Determination of Local Barley (*Hordeum Vulgare*) Crop Coefficient and Comparative Assessment of Water Productivity for Crops Grown Under the Present Pond Water in Tigray, Northern Ethiopia

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ABSTRACT

An experiment was carried out in 2010 at Mekelle, in northern Ethiopia, to measure the evapotranspiration, to estimate barley crop coefficient (k_c), and to evaluate the water productivity taking into account the major crops grown under the present pond irrigation system. Four locally made lysimters were installed in the middle of barley field to measure barley evapotranspiration. The single crop coefficient approach was used to estimate barley crop coefficient. The average seasonal evapotranspiration of barley was 375 mm which is similar to many other cereal crops in the region. The single crop coefficient values for early, vegetative, mid and late crop stages were 0.6 – 0.8, 0.6 – 1.0; 1.0 – 1.05 and 0.3 - 0.4 respectively. The result showed that these crop coefficient values obtained in this experiment were similar to the crop coefficient values obtained in the past except for k_c initial. Therefore, the assumption that local barley crop coefficient values differ from that of the documented values was incorrect. Furthermore, the major reason for mismanagement of irrigation water in barley fields was not due to use of wrong crop coefficient values but could be due to inadequate irrigation technical skill and knowledge of the farmer. The average economic water productivity (EWP) of barley for the very wet, wet, normal, dry and very dry seasons scenario were 0.99, 0.7, 0.65, 0.57, and 0.44 USD m^{-3}, respectively, whereas the corresponding crop water productivity (CWP) values for grain were 1.53, 1.08, 1.0, 0.88 and 0.68 kg m^{-3}, respectively. The EWP and CWP of barley were compared with onion and tomato under pond water irrigation at the five climatic scenarios. The crop water productivity for tomato and onion were 85 – 87% and 76 – 78% higher than that of barley, respectively. The corresponding economic water productivity for tomato and onion were 87 – 89% and 81 – 82% higher than that of barley, respectively. We concluded that growing tomato and onion would bring more income or yield per m^3 of pond water supplied than growing barley. The implication is that as supply and demand determines the price of products, farmers and extension workers need to balance the crop area coverage per irrigation scheme so that undesirable price falls and rises could be avoided. Evaluation of crops based on their water productivity would improve the productivity of irrigation schemes and ultimately improve food security in the arid and semi-arid areas where water scarcity is critical problem and irrigation is a necessity for crop production.

Key Words: Barley, Evapotranspiration, Crop coefficient, Water productivity.

1. INTRODUCTION

Barley is a major staple food crop in the highlands of northern Ethiopia. The crop is used for preparing various types of traditional food such as *Kita, Kolo, Beso, Enjera, Giat*, and many others. Although the day to day survival is linked to barley, little focus has been given to improve the productivity of the crop in the dry land area.

The climate over the northern Ethiopia is characterized by uncertainties of rainfall both in distribution and in amount. The crop yield has been severely affected mainly due to water stress that occurs during part of its growing period (Araya and Stroosnijder, 2010; Araya et al., 2010 a & b).

In this region, the sustainable food production could possibly be ascertained through judicious use of water. According to Fereres and Soriano (2006) the sustainable use of water has to consider maximizing yield per unit of water rather than maximum yield per unit of area. To put this concept into practice requires at least: (i) detailed information on the crop water relations and crop water productivities and (ii) Water supply for agriculture has to be developed/ explored. The former deals mainly with different evaluation techniques such as the application of crop water productivity (Bessembider et al., 2005) that aims at the viability of irrigation projects. For example, the economic water productivities (EWP) and crop water productivity (CWP) are some of the most important elements that can be applied in the evaluation of irrigation project (Araya et al., 2010c). Many farmers in the northern Ethiopia grow crops without considering the EWP and CWP for different cropping scenarios due to lack of local information on crop water relations and crop water productivities.

