



WATER HYACINTH GROWTH RATE IN EGYPTIAN IRRIGATION NETWORKS (AN EXPERIMENTAL APPROACH)

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ABSTRACT

Water hyacinth infestation along irrigation and drainage networks in Egypt is one of the utmost problems, which are facing our limited water resources. Water hyacinth growth in open channels reduces the designed channel cross section, hinders the water flow, decreases water levels, increases human diseases, and averts water from reaching canal ends. Also a significant amount of water is lost by evapotranspiration through such weeds. The purpose of this research is to study experimentally, the growth rate of water hyacinth in open channels in Egypt. The research also aims to develop a general equation to describe the growth rate of water hyacinth according to the year seasons. To carry out this study, 120 days experimental work was carried out harmonious with theoretical approach, for different factors of water hyacinth and time. It could be concluded that, the growth rate of water hyacinth, the maintenance time of open channels and the critical time for weed removal can be calculated in accordance with the obtained equations for specific seasons of the year.

Keywords: Aquatic Weed Infestation – Water Hyacinth - Growth Rate

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1 INTRODUCTION

Egypt is one of the countries which are facing great challenges due to their limited water resources, for this reason water pollution with different types of pollutants is an influential factor in the Egyptian water policy and budget. One of the different types of pollutants is floating weeds which affect in channel boundaries, bed morphology, and hydraulic efficiency of open channels. Amanda R. et al, (2011) stated that, water hyacinth is thought to be cold-sensitive and unable to survive temperatures below 20 degrees F. These plants obtain their nutrients directly from the water and have been used in wastewater treatment facilities. They prefer and grow most prolifically in nutrient-enriched waters. New plant populations often form rooted parent plants and wind movements and currents help contribute to their wide distribution. Linked plants form dense rafts in the water. The fibrous root system provides nesting habitat for invertebrates and insects. Leaf blades and petioles are occasionally used by coots. However, whatever benefits this plant provides to wildlife are greatly overshadowed by the environmental invasiveness of this noxious species. Water hyacinth reproduces sexually by seeds and vegetative by budding and stolon production. Daughter plants sprout from the stolons and doubling times have been reported of 6-18 days. The seeds can germinate in a few days or remain dormant for 15-20 years. They usually sink and remain dormant until periods of stress (droughts). Upon reflooding, the seeds often germinate and renew the growth cycle. (Gopal, 1987) reported that water hyacinth has been spread around the world by humans outside its native range in South America it can quickly grow

to very high densities (over 60 kg/m²), thereby completely clogging water-bodies. This has negative effects on the environment, human health and economic development. The productive potential of water hyacinth is reported to be tremendous. Hussein, (1992) reported that in 50 days, a single plant produces 43 offsets which produce 1894 offsets in another 50 days and after 200 days from the start, one expects to have 3,418,800 new offsets. He indicated that about 20 dry tons per hectare can be harvested from standing water hyacinth plants. Penfound, W.T., Earle, T.T., (1948) studied the biology of the waterhyacinth, the study stated that using initial number of weeds equal 10 water hyacinth plants produced (1610) offsets after three months, also the study stated that the water hyacinth plant can be doubled every two weeks if the environmental conditions are better. (Bashir and Bennett, 1986; Julien and Orapa, 1999) showed that the weed has been successfully controlled using classical biological control agents in many locations, including the White Nile, India and Papua New Guinea. The most appropriate management strategy is natural ways obvious, and is clearly dependent on how the plant responds to different environments. Models have been used to explore water hyacinth growth in different specific studies like, determinants and patterns of population growth in water hyacinth by (John R. Wilson, et al., 2005), the effect of the weed on the nutrient regime of a lake eco system by (Mitsch, 1975); the plant's potential as a bio fuel by (Lorber et al., 1984); the plant's potential for sewage treatment by (Polprasert and Khatiwada, 1998); Productivity of the water hyacinth *Eichhornia crassipes* by (Bock, J.H., 1969); The water hyacinth in the Nile System, Egypt, by (Batanouny, K.H., El-Fiky, A.M., 1975); and how to optimize a mechanical control program by (Guitierrez et al., 2000). All these models are variations of logistic growth in the plant, and are dependent on environmental factors. To aid the understanding of which factor causes variations in growth, it has been estimated the parameters of water hyacinth growth from a wide range of literature sources. In this paper it has been concentrated on the growth rate of water hyacinth, the area occupied by floating weeds during a period of time, and the number of floating weeds during a period of time in open channels in Egypt. For this purpose the authors applied mathematical modeling both as a method for research and to summarize our findings in a simple, predictive tool. In the discussion, we cover other factors that may limit water hyacinth growth, and discuss how these affect the interpretation of the model.

