Influence of Using Different Water Quantities and Irrigation Systems on Some Forest Trees growth Parameters

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Abstract: This study was carried out at Serapium forest which located in north eastern Egypt, within the Governorate of Ismailia. The experiment was conducted to assess the influence of different amounts of water with different irrigation system techniques (IRST) on some growth parameters [Height and root collar diameter (RCD)] for three forest tree species (*Tectona grandis*, *Khaya senegalens* and *Gmelina arborea*). Thus; experiment was laid out on block randomise design with two factors. First factor is amount of water which comprise into three treatments (Q_1, Q_2 and Q_3) approximately (130%, 100% and 70%) from total water applied with average (10.3, 7.7 and 5.1L/Tree/day) respectively. Second factor is four irrigation system techniques [bubbler, dripper on line (drip), dripper built-inline (GR) and sub-surface drip (SSD)] during period November 2013 to March 2015. The results revealed that the (IRST) has a significant influence on growth parameters [Height and root collar diameter (RCD)] for all tree species; however; amounts of water have not any significant influence on previous growth parameter unless the (RCD) for *Tectona grandis* and *Gmelina arborea* which acquired a significant influence for Q1 comparing with Q3. Moreover; ascertained that bubbler is the best technique which obtained a highest value for effective water use with tree height by (42.2cm/m^3 and 73.6cm/m^3) for (*Tectona grandis*, *Gmelina arbore)* respectively. Furthermore; using drip irrigation technique obtained a highest value for water use on tree height when irrigate a *Khaya senegalens* by (22.3 cm/m^3) comparing with other techniques.
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Key words: irrigation systems; water quantities; forest tree and water use.

1. Introduction

Numerous of countries have suffering from water scarcity and impairment management for water resources, thus; they focusing to deal with this problematic by more rationalized and efficient manner than ever before. Therefore, using treated waste water is one of the alternative water resources for irrigation especially in Egypt which located in arid and semi arid region. However; there are many obstacles will facing agricultural system when using this type of water for instance, a) finding means of lowering the current level of water demand by some efficient water use techniques, and b) promote economic return to the farmers to enhance economic incentives, These can be obtained through high production and increasing the water productivity using new irrigation approach. Likewise; impact low quality water in environment which compulsory to more mentoring and management.

Under treated wastewater application, micro-jet and micro-sprinklers do produce sprays that wet the soil surface and the plants. The workers are exposed to contact risks during their normal agricultural practices. Nevertheless; this risks are less with drip and bubbler systems, except during maintenance of the emitter **[Bucks.*et al.*, 1979].** Bubblers are much less sensitive to clogging than drippers and therefore require less maintenance. Furthermore; soil wetted area and direct contact risks are greatly reduced in comparison with sprinkler and surface irrigation methods.

Waste water use in the irrigation of tree plantations *Eucalyptus tereticornis, Populus deltoides* and *Leucaena leucocephala*. [**CSSRI, 1989]**; For all three species, trees irrigated monthly with sewage water showed a higher growth than trees irrigated with well water at the same frequency: the *Eucalyptus* was 6 percent taller after 48 months; the *Leucaena* was 12 percent taller after 36 months; and the poplar was 4 percent taller after 24 months.

Thus; the proportions between (height & diameter), between (crown height & diameter) and between (biomass & diameter) follow rules that are the same for all trees, big or small, as long as they are growing under the same conditions [**King, 1996; Archibald & Bond, 2003; Dietze. *et al.*, 2008**]. This is the basic principle of allometry and can be used to predict a tree variable (typically its biomass) from another dimension (e.g. its diameter). [**Dhôte, 1996**]; used a linear model to model tree diameter growth: below a certain circumference threshold, trees are

overtopped and no longer grow; above the threshold their growth shows a linear relationship with tree circumference. The threshold and slope of the relationship change with stand age and silviculture treatments.

On the other hand; the height growth of dominant trees is still the main basic principle in most growth and models [**Skovsgaard & Vanclay, 2008**]. The principle is recapitulation by **[Alder; 1980]** in the following sentence: "The height / age / fertility index relationship is the key to predicting growth of homogeneous stands.

Clearly, there is some tantalizing potential for using treated wastewater for irrigation forestry and agro-forestry, but much research is still to be done before this potential can be realized. Thus; The aim of this study is to test the influence of three quantities of water with average (10.3, 7.7 and 5.1 L/Tree/day) under four irrigation system techniques [bubbler, dripper on line (drip), dripper built-in line (GR) and subsurface drip (SSD)] on three forest tree species parameters (tree height, root collar diameter) beside the effective water use; to determine the best irrigation technique and water quantity which acquiring a significant results under such conditions.

2. Material and Methods

Experimental location

The experimental was carried out at Serapium forest which located in north eastern Egypt, within the Governorate of Ismailia; as a part of project "Establishment of plantation forests and development of sustainable forestry in desert lands of Egypt using sewage water education and research project"; The study site, established in late November of (2013-2015), (30° 28' 49.14"N - 32° 13' 29.86"E) where falls into an arid area. The site is about 30 m above sea level with an annual rainfall of 29 mm/year, temperatures of 21.6 °C, relative humidity of 53.9%, and wind speed of 2.5 m/s. The total annual evapotranspiration (ETo) is 1821 mm/year (table [1]).