The second prerequisite for sustainable use of water was developing/ exploring water source for agriculture. Some efforts were made by the government to store rainwater through household pond storage system. The constructions of the household ponds have been intensified since a decade with the main objective of supplementary irrigation. Following the construction of household ponds, many farmers have started growing barley with supplementary irrigation. However, mismanagement of water has been among the major problems observed in many of the irrigated barley fields. This could be due to lack of information on water requirement of local barley. General crop coefficient values for various crops including for barley are available in Doorenbos and Pruitt (1977) and Allen et al. (1998). The documented *k*c values are used for all cultivars of the same crop and climate conditions across the world. We hypothesized that the crop coefficient for the local barley cultivars grown in the northern semi-arid Ethiopia differ from the documented values and hence we suggested that developing at least indicative local *k*c values could save the scarce water in dry environment like the case of northern Ethiopia. To obtain accurate local *k*c value requires the use of standard lysimeters. However, standard lysimeters are very expensive and not available in our region. To solve this problem, we used locally made lysimeter to measure evapotranspiration and derive crop coefficient values (indicative) for the local barley.

Crop coefficient is a function of crop evapotranspiration and reference evapotranspiration. There are two approaches of determining crop coefficient: the single and dual crop coefficient approaches. The dual crop coefficient approach splits the evapotranspiration into evaporation and transpiration. This method is used under research and in real time irrigation scheduling (Allen et al., 1998). In the single crop coefficient, the effect of crop transpiration and evaporation are combined into a single k_c value. This single crop coefficient values are used for planning of a typical irrigation management (Allen et al., 1998). In our study, the single crop coefficient approach was used to derive the indicative k_c values for *Saesea* a local barley crop under the local environmental condition.

The objectives of this research are to: (i) study the evapotranspiration and crop coefficient of local barley (*Saesea*) under local climate using locally made lysimeter, (ii) Evaluate the economic water productivity and the crop water productivity of barley in comparison with some major vegetable crops grown under the present pond water use conditions in the northern Ethiopia.

2. MATERIALS AND METHODS

2. 1. Experimental Site

The experiment was conducted in 2010 (February to May) in northern Ethiopia (lat 13^o 29’ N and long 39^o 35’E, 2130 m above sea level (Fig. 1). The water content at field capacity of the 0 - 0.2 m layer is 27 vol% and at 0.2 to 0.6 m is 37 vol%. The corresponding values for the permanent wilting points are 14 and 22 vol%, respectively. The maximum rooting depth for the local barley is 0.6 m (Araya et al., 2010a).

Climate data such as rainfall, humidity, temperature, wind speed, sunshine hours and radiation data were obtained from the weather station at Mekelle University (about 200 m far-off the study site). At the site, the long-term average annual precipitation is about 600 mm, 70 to 80% of which is received between the month of June and September while the other 20 to 30% is received between the month of February and May. Reference evapotranspiration (ET_o) was computed based on the full data set using FAO-Penman-Monteith equation and ET_o software program (FAO, 2009). The average annual reference evapotranspiration is about 1700 mm. The minimum and maximum temperatures are 11^oC and 28^oC respectively.