2 OBJECTIVES

The purpose of this research is to study experimentally, the growth rate of water hyacinth in open channels in Egypt. The research also aims to develop a general equation to describe the growth rate of water hyacinth according to the year seasons. The research presents a comparison for water hyacinth growth in Egypt and some countries around the world; also it offers support for decision makers to choose the appropriate time for open channel maintenance, and the critical time for weed removal.

3 EXPONENTIAL AND LOGISTIC GROWTH MODEL

Due the lack of information about the growth rate of floating weeds in Egypt, and there is no equations to express about this growth. Therefore this paper will present new equations to deal with this problem. It is obvious that the rate of change of floating weed growth ($\frac{dw_g}{dt}$) is proportional to the initial growth of floating weeds w_0 Where:

$$\frac{dw_g}{dt} \propto w_0 \dots\dots\dots (1)$$

Consequently, equation (1) will be:-

$$\frac{dw_g}{dt} = kw_0 \dots\dots\dots (2)$$

Where:-

k= constant depends on year seasons (winter and summer).

Integration should be done to get p_w, then the above equation will be:-

$$\frac{dw_g}{w_0} = k.dt \dots\dots\dots (3)$$

Integration for growth will be from (0) to (p_w) and for time will be from (0) to (t).

$$\int_0^{w_g} \frac{dw_g}{w_0} = \int_0^t k.dt \dots\dots\dots (4)$$

Equation (4) will be:-

$$\ln w_g = k.t + c \dots\dots\dots (5)$$

Solving for w_g equation (5) will be:-

$$e^{\ln w_g} = e^{k.t+c} \dots\dots\dots (6)$$

w_g = e^{kt} .e^c, where (e^c) is constant Equation (6) will be:-

$$w_g = (c)e^{kt} \dots\dots\dots (7)$$

At the initial conditions time (t) equal zero then:

w_g = (c)e⁰, where e⁰ = 1, then c = w₀ at t = 0, Equation (4) will be:-

$$w_g = w_0 \cdot e^{kt} \dots\dots\dots (8)$$

Where:-

- w_g = the growth of floating weeds
- w₀ = the initial growth of floating weeds

Equation (8) expresses the number of total floating weeds (W_g) in an occupied area (A_w). For open channel maintenance the contractors aren't in numbers of weeds but in areas of floating weeds. Therefore the purpose of this paper is to help the ministry of irrigation to assess the accurate area of weed infestation during different seasons of the year, which in return means effort and money. Getting these objectives needs to study the area of floating weeds, Where area

of floating weeds (A_w) is a function of floating weed growth(w_g). Also (A_w) is a function of average diameter of floating weeds (d_w). Then the initial area of floating weeds (A_{w0}) will be:-

$$A_{w0} = n_0 a_{w0} \dots\dots\dots (9)$$

Where:

n_o = initial number of floating weeds in an specified area .
 a_{w0} = area of one plant of floating weeds.

The percentage of area covered by floating weeds on water surface can be obtained from the study which had been carried out by (Reda M.A. et. al in 2007). The percentage is called area factor (a_f), where it is 0.92 % of area occupied by weeds. Then the initial area of floating weeds

(A_{w0}) will be:-

$$Aw_0 = a_f n_0 a_{w0} \dots\dots\dots (10)$$

The general equation which can represent growth of floating weeds will be:-

$$Wg = a_f n_0 a_{w0} \cdot e^{kt} \dots\dots\dots (11)$$

Where:-

w_g = the growth area of floating weeds;
 n_o = initial number of floating weeds in an specified area;
 a_{w0} = area of one plant of floating weeds;
 t = time elapsed for growth = t_2-t_1
 t_1 = initial time for growth
 t_2 = specified time for growth
 a_f = area factor = 0.92
 k = constant depends on time of year seasons;

Where:-

$k=k_1$ (from December to February)
 $k=k_2$ (from February to April)
 $k=k_3$ (from April to August)
 $k=k_4$ (from August to December)

Equation (11) is an exponential model; it doesn't satisfy the natural behavior of floating weeds at all seasons of the year. Solving this problem by taking limits for equation (11) at $k = 0$, $k < 0$, and $k > 0$.

- If $k = 0$, limit of growth of floating weeds will lead to $W(t) = w_o$, it means no growth or transition period.
- If $k > 0$, limit of growth of floating weeds is, $\lim_{t \rightarrow \infty} w(t) = \infty$, it means growth to infinity.
- If $k < 0$, limit of growth of floating weeds is, $\lim_{t \rightarrow \infty} w(t) = 0$, it means growth to extinction (decay).

