J. of Plant Production, Mansoura Univ., Vol. 13 (6):251-263, 2022

Journal of Plant Production

Journal homepage & Available online at: www.jpp.journals.ekb.eg

Impact of Chitosan on Growth and Yield of Lemongrass Plant at Different Levels of Irrigation Water under Sandy Soil Conditions

Gehan F. Massoud[1*]; A. S. Dapor[1] and Mona A. M. El-Mansoury[2]

[1] Medicinal and Aromatic Plants Res. Dept., Horticulture Res. Inst., Agric. Res. Center, Giza, Egypt
[2] Water Requirements and Field Irrigation Res. Dept., Soils, Water and Environment Res. Inst., ., Agric. Res. Center, Giza, Egypt

Cross Mark

ABSTRACT

Growth attributes, yield and essential oil (EO) of lemongrass plant (*Cymbopogon citratus* (DC.) Stapf) in addition to some water relations and the economic return were assessed in response to the mutual effect of coefficients of cumulative pan evaporation (CPE) as a practical basis of irrigation scheduling at four levels (1.00, 0.85, 0.70 and 0.55 CPE) and foliar spraying with chitosan as antitranspirant compound (0, 50, 100 and 150 ppm). For this purpose, field study was implemented under sandy soil conditions during consecutive seasons of 2018 and 2019. Results exhibited that fresh and dry biomass per plant consequently, the herbage and dry yield per fed were enriched by irrigation scheduling at 1.00 and 0.85 CPE. However, irrigation scheduling at 0.70 and 0.55 CPE reduced all studied growth, yield attributes, oil yield and transpiration rate. EO yield per plant and per fed besides the oil main components were significantly enhanced by 1.00 or 0.85 CPE interacted with chitosan spraying at all levels in both harvests for the experimental seasons. The interaction between irrigation scheduling at 0.85 CPE and foliar spraying with 100 or 150 ppm chitosan significantly increased yield, oil productivity, and bioactive constituents particularly citral %. The premier productivity of irrigation water was recorded at 0.85 CPE compared with the other irrigation treatments. Hence, the optimum water requirement of 0.85 CPE interacted with foliar spraying of chitosan at 100 ppm as antitranspirant compound improved lemongrass yield, EO, economic return, water return and the productivity of irrigation water under water deficit conditions.

***Keywords*:** *Cymbopogon citratus*, chitosan, irrigation regime, yield, and productivity of irrigation water

INTRODUCTION

Cymbopogon citratus (DC) Stapf, family Poaceae (Graminae) mainly grows in tropical regions, especially Africa and South East Asia as economically valuable plant (Babarinde *et al*., 2016). It is perennial, aromatic tillers, rigid stems stand up from small rhizomatous rootstock forming tussocks and it is called lemongrass because of a distinctive lemon-like aroma due to citral component with two main geometric isomers (Oliveira *et al*., 2018). *C. citratus* oil is used in the food purposes and essential for pharmaceutical fields (Kumoro *et al*., 2020). Also, imperative for treating human disorders; digestive, bladder, toothache, cough, cold, (Ahmad and Viljoen, 2015). Citral is used in therapy of Alzheimer's disease (Orabi *et al*., 2015), a potent antimicrobial and anti-inflammatory agents as mentioned by (Korenblum *et al*., 2013; Boukhatem *et al*., 2014; Han and Parker, 2017). Lemongrass polysaccharides act as an effective anti-cancer drugs and cosmetic (Thangam *et al*., 2014; Ekpenyong *et al*., 2014). Lemongrass is used for skin issues owing to presence of vitamin A. According to Jain *et al*., 1994 sandy texture soil with higher acidity are the favorable conditions for leaf oil yield and citral content of the grass. Citral as a fundamental raw material for synthesis of diverse aromatic compounds is the major bioactive constituent of the essential oil of *Cymbopogon* shoots includes citral-a which documented the highest percentage (53.98 %), citral-b (34.40 %) as reported by Chinese *et al*., 2005. Thus, because of more desires for lemongrass oil, expansion of the cultivation area is needed.