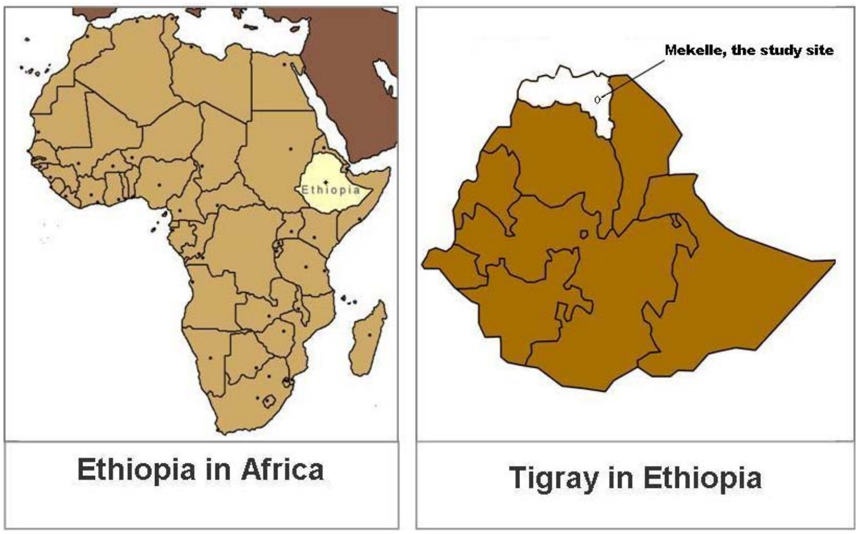

Figure 1. Map of Ethiopia and the study area in Tigray region

2.2. Locally Made Lysimeters (hereafter drums) and Crop Details

Evapotranpiration data of barley was collected using four drums (Fig. 2) which were installed at four representative positions of barley field. The design of the drums was similar to the one presented in Araya et al. (2010c). The drums were installed about 5 m apart. The drums had a diameter of 0.6 m and depth of 1 m. They were designed to replace the more expensive lysimeters and were suitable for barley since the maximum rooting depth of the local barley was only 0.6 m and the final plant population was about 100 to 155 plant per m^2. The drums had a solid base with an outlet for collecting drained water through a perforated iron sheet. On top of this sheet was 0.1 – 0.15 m of gravel and 0.1 - 0.15 m sand, covered with a 0.01 m thick sisal sheet (Fig.2). Deep percolation beyond the root zone was collected in a receptacle under the drums and measured using a calibrated cylinder.

The drums were placed in the field containing the holes left after the original soil column had been carefully removed. To minimize the boundary effect, the rim of the installed drums was set flush with the soil surface. Then the soil column was replaced in the drums with minimal disturbance, on top of the sisal cover. The drum was positioned exactly similar to the field condition. The drums including the field were irrigated and left for some time to minimize variation from the field. The common barley cultivar (*Saesea*) was sown in the drum and at the field by broadcasting in early February at a rate of 120 kg per hectare. The field and the drum were kept at field capacity throughout the growing period. All crop management techniques followed the recommended practices; for example, DAP (Di-amonium phosphate) and urea fertilizers were applied at a rate of 100 kg per hectare each (64 kg N and 46 kg P per hectare). The nitrogen in the form of urea was applied twice: half at sowing and the other half a month after planting. Crop biomass and yield were obtained after maturity.

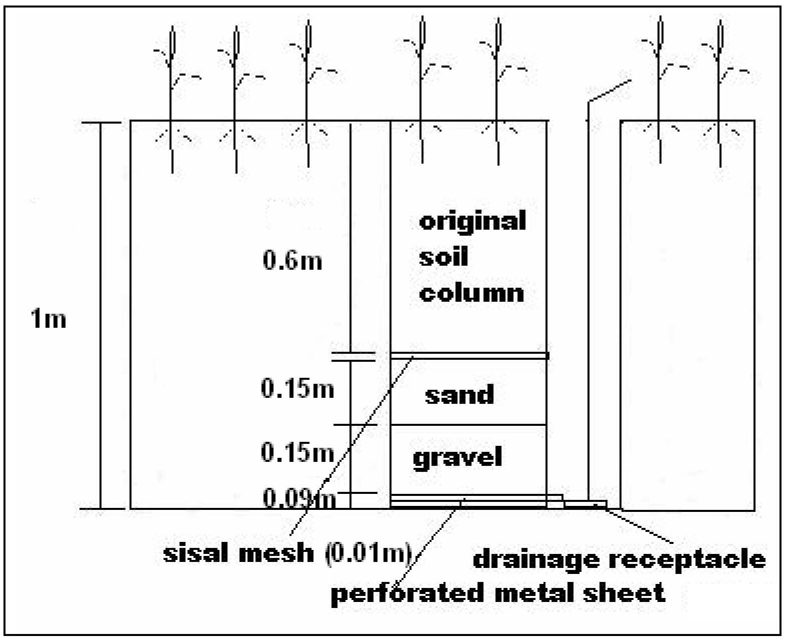

Figure 2. Sketch of the locally made lysimeter (drum) used in the field.

2.3. Soil Water Balance

Time domain reflectometry (TDR) (Eijkelkamp, 1996) was used to measure the soil moisture. Three glass fibre access tubes were installed at each drum to depths of 0.8 to 1 m. TDR reading were observed on alternate days at 0.1 m intervals before and after irrigation. For a proper calibration, gravimetric soil moisture was also measured.

In the drum experiments, a depth of about 15 - 45 mm irrigation water was applied uniformly using a calibrated plastic can every 3 to 4 days depending on the availability of soil water in the root zone. Barley evapotranspiration was computed from the water balance (Eq. 1) (Allen et al., 1998):

$$ET_c = I + P - D - Ro \pm \Delta S \qquad (1)$$

Where, ΔS is the change in soil moisture storage between soil moisture measurements (mm), I is irrigation (mm); P is rainfall (mm); D is drainage (mm); Ro is runoff (mm). There was no runoff because water application was controlled. Groundwater effect was ignored because the water table was deep.