Table 1: Climatic characteristics at Ismailia governorate. **(FAO AQUASTAT 2015)**

Month	Prc.	Wet days	Tem. max	Tem min.	Hum.	Sun shine	Wind (2m)	ETo
	mm/m		°C	°C	%	%	m/s	mm/d
Jan	5	4.5	19.1	13.7	58.9	68.1	2.2	2.4
Feb	5	3.5	20.7	14.9	56.1	70.1	2.6	3.2
Mar	5	2.5	23	11	52.1	71.7	2.8	4.2
Apr	2	1.1	28.1	14.6	46	74.1	2.8	5.7
may	2	0.6	31.5	17	45.1	78.8	2.8	6.8
Jun	0	0	34.4	20.1	48.4	87.3	2.8	7.5
Jul	0	0	35.2	21.8	51.9	85.3	2.5	7.3
Aug	0	0	34.9	22	54.6	86.5	2.4	6.8
Sep	0	0	32.8	20.4	56.4	81.9	2.4	5.7
Oct	1	1	29.7	17.5	57.2	82.9	2.4	4.6
Nov	5	2	25.1	13.5	59.5	76.7	2	3.1
Dec	4	3.4	20.6	9.7	61	65.5	2	2.3
Average								**4.9**

(*Prc*. = Precipitation; *Wet days* = Number of days per month with >0.1mm of precipitation; *Tmp*. *min*/*max* = minimum/maximum temperature; *hum*. = relative humidity; *Sun shine* = Sun shine as percentage of day length; *Wind* (*2m*) = wind speed at 2m; *ETo*= Reference evapotranspiration)

The soil of experimental site is sandy texture, none saline, and none calcareous. Silt and clay content; average 3.28% and 4.22% respectively; are quite low there for both field capacity and available water are very low 5.6 % and 4.5 %.And E.C. soil conductivity 1.37dS/m.

Experiment and irrigation systems design

Experiment was laid out on block randomise design with two factors. First factor is amount of water which comprise into three treatments (Q_1, Q_2 and Q_3) with average (10.3, 7.7 and 5.1 L/Tree/day) respectively. Second factor is four irrigation system techniques [bubbler (70Lph), on line dripper (drip-4Lph), dripper built-in line (GR- 16mm/4L/50cm) and sup-surface drip (SSD) (16mm/4L/50cm) with depth (20cm)] during period November 2013 to March 20159 (Fig. 1 & 2).

Furthermore; experiment was evaluate three tree species (*Tectona grandis*, *Khaya senegalens* and *Gmelina arborea*) which distributed into three blocks each block (66m * 53m) is subdivided into three plots with dimension (22m * 53m) (Fig. 3). Each plot contains one species with distance for plantation (4.4m * 2.2m).

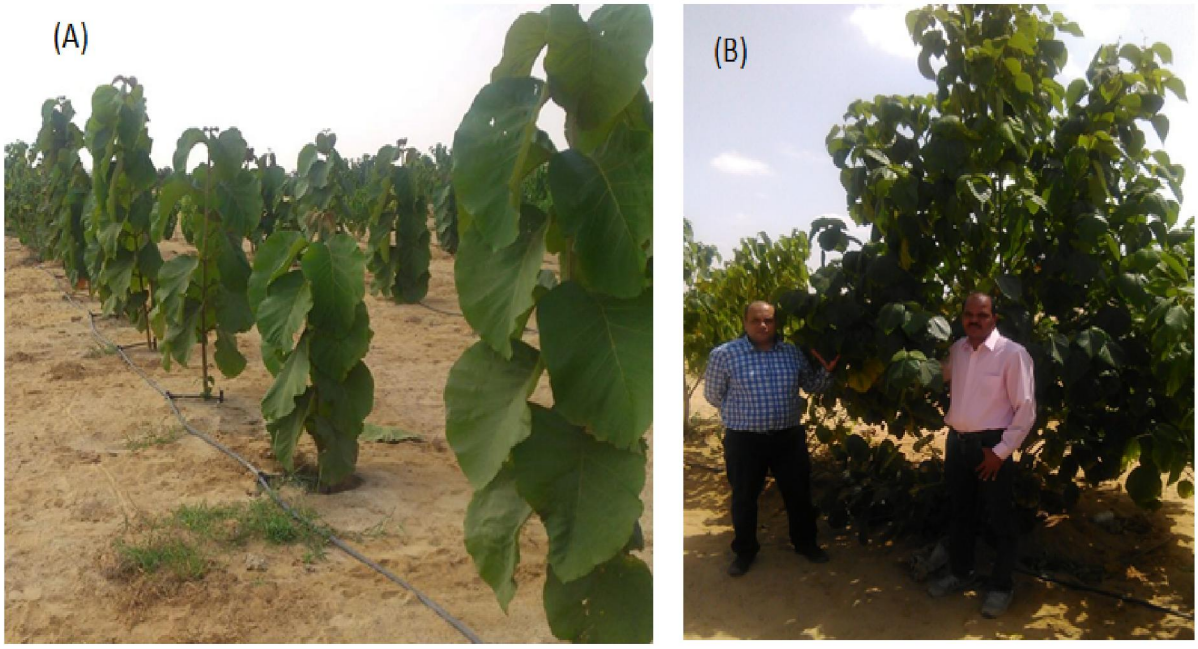

Fig. (1) *Tectona grandis* (A) and *Gmelina arbore* (B) under bubbler irrigation system technique

Fig. (2) Irrigation network system (valve box, flow meters and controller) (installation pipes).

The most commonly used Kc values come from the FAO "Irrigation and Drainage Paper #56: Crop Evapo-transpiration: Guidelines for Computing Crop Water Requirements." Unfortunately, the FAO database does not provide Kc value for all possible crops. Kc values for special crops such as *Tectona grandis*, *Khaya senegalens* and *Gmelina arborea*) should be based on the nearest crop category (e.g., seed oil crops or citrus trees), (FAO, 56). With an average (Kc_{min} = 0.15). Further; Crop water requirement and total water applied [table (2)] was calculated using an average Reference Evapotranspiration (ETo) and the Crop coefficients (Kc) by the following equations.

$$ETc = ETo * Kc \quad (1)$$

Where;
ETc Crop Evapotranspiration, (mm/day).
ETo Reference Evapotranspiration, (mm/day).
Kc Crop coefficients.

$$IRn = ETc - Peff \quad (2)$$

Where;
IRn Net irrigation requirement, (mm/day).
ETc Crop evapotranspiration, (mm/day).
Peff Effective dependable rainfall, (mm/day).

$$IRt = IRn/Ea \quad (3)$$

where;
IRt Total water applied (mm/day).
IRn Net irrigation requirement, (mm/day).
Ea Overall irrigation efficiency, (%). Approximately (95%)

Table 2: Total water applied for tree secrecies per day at Ismailia governorate.

