euro/m^3 (sandy soil), and 0.008 Euro/m^3 (clay loam) in farmers' plot and 0.186 Euro/m^3 (sandy soil), 0.038 Euro/m^3 (silty loam soil) and 0.055 Euro/m^3 (clay loam soil) in controlled plots. However, the potential economic water productivity of tomato in the area was about 0.724 Euro/m^3 of water. In addition to irrigation activities, the farmers used their shallow wells water for domestic and livestock purposes that highly affect the amount of water that must be added to their farmland. Besides, the farmers face problems related to market, storage facilities, absence of transportation, shortage of water and poor water management that highly discourages them not to produce more crops than the present.

Keywords: Groundwater, interacting systems, shallow wells, water productivity, Ethiopia.

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1. INTRODUCTION

1.1. General

Meeting the needs of people and reducing extreme poverty and hunger in the world is the main target of the Millennium Development Goals (MDGs) of the world by ensuring peoples` access to water for growing food and ensuring income. To meet the MDGS in relation to the reduction of hunger and poverty of the world in general and the rural areas in particular, potential shift from non-productive to productive water use is very essential.

Productivity of Water in Agriculture (PWA) has been defined differently by different authors. But can simply be described as the amount of crop harvested per unit volume of water used that is quantitatively or qualitatively depleted during the process (Kijne et al., 2003). PWA is also a measure of the economic, livelihood or biophysical outputs derived from the use of unit water. Such outputs are brick making, crop production, fishing, livestock watering, etc. per unit area, job/m^3, total biomass (Kg/m^3), and families per command area (International Rice Research Institute (IRRI), 2001). Water productivity is therefore a wider consideration of the products that comes from the diverted water for the irrigation as well as rain fed system (Cai et al., 2003). PWA is also a means of saving of water. According to IRRI **(**2001), means of saving water and increasing the productivity of water in agriculture can be through:

i. Changing crop varieties: improved verities that can provide increased yields for each unit of water consumed, or the same yields with fewer units of water consumed.
ii. Crop substitution: by switching from high to less water consuming crops, or switching to crops with higher economic or physical productivity per unit of water consumed.
iii. Deficit, supplemental or precision irrigation: with sufficient water control; higher productivity can be achieved using irrigation strategies that increase the returns per unit of water consumed.
iv. Improved water management: to provide better timing of supplies to reduce stress at critical crop growth stages leading to increased yields or by increasing water supply reliability so farmers invest more in other agricultural inputs leading to higher output per unit of water.
v. Optimizing non-water inputs: in association with irrigation strategies that increase the yield per unit of water consumed, agronomic practices such as land preparation and fertilization can increase the return per unit of water.
vi. Lessening of non-beneficial evaporation- by reducing: -evaporation from water applied to irrigated fields through specific irrigation technologies such as drip irrigation, or agronomic practices such as mulching, or changing crop planting dates to match periods of less evaporative demand.

Different people have different views on the aspect of increasing agricultural production by increasing physical output per unit of water, but the challenge is to grow more food with less water and improving livelihoods of the poor. According to IRRI (2001), a useful way to be termed when we think of productivity of water is in terms of welfare per drop. The International Rice Research Institute (IRRI) argues that ways of increasing productivity of water for a farmer can be having more yields using the same amount of water through the use of improved seed varieties, improved soil and fertility management practices that save the water that can be transferred to additional uses. For example in China, by only increasing the productivity of water through water management they improved the productivity of rice from half a kilogram that is normally produced from 1000 litters of water to more than 2 kilograms of rice per 1000 litters used. This experience indicates that much improved management of water will be necessary to reduce poverty and hunger and sustain the water resource of the world.

In addition to improving the PWA, knowing the economic productivity of water in agriculture in order to answer the question how to maximize the profitability of the water by optimizing the use of irrigation water properly is very essential (Raine, 1999). Economic productivity of water in agriculture is the economic return obtained in the season over the total water applied in the system.

1.2. Statement of the Problem

In Tigray, a Regional State in the northern Ethiopia, there are 35 Woredas, which are administrative units, with a total population of four million. Out of which, 75% of the populations are food insecure and seriously threatened by drought, which hit the region every 3 to 4 years (Hugo**,** 2003). A major climatic limitation for agricultural production in the region is erratic rainfall, often combined with intermittent dry spells that regularly intimidate the survival of crops. The study area is one of the food insecure and drought affected areas of the region. In the area, on average households harvest enough food for about 4.79 months of the year. The remaining food gap is supplemented by a combination of activities including: food purchased from the market, food for work and food relief. This is mainly due to erratic and unreliable nature of rainfall. The watershed has also significant problem in distribution of rainfall through out the rainy season. According to the rainfall data record only 5 % of the mean annual rainfall takes place in September; however, this month is the ripening period for most of the dominant crops. This is considered to be the main cause for the recurrent crop failure facing the area. Besides, the rain distribution throughout the month is not even, there is on average 5 -10 days difference has been observed between each rainstorm in some critical time. This uneven distribution of rain also has a negative impact on the normal growth of crops.

Currently in the study area, the farmers are practicing irrigation to cope up this problem. The source of water for the irrigation is groundwater tapped from shallow wells. In Debre Kidane watershed, within the year 2003 to 2005 around 360 shallow wells, which have water, were constructed by the households' for irrigation, domestic and livestock purpose. The households are nowadays benefited from the intervention by producing different high value crops twice to three times per year. Almost all the farmers measured the crop harvested but not the volume of water used to produce it. Besides almost all of the irrigators dose not knows when their crop needs water and when to stop irrigating their crop. They usually wait until the crop starts to wilt or the soil dried and irrigating their crop either until the furrow holds up water or the water in the shallow wells ended. This exposed the groundwater of the area to high risk and mismanagement. Consequently, the farmers becomes unable to utilize the groundwater efficiently and then increased production during the period of relatively low rainfall and dryer years. To avoid this unwise use of water and then to properly utilize the groundwater to increase agricultural production, improving the productivity of water in agriculture in the area is very crucial.

1.3. Objective

The main objective of this research work was to assess the current levels of productivity of shallow wells groundwater in agriculture, to identify the different water users and their corresponding demands, and identify the constraints related to PWA. Specifically the objectives of the research were the following.