2.4. Crop Coefficient

Barley crop coefficient (k_c) values for the initial, mid and late season stages were calculated by dividing the barley evapotranspiration (ET_c) (obtained from the water balance) by the reference evapotranspiration (ET_o) (effect of climate) (Eq. 2) which is described in Doorenbos and Pruitt (1977); Allen et al. (1998) and Liu et al. (2002) but the difference is that ET_c was derived from the drum.

$$k_c = \frac{ET_c}{ET_o} \qquad (2)$$

2.5. Irrigation Water Requirement and Crop Water Productivity

A survey was conducted on 48 household ponds in 2005 to study the economic water productivity and irrigation crop water productivity of the major crops grown under pond irrigation around the study site (at a radius of about 5 to 50 km) (Araya et al., 2006). Data on the pond capacity, the irrigation method, soil type, major crops grown in the area, and the cropping period were gathered (Araya et al., 2006). Taking the major crops grown under irrigation in the area (onion, tomato and barley) as a reference is necessary in the evaluation because comparisons have to be made to demonstrate that the choice of crop and cropping pattern determines the viability of any irrigation project.

The precipitation over the 1960 - 2009 was statistically evaluated. Test of homogeneity was applied and the data was proven to be consistent. The probability of exceedance of decadal rainfall over the record period was analyzed and this was used to determine the decadal dependable precipitation and classified in scenarios as: > 20% (very wet), 40 - 20% (wet), 60 - 40% (normal), 80 - 60% (dry) and < 80% (very dry). Grouping of the long-term decadal rainfall into five rainfall scenarios would make it more representative than just taking one long-term mean decadal rainfall value. Hence, it minimizes errors that could occur due to over or under estimation of the long-term rainfall data. In addition, the use of long-term mean values of the short range probability as described above is more accurate and representative than use of wider range. Mean values for these ranges were obtained and each respective probability level was used in the estimation of crop water requirement however about 25% of the rainwater was estimated to be lost as runoff (Araya and Stroosnijder, 2010). Thus, the net irrigation water requirement was computed based on Eq. 3:

$$NIWR = ET_c - R_p \times (0.75) \tag{3}$$

where, NIWR is net irrigation water requirement; R_p is the respective dependable decadal rainfall for each corresponding scenario. The 0.25 was deducted due to runoff hence 0.75 was taken as a multiplier. Gross irrigation (GIWR) requirement was estimated from the project efficiency and net irrigation water requirement as shown in Eq. 4:

$$GIWR = \frac{NIWR}{P_E} \tag{4}$$

where, P_E is project efficiency. The product of conveyance, distribution and field application gives project efficiency (Doorenbos and Pruitt, 1977). As the distance between irrigable area and pond was so short and the type of irrigation method was a direct water application (such as using plastic cans and pump), thus, only field application loss was considered. The major soil textures in the study area were loam and silt loam. Hence, the field application efficiency for medium textured soils was taken as 70% (Doorenbos and Pruitt, 1977). The total irrigable area by the household pond was estimated based on Eq. 5:

$$TIA = \frac{NPC}{GIWR} \tag{5}$$

where, TIA is total irrigable area (ha); NPC is the net pond capacity (m^3) and GIWR is gross irrigation water requirement (m^3 ha^{-1})

Economic water productivity (EWP) is expressed in gross income in USD per gross water supplied in m^3 while the crop water productivity (CWP) is expressed in gross weight of product (kg) per gross water supplied (m^3). EWP was computed from the estimated irrigable area, obtainable yield and from the seasonal price (USD) of the main product and bi-product as shown in Eq. 6. Local market price was considered because almost all of the products are consumed locally under the present condition. EWP was thus calculated based on Eq. 6:

$$EWP = \frac{GI}{GIWR} \qquad (6)$$

where, GI is gross income from the sale of grain and straw (USD); GIWR is gross irrigation water requirement (m^3).

The crop water productivity (CWP) was also computed based on Eq. 7:

$$CWP = \frac{GY}{GIWR} \qquad (7)$$

where, GY is the main yield (kg ha^{-1}).

