VOL 5(2), 62-82
Copyright © Madda Walabu University
ISSN: 2523-1901 (Online)
URL: http://jessd.mwu.edu.et/
Email: JESSDeditorials@mwu.edu.et

Journal of Equity in Sciences & Sustainable Development

DOI: https: //doi.org/10.20372/mwu.jessd.2022.1537

Full Length Research Paper

Estimation of Water Losses by Transpiration from Root and Leaf Clipped Eichhornia Crassipes (Water Hyacinth)

***Hana Teshome*[1] *and *Gelana Amente*[1]**

[1]*College of Natural and Computational Sciences, Haramaya University, Dire Dawa, Ethiopia.*

Article Info

Article History
Received: 8 April 2022
Accepted: 29 May 2022

Keywords:
Crop coefficient, Crop factor, Evapotranspiration, Pan Evaporation, Transpiration, Water hyacinth.

Abstract

Among several alien weeds Eichhornia Crassipes (water hyacinth) is ranked as one of the world's worst invasive weeds due to its ability to rapidly cover the entire water surface. This weed was introduced in Ethiopia in 1964 but its aggressiveness has been realized recently after it has invaded a number of lakes and rivers in the country. This study focuses on the estimation of water losses by transpiration from root-clipped, leaf-clipped plants (treatments) and makes comparison with those of the normal plants (control). Besides evaporative losses, crop factors and plant coefficients were also determined and compared. Plant transpiration losses were obtained from the difference in the volume of water from the pan containing the treatment and control plants and the volume of water lost from the pan evaporation. For this calibration first was done to correlate the depth of water level (in the pan) from the top of the pan to the water level in order to know the volume of water lost by evapotranspiration. Data analysis was made using Microsoft Office Excel and comparisons were made using one-way ANOVA followed by pair comparisons. Evapotranspiration estimation for Zeway area was done using the modified and optimized Temesgen-Melesse's method, and the study was conducted for 17 days. The result showed that the evapotranspiration by normal plants (control group), plants with clipped roots (CR), and plants with clipped leaves (CL) were 2.25L/d (7.96 mm/d), 0.85L/d (3.01 mm/d), and 1.51 L/d (5.34 mm/d), respectively, compared to mean daily pan evaporation of 0.88 L/d (3.11 mm/d). The transpiration rates from the normal and leaf-clipped plants were 1.37L/d (4.85 mm/d) and 0.72 L/d (2.55mm/d), respectively. The root-clipped plants did not show any transpiration at all. Additionally, the value of crop factors (Cp) calculated showed 1.09, 0.40 and 0.73 for C, RC and LC, respectively. The crop coefficient (Kc) result showed 1.42, 0.54, and 0.95 for C, RC and LC, respectively. ANOVA results of T, Cp showed significant differences between treatments and the control and also within treatments. The conclusion drawn is that root-clipping has better effect than clipping of leaves when it comes to reducing the rate of transpiration from the plant. It is better to find other physical methods of ill-managing the plant rather than trying to remove the entire plant from water bodies since it is too cumbersome.

* *Corresponding Email:* amente-gelana@gmail.com

1. Introduction

Polluted water is conducive for the growth of water plants due to eutrophication. Some of these plants are weeds that affect both the quality and the quantity of water in water bodies. One of the weeds that grow in polluted water is *Eichhornia crassipes* (water hyacinth).

Water hyacinth is a tropical species belonging to the Pontederiaceae family (Ndimele et al., 2011; Gichuki et al., 2012; Marlin et al., 2013), which is free floating in rooted forms. It is a perennial aquatic plant that originated in Amazon River Basin in South America (Sindhu et al., 2017). This species relies on asexual reproduction, vegetatively through the formation of stolons and also reproduced sexually through seeds (Adeyemi and Osubor, 2016; Yu et al., 2019). Under favorable conditions of temperature and high nutrient availability, the vegetative propagation is exceptionally quick and the edge of mat can even grow by 60 cm per month. Daughter plants sprout from the stolons and they can double within 6-18 days (Barrett, 1980).

At present, water hyacinth is ranked as one of the world's worst invasive weeds due to its ability to rapidly cover the entire water surface (Villamagna and Murphy, 2010; Bhattacharya et al., 2015) causing problems for millions of users of water resources. It has negative social, environmental and ecological impacts. The major impacts include hindrance to water transport, blockage of irrigation canals and rivers, interference to fishing activities, and reduction of water biodiversity (Yigrem and Yohannes, 2019). Above all, it increases water losses through transpiration relative to typical open-water evaporation (Villamagna and Murphy, 2010; Arp et al., 2017).

In Ethiopia, water hyacinth was officially reported in 1956 E.C. in Koka dam and the Awash River (Daniel et al., 2011; Wondie, 2013; Firehun et al., 2014; Tegene et al., 2014). However, its' damage has been recognized after 1965 (Wondie, 2013). The aggressiveness of the weed seems to be related to recent increased use of fertilizers. Though the exact cause and source of the water hyacinth invasion in lakes and reservoirs are not clearly known, conditions such as sedimentation, extensive fertilizer application in the agricultural parts of the catchment, and pollutants (nutrients) from the surrounding cities seem to be the most probable causes (Goshu et al., 2010; Ligdi et al., 2010).

Studies done thus far indicate aggressiveness of this weed in terms of its transpiration rate. Daniel (2009) found that the transpiration rate of water hyacinth using leaf area index (LAI) at Aba Samuel reservoir and observed that its transpiration exceeds evaporation by 3.49 to 4.85 times in dry and wet seasons, respectively. Habtamu et al. (2020) have used plant physiology parameters (e.g., leaf width, height, and number of leaves) to estimate the same thing indirectly and found transpiration rate of water hyacinth to be two times higher than *Cyperus papyrus* and *Typha latifolia.* Little (1967) obtained the crop factor (ET/E) for water hyacinth to be 4.2 with shield and 5.4 without shield. He found the crop factor of water hyacinth to be higher than those of the other two weeds; *Stratiotes* (2.9) and *Salvinia auriculata* (1.2). Johansson (1977) also found a similar result of transpiration/evaporation (T/E) ratio of 4.7. In all the works, ET estimations were made without affecting the plant in any way.