Average (ETo) mm/day	Average (KC)	Etc (mm/day)	IRt (mm/day)	(L/tree/day)
4.9	0.15	0.735	0.773	7.7

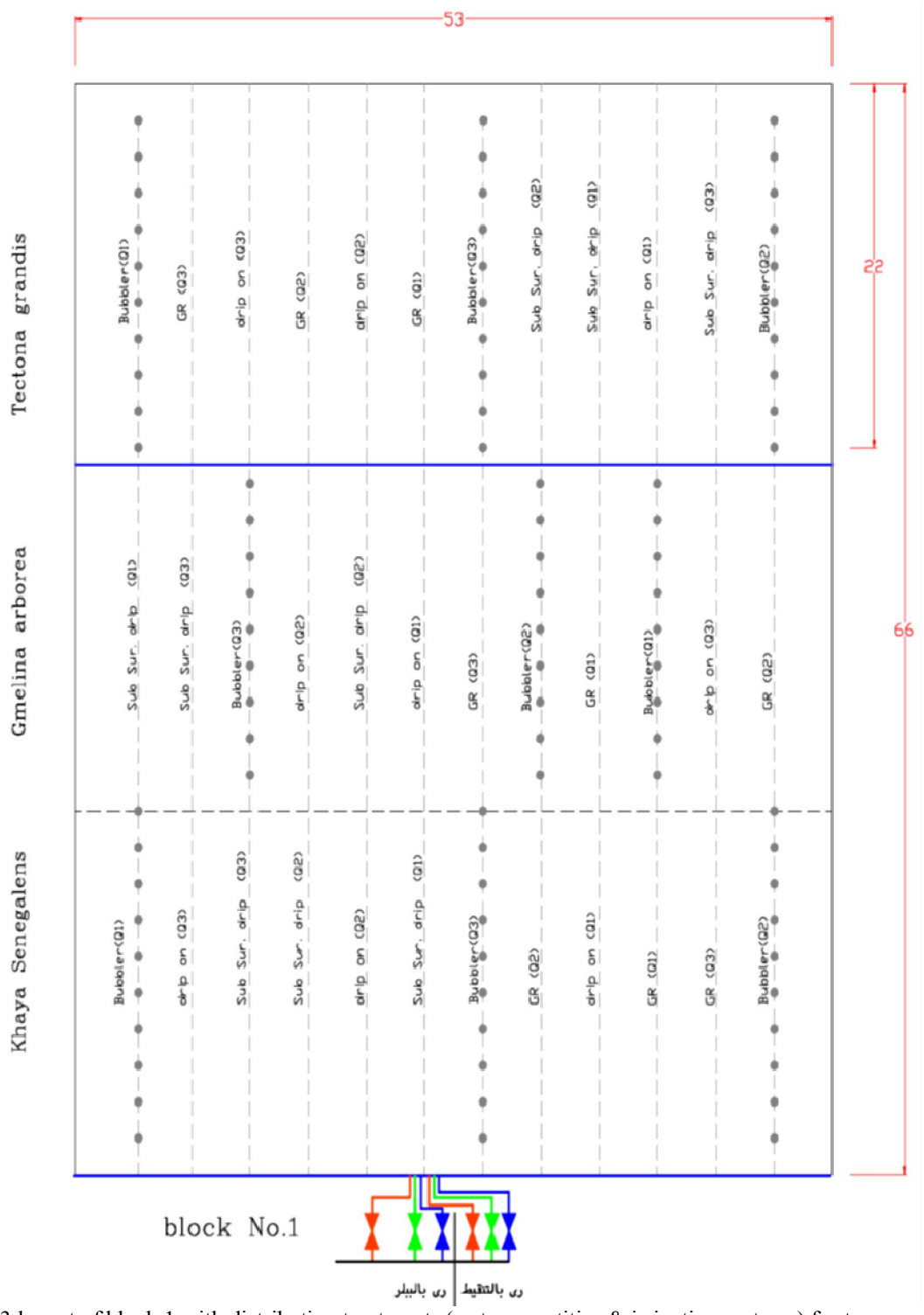

Fig. 3 layout of block 1 with distributing treatments (water quantities & irrigation systems) for tree species.

Measurements and calculations

Effective water use on growth parameters (Ht, RCD, Cr) with flowing equation (4).

$$EWUG = [Hi, RDC, Cr] / IRR_i \quad (4)$$

Where:-

EWUG Effective water use growth (Cm/m^3).
Hi Height of tree (Cm).
RCD Root collar diameter (cm).
IRR_i total irrigation water applied (m^3)

Root collar diameter (RCD) for a single-stemmed tree, RCD is equal to the single diameter for a multi-stemmed tree; RCD is calculated from the diameter measurements of all qualifying stems (≥ 1.5" diameter and at least one foot in length). Meeuwig and Budy 1981, Batcheler 1985.

$$RCD = \sqrt[n]{\sum_{1}^{n} (stim\,\text{dim}\quad)^2} \quad (5)$$

Where:

RCD Root collar diameter (cm)
n Number of stems at RCD

Statistical analysis for modelling:

The data were analyzed using the two way ANOVA on complete randomized block design procedure with Duncan's HSD test at $p<0.05$ using the COSTAT 3.03 System software.

The simple regression models with predictor variables $X_1;\ldots\ldots\ ;\ Xp$can be describe by equation (6).

$$y = B_0 + B_1X_1 + \ldots\ldots\ldots\ldots + B_pX_p + k \quad (6)$$

Where:

Variable y, called a response or dependent variable, depends on another variables $X_{(1..p)}$ which is called the independent or predictor variable (also called the regressor variable), B_0 is intercept, $B_{1\text{-}P}$is the slope parameters and the variability of the error (k) is constant for all values of the repressor.