Taking the limits to equation (11) showed another problem. This problem is the growth to infinity of floating weeds because it is illogic. Overcoming this problem of growth to infinity had been studied before by (Verhust-Pearl model),after Mohamed A. K., (2008), for population growth. The same equation can be applied for weed population or weed growth (w_g) where the model is called logistic model. The differential equation of this logistic model is,

$$\frac{dp}{dt} = kp(1 - \frac{p}{m}), \dots\dots\dots (12)$$

Where dp/dt is the change in population, p is the population, k is constant, and M is the carrying capacity. Logistic model equation can be rewritten for floating weeds growth as follows:-

$$\frac{dw}{dt} = kw(1 - \frac{w}{m}), \dots\dots\dots (13)$$

Where:-

dw/dt is the change in growth of floating weeds, w is the growth of floating weeds, k is constant, and M is the carrying capacity which means limited growth of weeds during a period of time (t). Equation (13) can be solved to get the non-constant solution as follows:-

$$\frac{dw}{w(1-\frac{w}{M})} = kdt \dots\dots\dots (14)$$

Taking integration for both sides in equation (14);

$$\int \frac{dw}{w(1-\frac{w}{M})} = \int kdt \dots\dots\dots (15)$$

Equation (15) will be:-

$$\ln|w| - \ln \left| 1 - \frac{w}{M} \right| = (kt + c) \dots\dots\dots (16)$$

Where, c is the integration constant. Solving and simplification of equation (16) using natural logarithm (e) for both sides. Equation (16) will be:-

$$e(\ln|w| - \ln \left| 1 - \frac{w}{M} \right|) = e(kt + c) \dots\dots\dots (17)$$

Equation (17) will be:-

$$\frac{w}{1-\frac{w}{M}} = ce^{kt} \dots\dots\dots (18)$$

Solving for w equation (18) will be:-

$$w = \frac{Mce^{kt}}{M+ce^{kt}} \dots\dots\dots (19)$$

Where, $w(0) = w_0$, $w_0 \neq 0$, and $w_0 \neq M$.
Solving equation (19) for (c) at time (0), where, $e^{kt} = 1$, $w = w_0$.

$$c = \frac{w_0M}{M-w_0} \dots\dots\dots(20)$$

Substituting with (c) in equation (19), after simplification it will be:-

$$w(t) = \frac{w_0M}{w_0+(M-w_0)e^{-kt}} \dots\dots\dots(21)$$

It is obvious from equation (21) that the limit of weed growth $w(t)$, when time tends to infinity equal the carrying capacity M

Where:-

$$\lim_{t \rightarrow \infty} w(t) = M \dots\dots\dots(22)$$

Finally From the previous equations the equation of floating weed growth can be expressed as in equation (23).

$$w = \frac{w_0M}{w_0+(M-w_0)e^{-kt}} \dots\dots\dots(23)$$

Equation (23) can be expressed in two ways. The first expression is as a population of floating weeds (numbers of weeds) during a period of time (t). The second is the occupied area by floating weeds during a period of time (t). The first way should use (w_0) as a number of weeds in specified area. Accordingly (w) will express the total number of weeds during a period of time (t). The second way should use (w_0) as an area of floating weeds during a period of time (t), consequently (w) will express the total area of weeds during a period of time (t).Where,

$$Aw_0 = 0.92n_0a_{w_0} .$$

The problem of time can be solved by dividing the year into four seasons as mentioned before. The research will deliberate only on the time from December to February and from April to August where:-

$$k=k_1 \rightarrow \text{zero (from December to February, where, } 1 \leq t \leq 90\text{days)}$$

$$k=k_3 > \text{zero (from April to August where, } 1 \leq t \leq 122 \text{ days)}$$

The values of constant (k) and the value of carrying capacity (M) will be mentioned during the solution of exponential and logistic model.

3.1 Solution of exponential and logistic model

To assess the implications of our model, it has been predicted how the dynamics of a water hyacinth infestation vary with time. This was done by specifying an initial plant density, $W(0)$, and determining the plant density attempt, $W(t)$, using the solutions of the exponential and logistic growth Equations (Equation (11) and Equation (23)). In these equations different parameters should be estimated one of them is the average diameter of floating weeds (d_w). The experimental work showed that the average diameter of different weed ages was 24.5 cm. as shown in table (1). From the average diameter (d_w), area of one plant can be calculated, where $a_{w_0} = 3.14 \times (24.5)^2 \div 4 = 0.047 \text{ m}^2$. Then the number of floating weeds in one square meter (n_0) will be 22 plants. The percentage of area covered by floating weeds on water surface or the area