Currently, this weed has infested a number of lakes in the country and attempts to remove the plant from water bodies have not been easy. So far, the expansion of water hyacinth in Ethiopia is tackled by using manpower and mechanical means to reduce the aggressiveness of the weed. However, both methods are cumbersome and time consuming. For instance, there were tremendous efforts done on Lake Tana in order to eliminate this weed using machineries but mostly manpower. Despite the challenge, The use of the two methods has brought satisfactory results on Lake Tana, Ethiopia, but with great challenge.. There are still other lakes such as Lake Zeway that are threatened by this weed. The effort made on Lake Tana was successful, but there is no guarantee to find such concerted effort at other places, first because of lack of willingness and due to the inability to find large number of manpower. The use of chemicals is out of question since it can affect the water and aquatic life in the water. Biological methods of tackling aggressiveness of this weed can take some time and may not be an immediate solution. Using this plant as animal feed is not an option until a method to remove the poisonous flavonoids that is in the plant is obtained. Using the plant as energy source (say by converting it into briquettes) does not seem to be vaiable since the plant is of low energy density fuel like many other agricultural residues. In fact an unpublished MSc work done on briquettes by Dereje Alemu has also revealed this result. All these indicate that there is no economic benefit that can motivate people to willingly be involved in the removal of the plant. For this reason, trying other methods is imperative. For the purpose of eliminating the weed or at least for alleviating the invasive property of the weed it is necessary to physically affect the plant in some form, but none of the works done thus far have addressed this problem. In this study, attempts were made to see how clipping the leaves or the roots affect the rate of transpiration of the plant.

2. Materials and methods

2.1. About the Study Area

The water hyacinth samples used to carry out this research were obtained from Zeway Lake. Lake Zeway is one of the lakes in Ethiopia and it is located in Oromiya regional state, East Shewa zone, Dugda district, Zeway town. The geographical coordinates of the study area are 7.935^{o}N latitude, 38.728^{o}E longitudes, and it is situated at an average elevation of 1640 m above sea level. The field experiment was conducted adjacent to the Lake. Map of Zeway area and the Zeway Lake is shown with the specific location of the experimental site in Fig. 1.

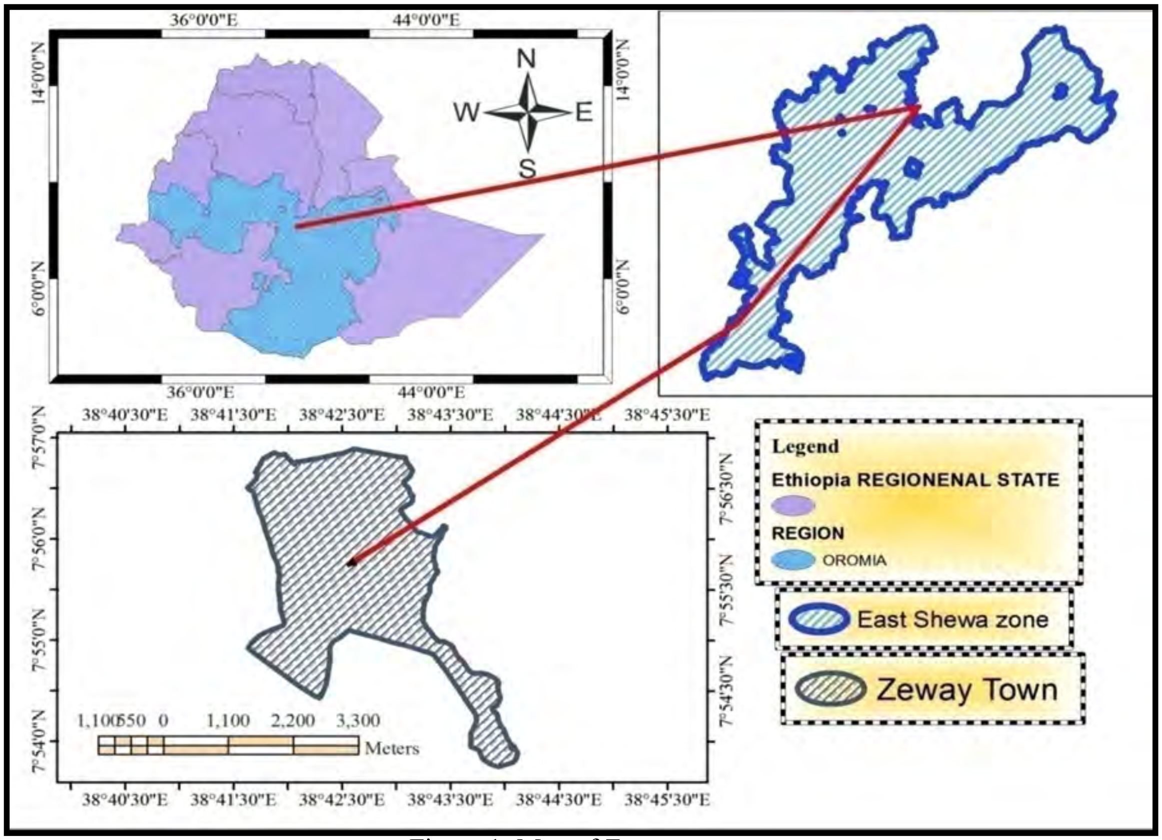

Figure 1: Map of Zeway town

2.2. Experimental materials

The materials used in this experiment were, evaporation pans with top inner diameters of 60 cm and depths of 16 cm, wooden base for the pans with height of 12 cm and length and width of 60 cm each, water hyacinth plants collected from Zeway Lake, digital balance, wire mesh, Styrofoam with thickness of 1 cm, 1 wooden meter stick, 1 plastic meter stick for measuring the depth of water in the pan, graduated plastic cylinder, 2L plastic bottle, mobile phone and pairs of scissors.

2.3. Experimental procedure

In this experimental work, two treatments (water hyacinth plants of one group with clipped leaves and the other group with clipped roots) were used along with normal (unclipped) plants those were taken as control group. The treatments and the control were each considered in three replications making a total of nine experimental units. In addition, three pans were also used to measure open water evaporation at the site. In total twelve experimental pans were used.

2.3.1. Site preparation

The site for the experiment was selected such that all the experimental units get full sunlight throughout the day. For this purpose, a site free from shades and bushes was selected. The experimental area was cleaned to make it suitable for the experiment. The area was fenced by mesh wire to protect from any sort of intruders that may tamper with the experiment. Then the ground was leveled to make sure the wooden bases were placed on the leveled surfaces. The pans were labeled and placed on the wooden bases and each experimental unit was checked by spirit level to make sure that the water level in the pan stays horizontal.

2.3.2. Indirect estimation of water volume

In this experiment it was not possible to use gravimetric method since it was not easy to get a balance that could measure large weight with high accuracy. For this reason it was necessary to estimate the volume of water transpired by using change in volume of water in the pan. This necessitated calibration to be made to correlate the depth of water level (in the pan) from the top level of the pan to the water level in order to know the volume of water left in the pan. To do this, the set up shown as a sketch in Figure 2 was used.