3. Result and Discussion

a) Influence of different irrigation systems on growth parameters:

Total tree height.

Impact of different irrigation systems on three tree species is significant especially on total height parameter as indictor for growth. As shown in fig.(4) that bubbler irrigation system has a significant influence value for total height comparing with other irrigation system techniques specially for *T. Grandis* and *G. Arborea* by average total height (164.83cm and 189.71 cm) respectively. However; the highest significant value was recorded under drip irrigation system with *K. Senegalens* comparing with others irrigation approaches by (59.23cm) as an average for total height parameter. Inasmuch as ; that the *T. Grandis* and *G. Arborea* need to irrigate by all amount of water in shortage time to maximizing water use on some physiology operations which appearing on some growth parameters as tree height. However; using others techniques are not occurring the same impact because that the drip, GR and SSD need for longer time to apply water requirements comparing with bubbler systems.thus; trees cannot use the amount of water effectively. On the other hand; with *K. Senegalens* has a Reverse behaviour because that significant value perceptible with drip and bubbler irrigation systems comparing with other irrigation techniques. Inasmuch as; that previous irrigation techniques are located beside the tree however GR and SSD are irrigating depend on wetting elongated line concept. Thus, this type of tree species need to irrigate by localized techniques with applying water requirement in a significant time to get an opportunity for using water effectively.

Root collar diameter.

Furthermore; as shown in fig (5); the root collar diameter (RCD) has a different responses depend on type of trees and type of irrigation system techniques. Consequently; under *T. Grandis* the RCD recoded a highest significant value by 39.8mm with bubbler irrigation technique comparing with other irrigation system approaches. By the same way; influence of bubbler on RCD for *G. Arborea* has a significant value comparing with different irrigation manners which recorded 51.7mm as an average value. However; it is dispiriting under *K. senegalens* tree species whereas there is not any significant differentiation among irrigation system techniques especially with (LSD.05=5.184) but the best irrigation system which recording a highest average value is bubbler irrigation system approach by 25.7mm. Thus; with all different three tree species bubbler irrigation system is considered the best irrigation technique which fulfils a highest effectiveness on RCD expansion for all tree species. This because that schedule irrigation time programme is less for bubbler than other irrigation techniques. Thus; it gives tree a occasion to use water with best way.

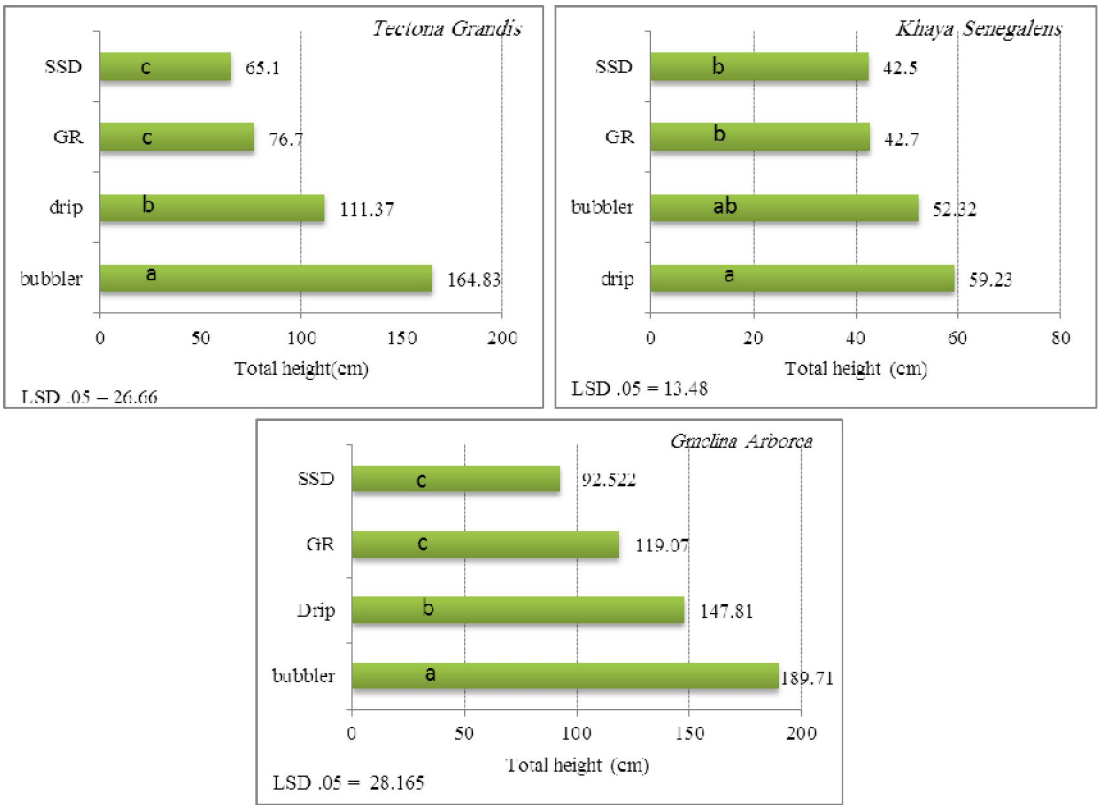

Fig.4 Influence of different irrigation systems on total height for tree species.