occupied by plants in one square meter of water surface in open channels can be obtained from the study, which had been carried out by (Reda M.A. et al, 2007). The percentage of area factor (a_f) is 0.92 % of area occupied by weeds and the unoccupied area is 0.08%. Data were collected from the experimental work for different weed ages and different time. The rate of change of weed growth (k) in the period (from April to August) is inversely proportional to the time (t). The equation which governs this relation is

$$[\ln(k) = -(t+149.5) / (77.97)] \dots\dots\dots(24)$$

Where:-

t is time from April to August, $k(30 \text{ days}) = 0.1, k(60 \text{ days}) = 0.068, k(90 \text{ days}) = 0.046,$ and $k(120 \text{ days}) = 0.0315$

After using equation (11) of weed growth, the different values of (k) with time (t), the expected values of weed growth $w(t)$, and the area occupied by weeds A_w are shown in tables (from 3 to 7). The carrying capacity (M) is required for using equation (23) of logistic model. Table (8) is showing the values of carrying capacity (M).

Substituting values of carrying capacity (M) in equation (23), the growth of weeds (w) will be as in tables (9 to 11)

4 EXPERIMENTAL WORK

The experiment was conducted in the Delta Breeding Station, Channel Maintenance Research Institute (CMRI), in the period 1 September 2014 to 30 December 2014 i.e. with a duration of 120 days. Seven aquariums and basins (3 glass aquariums and 4 Concrete basins) of 100 and 13500 liters capacity respectively were used for the studies with water hyacinth. Different plants of different ages (mature and young plants) were put in each basin as shown in photos from 1 to 4. Water from River Nile was used in the studied aquarium and basin.

Methods of data collection: Leaf length was measured as length of the leaf from the base to the leaf tip, whilst leaf width was measured as the distance at the middle section of the leaf where it is broadest. Total leaf length and width were recorded as the sum of all the individual leaf lengths and widths for one particular plant. Total leaf area was deduced from leaf length and width as described in table (1) and (2).

Determination of leaf diameter: The method employed in the determination of leaf diameter was modified from the procedure used by Darkwa (2008). The leaves of plants from both species grown in the basins were obtained through a destructive sampling. The product of the length and broadest part of the leaf (width) was recorded as measured leaf area for all these leaves. The results of these measurements are summarized in tables (1) & (2).

5 RESULTS AND DISCUSSION

5.1 Model Validation and Parameter Estimation

Checking the validity of equations above has been carried out using the collected data from experimental work by substituting the values of initial weed growth, time of growth, and the obtained number of weeds from the experiments in equations (11) and (23). The initial numbers were (2) plants and the obtained weed numbers were (30) offsets after (22) days. The calculated

weed rate growth was (0.123). Applying equation (11) for getting weed growth after (22) days, it was (29.939) offsets. It is obvious that there is slightly difference between the two values. Another case was carried out using (30) plants as initial weed growth, and the obtained weed numbers were (1200) offsets after (120) days. The calculated weed rate growth was (0.032). Applying equation (11) for getting weed growth after (120) days, it was (1314.5) offsets. The data were tabulated in tables from (3) to (6). It is obvious that the difference between the two values isn't big. The rate of weed growth in this period can be obtained from equation (24)

Another check for weed growth by using one (1) plant as initial weed growth, and the obtained weed numbers were (2) offsets after (10) days. The calculated weed growth rate was (0.11). Applying equation (11) for getting weed growth after (10) days, it was (2) plants. It is obvious that no difference between two values.

Obied M., (1962) carried out an experiment in Sudan to study floating weed growth, using abundant swimming pool the experiment had been started by using 2 plants of water hyacinth as an initial number. The produced offsets of floating weeds after 2 months became 30 offsets, and after 3 months became 130 offsets. Comparing the results of Obied's experiment and the present results in this paper, it will be as follows, the produced offsets of floating weeds when using 2 plants of water hyacinth as an initial number, after 2 months became 31.6 offsets, and after 3 months became 125.60 offsets, when using rate of change equals 0.064. It is obvious that the difference between two results is slightly difference. Bock J.H., (1969) studied the productivity of water hyacinth plant; she used power equation to express the productivity of water hyacinth plant. The derived equation was $N_t = N_1 x^t$. Where, (N_t) is the produced number of water hyacinth after time (t) in days, (N_1) is the initial number of plants, and (x) is the rate of change in plant productivity. Bock 1965, found that, during her experimental work which published it in 1969, the rate of change of water hyacinth (x) in California is 1.32 in August, 1.066 in (5 May to 9 May), 1.049 in (9 May to 21 May), 1.056 in (21 May to 7 June), and 1.077 in (7 June to 14 June). The results of Bock's experiment showed that for different periods of time, the growth rate is changeable. The result of Bock's study matches with the result of present paper. Because the present paper showed that for different periods of time the growth rate of water hyacinth is different in values. But Bock's equation has some limitations, the first one is the unlimited weed growth with time, and the second limitation is the term (x) which represents the rate of change of weed growth, when (x) equals one the number of produced weeds (N_t) will be the same number of initial weed number (N_1) at any time (t). In the present work these limitations have been taken into consideration in the new derived equation.