- To assess the current levels of productivity of shallow wells groundwater in agriculture:
- To identify the different water users and their corresponding demands: and,
- To identify constraints in the irrigation schemes related to PWA.

2. METHODS AND MATERIALS

2.1. Description of the Study Area

The study area, Debrekidan watershed, is located in Tigray region, which is the northern regional state of Ethiopia, at a distance of about 120 km northeast of Mekelle town, which is the capital of the Regional State. Geographically, it is positioned between 39º 25’ to 39º 30' E and 13º 52’ to 13º 57' N, having an aerial coverage of about 45.09 square kilometers with the mean altitude of 2200 meters above sea level.

The mean annual rainfall of the area is 524.08 mm. Monthly rainfall distribution of the area is concentrated mostly in the mid of June to the mid of September. The mean annual temperature is 18.1 ºC, and the yearly average maximum and minimum temperature is 25.1ºC and 10.8ºC, respectively. The annual range of temperature is 3.7ºC.

The watershed comprises two Tabias, which are the smallest administrative units. These are Debre Birhan and Selam. The total number of population is 13, 279. Out of this, 50.3% are female and 49.7% males. The number of households is 3761 from which about 35% is female headed and 65% male headed.

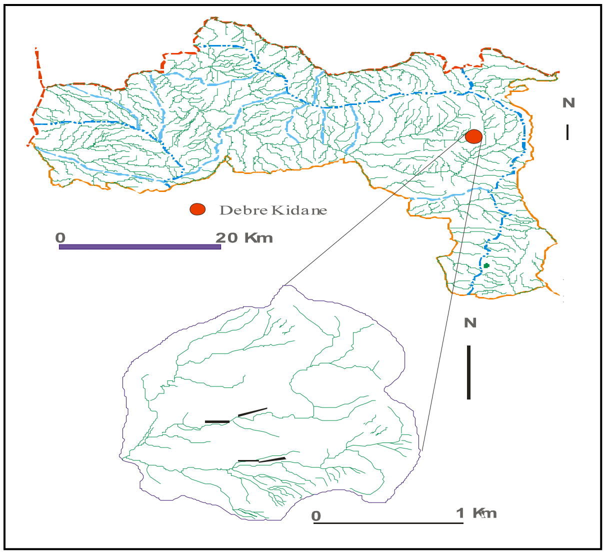

Figure 1. Location map of the watershed.

2.2. Methods

The data for the study was collected from both primary and secondary sources. Primary data were obtained from a formal household questionnaire survey, key informant discussion and direct observations on farmers' fields. The questionnaires generally included current levels of productivity of water in agriculture in rain fed and irrigated agriculture, different water users and their corresponding demands and constraints in the irrigation schemes related to PWA. Moreover, some general information about major problems of the farmers on the efficient utilization of groundwater for irrigation and socio-economic condition of the community were also included in the questionnaires. The sample population for the study was drawn from the two Tabias of the study area. By using stratified sampling the sample populations were drawn both from farmers who practiced irrigation and farmers who practiced only rain fed agriculture. The total number of households was obtained from Woreda Bureau of Agriculture (WBoA) (Table 1). Having this number, systematic random sampling was used to select total sample populations from each stratum. Accordingly, samples were taken from each respective groups based on a sample of 10% of household from farmers who have shallow wells and 2% from farmers who practice only rain fed agriculture. A total number of 36 households who have shallow wells and 72 households who don't have shallow wells were selected for this study. Data analysis was done using SPSS version 10.

Table 1. Total number of household and samples size selected from each Tabia

Tabias	TT HHS SW	Sample Size	TT HHS	Sample Size
Debre Birhan	226	23	2200	44
Selam	134	13	1400	28
Total	360	36	3600	72

Source: Woreda's Bureau of Agriculture (WBoA).
TT HHS SW: Total household that have shallow wells.
TT HHS: Total household that don't have shallow wells.

2.3. Fieldwork

To examine the productivity of shallow wells groundwater in agriculture in the study area tomato, which is a common irrigated vegetable crop of the area, was planted on the field. To conduct the field experiment, tensiometer was used for scheduling purpose. After the installation of the tensiometer, the tomato seedlings were transplanted in three different soil types (clay loam, silt loam and sand soils) with three replicas. On both cases the variety of tomato was the same which is 'Roma VF' (*lycopersicum*). From the transplanting date onwards the amount of water that was added in each irrigation time was measured (Table 2). For comparison purpose the amount of water that was added in each irrigation time on three farmers` filed plant (tomato) in different soil type was measured. The soil types on the three farmers' farm plots are the same to that of the controlled plots. Prior to conducting this experiment on the field, different field works as well as laboratory analysis which are related to the study, like maximum infiltration rate, soil particle size, maximum rooting depth, and available water in the soil were carried out.

Table 2. Irrigation scheduling date and amount of water in application time
Area planted: 0.062 m^2
Transplanting date: December 8/2005

Date of irrigation			Amount of water Added (mm)		
Sand	Silt loam	Clay loam	Sand	Silt loam	Clay loam
Dec.15	Dec.18	Dec.21	161.29	806.45	967.74
Dec.24	Dec.31	Jan.6	161.29	806.45	967.74
Jan.2	Jan.13	Jan.22	161.29	806.45	967.74
Jan.11	Jan.26	Feb.7	161.29	806.45	967.74
Jan.20	Feb.8	Feb.23	161.29	806.45	967.74
Jan.29	Feb.21	Mar.5	161.29	806.45	1774.19
Feb.8	Feb.28	Mar.15	161.29	1612.90	1774.19
Feb.17	Mar.7	Mar.25	161.29	1612.90	1774.19
Feb.21	Mar.14		161.29	1612.90	

Feb.25	Mar.21		161.29	1612.90	
Mar.5			322.58	1612.90	
Mar.9			322.58		
Mar.13			322.58		
Mar.17			322.58		
Total amount of water			2903.23	12903.23	10161.29

2.3.1. Determination of Soil Particle Size

To determine the particle size distribution of the soil, Pipette method was used.