3. RESULTS AND DISCUSSION

3.1. Crop Development Stages

The crop growing season has been divided into four based on Doorenbose and Pruitt, (1977). Table 1 shows the length of crop development stages of the three crops (onion, tomato and barley) grown under irrigation in the region particularly around the study site. The initial stage refers to crop germination/transplanting. It also refers when the soil surface is not covered by the crop (canopy cover < 10%). The crop development stage denotes the vegetative period of the crop that includes from the end of initial stage to full canopy cover (canopy cover 70 – 80%). The mid-season stage represents the period between full ground cover to the time of start of maturity (leaf yellowing). Late season stage stands for the crop period from end of mid season stage to full maturity.

Table 1. The length of growth stages (days) of the crops grown under irrigation near the study site, in Tigray, northern Ethiopia.

Crop	***Initial***	***Vegetative***	***Mid***	***Late***	***Total (days)***
Onion	15	25	70	30	140
Tomato	30	30	50	30	140
Barley	18 -20	18 - 20	28 - 30	18 - 20	82 - 90

3.2. Reference Evapotranspiration and Crop Evapotranspiration

The relationship between reference evapotrnaspiration (ET_o) and barley crop evapotranspiration (ET_c) is shown in Fig. 3. The evapotranspiration of the crop varied across the growing stages.

The ET_c at the early stage was lower than the ET_c at the vegetative and mid season stages (Fig. 3). There was higher ET_c at vegetative than initial stage and mid than vegetative stage mainly caused by change in plant characteristics. The trend is in agreement with reports for various crops documented in the past (Doorenbose and Pruitt, 1977; Allen et al., 1998).

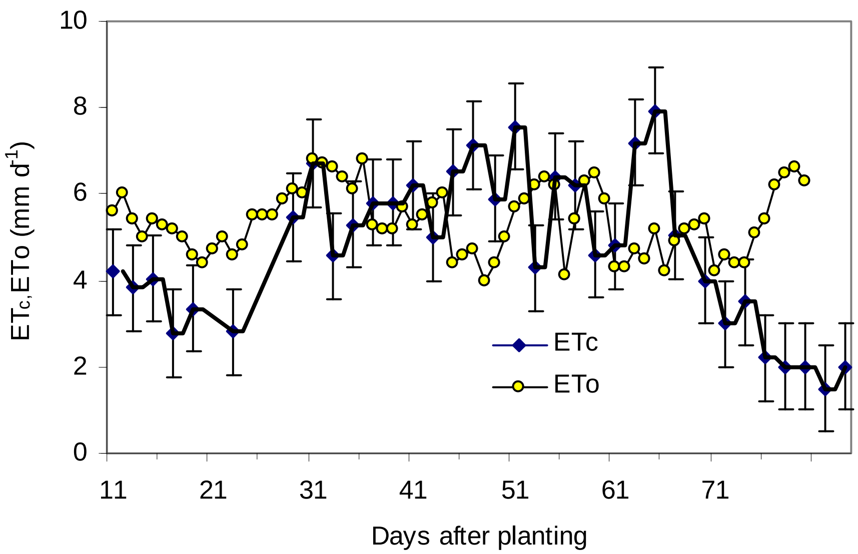

Figure 3. The ET_o and the measured ET_c for barley in 2010 at Mekelle, northern Ethiopia.

ET_o was higher than the ET_c during the initial and development stages whereas ET_c was higher than the ET_o during the mid stage of the crop. The ET_c and ET_o at initial stage varied from 3 to 4 mm per day and 4.4 to 5.4 mm per day respectively. The difference could be attributed mainly to low canopy cover of the crop at sowing. The majority of evapotranspiration at sowing come from soil evaporation (Allen et al., 1998), in contrast, reference evapotranspiraion refers to a (reference grass) well grown green grass, fully covering the ground (Doorenbose and Pruitt, 1977) and hence the well grown reference grass is assumed to extract and to use more water for its evapotranspiration than a crop just sown before few days. ET_c and ET_o increased during the vegetative stage from 3.3 to 6.7 and 4.6 to 6.8 mm per day respectively. Like the initial stage, the difference could be mainly due to the effect of crop characteristics because ET_c is affected by the nature of the crop (leaf arrangement, stomata and plant height) and crop growth stage. Both ET_c and ET_o reached their equilibrium approximately at 30 days after planting. This implies that the crop has fulfilled at least equivalent to the requirement of the reference (hypothetical) grass as defined in FAO-56. ET_c of barley was slightly higher than the ET_o during the time between 35 and 65 days after planting (Fig. 3). This difference was mainly attributed to change in plant characteristics. Barley crop at this stage acquires higher canopy cover and relatively deeper roots to extract water from deeper soil profile and hence most of evapotranspiration comes from transpiration while minimizing evaporation. ET_c starts to decline at 65 days after planting and reached its minimum level at 84 days after planting and afterwards.