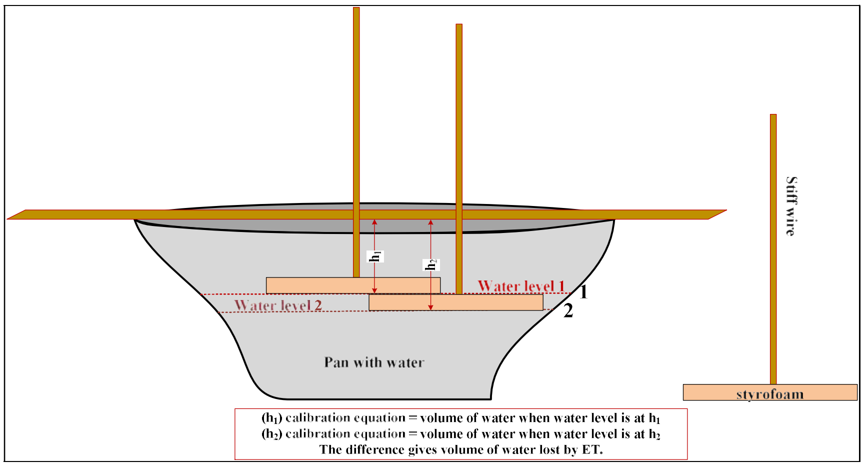

Figure 2. Sketch showing how calibration was done to relate *d* to *V*.

First a meter stick was placed horizontally on top of the pan. Then water was added to the pan 2 L at a time. After every 2 L was added, a stiff wire connected to a Styrofoam was inserted into the pan and allowed to reach the water level. Then the distance from the base of the Styrofoam to the horizontal meter stick was measured accurately in millimeters (shown as d_1 and d_2 in the figure). Every time a given volume of water was added the depth slightly reduced from d_1 to d_2. The depth difference was then correlated to the volume of water added. Plots of volume versus depth of water were done in order to get the calibration equation. The calibration equation was then used to get the volume of water lost by ET/E from the depth of water.

2.3.3. Experimental setup

Equal volumes of water were added (up to about three-fourth of the total capacity of the pan) into each pan (leaving sufficient room for the water hyacinth plants). To three of the 12 pans equal weights of hyacinth plants were prepared and then the leaves were clipped after which the plants were carefully placed on the water in the pans. To the other three pans plants of the same weight whose roots were clipped were placed on the water in the pans. Three other pans were used for the control (unclipped or normal) plants. The last three pans were used for free water evaporation determination. Initial depths of all the units were measured after the setup was completed. Arrangements of the plants are shown in Fig. 3.

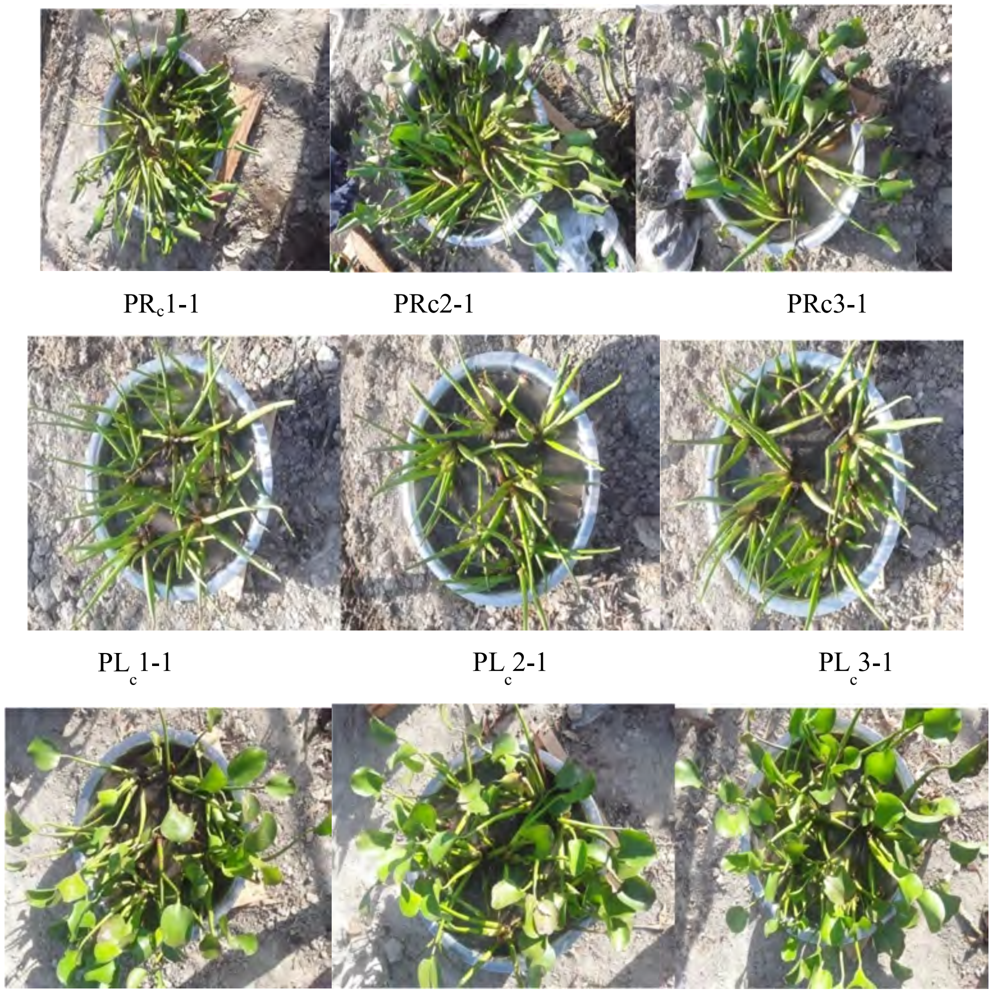

Figure 3. Setups of the pans with root clipped plants (top row), leaf clipped plants (middle row) and normal (unclipped) plants (bottom row).

2.4. Data collection

Data collection was done in March which is the warmest month in Zeway, with the average maximum temperature of 26.86 °C. The average relative humidity in March and April is 50%. Initial water hyacinth plant masses placed in each experimental unit were measured using digital balance. Mass measurements were also repeated at the end of the experiment. The masses of the clipped roots and leaves were also measured as indicated in Table 1

Table 1: Initial masses of treatments and the control plants in each pan.