Equation (23) can be checked using carrying capacity (M) for 120 days, representing the maximum number of weeds, during this period of time. The chosen time was (360 days) as infinity time for weed growth, because the limit of time should be near from end of the year. The values of (M) were calculated and tabulated in table (11), carrying capacity factor can be checked using the values in table (11). Substituting these values in equation (23), the value of (M) was 1080730 offsets for different initial weed number (w_0), and different relative growth (k) at time (t) equals 360 days. The obtained weed numbers were 1080730 offsets for the same conditions. It means that the carrying capacity (M) equals the obtained weed number. So the carrying capacity (M) is valid to govern the weed growth to a limit number of weed during specified time. It means also that the growth will be limited and will not be to infinity.

Checking equation (23) for expected weed growth has been done using two (2) plant as initial weed number, the obtained weed numbers were (22.5) offsets after (22) days. The calculated weed growth rate was (0.11). Applying equation (23) for getting weed numbers after (22) days, it was (22.49) offsets. It is obvious that no difference between two values. The same procedure can

be applied for the other 3 seasons in Egypt. The remaining periods of weed growth for different rate of weed growth will be studied in future paper.

5.2 Model predictions

Prediction of equations above has been carried out by comparing the collected data from experimental work and the calculated values from present derived equations. The data were tabulated in tables from (3) to (6), by substituting in equation (11) the values of initial weed growth, time of weed growth, and the obtained number of offsets from the experiments. Prediction of model was carried out using (30) plants as an initial weed growth, and the obtained weed numbers were (1200) offsets after (120) days. The calculated weed rate growth was (0.032). Applying equation (11) for predicting weed growth after (120) days. It was (1314.5) offsets. It is obvious that the difference between two values isn't big.

Another check for weed growth by using one (1) plant as initial weed growth, and the obtained weed numbers were (2) offsets after (10) days. The calculated weed growth rate was (0.11). Applying equation (11) for predicting weed growth after (10) days. It was (2) offsets. It is obvious that no difference between two values.

Checking equation (23) for expected weed growth has been done using two (2) plants as initial weed growth, and the obtained weed numbers were (22.5) offsets after (22) days. The calculated weed growth rate was (0.11). Applying equation (23) for getting weed growth after (22) days. It was (22.49) offsets. It is obvious that no difference between two values.

The new derived equation in this paper equation (11) is a general equation; it can be used for weed growth calculations. Applying this equation in Egypt only needs change of some factors according to weed growth rate for different times. This equation can be used in two ways in Egypt;

- The first way is as floating weed growth area. In this case equation (11) should be applied using area factor (a_f) = 0.92 and area of one plant (a_{wo}) = 0.047 m². The weed growth in this case will be in square meters. The engineer who is concerned with open channel maintenance and floating weed control; should use this method to assess the amounts of floating weeds in open channels.
- The second way is as floating weed growth number. In this case equation (11) should be applied using area factor (a_f) = 1 and area of one plant (a_{wo}) = 1. The weed growth in this case will be in plant number (offsets) not in m².

The new derived equation in this paper Equation (23) is a general equation; it can be used as equation (11) for weed growth calculations, but equation (23) is better than equation (11) because the weed growth in equation (11) is endless weed growth but in equation (23) the carrying capacity factor (M) which controls weed growth and solves this problem. In this experiment, carrying capacity has been calculated in this paper for one season from April to August. Carrying capacity has been estimated for period 120 days. Carrying capacity values are tabulated in table (9). Equation (23) can be used also in two ways in Egypt;

- The first way is as floating weed growth area. In this case equation (23) should be applied using area factor (a_f) = 0.92 and area of one plant (a_{wo}) = 0.047 m². The weed growth in this case will be in m². Equation (23) will be

$$W_g = a_f \times a_{wo} \times w, \text{ where } w \text{ is as in equation (23), } w = \frac{woM}{wo + (M - wo)e^{-kt}}$$

-The second way is as floating weed growth number. In this case equation (23) should be applied using area factor (a_f) = 1, and area of one plant (a_{wo}) = 1. The weed growth in this case will be in plant number (offsets) not in m^2 .