Table 3. Laboratory soil texture analysis result (by Pipette method)

Sample code	**Depth**	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Texture class**
S1	0-30	93.2	4.3	2.5	Sand
S2	31-60	89.7	6.7	3.6	Sand
S3	61-100	87	9.23	3.77	Sand
LC1	0-30	31.8	33.1	35.1	Clay Loam
LC2	31-60	9.1	16.9	74	Clay
LC3	61-100	6	13	81	Clay
SL1	0-30	18.4	68.6	13	Silt Loam
SL2	31-60	28.3	35.1	36.6	Clay loam
SL3	61-100	7.8	4.6	87.6	Clay
SI1	0-30	9	87	4	Silt
SI2	31-60	28.2	37.6	34.2	Clay loam
SI3	61-100	7.8	4.6	87.6	Clay
SA1	0-30	61.5	23	15.5	Sandy Loam
SA2	31-60	94	3.2	2.8	Sand
SA3	61-100	90.1	5.8	4.1	Sand

2.3.2. Maximum Infiltration Rate

The infiltration rate of the soil was measured using double ring infiltrometer. The two rings were driven into the soil and filled with water (both equal) and the amount of water needed to maintain the constant level to estimate vertical infiltration was measured. Measurements were taken on each slope variation, in consideration of soil class (texture), and different land uses

2.3.3. Determination of Total Available Water (TAW) in the Soil

To determine TAW in the soil, both disturbed and undisturbed soil samples were taken from three profile pits which were excavated in the targeted soil types. From the pits 36 undisturbed and 9 disturbed samples were taken.

Table 4. Estimated WP, FC and TAW of the three soil types

Soil Types	FC (m^3m^{-3})	WP (m^3m^{-3})	Maximum Ze (m)	TAW	RAW
Sand	0.07	0.02	0.5	25	11.7
Silt loam	0.35	0.07	0.5	140	70.8
Clay loam	0.37	0.10	0.5	135	67.5

Where FC is field capacity; WP is permanent wilting point; Ze is maximum rooting depth; TAW is total available soil water in the root zone; and, RAW is initial soil moisture depletion or readily available water (RAW).

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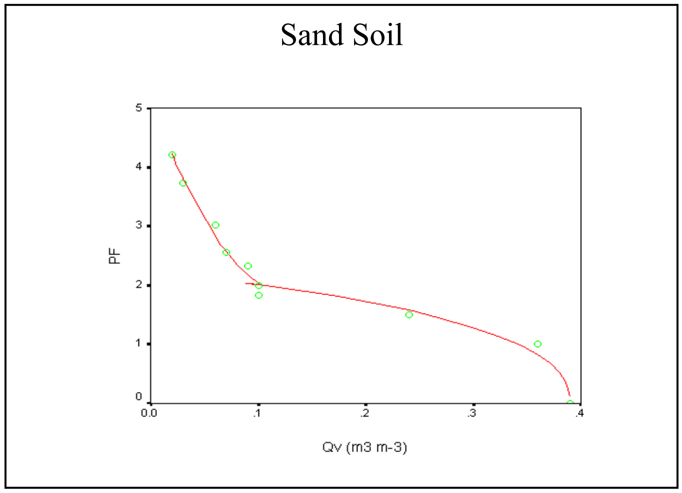

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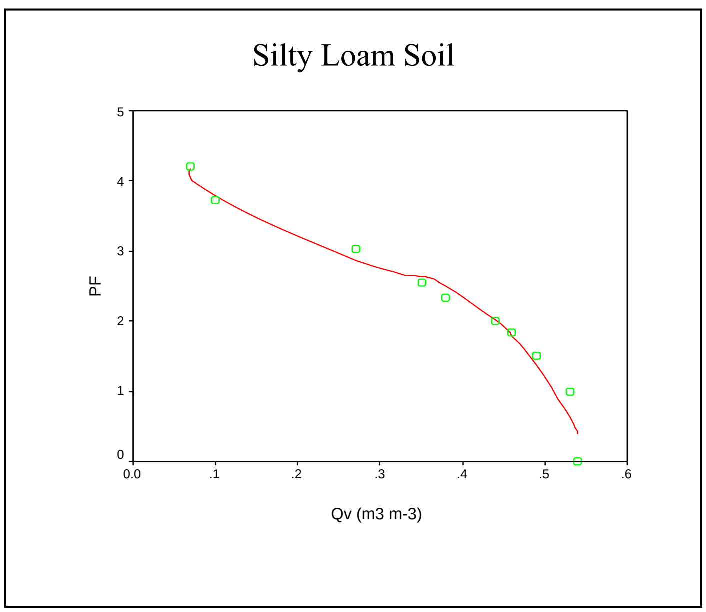

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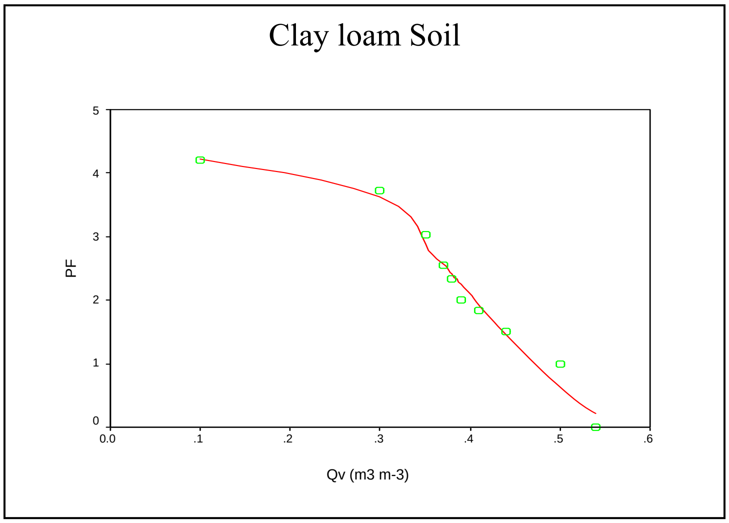

Figure 2 (A, B, C). Water retention curve of the three soil types.