Treatment	Replication code	Plant mass (kg)	Clipped mass (kg)	Final mass (kg) (Difference)
Normal plants (C)	C1	2.50	0.00	2.50
	C2	2.55	0.00	2.55
	C3	2.50	0.00	2.50
	RC1	2.50	1.30	1.20

Clipped Roots (RC)	RC2	2.50	1.40	1.10
	RC3	2.50	1.35	1.15
Clipped Leaves(LC)	LC1	2.55	0.10	2.45
	LC2	2.50	0.10	2.40
	LC3	2.55	0.10	2.45

In this study, data was gathered over a period of seventeen days. Measurements of water losses from all experimental units were determined by measuring the new depth, finding the depth difference and using the slope of calibration equation to evaluate the water volume loss from the depth difference. Measurements were made every third day for the first 10 days and every second day for the remaining 8 days. Known volume of water was added into each pan whenever the water level dropped after which the new depth measurements were made.

Depth measurement of each pan was done two times (one before and one after) whenever additional water was added (see Appendix). Measurements were conducted from March 21 up to April 7. There were eight data of measured depth of water level, out of which the first 3 were taken in 3-day gap and the remaining five were taken in 2-day gap. The reason to switch from 3-day gap to 2-day gap was due to high evaporation rate that necessitated water refill when the gap was 3 days. In order to find the volume of water evaporated, first the measured depth data were converted into change in depth and the depth was changed to volume of water using the calibration equation.

During each measurement day, pictures of each plant sample were taken and the day and sample number was recorded as shown in Table 2. The pictures were for qualitative observations of the condition of the plants, especially the changes of plants with clipped roots and clipped leaves. Secondary data that satisfy the modified and optimized Temesgen Melesse's equation (Mengistu and Amente, 2020) were obtained from Hawasa meteorological station.

Table 2. Codes of pictures taken and the days on which measurements were taken.

Treatment	Replication (code)	Measurement period (on day)							
		1	4	7	10	12	14	16	18
Clipped roots (RC)	R_c1	PRC1-1	PRC1-4	PRC1-7	PRC1-10	PRC1-12	PRC1-14	PRC1-16	PRC1-18
	R_c2	PRC2-1	PRC2-4	PRC2-7	PRC2-10	PRC2-12	PRC2-14	PRC2-16	PRC2-18
	R_c3	PRC3-1	PRC3-4	PRC3-7	PRC3-10	PRC3-12	PRC3-14	PRC3-16	PRC3-18
Clipped	LC1	PLC1-	PLC1-	PLC1-	PLC1-	PLC1-	PLC1-	PLC1-	PLC1-

leaves		1	4	7	10	12	14	16	18
(LC)	LC2	PLC2-1	PLC2-4	PLC2-7	PLC2-10	PLC2-12	PLC2-14	PLC2-16	PLC2-18
	LC3	PLC3-1	PLC3-4	PLC3-7	PLC3-10	PLC3-12	PLC3-14	PLC3-16	PLC3-18
Normal plant (control) (C)	C1	PC1-1	PC1-4	PC1-7	PC1-10	PC1-12	PC1-14	PC1-16	PC1-18
	C2	PC2-1	PC2-4	PC2-7	PC2-10	PC2-12	PC2-14	PC2-16	PC2-18
	C3	PC3-1	PC3-4	PC3-7	PC3-10	PC3-12	PC3-14	PC3-16	PC3-18

At the end of the experiment (day18), the masses of the plants of each experimental unit were measured and recorded. In addition, the volume of water that remained in the pan were also measured and recorded. The difference between ET and E gives the amount of water lost by transpiration, according to Eq. 2.3b.

2.5. Data analysis

The data obtained was analyzed by using Microsoft office excel 2007 Statistical analyses were also made using Microsoft office excel.

Evapotranspiration can be estimated using empirical equations such as Penman-Monteith equation but when there is limited data in terms of input variables, from among the temperature-based methods the modified and optimized Temesgen-Melesse's method is an option since it has been applied on data of several meteorological stations in Ethiopia (Mengistu and Amente, 2019). It can also be estimated from pan evaporation measurement using a correction factor.

2.5.1. Modified and optimized Temesgen-Melesse's temperature-based ET method

From among temperature based methods the modified and optimized Temesgen-Melesse's temperature-based method is one of the simplest. The benefit of this method is that it uses only one meteorological variable, maximum temperature of the location. Correction and modification were made on TM-method and the corrections were done in two stages, first by replacing the variables T_{mx} with average maximum temperature ($\bar{T}_{mx}$), which is a constant, and second by replacing the values of 2.5 with a value n that could be optimized (Mengistu and Amente, 2020). The equation is expressed as

$$TM_{mod\ optET} = \frac{T_{mx}^{n_{opt}}}{48\,\bar{T}_{mx} - 330} \quad (2.1)$$

Where $TM_{modoptET}$ is the modified and optimized Temesgen-Melese's evapotranspiration (mm/day), $\bar{T}_{mx}$ is mean maximum temperature (°C) of the location, T_{mx} is daily maximum temperature during the study period, and n^{opt} is optimized (calibrated) power parameter.

2.5.2. Estimation of ET using pan evaporation data

The crop coefficient can be obtained from the FAO tabulated data provided that the plant or crop under investigation is listed in the table. If that is not the case, results of previous studies are considered and the value that corresponds to the nearest agro-climatic condition is considered. The Equation has the form of

$$ET_p = C_p E_{pan} \quad (2.2)$$

Where: ET_p is the plant evapotranspiration that is to be determined (mm/day), ET_{pan} is pan evaporation data (mm/day) and C_p is the crop factor that is obtained from table (if available) or from previous study.

For pan evaporation the loss indicates evaporative loss (E). For a pan containing aquatic plant with water, the difference gives evapotranspiration (ET). For the same sized pan, the difference between ET and E gives the amount of water lost by transpiration, i.e.

$$T = ET - E. \qquad (2.3a)$$

For measurements taken in time gap of n days, daily transpiration (T_d) is obtained by dividing T with n.

$$T_d = \frac{T}{n}. \qquad (2.3b)$$

2.5.3. Crop/plant Coefficient Concept

Crop coefficient (K_c) is a constant that is usually determined experimentally for a given crop. The K_c values represent the integrated effects of numerous factors such as changes in leaf area, plant height, crop characteristics, etc. Factors affecting the value of the crop coefficient (K_c) are mainly the crop characteristics, crop planting or sowing date, rate of crop development, length of growing season and climatic conditions. By using the TM modified and optimized-ET instead of FAO Penman-Monteith definition for ET_O, crop coefficients can be calculated at research sites by relating the measured crop evapotranspiration (ET_c) with the calculated ET_o. K_c is defined as the ratio of the evapotranspiration of the crop (ET_c) to the potential evapotranspiration (ET_o).

$$K_c = \frac{ET_c}{ET_o} \qquad (2.4)$$

Both evapotranspirations are given in the same units and therefore K_c is a unitless number. The differences in the crop canopy and aerodynamic resistance relative to the hypothetical reference crop are accounted for within the crop coefficient. The K_c factor serves as an aggregation of the physical and physiological differences between crops and the reference definition.