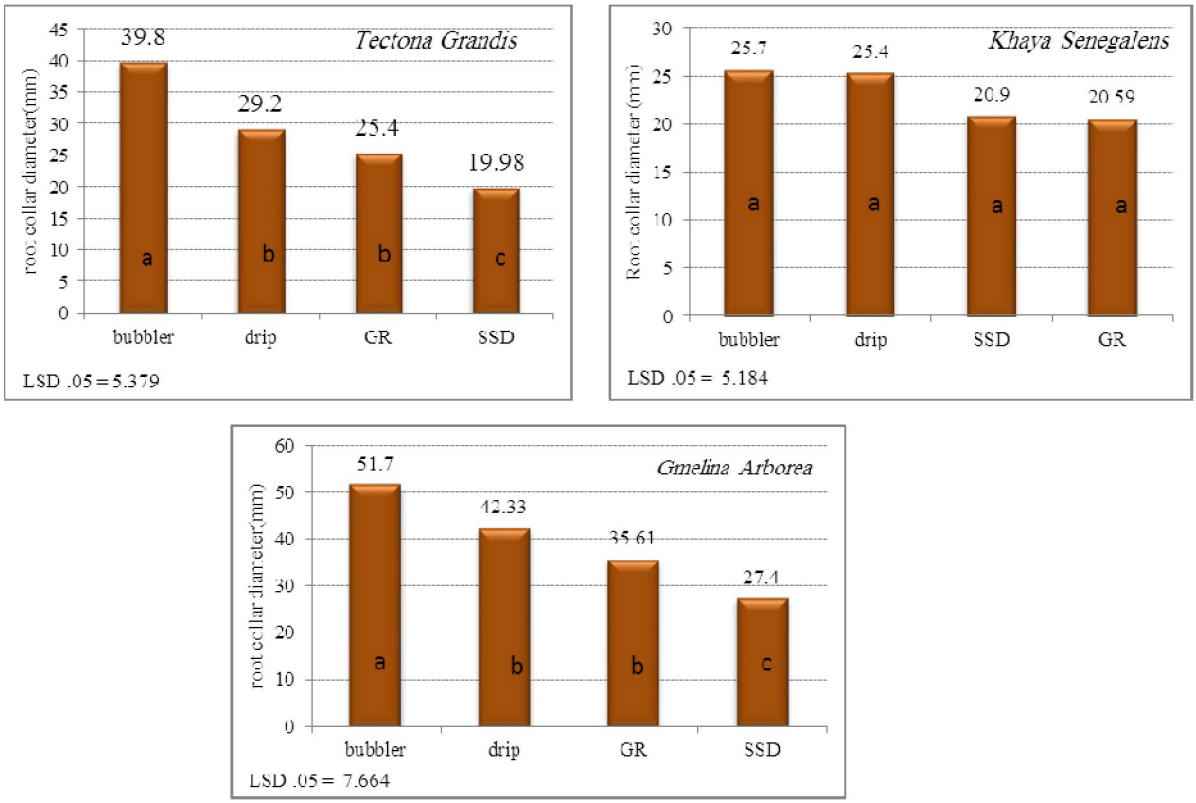

Fig.5 Influence of different irrigation systems on root collar diameter for tree species