6 CONCLUSION

It could be concluded that:-

Floating weed growth can be calculated in general using the new derived exponential equation. In Egypt; the new derived exponential equation can be used by two ways. The first way is as floating weed growth area. In this case equation (11) should be applied using area factor (a_f) = 0.92 and area of one plant (a_{wo}) = 0.047 m^2 . The weed growth in this case will be in m^2 . The second way is as floating weed growth number. In this case equation (11) should be applied using area factor (a_f) = 1 and area of one plant (a_{wo}) = 1. The weed growth in this case will be in plants not in m^2 . The rate of change of weed growth (k) in the period (from April to August) is inversely proportional to the time (t). The equation which governs this relation is logarithmic equation. The new derived equations in this paper are general equations; it can be used for weed growth calculations. The weed growth in exponential equation is endless weed growth but using the carrying capacity factor (M) will control weed growth solving this problem.

RECOMMENDATIONS

It is recommended that:-

- More experiments should be carried out for more intensive data.
- Hydraulic characteristics of open channels should be studied in accordance with weed growth using new derived equations.
- Equations in this paper should be verified, not only in Egypt but also in other countries to improve the factors in these equations.
- Ministry of water resources should pay attention for weed growth and weed control.
- Open channel maintenance and weed control should be done using new equations.

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TABLES AND PHOTOES

Table 1. Experiment of water hyacinth specifications in basins

N o.	Aquariu m no.	No.of plants	T N	Specifications of water hyacinth				
				Root length (cm)	leaf length (cm)	leaf width (cm)	No .of Leaves	Diameter of Leaves(cm)
1	1	6	2	10	5	6	5	10
				15	5	7	6	10
				10	4	6.5	4	12
				10	5	7	5	15
				8	3	7	5	8
				6	3	7	5	10
2	2	6	3	10	5	7	5	10
				8	5	5	6	10
				10	4	6	4	15
				8	5	7	5	10
				8	5	6	5	8
				7	3	5	5	8
3	3	6	4	10	5	6	5	10
				15	5	7	6	10
				10	4	7	4	15
				10	5	6.5	6	15
				8	3	6.5	5	15
				6	3	5	6	10

Table 2. Experiment of water hyacinth specifications in aquarium

N o.	Aquariu m no.	No.of plants	T N	Dimetions of plant parts				
				Root length (cm)	leaf length (cm)	leaf width (cm)	No .of Leaves	Diameter of plant (cm)
1	1	1	1	30	38	8.5	9	40
2	2	2	2	20	20	7	12	35
3				20	18	6.5	11	20
4	3	3	3	20	10	7	15	20
5				10	3	7	11	15
6				6	3	7	5	10
7	4	4	4	20	26	7	8	30
8				30	29	9	11	30
9				30	26	9	9	25
10				20	18	9	10	20

Table 3. Expected weed growth from April to August for $k = 0.11$

No.	$a_{w_0}(m^2)$	a_f	w_0	k	$t=(t_2-t_1)$	$A_w(m^2)$	$w(t)$
1	0.047	0.92	2	0.110	5	0.15	3.5
2	0.047	0.92	2	0.110	10	0.26	6.0
3	0.047	0.92	2	0.110	15	0.45	10.4
4	0.047	0.92	2	0.110	20	0.78	18.1
5	0.047	0.92	2	0.110	25	1.36	31.3
6	0.047	0.92	2	0.110	30	2.35	54.2
7	0.047	0.92	2	0.110	35	4.07	94.0
8	0.047	0.92	2	0.110	40	7.06	162.9
9	0.047	0.92	2	0.110	45	12.24	282.3
10	0.047	0.92	2	0.110	50	21.21	489.4
11	0.047	0.92	2	0.110	55	36.77	848.2
12	0.047	0.92	2	0.110	60	63.73	1470.2
13	0.047	0.92	2	0.110	65	110.47	2548.2
14	0.047	0.92	2	0.110	70	191.46	4416.7
15	0.047	0.92	2	0.110	75	331.86	7655.3
16	0.047	0.92	2	0.110	80	575.19	13268.5
17	0.047	0.92	2	0.110	85	996.95	22997.6
18	0.047	0.92	2	0.110	90	1727.97	39860.7
19	0.047	0.92	2	0.110	95	2995.00	69088.7
20	0.047	0.92	2	0.110	100	5191.09	119748.3
21	0.047	0.92	2	0.110	105	8997.48	207554.1
22	0.047	0.92	2	0.110	110	15594.91	359743.7
23	0.047	0.92	2	0.110	115	27029.93	623526.9
24	0.047	0.92	2	0.110	120	46849.70	1080729.9