3. Results and Discussion

The first part of the result deals with the statistical comparisons of transpiration rates from the clipped and normal water hyacinth plants. Crop factor (C_p) values obtained from ET and pan evaporation and crop coefficient (K_c) obtained from measured ET and empirically calculated ET is also going to be compared statistically.

3.1. Transpiration rates of the treatments and the control

In order to calculate the transpiration rates of the treatment groups and the control, it was necessary to know the volume of water lost by evapotranspiration and evaporation. This measurement was carried out indirectly using the depths of water in the pans and using the calibration equation.

3.1.1. Measured pan evaporation

In order to calculate the rate of transpiration from the treatments (water hyacinth with clipped roots and clipped leaves) and that of the control (unclipped plant), equations 2.3a and 2.3b were used. But to use the equations it is necessary to calculate the pan evaporation (E) and the ETs of the treatment groups, separately. Table 3 shows the pan evaporation rates (calculated from water level depths).

Table 3: Pan evaporation rates tabulated with the mean, standard deviation (SD), and coefficient of variation (CV).

Gap (d)	R1, E (L)	R2,E (L)	R3, E (L)	mean E(L)	SD	CV
3	2.38	2.63	2.29	2.43	0.18	0.07
3	1.53	1.44	1.70	1.56	0.13	0.08
3	1.87	2.12	1.95	1.98	0.13	0.07
2	2.42	2.80	2.04	2.42	0.38	0.16
2	2.17	1.91	2.17	2.08	0.15	0.07
2	2.55	2.55	2.42	2.50	0.07	0.03
2	2.04	2.29	1.53	1.95	0.39	0.20
Total evaporation over 17 days (L)				14.93		
Daily mean evaporation (L)				0.88		

R1, R2, and R3 represent replications.

As observed in the table, the mean daily evaporation of the 17 days is 0.88 L d^{-1}. Since we are going to use the same unit throughout, there is no need to convert to mm d^{-1} at this time.

3.1.2. Transpiration values of the control group

Evapotranspiration of the control group was also measured with three replications and the calculation, of ET was performed by the same method as mentioned in 3.1.1.The transpiration rate of the control group was calculated by subtracting the pan evaporation value from the ET as indicated in Eq. 2.3a. Table 4 summarizes the transpiration of the control group.

Table 4: Transpiration of the control group shown with the daily mean and the ratio, T/E

Gap (d)	Mean control ET (L)	Pan E (L).	Control T (L)	T/E
3	6.14	2.43	3.71	1.5
3	6.45	1.56	4.90	3.1
3	5.60	1.98	3.62	1.8
2	4.25	2.42	1.83	0.8
2	5.18	2.08	3.10	1.5
2	5.56	2.50	3.06	1.2
2	5.05	1.95	3.10	1.6
Total	38.24	14.93	23.31	11.55
Daily mean	2.25	0.88	1.37	0.68
T/E			1.56	

The amount of transpiration rates are obtained from the difference between the evapotranspiration of the control group and the pure water evaporation measured from pan measurement method. The table shows that the daily mean transpiration is higher than the pan evaporation by a factor of 1.56 (= 1.37/0.88). It indicates that the plant transpires more water than free water evaporation. The combined daily mean transpiration and evaporation from the control is 2.25 L and this is greater than free water evaporation by a factor of 2.56 (=2.25/0.88).

Strictly speaking, in the control group the water hyacinth plant covers large area of the surface of the pan. This limits the amount of solar radiation that falls on the water underneath the plants (shading effect) such that the amount of evaporation from underneath the plant is very low. Therefore much of the ET measured is from transpiration and only a small fraction comes from evaporation. That causes the *T/E* value to be undermined.

The result of 2.25 L d^{-1} obtained here for the control group comes to 7.96 mm d^{-1}. The result obtained here is about one third of the result obtained by Johansson (1977) during a brief experiment in Hale reservoir in the Pangani River, Tanzania, in May 1977. Furthermore, the ratio of T/E obtained by the same indicated 4.7 while in our case it is 1.56. The difference could be attributed to the very high maximum temperature (36°C) and slightly lower daytime relative humidity (35%) during the time of the experiment compared to ours (maximum temperature of 31°C on average and humidity of nearly 50%). The other point is that Johansson covered the pan with plastic to reduce evaporation, which we believe has introduced more heat into the system due to the greenhouse effect. That must have put the plant under extreme heat stress and that must have increased the transpiration rate.

Daniel (2009) in his research on water surface covered by water hyacinth in Aba Samuel wetland, Ethiopia, obtained water loss of 18.57 mm and 12.33 mmd^{-1} during dry and wet seasons, respectively. This value is still higher than what was obtained in this study.

3.1.3. Transpiration of the treatment groups

In this part, the mean transpiration rates of the treatments with clipped roots and clipped leaves are shown together (Table 5). All the calculations were done in the same way as done in subsection 3.1.2.

Table 5: ET and transpiration rates of root-clipped and leaf-clipped plants.

Gap (d)	Mean RC ET (L)	Pan E (L)	RC T (L)	Mean LC ET (L)	LC T (L)
3	2.519	2.434	0.085	4.05	1.61
3	1.500	1.557	-0.057	3.45	1.90
3	1.896	1.981	-0.085	3.28	1.30
2	1.868	2.420	-0.552	2.29	-0.13
2	2.123	2.080	0.042	4.37	2.29
2	2.547	2.505	0.042	4.37	1.87
2	1.910	1.953	-0.042	3.91	1.95
Total	14.36	14.93	-0.57	25.73	10.80
Daily mean	0.85	0.88	-0.03	1.51	0.64
T/E			-0.03		0.72

Table 5 indicates nearly zero (-0.03) transpiration from the plants with clipped roots. That means, there was no transpiration at all for this group since T/E is also almost nonexistent. Plants with clipped leaves showed transpiration rate which is lower than free water evaporation (~ 73%). For these plants the transpiration rate accounted for ~ 47% of the total ET. Thus despite the fact that the leaves are nonexistent there was still transpiration of a little less than half of the total ET for these plants. The result indicates that root clipping (water input) works better than leaf clipping (transpiration) when it comes to conserving water loss by water hyacinth. Looking at the two treatments and the control together reveals how transpiration exceeds the pan evaporation and how negligible the clipped-root plant transpiration is (Fig. 3).