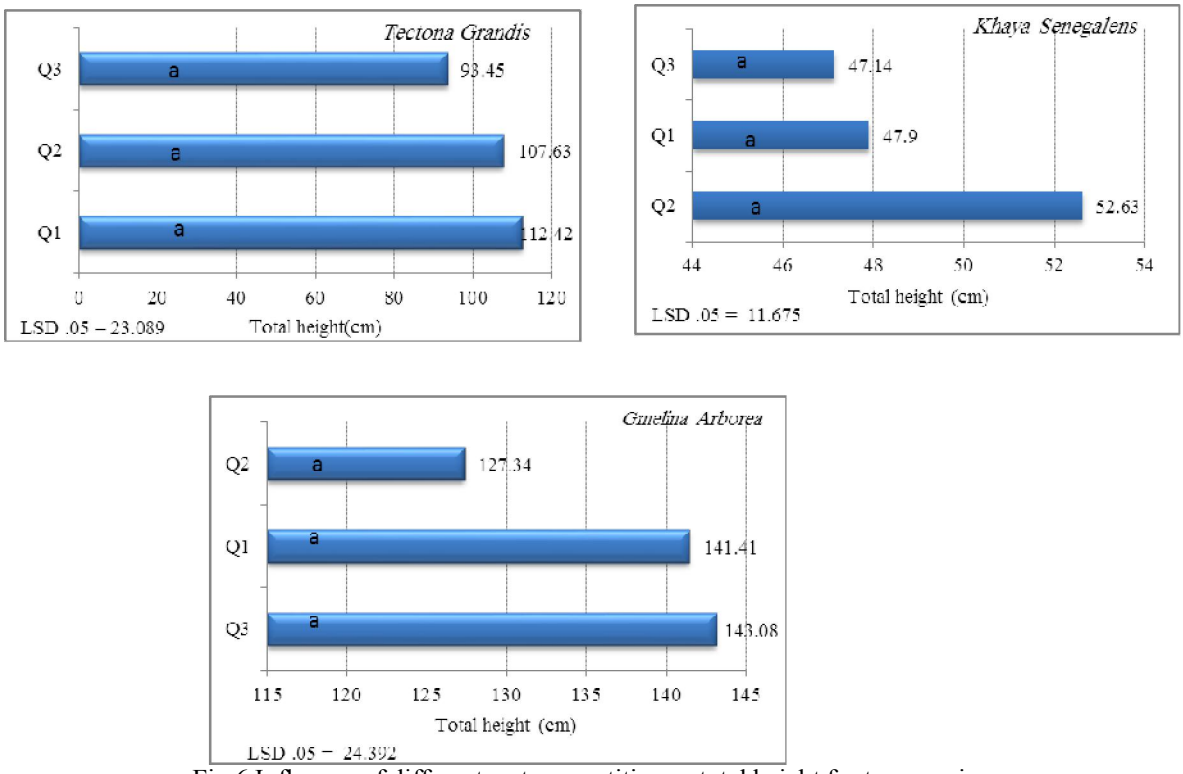

Fig.6 Influence of different water quantities on total height for tree species

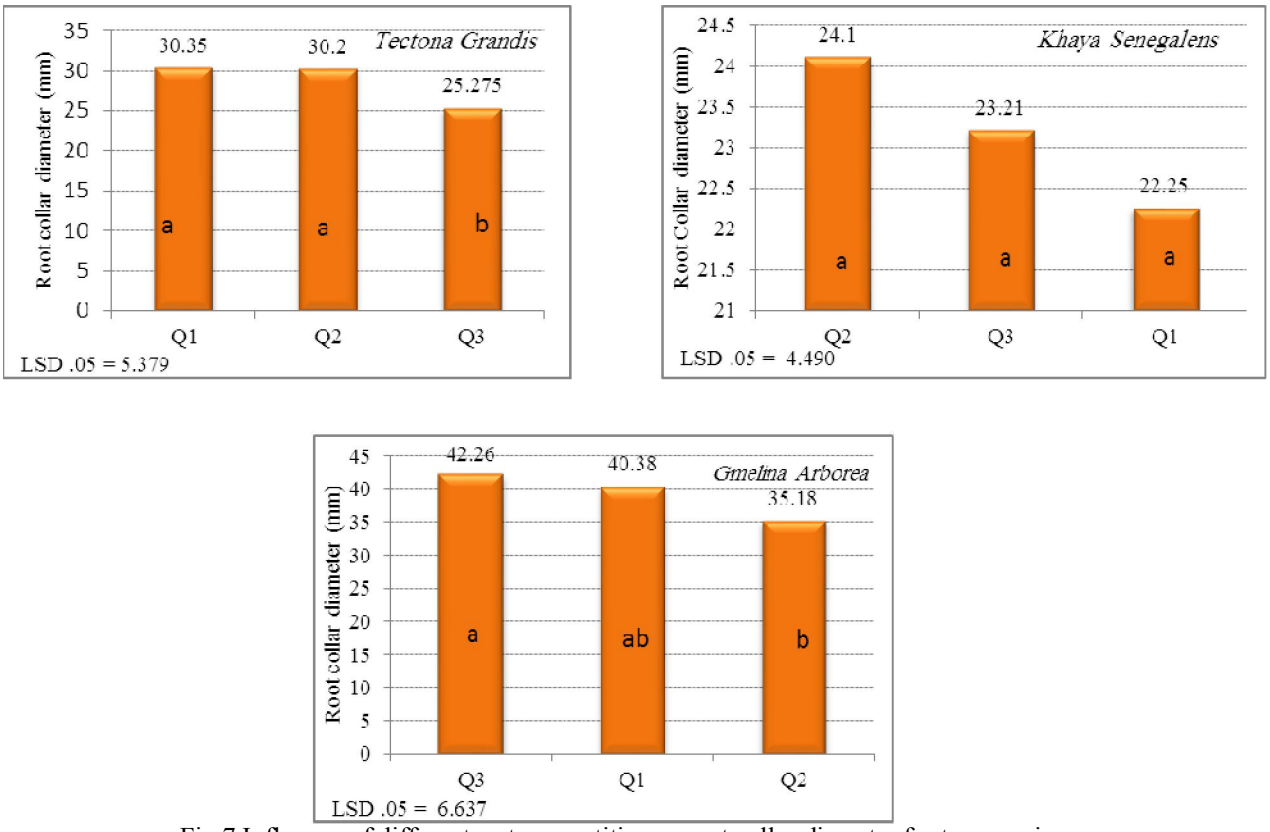

Fig.7 Influence of different water quantities on root collar diameter for tree species

b) Influence of different water quantities on growth parameters:

Total tree height.

By all the odds; that the water quantities have leverage on all tree species, however; as shown at fig (6). There is not any significant influence for different water quantities on total tree height. Nevertheless there are a different variation values between water treatments. For instance; under water quantities Q1 which used for irrigate *T.Grandis*had recorded a highest value for tree height by 112.42cm comparing with other quantities Q2 and Q3 which recorded (107.63 and 93.45cm) respectively. On the other hand; with *K.senegalens* the highest value observed with Q2 by 52.63cm where other quantities (Q1 and Q3) had obtained a lowest value by 47.9 and 47.14cm respectively. Finally; with *G. Arborea* the lowest quantity of water acquired a highest value for tree height by (143.08cm) subsequently Q1 by (141.41cm) then Q2 by (127.34cm). Doubtless; this give an allusion about different behaviour response between tree species and water quantities at this stage of grow. Thus, *T.Grandis* and *K.senegalens* need almost to irrigate by highest amount of water (Q1) to expand its total height comparing with a lowest amount of water (Q3). May; it is not have the same influence at this growth parameter.This because When the available water content in the environment gradually decreases, stomata conductance decreases substantially, reducing transpiration, but without significantly affecting photosynthesis, because stomata closure reduces the flow of water vapour more than the flow of CO2 (**Kozlowski and Pallardy, 1997**) resulting in reduced leaf area and growth, decreased root development and expansion, affecting plant height and canopy establishment **(Martínez *et al.*, 2002**). Thus; Transpiration rates decreased with the age of the trees (**Rojas *et al.*, 2012).** In contrast; *G.Arborea* needs to irrigate by low (Q3) water quantity to enhance and improve its height.

Root collar diameter.

Distinctly; there are a different impacts for water quantities on (RCD) for tree species as shown at fig.(7). For instance; highest amount of water (Q1) has a significant influence on RCD for *T.Grandis* by mean average (30.35mm) comparing with lowest quantities (Q3) which obtained (25.27mm). On the contrary; with *G.Arborea* the significant influence on RCD was obtained under lowest amount of water (Q3) by (42.26mm) comparing with Q1 and Q2 which recorded (40.38 and 35.18mm) respectively. Moreover; there is not any significant influence between Q1 and Q2 on RCD for *G.Arborea*. On the other hand; with *khaya;* there is not any significant influence for different water quantities Q1, Q2 and Q3 on RCD. However; the highest value came with Q2 which obtained an average value by (24.1mm). Inasmuch as; that the *T.Grandis and K.senegalens* need for largest amount of water to get a good response and expand (RCD), however; with *G. Arborea* does not need to irrigate by high amount of water this type of tree need to low amount of water to give a high response value.

c) Effective water use on some growth parameters for trees.