Currently and further in the future, the climatic alterations cause globally augmentation of the environmental issues and abiotic stresses particularly water deficit stress (Pirbalouti *et al*., 2013) that affects yield and quality of medicinal and aromatic plants. Water stress as one of the greatest critical abiotic stresses is a limiting factor in agricultural applications sector in which 70% of the entirely water ingesting was happened affecting food security (FAO 2015). Water stress is expected to adversely results on plant–water potential, plant biochemistry, physiology, anatomy, and morphology (Mirzaie *et al*., 2020 b) such as reducing biomass by limiting soil moisture content and nutrients availability (Malekpoor *et al*., 2016). Moreover, Singh *et al*., 2015 stated that water deficit causes oxidative stresses and induction of reactive oxygen species that leads to damage of the plant cell. Upgrading of growth, yield, net returns, and water use efficiency depends on irrigation management strategies and use of optimum irrigation schedule that refers to well-timed irrigation supply with both promising crop yields and saving water (Rai, 2017) to cope with insufficiency and scarcity water supplies. An evaporation pans as indicator to the crop water use rate is an open water pan exposed to an identical climatic circumstances of the studied crop. There is a relationship between pan evaporation and crop evapotranspiration. It is worthy mention that evaporation pans act as a precise allusion for both crop evapotranspiration and irrigation scheduling, which is important for adaptation of globally climatic variation (Ertek 2011).

The increasing request for limited water resource and the deleterious effects of drought on productivity and quality could be circumvented by plant adjustments for instance osmotic modifications, stomata closure, important physiological and biochemical variations and leaf rolling (Farouk and Ramadan,

*** Corresponding author.**
E-mail address: gehan.fawzy75@gmail.com
DOI: 10.21608/jpp.2022.139065.1110

2012; Khalil, 2015; Khalil and El-Ansary, 2020). Drought occasions might be countered by many ways such as foliar application of anti-transpirants to avoid water loss (Bittelli *et al*., 2001). Chitosan is among anti-transpirant compounds (poly (1, 4) -2-amino-2-deoxy-β- D glucose) which is the deacetylated derivative of chitin (Iriti *et al*., 2009). Chitin mainly consisted of a linear polymer of D-glucosamine and N-acetyl-D-glucosamine and chitin accessible in some algae, amoebae, yeasts also in some insects, mollusks, the exoskeleton of some filamentous fungi cell wall particularly *Asperigullus niger*, crab and shrimp shells (Pandey *et al*, 2018). Chitin and chitosan differ mainly due to acetylation degree. Chitin demineralization occurs by acids then a deproteinization process through a base leads to chitosan production (Kaya *et al*. 2015).

Chitosan compound is hopeful, bioactive, ecofriendly, biocompatible, non-toxic, biodegradable, and cost effective thus it has been involved in wide views including biotechnology, agricultural prospects and in biomedicine (Katiyar *et al*. 2014). Regarding agricultural applications particularly in arid and semi-arid districts, chitosan and its oligomers used for plant protection, stimulus of plant growth, yield, induction and elicitation many defense responses against environmental stresses in particular water deficit (Malerba and Cerana 2016; Aly *et al*., 2019; Hidangmayum *et al*., 2019). Chitosan as a valuable anti-transpirant compound reduce water loss with maintaining yield (Khalil and Badr Eldin, 2021).

Overall, aromatic grass oil as a valuable product has a potential effect to attract both current and future aromatic lemongrass growers. This work was conducted due to inadequately authors' knowledge and the preceding studies are still lacking regarding the combined effects of foliar application of anti-transpirant chitosan and wise application of water consumptive use on lemongrass yield and quality grown in sandy soil under arid conditions, water use efficiency (WUE) and seasonal consumptive use (ET_C) of plant and net returns.