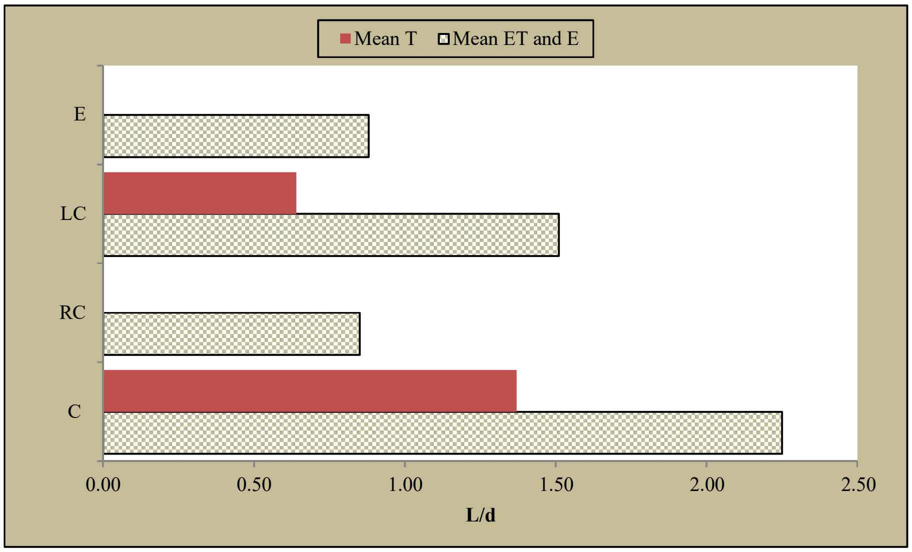

Figure 3: Mean daily amount of water freely evaporated (E), transpired and evapotranspired from the two treatments (LC and RC) and form the control (C), respectively.

Statistical comparison is also necessary in order to know whether the treatments significantly varied from the control or not. Table 6a shows the results of one-way ANOVA and Table 6b the pair comparisons.

Table 6a: One-way ANOVA to show transpiration differences between the treatments and the control

Source	df	SS	MS	F	Fc	Significance
Treatment	2	38	19.16	38.6	3.55	S*
Error	18	8.9	0.50			
Total	20	47				

The table shows significant difference at p = 0.05 level. Fc is critical F value at 0.05 for treatment MS degree of freedom (df) of 2 and and error MS df of 18

Table 6b. Pair comparisons made using critical difference (CD) method

Btn	SE(d)	t	CD= t*SE(d)	PD	PD - CD	D/ND
C & LC	0.38	2.05	0.78	3.31	2.53	D

C & RC	0.38	2.05	0.78	1.79	1.00	D
LC & RC	0.38	2.05	0.78	1.52	0.73	D

Pair comparisons using LSD was calculated using SE(d) =2(0.51)/7 and the critical t value at 0.05 level and error degree of freedom of 18. PD represents the pair difference and D/ND represents significant difference/non-significant difference. Since all the values under PD – CD are positive, the pair comparisons show significant differences between the control and LC, the control and RC, and between LC and RC. That means, all the three are different from each other. This clearly indicates that clipping the roots of the plant has great significance in reducing the rate of transpiration at least in the short-term.

3.2. Calculated Evaporation Coefficients (Crop Factor, C_p)

The crop factor of a plant is the ratio of plant ET and free water evaporation (Eq. 2.2). For instance, the value of C_p for the normal plant (control) is calculated as:-

$$C_p = \frac{ET}{E} = \frac{2.25}{0.88} = 2.56.$$

It is a unitless quantity so long as the same units are used in both cases. The result for each of the measurement days is shown in Table 7.

Table 7: Crop factor values of the two treatments and the control group.

Day	Control C_p	RC C_p	LC C_p
3	2.52	1.03	1.66
6	4.14	0.96	2.22
9	2.83	0.96	1.66
11	1.76	0.77	0.95
13	2.49	1.02	2.10
15	2.22	1.02	1.75
17	2.59	0.98	2.00
Total	18.55	6.74	12.33
Daily mean	1.09	0.40	0.73

The table clearly shows that the control group C_p is higher than those of the two treatments. The fact that the control C_p is nearly equal to one implies that the contribution of evaporation to ET is almost nonexistent and ET is almost equal to transpiration. The C_p values of the treatments are less than one and it indicates that ET is less than E, which means, either transpiration is nonexistent or very low, and evaporation is also reduced in the case of the treatments due to the shading effects of the plants.

Little (1967) conducted controlled experiments for on water hyacinth grown in 24 cm diameter jars in a greenhouse in England for over 40 days in spring and 20 days in early summer in August 1966. The results he obtained for ET/E were 4.2 and 5.4 with shield and without shield plants, respectively. The result from this study shows about 2.25, which means, it is about a half of the result obtained by little.

In order to see whether there is significant difference or not comparisons were made using one-way ANOVA and the result is shown in Table 8a.

Table 8a: ANOVA table to compare crop factor values of the two treatments and the control.

Source	df	SS	MS	F	Fc	Significance
Treatment	2	10	4.983	20.3	3.55	S*
Error	18	4.4	0.245			
Total	20	14				

The table shows significant difference at $p = 0.05$ level.

Table 8b. Pair comparisons made using critical difference (CD) method

Btn	SE(d)	t	CD= t*SE(d)	PD	PD - CD	D/ND
C & LC	0.38	2.05	0.78	1.7	0.91	D
C & RC	0.38	2.05	0.78	0.9	0.10	D
LC & RC	0.38	2.05	0.78	0.799	0.01	D

Pair comparisons using LSD were calculated using SE(d) =2(0.51)/7 and the critical t value at 0.05 level and error degree of freedom of 18. PD represents the pair difference and D/ND represents significant difference/nonsignificant difference. Since all the values under PD – CD are positive the pair comparisonsThe table show that there is are significant difference among the three. Pair comparisons among the three also show that pair-wise the three are significantly different from each other.

3.3. Calculation of K_c of the two treatments and the control

In order to obtain K_c it is necessary to find ET of the area using the empirical equation. Thus the first step in this section is to determine the ET using equation 2.4.