Rationally; there are a highest response for both RCD and trees height to unit of water with a various impact depend on type of irrigation system techniques. For instance; as shown in fig.(8) under tree of *K.senegalens*–the best effective water use came with drip irrigation technique by (22.4cm/m^3) for tree height parameter and (9.7mm/m^3) for RCD. However; the lowest response for water unit obtained with GR, which recoded (16cm/m^3) and (7.7mm/m^3) for tree height and RCD respectively.

Noticeable; that the effective water use under *T. Grand is* acquired highest value for tree height with bubbler irrigation technique by (42.2cm/m^3) and by (19.1mm/m^3). On the other hand; with SSD irrigation technique the effective water use recorded lowest value for both tree height and RCD by (24.3cm/m^3) and (11.7mm/m^3) respectively. Finally; under *G. Arborea* the best irrigation technique was bubbler which recoded highest value for effective water use especially with tree height by (73.3cm/m^3) and by (20mm/m^3) with RCD. Furthermore, the drip irrigation system comes second at the best technique which obtained a good response for water unit under both RCD and tree height by (16.2mm/m^3) and (56.5cm / m^3) respectively. However; SSD technique is not the best way to irrigate this type of tree because the lowest response for water unit had recoded to both Tree height and RCD by (36.1mm/m^3) and (11mm/m^3) respectively. Inasmuch as; that the water distribution and wetting patterns under Bubbler and drip are differ from GR and SSD irrigation techniques. For GR and SSD systems that irrigate a relatively long wetted zone for each row plant, salt may accumulate within each zone in a pattern. In contrast, for an irrigation system employing drip emitters or bubblers, salt tends to accumulate mainly in the outer fringes of the wetted zone (**Walter, 1988**). Moreover; The irrigation water delivered by each bubbler is distributed uniformly by filling small level basins, surrounded by low ridges, with equal quantities of water **(Rawlins, 1977- FAO, 1997)**. By the simple means described, the principles of efficient irrigation can thus be implemented.

d) Statistical model

Occasionally; a model is a schematic representation of the conception of a system or an act

of mimicry or a set of equations, which represents the behaviour of a system (**Murthy, 2003**). Furthermore; Crop and plant growth model is a very effective tool for predicting possible impacts of different factors on crop growth and yield. Crop growth models are useful for solving various practical problems in agriculture. Thus; the regression models (using multiple regression at statistical program COStat which collect all parameters to determine the total tree height for various species under such conductions are:-

$H_T = 5.062*RCD_T - 3.565*Q - 30.366$ ($R^2=0.94$)

$H_m = 3.499*RCD_m + 2.624*Q - 7.488$ ($R^2=0.89$)

$H_K = 2.177*RCD_K + 1.503*Q - 5.486$ ($R^2=0.705$)

Where:-

H_T = Total Height for *T.Grandis*(Cm).

H_m = Total Height for *G.Arborea*(Cm).

H_K = Total Height for *K.senegalens*(Cm).

RCD_T = Root Collar Diameter for *T. Grandis* (mm).

RCD_m = Root Collar Diameter for *G. Arborea* (mm).

RCD_K = Root Collar Diameter for *K. senegalens* (mm).

Q = total water applied (m^3/tree/year).

Hence the previous models are represents the behaviour of a system under such conditions by knowingly two parameters total water applied per tree during year and Root Collar Diameter (RCD) the model can predicate the total tree height for each tree.