Table 4.Expected weed growth from April to August for k = 0.068

No.	$a_{wo}(m^2)$	a_f	w_o	K	$t=(t_2-t_1)$	$A_w(m^2)$	$w(t)$
1	0.047	0.92	2	0.068	5	0.12	2.8
2	0.047	0.92	2	0.068	10	0.17	3.9
3	0.047	0.92	2	0.068	15	0.24	5.5
4	0.047	0.92	2	0.068	20	0.34	7.8
5	0.047	0.92	2	0.068	25	0.47	10.9
6	0.047	0.92	2	0.068	30	0.67	15.4
7	0.047	0.92	2	0.068	35	0.94	21.6
8	0.047	0.92	2	0.068	40	1.32	30.4
9	0.047	0.92	2	0.068	45	1.85	42.7
10	0.047	0.92	2	0.068	50	2.60	59.9
11	0.047	0.92	2	0.068	55	3.65	84.2
12	0.047	0.92	2	0.068	60	5.13	118.3
13	0.047	0.92	2	0.068	65	7.20	166.2
14	0.047	0.92	2	0.068	70	10.12	233.5
15	0.047	0.92	2	0.068	75	14.22	328.0
16	0.047	0.92	2	0.068	80	19.98	460.9
17	0.047	0.92	2	0.068	85	28.07	647.5
18	0.047	0.92	2	0.068	90	39.44	909.7
19	0.047	0.92	2	0.068	95	55.41	1278.1
20	0.047	0.92	2	0.068	100	77.84	1795.7
21	0.047	0.92	2	0.068	105	109.37	2522.9
22	0.047	0.92	2	0.068	110	153.65	3544.5
23	0.047	0.92	2	0.068	115	215.88	4979.8
24	0.047	0.92	2	0.068	120	303.29	6996.4

Table 5. expected weed growth from April to August for $k = 0.046$

No.	$a_{wo}(m^2)$	a_f	w_o	K	$t=(t_2-t_1)$	$A_w(m^2)$	$w(t)$
1	0.047	0.92	2	0.046	5	0.11	2.5
2	0.047	0.92	2	0.046	10	0.14	3.2
3	0.047	0.92	2	0.046	15	0.17	4.0
4	0.047	0.92	2	0.046	20	0.22	5.0
5	0.047	0.92	2	0.046	25	0.27	6.3
6	0.047	0.92	2	0.046	30	0.34	7.9
7	0.047	0.92	2	0.046	35	0.43	10.0
8	0.047	0.92	2	0.046	40	0.55	12.6
9	0.047	0.92	2	0.046	45	0.69	15.8
10	0.047	0.92	2	0.046	50	0.86	19.9
11	0.047	0.92	2	0.046	55	1.09	25.1
12	0.047	0.92	2	0.046	60	1.37	31.6
13	0.047	0.92	2	0.046	65	1.72	39.8
14	0.047	0.92	2	0.046	70	2.17	50.1
15	0.047	0.92	2	0.046	75	2.73	63.0
16	0.047	0.92	2	0.046	80	3.44	79.3
17	0.047	0.92	2	0.046	85	4.33	99.8
18	0.047	0.92	2	0.046	90	5.45	125.6
19	0.047	0.92	2	0.046	95	6.85	158.1
20	0.047	0.92	2	0.046	100	8.63	199.0
21	0.047	0.92	2	0.046	105	10.86	250.4
22	0.047	0.92	2	0.046	110	13.66	315.2
23	0.047	0.92	2	0.046	115	17.20	396.7
24	0.047	0.92	2	0.046	120	21.64	499.3