MATERIAL AND METHODS

Under field conditions this investigation was undertaken at a private farm in Kalabsho region, Bilqas, El-Dakahlia Governorate, Egypt during two succeeding experimental seasons of 2018 and 2019 underneath sandy soil circumstances using drip irrigation to study the effect of different irrigation scheduling treatments based on coefficient of cumulative pan evaporation (CPE) that intended as the daily evaporation sum as the irrigation water levels from pan evaporation readings; IR_1 (1.00 of cumulative pan evaporation, CPE), IR_2 (0.85 CPE), IR_3 (0.70 CPE) and IR_4 (0.55 CPE) interacted with effect of diverse foliar chitosan applications (0, 50, 100 and 150 ppm) on plant growth, herbage yield, oil yield and constituents of *Cymbopogon citratus* DC, Stapf as well as some plant water relationships. The meteorological records of the investigational site in Fig. 1 were obtained from Mansoura weather station according to the Central Laboratory for Agricultural Climate, Agric. Res. Center, Ministry of Agriculture and Land Reclamation, Egypt as air temperature (Temp.) and relative humidity (Rh.) were recorded daily then monthly were calculated as mean values. Wind speed (WS) and pan evaporation (Ev) were daily calculated.

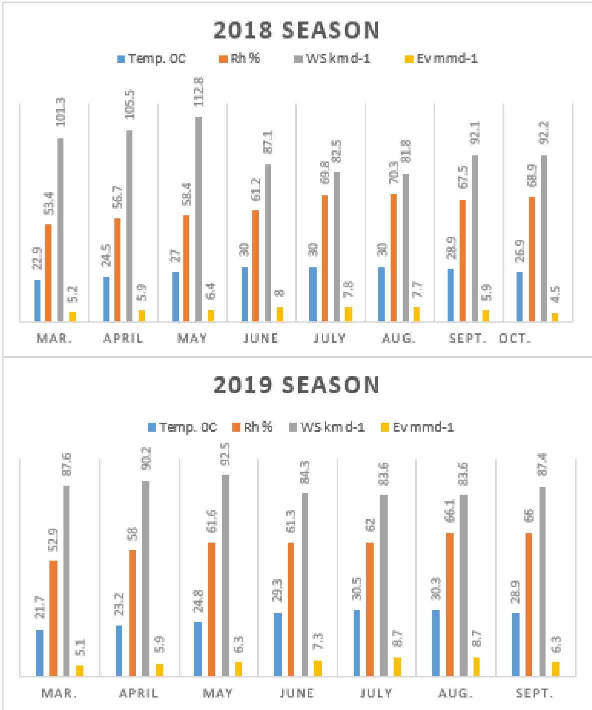

Fig 1. The meteorological records of the experimental site during 2018 and 2019 experimental seasons

Temp.: Air Temperature (°C); Rh: Relative humidity (%); WS: Wind speed (km d^{-1}) Ev: Pan Evaporation (mm d^{-1})

The analyses of the soil samples taken before cultivation procedure were evaluated according to klute (1986) and Jackson (1973) and revealed that soil characteristics as average of both 0-30cm and 30-60 cm soil depths were sandy in texture, pH was determined at 1: 2.5 soil water suspensions and some soil properties for both experimental seasons were illustrated (Table 1). The electrical conductivity and pH of the applied irrigation water were 1.85 dsm^{-1} and 8.28, respectively.

Table 1. some soil properties of the experimental site during 2018 and 2019 experimental seasons

Determinations	Soil fractions (%)			pH (1:2.5)	$CaCO_3$(%)	Organic matter(%)	EC (dSm^{-1})	Available nutrients (ppm)		
Experimental seasons	Clay	Silt	Sand	soil water suspension				N	P	K
2018 season	5.66	16.3	77.99	8.33	2.04	0.59	2.97	24.35	24.41	238.5
2019 season	7.8	17.25	74.89	8.07	1.36	0.68	3.81	19.76	24.88	249.8