2.3.5. Determining when to Irrigate and How Much to Irrigate

Appropriate water application depths in combination with a variable irrigation interval, result in an efficient use of irrigation water. The selected value for the net water application depth depends on the soil type, crop type, and irrigation method practiced on the irrigation fields (Campos et. al., 2003; Fabião et. al., 2003: Ortega et. al., 2002; Pacucci et. al., 2006; Rijo and Arranja, 2005).

2.3.5.1. Determining When to Irrigate

In this study, irrigation schedules were developed by the help of tensiometer. Irrigation water application started when tensiometer reading at 50% soil water depletion.

To determine at what tensiometer reading that irrigation should start, formula was generated using the pF and volumetric moisture content.

2.3.5.2. Determining How Much to Irrigate

Enough irrigation water should be applied to replace the depleted plant-available water within the root zone. Root depth and root distribution are important because they determine the depth of the soil reservoir from which the plant can extract available water (Evans et al., 1996). Irrigation amounts should be computed to replace only the depleted plant-available water within the effective root zone. The depleted volume is referred to as the net amount of water to be replaced. Additional water must be applied to account for irrigation inefficiencies so that the desired (net) amount reaches the root zone. Inefficiencies might include leakage at couplings, surface runoff, or percolation below the effective root depth (Cassel et al., 2002). Irrigation efficiency is the

water used by the crop effectively. To determine the amount of water that is applied on the pot, the following formula was used (Evans et al., 1996).

Net irrigation amount at a specific effective root depth = 50 Percent depletion of RAW *effective root depth (1)

Gross water application at a specific effective root depth= Net irrigation amount / irrigation efficiency (2)

2.3.6 Method of Computing Crop Water Requirement (CWR)

The amount of water that is needed by a particular crop within the full plant growth was calculated by using Cropwat 4 windows (FAO, 1998). The required input data that is needed to use the program are monthly precipitation, minimum and maximum temperature, planting date, crop type, percentage of plot size (i.e. plots covered by a particular crop), soil texture class, total available water content, maximum infiltration rate, maximum rooting depth in mm (Z_e), and initial soil moisture depletion (RAW).

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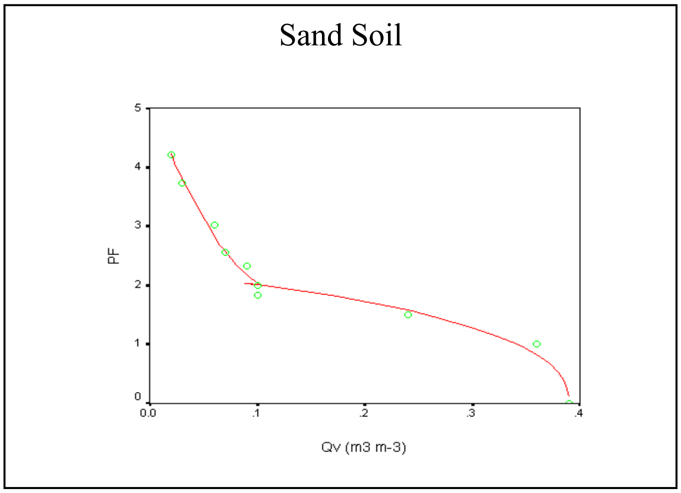

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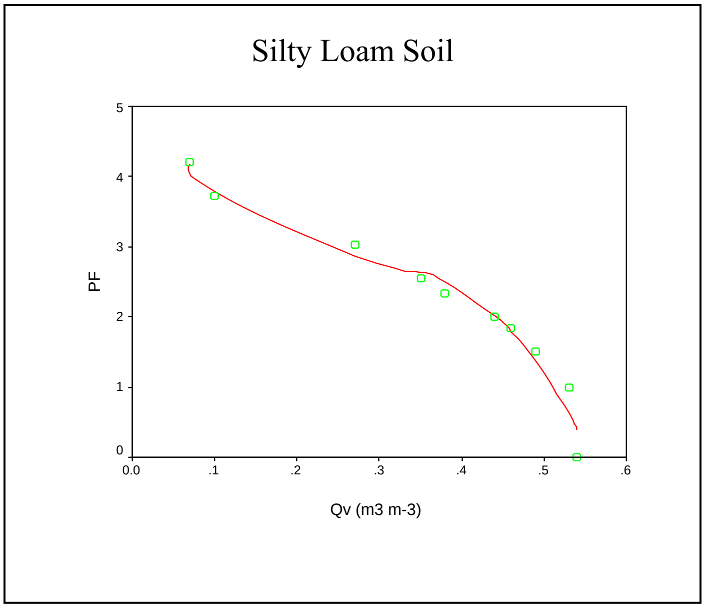

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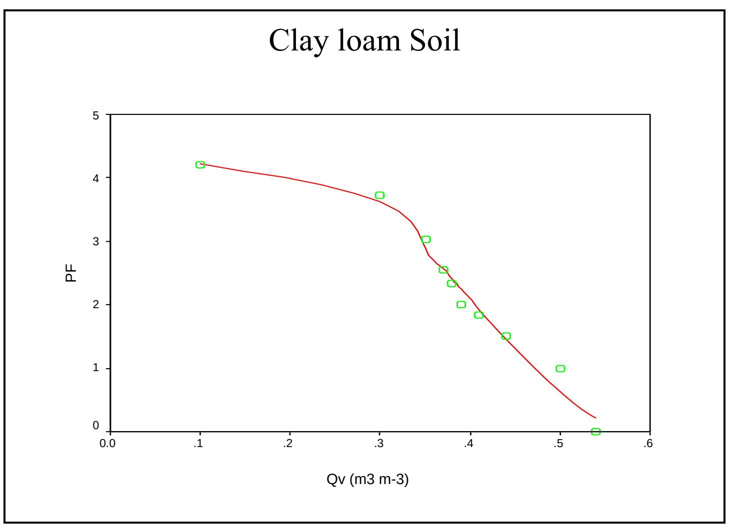

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3. RESULTS AND DISCUSSION

3.1. Productivity of Water

3.1.1. Productivity of Water under Rain fed Agriculture

The rainfall water productivity in agriculture is different in different crops and also its productivity is not always constant rather it is highly dependent on the amount of rainfall that the area received. As shown in the Table 5 below, rainfall water productivity was highest for mixed crops (0.37 kg/m^3) followed by wheat (0.30 kg/m^3) and barley (0.25 kg/m^3). In effective rain fall water productivity, the highest water productivity was obtained for teff (0.92 kg/m^3) and the lowest was for sorghum (0.31 kg/m^3). The effective rainfall water productivity of teff is 112.2 % of the potential water productivity of the area, which is an indication of better productivity performance as compared to the other crops in the year 2005/06 rain fall season. Although maize has less effective water productivity next to sorghum (0.31 kg/m^3), its water productivity is 45.33 % of the potential water productivity of the area, which is also an indication of better productivity performance next to teff. The effective rainfall water productivity for wheat, millet and mixed crops was 30.46%, 28.93% and 26.87% of the potential water productivity of the area, respectively.