Table 6. expected weed growth from April to August for k = 0.032

No.	$a_{wo}(m^2)$	a_f	w_o	k	$t=(t_2-t_1)$	$A_w(m^2)$	$w(t)$
1	0.047	0.92	2	0.032	5	0.10	2.3
2	0.047	0.92	2	0.032	10	0.12	2.7
3	0.047	0.92	2	0.032	15	0.14	3.2
4	0.047	0.92	2	0.032	20	0.16	3.8
5	0.047	0.92	2	0.032	25	0.19	4.4
6	0.047	0.92	2	0.032	30	0.22	5.1
7	0.047	0.92	2	0.032	35	0.26	6.0
8	0.047	0.92	2	0.032	40	0.31	7.1
9	0.047	0.92	2	0.032	45	0.36	8.3
10	0.047	0.92	2	0.032	50	0.42	9.7
11	0.047	0.92	2	0.032	55	0.49	11.3
12	0.047	0.92	2	0.032	60	0.57	13.2
13	0.047	0.92	2	0.032	65	0.67	15.5
14	0.047	0.92	2	0.032	70	0.79	18.1
15	0.047	0.92	2	0.032	75	0.92	21.2
16	0.047	0.92	2	0.032	80	1.08	24.9
17	0.047	0.92	2	0.032	85	1.26	29.1
18	0.047	0.92	2	0.032	90	1.48	34.1
19	0.047	0.92	2	0.032	95	1.73	39.9
20	0.047	0.92	2	0.032	100	2.02	46.7
21	0.047	0.92	2	0.032	105	2.37	54.6
22	0.047	0.92	2	0.032	110	2.77	64.0
23	0.047	0.92	2	0.032	115	3.25	74.9
24	0.047	0.92	2	0.032	120	3.80	87.6

Table (7) the values of carrying capacity (M)

carrying capacity	Relative growth (k)	Time (t)	M for (weed areas)	M for (weed numbers)
M	0.110	120	46849.70	1080729.9
M	0.068	120	303.29	6996.4
M	0.046	120	21.64	499.3
M	0.032	120	3.80	87.6

Table (8) weed areas and weed numbers for different carrying capacity (M)

Area of weeds	Weed Numbers	Initial weed number	Carrying capacity m^2	Carrying capacity plant number	Relative growth	Time in days
w_1	w_2	w_o	M_1	M_2	k	t
0.97499	22.49129	2	46849.7	1080730	0.11	22
0.38662	8.918765	2	303.29	6996.4	0.068	22
0.23685	5.463871	2	21.64	499.3	0.046	22
0.17129	3.951463	2	3.8	87.6	0.032	22

Table (9) weed areas and weed numbers for different carrying capacity (M)

Area of weeds	Weed Number s	Initial weed number	Carrying capacity m ²	Carrying capacity plant number	Relative growth	Time in days
w ₁	w ₂	w _o	M ₁	M ₂	k	t
23424.87	540365.4	2	46849.7	1080730	0.11	120
151.6686	3498.693	2	303.29	6996.4	0.068	120
10.84374	250.1435	2	21.64	499.3	0.046	120
1.977922	45.62676	2	3.8	87.6	0.032	120

Table (10) weed areas and weed numbers for different carrying capacity (M)

Area of weeds	Weed Number s	Initial weed number	Carrying capacity m ²	Carrying capacity plant number	Relative growth	Time in days
w ₁	w ₂	w _o	M ₁	M ₂	k	t
46849.7	1080730	2	46849.7	1080730	0.11	360
303.2943	6996.399	2	303.29	6996.4	0.068	360
21.64434	499.292	2	21.64	499.3	0.046	360
3.795852	87.56279	2	3.8	87.6	0.032	360

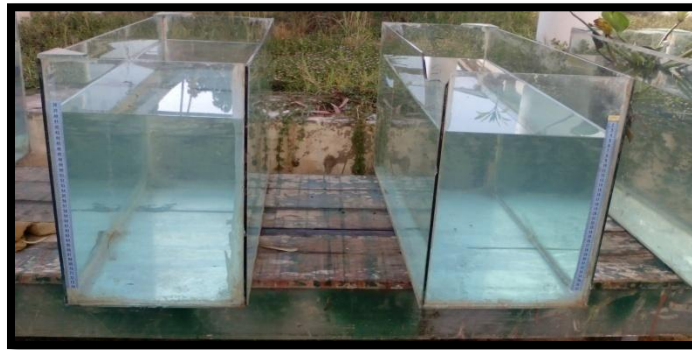


Photo (1) aquarium at the beginning of water hyacinth experiment



Photo (2) experiment of water hyacinth in aquarium



Photo (3) experiment of water hyacinth specifications

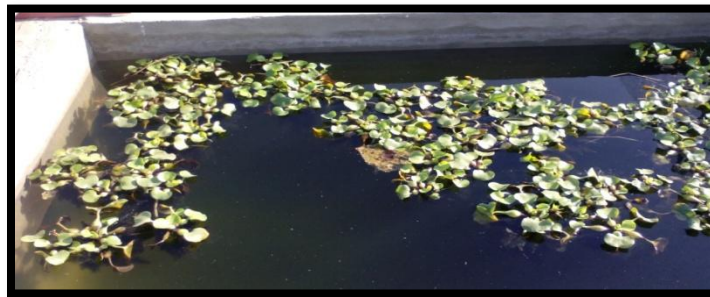


Photo (4) experiment of water hyacinth in basins