Nagaz et al. (2008) estimated the seasonal ET_c of barley to be about 340 mm whereas in our experiment the seasonal ET_c was about 375 mm. The difference could be attributed to differences in climate and cultivar characteristics.

Table 2. Crop coefficient (k_c) values used for crops grown under irrigation near the study site in Tigray, northern Ethiopia

Crop	***Initial***	***Vegetative***	***Mid***	***Late***	***Source***
Onion	0.6	0.75	1.05	0.75	Doorenbos and Kassam (1979); Allen et al. (1998)
Tomato	0.45	0.75	1.15	0.7	Doorenbos and Kassam (1979); Allen et al. (1998)
Barley	0.35	0.75	1.05 – 1.2	0.15-0.45	Doorenbose & Pruitt (1977); Brouwer & Heibloem (1985); and Allen et al.(1998)
Barley	0.6 –0.8	0.6 – 1.0	1.0 - 1.05	0.3 – 0.4	Local experiment result

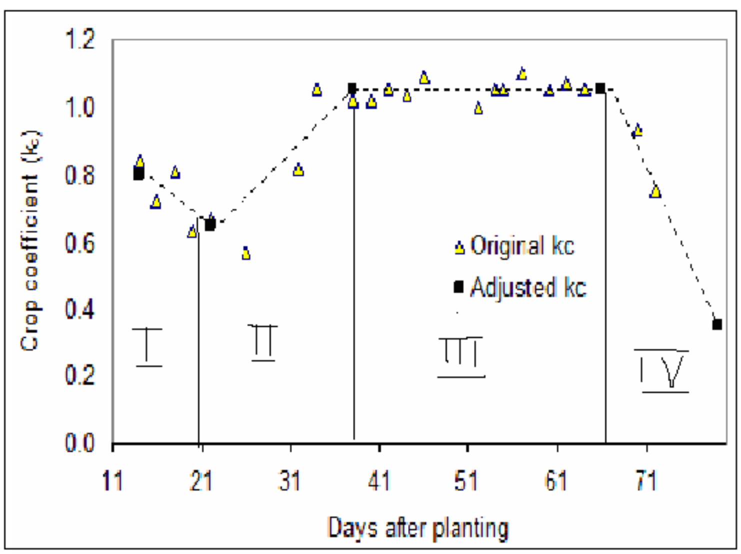

Figure 4. The original and adjusted crop coefficient (k_c) values for barley obtained during the experimental season in 2010 at Mekelle, northern Ethiopia. I, initial stage; II, crop development stage; III, mid season stage; IV, late season stage

3.3. Crop Coefficient (k_c)

The single crop coefficient values for barley are given in Table 2. Accordingly, the k_c values increased from initial stage to mid season stage and decreased during the late season stage (Fig. 4). Fig. 4 shows the relationship between the original and adjusted k_c values. In this case, the adjusted k_c values are the single representation of k_c based on crop stage while the original k_c values are the mean of the k_c values for each observation event. The k_c value for vegetative stage can also be obtained by interpolation.

There was also an increasing trend in k_c during the first few days after germination attributed to frequent wetting and soil evaporation. k_c value started to decline at the end of initial stage because of decrease in soil evaporation. Then, the development (vegetative) stage k_c values started to increase up to the mid season stage and form a plateau for about 30 days and later declined during the late season stage (k_c started to decline at 66 days after planting). The later trend agreed well with previous studies (Doorenbose and Pruitt, 1977; Allen et al., 1998). The k_c value for the initial stage varied widely compared to the other growth stages of the crop. Allen et al. (1998) stated that evapotranspiration during the initial stage is dominated by evaporation component. Thus, the interval between wetting events, the magnitude of the wetting events and evaporative power of the atmosphere determine the values of k_c at initial stage. Generally, the k_c values for crop development, mid and late season stage of barley obtained in our experiment were similar to that of the values documented in FAO publications as shown in Table 2. Thus, this research verified that the local barley crop coefficient did not differ much from that of the documented crop coefficient in the past. Hence, the reason for the mismanagement of irrigation water in barley fields was not due to wrong k_c value but could be due to other factors such as lack of awareness, lack of skill, technology and lack of adequate knowledge in applying the documented k_c values into practice.