3.3.1. Estimation of ET using the modified and optimized TM method

The estimation of ET using the modified and optimized TM method requires three parameters, two geographical parameters of latitude and altitude and meteorological parameters that are mean maximum temperature of the location and daily maximum temperature values of the area during the study period. Calculation was done using Eq. 2.1. Maximum temperatures of Zeway data for the duration of the experiment were obtained from Hawasa meteorological station, Ethiopia. The optimized *n* value (n^{opt}) and the $\overline{T}_{mx}$ values were obtained from the previous works of Mengistu and Amente (2020). The optimized *n* (n^{opt}) for Zeway station made use of latitude, 7.56^{o}N, altitude, 1640 m, 30-year average maximum temperature of Zeway that is 26.86^{o}C, and the result obtained for the optimized n is 2.494 (Mengistu and Amente, 2020). Based on these values, the calculated ET in (mm/day) during the 17 days is shown in Table 9.

Table 9. Estimation of ET by the modified and optimized TM method.

T_{mx} (^{o}C)	Mean T_{mx}	ET (mm/d)

29.8	26.86	4.88
30.2	26.86	5.05
31.8	26.86	5.74
32	26.86	5.83
32.4	26.86	6.02
31.8	26.86	5.74
30.8	26.86	5.30
28.8	26.86	4.49
31.6	26.86	5.65
31.2	26.86	5.48
31.4	26.86	5.56
32.2	26.86	5.92
31.8	26.86	5.74
31.4	26.86	5.56
32	26.86	5.83
31.8	26.86	5.74
32.8	26.86	6.20
Mean ET		5.60
SD		0.43

3.3.2. Calculation of K_c

Crop coefficient is calculated using the mean ET of the area during the 17 days (5.60 mm d^{-1}) and Eq. 2.4. Since the measured ET is in liters conversion is necessary for unit compatibility. For this, the liter is converted to mm after which the quantity is divided by the top surface area of the pan. That means,

$$ET_{mm} = \frac{ET_L \times 10^6}{\pi\left(\frac{D}{2}\right)^2} \qquad (3.1)$$

In the equation *D* is the diameter of the pan (60 cm), ET_L is the measured ET in liters, and ET_{mm} is the same ET in mm.

T

The diameter of the pan is 60 cm (= 600 mm) and therefore

$$ET_{mm} = \frac{ET_L \times 10^6}{\pi(300)^2} = \frac{ET_L \times 10^6}{282600}$$

$$= 3.5386ET_L \qquad (3.2)$$

Thereafter it is possible to use Eq. 2.4 to find K_c as

$$K_c = \frac{ET_{mm}}{ET_o} = \frac{3.539ET_L}{5.60\ mm} = \frac{3.54ET_L}{5.60\ mm}.$$

Table 10 shows the crop coefficient values of the two treatments and the control.

Table 10: crop coefficient values of the two treatments and the control

	ET(L)	ET (mm)	ET_o (mm)	K_c
C	2.25	7.96	5.6	1.42
RC	0.85	3.01	5.6	0.54

LC	1.51	5.34	5.6	0.95

The three K_c values are different from each other; that of the control are by over one and half times greater than that of the treatment with clipped leaves and almost three times that of the treatment with clipped roots. The value obtained for the control shows that the plant ET is higher than the potential ET of the area.

Dooenboss and Pruitt (1992) obtained crop coefficient value of 1.1 for water hyacinth under light to moderate wind and 1.15 under strong wind. The result obtained in this work is higher by about 0.3. The difference could be due to the size and type differences of the containers used or the extent to which the plant covers the pan. It could also be due to differences in maturity levels of the plants. More coverage of the container by the plants indicates reduced solar radiation reaching the water surface underneath the plant that in turn reduces evaporation and increases transpiration. Smaller size container may experience reduced obstacle to wind that implies increased aerodynamic contribution to the ET.

3.3.3. Weight gain/loss by the plants

Table 11 shows the initial weight which was measured on the first day, the final weight measured on the last day and weight differences of the control, of plants with clipped-leaves and plant with clipped-roots (the two treatments). The pictures of the initial and final day of the plants are also shown in Figure 4 for illustration.

Table 11. Measured initial and final masses of the control(C) ,RC, and LC.

Treatment	Replication code	Initial weight (kg) (first day)	Final weight (kg) (last day)	Difference (Kg) (gained weight)
Normal plants (C)	C1	2.50	4.30	1.80
	C2	2.55	5.20	2.65
	C3	2.50	4.20	1.70
Clipped Roots (RC)	RC1	1.20	1.40	0.20
	RC2	1.10	1.60	0.50
	RC3	1.15	1.30	0.15
Clipped Leaves(LC)	LC1	2.45	4.40	1.95
	LC2	2.40	4.60	2.20
	LC3	2.45	5.05	2.60

Clipped roots	PR$_c$1-1	PRc2-1	PRc3-1	DAY 1 and Day 18 (pictures taken)
				
	PR$_c$1-18	PRc2-18	PRc3-18	

			
Clipped leaves	PL_c1-1	PL_c2-1	PL_c3-1
			
	PL_c1-18	PL_c2-18	PL_c3-18
			
Control group	PC1-1	PC2-1	PC3-1
			
	PC1-18	PC2-18	PC3-18
			

Figure 4: The first and the last day pictures of the RC plants, LC plants and C (unclipped) plants.

All the plants showed weight gain regardless of the initial conditions. The fact that plants with clipped-roots and clipped-leaves gained weight indicates that the plants have managed to develop roots and leaves, respectively. It implies that in the long run, the plants could recover and the effect of clipping is a short term solution to the problem enhanced transpiration by the plant.

4. Conclusion and Implications

The study was conducted to estimate and compare the transpiration of *Eichhornia crassipes (*water hyacinth), for normal, clipped-roots and clipped-leaves plants. The samples were obtained from Zeway Lake. The experiment was conducted for a total of 17 days. As observed from result plants with clipped-roots did not show any transpiration and the ones with clipped-leaves had transpiration rate that accounted for 47% of the total ET. C_p values were 37% and 67% of the normal plant for the plants with clipped-roots and clipped-leaves, respectively. K_c values of the clipped roots and clipped leaves plants were 38% and 67% of that of the normal plant, respectively.

From this study we can conclude that there were statistically significant differences in terms of the amount of transpiration, C_p and K_c between the treatments and the control and between the two treatments as well. Root clipping is more effective in reducing transpiration rate than clipping the leaves at least in the short-term. Root clipping is also advantageous in reducing the total mass gain of the plant at the end of the experiment, which means it would be easier to remove the plants with clipped roots from water bodies.