In the study area, with the exception of teff, the potential water productivity that was supposed to be gained in the area is 50% greater than the current rainfall water productivity for all the crop types. This implies that irrigation activities are very crucial in the area to fill the productivity gap of the rain fed agriculture.

Table 5. Productivity of Water under Rain fed Agriculture

Crop Types	P (ML/ha)	Pe (ML/ha)	CWR (ML/ha)	Yield (kg/ha)	MPY (kg/ha)	Productivity of water (kg/m^3)		
						PWP	PePW	PoWP
Wheat	4.02	2.60	2.99	1200	4500	0.30	0.46	1.51
Teff	4.02	0.77	2.19	700	1800	0.17	0.92	0.82
Maize	4.02	2.38	3.33	800	2500	0.20	0.34	0.75
Mixed crops	4.02	2.78	2.83	1500	5700	0.37	0.54	2.01
Millet	4.02	2.55	2.89	900	3500	0.22	0.35	1.21
Barley	4.02	2.77	2.93	1000	5200	0.25	0.36	1.77
Sorghum	4.02	2.78	2.84	850	4600	0.22	0.31	1.62

Where P is Total Rainfall; Pe is Effective Rainfall; CWR is Crop Water Requirement; MPY is Maximum Potential Yield of the area; PWP is Total Rainfall Water Productivity; PePW is Effective Rainfall Water Productivity; and, PoWP is Potential Water Productivity. The yield and maximum potential yield data of the area was obtained from the area's Woreda's Bureau of Agriculture (WBoA) and the yield data was for 2005/06 rain fall season.

3.1.2. Productivity of Water under Irrigated Agriculture

3.1.2.1 Productivity of Water under Existing Irrigation Practices

In the study area farmers irrigate both vegetables and cereal crops. The common vegetable crops that are produced are tomato, potato, green pepper, onion and cabbage, and that of cereal crop is maize. As shown in the Table 6 below, the highest diverted water productivity was obtained for maize (0.24 kg/m^3) and the lowest water productivity was for green pepper (0.07 kg/m^3). The table also shows that the actual diverted and applied water was higher than the crop water requirements for all the crops. This implies that large amount of water is discharging from the shallow wells which might affect the sustainability of the wells for future use.

Table 6. Productivity of water under irrigated agriculture

Crop Types	Total amount of water diverted (ML/ha)	CWR (ML/ha)	Yield (kg/ha)	MPY (kg/ha)	Productivity of water (kg/m^3)	
					DWP	PWP
Tomato	12.89	2.87	1870	15000	0.15	5.22
Onion	17.09	2.14	1315	10000	0.08	4.67
Pepper	11.29	2.79	800	15000	0.07	5.38
Potato	18.65	2.94	1600	40000	0.09	13.59
Cabbage.	16.32	2.21	3600	35000	0.22	15.85
Maize	9.98	3.27	2400	2500	0.24	0.77

Where DWP is Diverted Water Productivity (Yield/total water diverted). The yield and maximum potential yield data of the area was obtained from the area's Woreda's Bureau of Agriculture (WBoA) and the yield data was for 2005/06 irrigation seasons.

3.1.2.2 Productivity of Water on Tomato Irrigation in Controlled and Farmers Plot

According to Table 8, tomato plant used much water in its growing time where it planted in silty loam soil (8.06 ML/ha followed by clay loam soil (6.13 ML/ha) and sandy soil (1.94 ML/ha).

Regarding irrigation interval, sandy soil needs more frequent irrigation than silty loam and clay loam soils. From the result, sandy soil needs irrigation within five days from transplanting date, nine days interval until flowering stage and four days interval until harvesting. In silty loam soil, the irrigation interval is also depends on its stage of growth, which means within eight days from transplanting date, thirteen days interval until flowering stage and seven days interval until harvesting. In the clay loam soil, it needs irrigation within eleven days from transplanting date, sixteen days interval until flowering stage and ten days interval until harvesting.

Soil type	Irrigation intervals													
Sand soil	Dec.15	Dec.24	Jan.2	Jan.11	Jan.20	Jan.29	Feb.8	Feb.17	Feb.21	Feb.25	Mar.5	Mar.9	Mar.13	Mar.17
Silt loam soil	Dec.18	Dec.31	Jan.13	Jan.26	Feb.8	Feb.21	Feb.28	Mar.7	Mar.14	Mar.21				
Clay loam soil	Dec.21	Jan.6	Jan.22	Feb.7	Feb.23	Mar.5	Mar.15	Mar.25						

Figure 3. Irrigation scheduling for tomato on the three soil types.

Table 7. Amount of water applied on the field

Reading taken from pF curve	Irrigation efficiency	IWA (m^3)			IWA (m^3)		
		Ze	NIA	GIA	Ze	NIA	GIA
0.045	0.95	0.25	0.01	0.01	0.50	0.02	0.02
0.21	0.95	0.25	0.05	0.05	0.50	0.11	0.10
0.235	0.95	0.25	0.06	0.06	0.50	0.12	0.11

Where IWA is Irrigation Water Application; Ze is Maximum root depth; NIA is Net Irrigation Amount; and, GIA is Gross irrigation Amount.

The overall result (Table 8) shows that high water productivity was obtained from sandy soil (1.34 kg/m^3) followed by clay loam soil (0.39 kg/m^3) and silty loam soil (0.28 kg/m^3).