3.4. Crop Water Productivity (CWP)

The average gross and net pond capacity in the surveyed sites were 180 m^3 and 127 m^3 respectively (Araya et al., 2006). The average obtainable yields of barley, onion and tomato which are the main products under irrigation in the study area were 2000 kg ha^{-1}, 18000 kg ha^{-1} and 25000 kg ha^{-1} respectively. The barley straw (bi-product) was also considered in the analysis (8000 kg ha^{-1}). The average current season price per kg of the product was considered in the analysis. Accordingly, the mean of one season price per kg of barley, onion and tomato was respectively 0.4, 0.8 and 0.75 USD. The average current season of local market price of barley bi-product was estimated to be 0.0615 USD per kg.

Table 3. Crop water productivity (CWP, kg m^{-3}) of onion, tomato and barley under the present pond water use in Tigray, northern Ethiopia.

Crop	*Very wet*	*Wet*	*Normal*	*Dry*	*Very dry*
Onion	7.0	4.8	4.3	3.7	2.9
Tomato	12.2	7.7	6.9	6.0	4.6
Barley	1.53	1.08	1.0	0.88	0.68

Table 3 indicates the crop water productivity in terms of gross produce obtained per gross pond water supplied. In this case, crops have different water productivity due to difference in water requirement and productivity per given area of land. The analysis showed that CWP of tomato was substantially higher than that of the onion and barley and the CWP of onion was considerably higher than that of barley. The crop water productivity for tomato and onion were 85 – 87% and 76 – 78% higher than that of barley, respectively.

The crop area coverage per pond water supplied across the various seasons scenarios were evaluated. The result showed that a very dry season scenario has lower crop area coverage than that of the other seasons. Consequently, the yield obtained per gross pond water was small. Higher yields of tomato per a given drop of water were obtained compared to onion and barley (Araya et al., 2006). Hence, tomato has relatively higher crop water productivity.

Table 4. Economic water productivity (EWP, USD m^{-3}) of onion, tomato and barley under the present pond water use in Tigray, northern Ethiopia.

Crop	*Very wet*	*Wet*	*Normal*	*Dry*	*Very dry*
Onion	5.6	3.9	3.4	3.0	2.3
Tomato	9.2	5.8	5.2	4.5	3.4
Barley	0.61+(0.38)	0.43+(0.27)	0.4+(0.25)	0.35+(0.22)	0.27+(0.17)

Note: the values in bracket are the gross income gained from the sale of the straw.

3.5. Economic Crop Water Productivity (EWP)

Increase in crop production per unit of water does not necessarily result into an increase in the farmer's income because of the non-linearity of crop yield with the price of products. Table 4 shows the economic water productivity of barley, onion and tomato. Accordingly, we found out that tomato has the highest irrigation EWP followed by onion. Barely has the lowest irrigation. The economic water productivity for tomato and onion were generally 87 – 89% and 81 – 82% higher than that of barley, respectively. Though, the sale of the bi-products (straw) was also considered for barley, the yield per equivalent unit area and the price of barley was lower than onion and tomato. Tomato is perishable and most producers do not allocate larger area for tomato unless they made a deal in advance with their clients. Experience showed that there have been seasonal price fluctuations. Thus, there need to be assessment on the EWP parameters based on the anticipated prices before planting and it is also good to know client's and other producers interest in order to optimize the EWP. Understanding the interest of the farmer and consumer in advance would help in improving or in optimizing the economic water productivity.

Hence, in evaluating EWP, it is essential to study the economic gross income from each drop of water supplied.

Generally, EWP and CWP declined from very wet to very dry climatic scenario because, in very dry scenario, the pond water was enough only for a relatively smaller cropland compared to the other climatic scenarios. Thus both EWP and CWP increase with increase in rainfall.

4. CONCLUSION

The crop evapotranspiration of barley during the main growing season was approximately 375 mm per season. However, this amount can be slightly affected by intra-seasonal weather variability especially with reference to evapotranspiration. For example, in the normal summer cropping season, the reference evapotranspiration may reach 350 mm whereas during the experimental period it has reached about 485 mm.