The work done in this particular case gives insight into alternative ways to fight the plant instead of using the usual manpower and mechanical means of removing the plant from water bodies. Removing the plant becomes easier after the plant is somewhat stressed initially so as to reduce its weight. The study shows the importance of focussing on the water intakerather than the water output. Thus, in order to adversely affect the weed, it is necessary to limit the water intake of the plant. For instance, wrapping the root of the plant with say, disposable plastic wrap or floating the root of the plant by using used highland bottles can deny the accessibility of the plant to water.

Conflict of Interests

The authors declare that there's no conflict of interest concerning to the publication of this article

References

Adeyemi, O. and Osubor, C. C. (2016). Assessments of nutritional quality of water hyacinth leaf protein concentrate. *The Egyptian Journal of Aquatic Research*, 42(3): 269–272.

Arp, R.S., Fraser, G. C., and Hill, M. (2017). Quantifying the water savings benefit of water hyacinth (*Eichhornia crassipes)* control in the Vaalharts Irrigation Scheme: Vital Repository 7.0.*Water SA*, *43*(1): 58–66.

Barrett, S. C. 1980. Sexual reproduction in *Eichhornia crassipes* (water hyacinth). II. Seed production in natural populations. *Journal of Applied Ecology*, 113-124.

Bhattacharya, A., Haldar, S., and Chatterjee, P. K. (2015).Geographical distribution and physiology of water hyacinth (*Eichhornia crassipses*) the invasive hydrophyte and a biomass for producing xylitol. *International Journal of Chem. Tech. Research*, *7*(4): 1849-1861.

Daniel, W. (2009). Potential of Water Hyacinth (*Eichhornia Crassipes* (Mart.) solms) For the Removal of Chromium from Waste Water in Artificial Pond System.

Daniel, W., Feleke, Z. and Seyoum, L. (2011). Potential of water hyacinth (*Eichhornia crassipes* (*Mart.)* Solms) for the removal of chromium from tannery effluent in constructed pond system. *SINET, Ethiop. J. Sci.,* 34(1): 49–62.

Dereje Alemu, 2022. Determination of the Optimum Mass of Clay Binding Agent in the Briquette Production from Water Hyacinth, Unpublished MSc. Thesis, Haramaya University.

Dooenboss, J., and Pruitt, W.O. (1992). Crop Water Requirements (FAO Irrigation and Drainage Paper 24) (Revised 19), Rome: Food and Agriculture Organization of the United Nations.

Firehun, Y., Struik, P. C., Lantinga, E. A., and Taye, T. (2014). Water hyacinth in the Rift Valley water bodies of Ethiopia: Its distribution, socio-economic importance and management. Management of water hyacinth *(Eichhornia crassipes [Mart.] Solms) using bioagents in the Rift Valley of Ethiopia*, 17.

Gichuki, J., Omondi, R., Boera, P., Okorut, T., Matano, A. S., Jembe, T., and Ofulla, A. (2012).Water Hyacinth (*Eichhornia crassipes*) (Mart.) Solms-Laubach dynamics and succession in the Nyanza Gulf of Lake Victoria (East Africa): implications for water quality and biodiversity conservation. *The Scientific World Journal*, *2012*.

Goshu, G., Byamukama, D., Manafi, M., Kirschner, A. K., and Farnleitner, A. H. (2010).A pilot study on anthropogenic faecal pollution impact in Bahir Dar Gulf of Lake Tana, Northern Ethiopia. *Ecohydrology and Hydrobiology*, *10*(2-4): 271-279.

Habtamu, M., Tadesse, M. and Dessalew, T. (2020).Water quality and transpiration responses of *Eichornia crassipes* at Lake Tana, Ethiopia. *Sustainable Water Resources Management*, 6: 42.

Johansson, D. (1977).The water hyacinth in the Pangani River: Tanzania - Ecology and effects on hydroelectric power station. *Great Ruaha Power Project, Tanzania.*

Ligdi, E. E., El Kahloun, M. and Meire, P. (2010). Ecohydrological status of Lake Tana A shallow highland lake in the Blue Nile (Abbay) basin in Ethiopia. *Ecohydrology and Hydrobiology*, *10*(2-4): 109-122.

Little, E. C. S. 1967.Progress report on transpiration of some tropical water weeds. *International Journal of Pest Management C*, *13*(2): 127-132.

Marlin, D., Hill, M. P., and Byrne, M. J. (2013).Interactions within pairs of biological control agents on water hyacinth, (*Eichhornia crassipes*).*Biological Control*, *67*(3): 483-490.

Mengistu, B., and Amente, G. (2019). Three methods of estimating the power of maximum temperature in TM–ET estimation equation. *SN Applied Sciences*, *1*(11): 1-26.

Mengistu, B., and Amente, G. (2020). Reformulating and testing Temesgen-Melesse's temperature-based evapotranspiration estimation method. *Heliyon*, *6*(1): e02954.

Ndimele, P. E., Kumolu-Johnson, C. A., and Anetekhai, M. A. (2011). The invasive aquatic macrophyte, water hyacinth {*Eichhornia crassipes* (Mart.) Solm-Laubach: Pontedericeae}: problems and prospects. Research Journal of Environmental Sciences, 5(6): 509.

Sindhu, R., Binod, P., Pandey, A., Madhavan, A., Alphonsa, J. A., Vivek, N. and Faraco, V. (2017). Water hyacinth a potential source for value addition: an overview. *Bioresource technology*, *230*: 152-162.

Tegene, S., and Ayele, N.(2014).Prevalence and intensity of water hyacinth infestation in the water bodies of Rift Valley, Ethiopia. *The Journal of Agriculture and*

Natural Resources Science, *1*(2): 118-126.

Villamagna, A. M., and Murphy, B. R. (2010). Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes):* a review. *Freshwater biology*, *55*(2): 282-298.

Wondie, Z. (2013). Assessment of water hyacinth (*Eichhornia crassipes* (Mart) Solms) in relation to water quality, composition and abundance of plankton and macro-invertebrates in the north-eastern part of Lake Tana, Ethiopia.*(Doctoral dissertation, M. Sc. Thesis, Addis Ababa University, Addis Ababa).*

Yigrem, M. and Yohannes, M. (2019). Distribution, Impacts and Management Option for Water Hyacinth (*Eichhornia Crassipes* [Mart.] solms) in Ethiopia: A Review. *Journal of Advances in Agriculture.*10.

Yu, H., Shen, N., Yu, D., and Liu, C. 2019. Clonal integration increases growth performance and expansion of *Eichhornia crassipes* in littoral zones: A simulation study. *Environmental and Experimental Botany*, *159*:13-22.