Table 8. Productivity of water in tomato plantation in experimental plot

Soil Types	Total amount of water used by the plant (ML/ha)	Yield (kg/ single tomato)	Yield (kg/ha)	Tomato water Productivity (Yield/total Water diverted) (kg/m^3)
Sandy soil	1.94	3.5	2600	1.34
Silty loam	8.07	3.0	2228.57	0.28
Clay loam	6.13	3.25	2414.29	0.39

In the farmers plot, a farmland that are found in sandy soil irrigated within seven days interval from transplanting to flowering stage and four days interval until harvesting. On the other hand a farmland, which is a silty loam soil, irrigated within ten days interval from transplanting to flowering stage and five days interval until harvesting. In clay loam soil, the irrigation took place within ten days interval from transplanting to flowering stage and seven days interval until harvesting. On both plots the farmers irrigated their land using motor pump and the irrigation lasts for half an hour for half hectares of land.

Table 9. Productivity of water in tomato plantation on farmers plot

Soil Types	Total amount of water used by the plant (ML/ha)	Yield (kg/ha)	Tomato water Productivity (Yield/total water diverted) (kg/m^3)
Sand	3.07	1886	0.06
Silt loam	21.12	1722	0.08
Clay loam	24.96	1476	0.06

The diverted water productivity was highest in silty loam soil (0.08 kg/m^3) followed by sandy and clay loam soils equally (0.06 kg/m^3). As shown in Table 9, the actual water diverted to produce 1886 kg/ha in sandy soil, 1722 kg/ha in silty loam soil and 1476 kg/ha in clay loam soil was 3.07 ML/ha, 2.11 ML/ha, and 24.96 ML/ha, respectively. The computed water requirement of the crop was 2.87 ML/ha (Table 6), which is much lower than the applied water in each soil types. Moreover, the diverted water productivity for each soil types on farmers plot was far less than the experimental plot. The diverted water productivity in sandy soil was 4.47% of the diverted water productivity in controlled plots, 28.95% in silty loam soil and 15.23% in clay loam soil, respectively. However, the amount of diverted and applied water on farmers plot to each soil types was by far greater than that of the amount of diverted and applied water on the controlled plot for each corresponding soil types. The amount of applied water in the sandy, silty loam and clay loam soil in the controlled plot is 6.3%, 38.189%, and 24.56% of the applied water in farmers plot. This indicated that the low productivity of water in the farmers plot might be due to the excess utilization of water. Nevertheless, the diverted and applied water productivity in the controlled plots is lower than the potential water productivity in the area. The diverted water productivity for tomato in the sandy, silty loam and clay loam soils is 25.73%, 5.29%, and 7.55% of the potential water productivity, respectively. The same result was obtained from the study that was conducted in the nearby area by Gebreegziabher (2005). According to him the water productivity result indicated that the unit crop production per unit supplementary irrigation applied was 75% lower than the maximum potential water productivity in the area.

3.2. Economic Water Productivity

3.2.1. Economic Water Productivity under Rain fed Agriculture

Table 10 below shows the economic water productivity of rain fed agriculture. In order to calculate the economic water productivity average price of the common crops in the region for the rain fed market season (December- January) was taken. The result in the table indicates that the highest economic water productivity under rain fed condition was obtained for teff (0.229 Euro/m^3) and the minimum productivity was for maize (0.041 Euro/m^3).

Table 10. Economic Water Productivity under Rain fed Agriculture

Crop Types	Yield kg/ha	Price of Crop (Euro/kg)	Price of Crop (Euro/ha)	P (m^3/ha)	Pe (m^3/ha)	EWP in Euro/ m^3	
						EPP	EPeWP
Wheat	1200	0.22	266.42	4016	2604.1	0.066	0.102
Teff	700	0.25	174.84	401.6	765	0.435	0.229
Maize	800	0.12	96.21	401.6	2374.9	0.240	0.041
Mixed crops	1500	0.23	346.90	401.6	2775.9	0.864	0.125
Millet	900	0.18	158.19	401.6	2550.3	0.394	0.062
Barley	1000	0.21	212.77	401.6	2767.4	0.530	0.077
Sorghum	900	0.22	199.81	401.6	2775.9	0.498	0.072

Where EWP is Economic Water Productivity (Economic return of crop /Total P (Pe); EPP is Economic Rainfall Water Productivity; and, EPeP is Economic Effective Rainfall Water Productivity.

3.2.2 Economic Water Productivity under Irrigated Agriculture

The economic productivity of the diverted water for each crop is different according to the price of the vegetables on the market as well as the amount of yield that gained. Table 11, 12 and 13 show the diverted economic water productivity of the existing irrigation practice, farmers' plot and experimental plots, respectively. In order to calculate the economic water productivity average price of the common crops in the region for the irrigation market season (May – June) was taken. The water used for calculation includes both the actual diverted/supplied water and the actual water consumed by the crop.

Table 11. Economic water productivity under existing Irrigation practices

Crop Types	Yield kg/ha	Price of Crop (Euro/kg)	Price of Crop (Euro/ha)	Total amount of water diverted (m^3/ha)	EDWP (Euro/m^3)
Tomato	1870	0.14	259.48	12891.4	0.020
Potato	1315	0.42	547.41	17088	0.032
Onion	800	0.46	370.03	11294.1	0.033
Pepper	1600	0.37	592.04	18651.4	0.032
Cabbage	3600	0.06	199.81	16320	0.012
Maize	2400	0.12	288.62	9984	0.029

Where EDWP is Economic Diverted Water Productivity. The yield data of the area was obtained from the Woreda's Bureau of Agriculture (WBoA) and the yield data was for 2005/06 irrigation seasons.