The average k_c values for initial, development, mid and late stages of local barley were 0.6 – 0.8, 0.6 – 1.0; 1.0 – 1.05 and 0.3 - 0.4 respectively. These values can be applied in the determination of irrigation water requirement of local barley in the region. With the exception for the initial stage, the crop coefficient value of local barley was found to be similar to that of the documented values in the past. Thus, the assumption that the local barley crop coefficient differs from that of the documented crop coefficient was found to be incorrect. The mismanagement of the irrigation water in barley fields could be due to little follow-up, lack of awareness, lack of adequate knowledge and lack of irrigation skill of the farmers. This problem can be minimized through intensive training.

In this study, growing tomato showed higher EWP and CWP than growing onion and barley. This is because the price and the productivity of tomato per unit of water supplied are higher than that of onion and barley. Evaluation of crops based on their water productivity as presented in this research would improve the productivity of irrigation schemes and ultimately improve food security.

As supply and demand determines the price of products, farmers and extension workers need to understand the cropping pattern of the irrigation sites. The extension workers have to give advice in order to balance the area coverage per each crop from the irrigation projects so as to avoid undesirable extreme price falls and rises. Such measures could improve the water productivity of the pond irrigation system.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Allen, R.G., Periera, L.S., Raes, D & Smith, M. 1998. Crop evapotranspiration. Guidelines for computing crop water requirement. FAO Irrigation and Drainage Paper No. 56. FAO, Rome.

Araya, A., Daniel, T & Addisu, G. 2006. Pond water productivity under the present use in Tigray region, Northern Ethiopia. Dryland coordination group project Mekelle University, Ethiopia

Araya, A., Solomon Habtu, Kiros Meles Hadgu, AfewerkKebede & TaddeseDejene. 2010a. Test of AquaCrop model in simulating biomass and yield of water deficient and irrigated barley (*Hordeum vulgare*). *Agric. Water Manage,* **97**: 1838–1846.

Araya, A., Keesstra, S. D & Stroosnijder, L. 2010b. A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. *Agric. For. Meteorol*, **150**: 1047-1064.

Araya, A & Stroosnijder, L. 2010. Effects of tied ridges and mulch on barley (*Hordeum vulgare*) rainwater use efficiency and production in Northern Ethiopia. *Agric. Water Manage*, **97**: 841-847.

Araya, A., Stroosnijder, L., Girmay, G & Keesstra, S. D. 2010c. Crop coefficient, yield response to water stress and water productivity of teff (*Eragrostis tef* (Zucc.). *Agric. Water Manage*, Doi:10.1016/j.agwat.2010.12.001

Bessembider, J. J. E., Leffelaar, P. A., Dhindwal, A.S & Ponsioen, T. C., 2005. Which crop and which drop, and the scope for improvement of water productivity. *Agric. Water Manage*, **73**: 113-130.

Brouwer, C & Heibloem, M. 1985. Irrigation water needs. Irrigation water management training manual no.3. Part II Determination of irrigation water needs. FAO/IILRI. pp.II. 26

Doorenbos, J & Pruitt, W. O. 1977. Crop water requirements. Irrigation and drainage paper no. 24. FAO, Rome, Italy.

Doorenbos, J & Kassam, A. H. 1979. Yield response to water. FAO irrigation and drainage paper no. 33. FAO, Rome Italy

Eijkelkamp. 1996. TRIME-FM TDR Moisture probe: Owner's Manual. Giesbeek, Netherlands.

FAO. 2009. ETo program. Calculation of Reference Evapotranspiration with various calculation methods. Version 3.1. FAO, Rome Italy.

Fereres, E & Soriano, M. A. 2006. Deficit irrigation for reducing agricultural water use. *J. Experimental Botany,* **58**: 147-159.

Liu, C., Zhang, X & Zhang, Y. 2002. Determination of daily evaporation and evapotranspiration of winter wheat and maize by large scale weighing lysimeter and micro-lysimeter. *Agric. For. Meteorol*, **111**: 109-120.

Nagaz, K., Toumi, I., Masmoudi, M.M & Mechilia, N.B. 2008. Soil salinity and barley production under full and deficit irrigation with saline water in Arid conditions of Southern Tunisia. *Res. J. Agron*, **2**: 90–95.