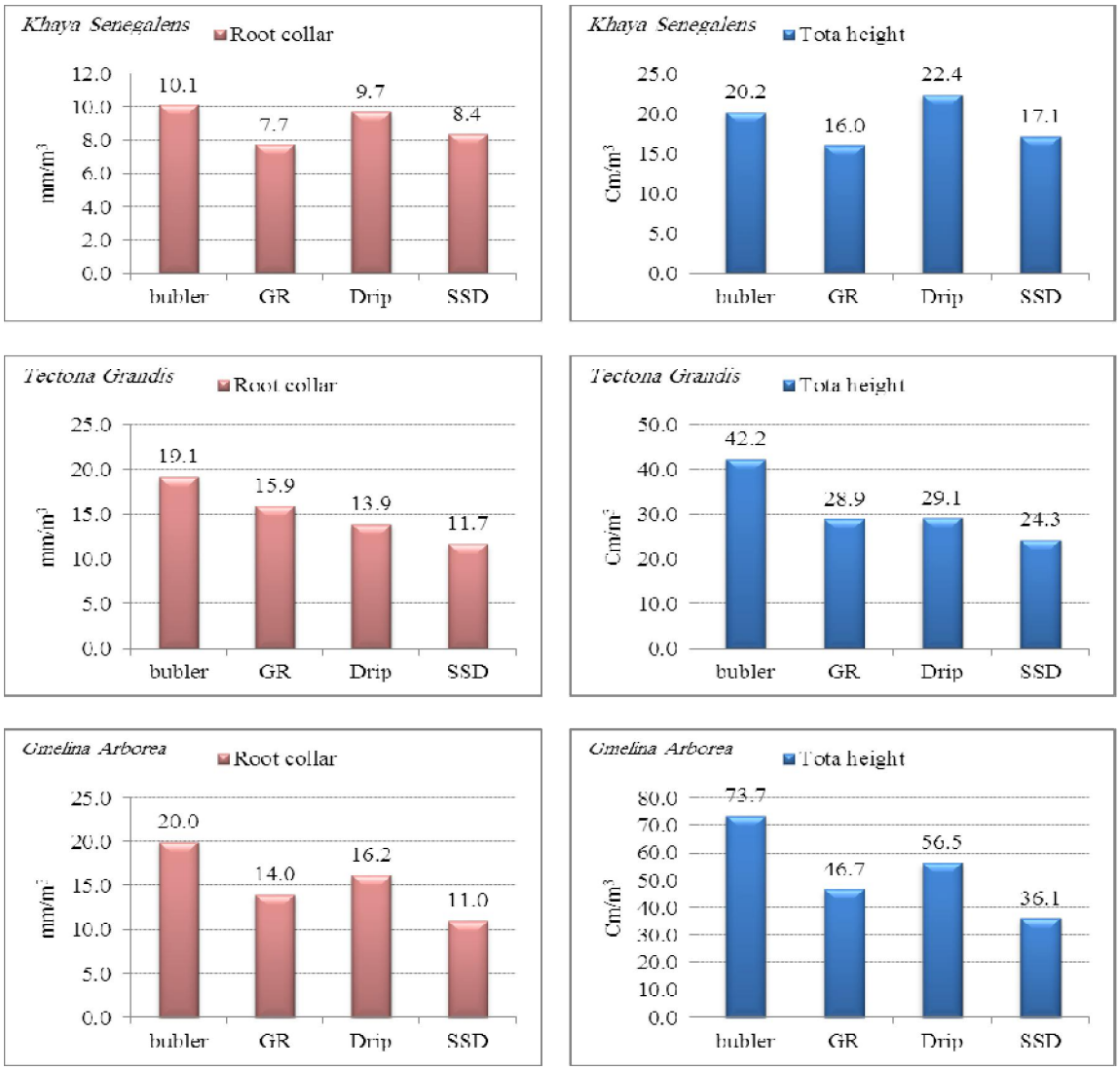

Fig.8 Response of (RCD) and Total Height of trees for effective water use under different irrigation system techniques

4. Conclusions

Noticeable, that the different techniques for irrigation system have a significant contribution for different growth parameters. Hence, choice from various irrigation methods is considered vital processes to ensure the success of any agricultural project specially when establish a forest at desert land. From the previous data analysis; the bubbler irrigation system technique is recommended when planted a *T. Grandis* and *G. Arborea* and drip (on line) irrigation technique comes second. On the other hand; the drip (on line) irrigation system comes at the first choice when planted *K. Senegalens* then recommended bubbler irrigation system as a second choice. Furthermore; there are not significant influences for water quantities on some growth parameters but generally *T. Grandis* and *K. senegalens* need almost to irrigate by highest amount of water (Q1) to expand its total height comparing with a lowest amount of water (Q3), in contrast; *G. Arborea* needs to irrigate by low (Q3) water quantity to enhance and improve its height. Finally; using a models equations help to predict which amount of water can use to get a highest value for some different growth parameters such as (RCD and Total height of tree).

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References

1. Alder, D. 1980. Estimation des volumes et accroissement des peuplements forestiers – Vol. 2. Étude et prévision de la production. Études FAO: forêts No. 22/2. Rome, FAO. 194 pp.
2. Andrea Rojas, Leonardo Moreno, Luz Marina Melgarejo, and Miguel A. Rodríguez M. (2012) Physiological response of gmelina (*Gmelina arborea Roxb.*) to hydric conditions of the colombian Caribbean, Agronomía Colombiana 30(1), 52-58, 2012.
3. Archibald, S. and Bond, W.J. 2003. Growing tall vs growing wide: tree architecture and allometry of *Acacia karroo*in forest, savanna, and arid environments. *Oikos*, 102(1): 3–14.
4. Batcheler, C.L. 1985. Note on measurement of woody plant diameter distributions. N. Z. J. Ecol. 8:129-132.
5. Bucks D.A., Nakayama F.S. and Gilbert R.G. (1979): Trickle irrigation, water quality and preventive maintenance. Agricultural Water Management, 2: 149-162.
6. CSSRI.1989. *Sewage water: utilization through forestry.* Karnal, India, Central Soil Salinity Research Institute.
7. Dhôte, J.F. 1996. A model of even-aged beech stands productivity with process-based interpretations. *Ann. Sci. For.*, 53(1): 1–20.
8. Dietze, M.C., Wolosin, M.S. and Clark, J.S. 2008. Capturing diversity and interspecific variability in allometries: A hierarchical approach. For. Ecol. Manag., 256(11): 1939–1948.
9. FAO (1997). Small-scale irrigation for arid zones: Principles and options," published in 1997 by the United Nations Food and Agriculture Organization. on the Web at- http://www.fao.org/docrep/w3094e/w3094e00.htm.
10. Fao Aquastat. Fao's Information System on Water and Agriculture: Climate Information tool. Aquastat Climate characteristics. http://www.fao.org/nr/water/aquastat/main/. (August 2015).
11. FAO (56).Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Richard G. Allen, Luis S. Pereira, Dirk Raes and Martin Smith. Rome (1988). Pp 133-134.
12. King, D.A. 1996. Allometry and life history of tropical trees. *J. Trop. Ecol.*, 12: 25–44.
13. Kozlowski, T.T. and S.G. Pallardy. 1997. Physiology of woody plants. 2nd ed. Academic Press, San Diego, CA.
14. Martínez, T., J. Vargas, A. Muñoz, and J. López. 2002. Respuesta al déficit hídrico en Pinusleiophylla: consumo de agua y crecimiento en plántulas de diferentes poblaciones. Agrociencia 36, 365-376.
15. Meeuwig, R O. and J.D. Budy.1981.Point and line-intersect Sampling in pinyon-juniper woodlands USDA For. Serv. Gen. Tech. Rep. INT-104, 38P.
16. Murthy, V.R.K. (2003) Crop growth modelling and its Applications in agricultural Meteorology- Satellite Remote Sensing and GIS Applications in Agricultural Meteorology- Proceedings of a Training Workshop held 7-11 July 2003 in Dehra Dun, India 2003: pp.235-261.
17. Rawlins, S.L. 1977. Uniform irrigation with a low-head bubbler system. Agric. and Water Manage, 1: 167-178.
18. Skovsgaard, J.P. and Vanclay, J.K. 2008. Forest site productivity: a review of the evolution of dendrometric concepts for even-aged stands. Forestry, 81(1): 13–31
19. Walter h. Gardner. 1988. Water Movement in Soils. Factsheet-Washington State University:23-27. at: www.ore-max.com/pdfs/resources/water_movement_in_soil.pdf.