Table 12. Economic productivity of water in tomato plantation in farmers plot

Soil types	Total amount of water used by the plant (ML/ha)	Yield (kg/ ha)	Price (Euro/kg)	Price (Euro/ha)	EWP (Euro/m^3)
Sand	30.72	1886	0.14	261.70	0.009
Silt loam	21.12	1722	0.14	238.95	0.011
Clay loam	24.96	1476	0.14	204.81	0.008

Table 13. Economic productivity of water in tomato plantation in experimental plots

Soil Types	Total amount of water used by the plant (ML/ha)	Yield (kg/ ha)	Price (Euro/kg)	Price (Euro/ha)	EWP (Euro/m^3)
Sand	1.94	2600	0.14	360.78	0.186
Silt loam	8.07	2228.57	0.14	309.24	0.038
Clay loam	6.13	2414.29	0.14	335.01	0.055

Table 14. Potential economic productivity of water in tomato plantation

Plant Type	CWR (ML/ha)	MPY (kg/ha)	Price (Euro/kg)	Price (Euro/ha)	PEWP (Euro/m^3)
Tomato	2.87	15000	0.14	2081.41	0.724

Where PEWP is Potential Economic Water Productivity. The maximum potential yield of the area was obtained from the Woreda's Bureau of Agriculture (WBoA) and the yield data was for 2005/06 irrigation seasons.

As shown in the Table 11, the average diverted and applied economic water productivity of the existing irrigation practice was around 0.026 Euro/m^3. Of all the crops, onion had the highest economic water productivity per (0.033 Euro/m^3) and cabbage had the lowest (0.012 Euro/m^3). In the farmers plot, the highest economic water productivity was obtained from silty loam soil which was 0.011 Euro/m^3 whereas the lowest economic water productivity were obtained from sandy soil and clay loam soil, which was 0.009 Euro/m^3 and 0.008 Euro/m^3, respectively. On the controlled plots, the highest economic water productivity among the three soil types were achieved from sandy soil (0.186 Euro/m^3) and the lowest was from silty loam soil (0.038 Euro/m^3). On both conditions, the economic water productivity of the crops was less than that of the potential one. As shown in the Tables 11-13, the economic water productivity of tomato was 0.02 Euro/m^3 in existing irrigation activities, 0.009 Euro/m^3 (sandy soil), 0.008 Euro/m^3 (clay loam) and 0.011 Euro/m^3 (silty loam soil) in farmers plot and 0.186 Euro/m^3 (sandy soil), 0.038 Euro/m^3 (silty soil) and 0.055 Euro/m^3 (clay loam) in controlled plots. The reason for the highest economic water productivity in the control plot was due to the variation in yield and amount of water diverted. However, the potential economic water productivity of tomato in the area is about 0.724 Euro/m^3, which is far greater than the actual one. In general, the study investigated that the economic water productivity of each soil types is highly dependent on the amount of water that is used by the plant throughout the growing season as well as the price of crops on the market.

3.3. Interacting Systems

Worldwide, people require water for a wide range of activities essential to their livelihoods. These include domestic (drinking, washing, cooking and sanitation) and productive uses, such as small-scale irrigation, livestock watering, post-harvest processing or micro-enterprises. In most rural areas of the developing countries, people use the water for different purposes from a reservoir like shallow wells, ponds, springs, etc (Koppen, 2004). As Mentesnot et al., (2005) described, these kind of water uses are called interacting systems, which means using the water from one reservoir for different purposes. In the study area, in addition to the irrigation water use, the water from the shallow wells is used for domestic and livestock purposes. Totally, in the watershed, there are two hand dug wells, which are fitted with hand pump, and two springs which were constructed and developed for domestic and livestock purposes. However, the water procured from these sources do not satisfy the required need of the farmers. Therefore, farmers are forced to use their shallow well water for these purposes apart from using it for irrigation. As has been learnt from the interview, out of the total 36 households who have shallow wells, 31 (86.1%) use the water for domestic purposes as well as livestock. Of these, 23 (63.9%) of them use the water only to perform domestic tasks while 8 (22.2%) of them use the water for both domestic and livestock purposes.

3.3.1. Domestic Use

As it has been discussed earlier, one of the uses of shallow well water, according to the farmers interviewed, is helping them to carry out domestic tasks.
As shown in the Table 15 below, the water intake of the farmers from their shallow wells for domestic purpose ranges from 0.02 m^3 per day to more than 0.05 m^3 per day. The intake amount is highly dependent on the family size as well as the number of farmers' relatives who don't have shallow wells. Accordingly, 25% of the respondents said that they use 0.02-0.03 m^3 of the shallow wells water per day. Those who claimed to use 0.031-0.04 m^3 per day account for 27.8%. 5.6% said that they use 0.041-0.05 m^3 per day. 27.8% of the farmers replied that their consumption mounts over 0.051m^3 per day. Beside, the remaining sample farmers, 13.8%, said that they did not use their shallow well water for domestic purpose unless the water in the fitted hand pump wells are dried which is starting from March onwards until the rain begins. This means that almost all of the sample populations use their shallow well water for domestic purposes.

Table 15. Amount of water used for domestic purpose

Water need for domestic purpose (m^3 /day)	Frequency	Percent
0.02-0.03	9	25
0.031-0.04	10	27.8
0.041-0.05	2	5.6
$\geq$0.051	10	27.8
Total	31	86.2

An informal discussion was held on these subjects. According to them, the majority of the respondents who claimed to use more than 0.03 m^3 of water per day said that their intake could be high because their relatives use their shallow well water. As shown in the Table 16 below, a total of 2520 populations use the shallow wells water for domestic purpose that the consumption of the water reaches 50.4 m^3 per days.

Table 16. Total number of total households and their estimated total water demand

Tabias in the Watershed	Total no of population who use the shallow wells water for domestic purpose	Water Demand (m^3/head/day)	Total water demand (m^3/day)	Annual water Need (ML)
Debre Birhan Tabia	1582	0.02	31.64	11.55
Selam Tabia	938	0.02	18.76	6.85
Total	2520		50.4	18.40

To compute the total domestic water demand of the population, 0.02 m^3/head/day was used. The rate was used because it is taken as a standard for designing rural water schemes in the rural areas of Ethiopia (Mentesnot et al., 2005). As the above table indicated, the estimated water demands of the population who have shallow wells are 50.4 m^3 per day or 18.40 ML per annum. This implies that large amounts of water from the shallow wells are used for domestic purpose beside the irrigation activities.

3.3.2. Livestock Use

During the interview, the farmers explained that at the time of rainy season all the ponds are filled with water, so they use it for their livestock. However, after the rain stops and the ponds dried up they start using their shallow wells water for their livestock. They further stated that although the consumption of water from the shallow wells for their animals affect the availability of water for irrigation activity, the absence of alternative means forced them to use it for watering their animals. As shown in the Table 17 below, to fulfill all the water requirements of the livestock, a total of 5.39 m^3 of water per day are needed. This figure shows that large volume of water is withdrawn diurnally from the wells.

Table 17. Total livestock and total water consumption in litters per day during dry season

Type of livestock	Number of livestock	Water demand of livestock in m^3/head/ day during dry season	Water demand of livestock in m^3/ day during dry season
		Dry season	Dry season
Cow	312	0.005	1.56
Oxen	226	0.005	1.13
Sheep	547	0.003	1.37
Goat	96	0.002	0.19
Donkey	239	0.004	0.96
Camels	23	0.008	0.18
Total	1443		5.39

In general these high consumption of water for domestic and livestock purpose affects the amount of water that must be added to their farmland during irrigation time particularly when there is no rain in the area. If the present trend continues, there will be high demand for more water in the future by the increasing number of population and livestock in the study area.

3.4. Constraints in the Scheme

The farmers transport their product to the nearby market which is found in a small town called Hawzen. The watershed is connected to Hawzen by all weather ….road. However due to lack of means of transport, the farmers are forced to use animals as transportation means. From the total respondents 72.22% claimed that they use their animals to transport their products to the market place. According to them this way of transporting vegetables to the market place reduces the quality of the products and whenever there is price reduction the farmers prefer to sell their products in a very low price or dispose it in the market place than returned it home. In addition to absence of transport, price fluctuation caused by unpredictable production level elsewhere in the nearby watershed is another problem that highly discourages the farmers. As shown in the Table 18 below, almost all the respondents said that the prices of the products are not constant. They depend on the amount of products that are produced by the farmers in the watershed as well as in the surrounding watersheds. The proportion of demand and supply is also another factor that determines the price of the vegetables in the market. According to the farmers, the problem is highly aggravated by absence of storage facilities. As the study area has a climate of semiarid, the vegetables are spoiled within a few days after ripen. As the farmers explained, due to storage problem, they lost the income that they expected to get from the products. As shown in the Table 18 all of the respondents said that storage facilities are a significant role in the production of vegetables. If they get storage facility in the market place or near homestead, they can store their products and sell them at the time when the price gets high rather than selling them for low price or dispose them in the market place.

Table 18. Factors that affecting the farmers not to use the water effectively

Constraints	Frequency	Percent
Price fluctuation, absence of storage facilities , transport problem and shortage of water	26	72.22
Price fluctuation, absence of storage facilities, shortage of water and water management problem	7	19.44
Price fluctuation, absence of storage facilities and transportation problems	3	8.33
Total	36	100

Beside the above problems, shortage of water for irrigation activities is also the main constraints in the study area. As Table 18 shows, 91.66% of the respondents said that the water in the shallow wells reduced and even sometimes dried around February which is the main irrigation time. Due to this, as they explained, they were forced to use the water less than the crop water requirement.

Water management problem also another constraints in the area. From the total respondents, 19.44% of the sample farmers argue that water management problem is one of the limiting factors in the study area. These problem mainly observed in the area where the shallow wells are constructed by the government and used by the group farmers.

4. CONCLUSION

The construction of shallow wells is a recent phenomenon in the study area. In the year between 2003 and 2005 alone, around 360 functional wells were built up with the intention of producing different crops and vegetables through irrigation activity and providing water for domestic and livestock purposes. The farmers in the area are nowadays benefiting from the well water by producing different vegetables and crops twice to three times per year. Although the farmers produced those crops using the shallow wells water, they only measured the crop harvested but not the volume of water used to produce it. However, measuring the productivity of water in agriculture is very essential for efficient utilization of the shallow wells water. In the study area both rain fed and irrigated agriculture water productivity was very low compared to the potential productivity of water.

In the study area the highest rainfall water productivity was gained from teff followed by mixed crop and wheat. But in effective rain fall water productivity, the highest water productivity was obtained from teff (0.92 kg/m^3) and the lowest was for sorghum (0.31 kg/m^3). Though the effective rainfall water productivity of maize less next to sorghum (0.31 kg/m^3), its water productivity is 45.33 % of the potential water productivity, which is an indication of better productivity performance as compared to the other crops. Regarding the diverted and applied water productivity, the highest was obtained for maize (0.24 kg/m^3) and the lowest productivity was from green pepper (0.07 kg/m^3). Furthermore, the actual diverted and applied water was higher than the crop water requirements for all the crops.

On the controlled and farmers plot, the diverted and applied water productivity for each soil types on farmers plot was higher than the controlled plot. On the contrary, the amount of diverted and applied water on farmers plot to each soil types were much greater than that of the amount of diverted and applied water on the controlled plot for each corresponding soil types. The amount of applied water in the sandy soil, silty loam and clay loam soil in the controlled plot is 6.3%, 38.189%, and 24.56% of the applied water in controlled plot. The reason for the low productivity of water in the farmers' plot might be due to the excess utilization of water. Though the productivity of water in the controlled plot was higher than the farmer's plot it was by far less than the potential water productivity in the area, which is 27.73% (sandy soil), 5.29% (silty loam soil), and 7.55% (clay loam soil) of the potential water productivity.

Concerning the economic water productivity, the results of the study indicated that the highest economic productivity under rain fed condition was obtained for teff (0.229 Euro /m3) and the minimum productivity was for maize (0.041 Euro /m^3) and the average economic productivity of the irrigated agriculture was estimated to be 0.026 Euro/m^3.

In addition to irrigation activities, the water in the shallow wells is also used for domestic and livestock purpose. From the result of the study, 50.4 m^3 and 5.3895 m^3 of water per day for domestic and livestock purpose was used, respectively. This high consumption of water for other purposes highly affects the availability of water for irrigation purpose.

Likewise, the farmers in the study area face a problems related to market, storage facilities, absence of transportation, shortage of water and poor water management that highly discourage them not to produce more crops than the present.

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