The trial included sixteen interaction treatments, which were arranged in split plot system with three replicates based on a randomized complete block design and randomly allocated as the combinations between four levels of irrigation scheduling treatments and four foliar spray applications of chitosan as main and sub-plots, respectively. Individual clumps procured from the Medicinal and Aromatic Plants (MAP) Dept. of Hort. Res. Inst., Agric. Res. Center were detached into rooted slips and those uniform divisions were transplanted about at 0.15 m depth on 25th and 27th of March in respective of the 1st and 2nd experimental seasons in the experimental units, each unit contained eighteen plants spaced at 0.5m, with three dripper lines at three rows which was 0.6 m apart, between each two neighboring experimental units, a guard row was left to avoid overlapping and water undertaking. Ten days from transplantation for both seasons, scheduling treatments initiated from the 2nd irrigation which every two days were applied thereafter to lemongrass plants. Chitosan powder product (poly - (1, 4-B-D-glycopyranosamine); 2-Amino-2-deoxy- (1->4) - B-D-glucopyranan), medium molecular weight, from crab shells, was accessible by dissolving in 5 % acetic acid and was attained from El-Gomhouria Co. for chemicals and medical supplies, El-Mansoura, Egypt. Foliage applications of chitosan solution were done at three weeks intervals starting four weeks after transplanting and clogged two weeks before each harvest in the two experimental seasons.

Irrigation water (IW) was under drip irrigation system which consists of a pumped unit that contains a pump, control unit, groups of pipes which differ in its diameter and distribution lines. The control unit of the system contains a venture injector (25.4 mm), fertilizer tank, disk filters, control valves and a water flow meter. Distribution lines consists of polyethylene pipes manifolds laterals of 16 mm in diameter and 40 m in length had in- line emitters spaced 0.5 m apart, each delivering 4L h^{-1}at a pressure of 1 bar. Drip irrigation lines were spaced 0.6 m apart equally spaced between every other row of lemongrass. Water was applied from a pressurized hydrant and filtered through gravel and re-filtered through disk filters.

All recommended agricultural and conservative practices were performed. Fertilization as ammonium sulfate (20.5% N), calcium superphosphate (15.5 % P_2O_5) and potassium sulfate (48 % K_2O) as NPK sources were applied in respective of the rates of 82 kg N / fed, 46.5 kg P_2O_5 / fed and 48 kg K_2O / fed. Two weeks prior to planting date during the final soil preparation entirely amount of P_2O_5 and organic manure at 10 m^3/fed were added, N and K_2O were added coincided with irrigation (C.A.A.E.S, 2014). Also, diseases control and manually eliminated weeds were done when needed. The amount of water was calculated by the following equation;

$$A = Q \times T$$

where: A = the volume of water delivered to the plot (m^3)
Q = the amount of applied water (m^3/ minute) and
T = the time of irrigation (minute).

Data were collected twice per season at the end of the experiment, the 1st harvest was done on 9th and 4th July in respective to 1st and 2nd seasons and the 2nd harvest was done on17th October. At each harvest time the observations were noted down;

Growth and yield attributes

Growth and yield characters viz. shoot length (cm), tillers number per plant, fresh and dry biomass (g/ plant) were evaluated; fresh biomass directly weighed and dry biomass (g/ plant) was recorded by air drying each plant shoot till unceasing weight. Additionally, the herbage and dry yield (ton fed^{-1}) was assessed.

Plant analytical determinations

The percentage of essential oil (EO) was measured by a Clevenger glass apparatus through hydro-distillation of 100 g samples that were scratch into small pieces as the time of distillation for extraction of EO were found to be 130 min *(*Ehlert *et al*, 2006*)* adapting to Egyptian Pharmacopoeia (1984). Oil yield per plant (ml) was estimated by multiplying the percentage of oil by herb yield average then multiplying the oil yield per plant by total plants number per fed to obtain the essential oil yield per fed (L). The extracted EO were dehydrated by anhydrous sodium sulfate and stored in locked vials at 2 ◦C until the GC analysis. The components of the extracted EO from the irrigated plants at 1.00, 0.85 and 0.70 CPE under all levels of chitosan foliar spraying were identified in the second harvest of the second experimental season by comparison of their mass spectra with those of authentic compounds or with those of a computer library according to Robert (1995).

Transpiration rate from fully expanded of 4-5 leaves of five randomly chosen plants of 90-day-old lemongrass plant for each harvest in each replication was measured using a Li-1600M steady state porometer.

Lemongrass yield-water relatives

The amount of applied water was measured using flow meter. Productivity of irrigation water (PIW) was calculated according to Ali *et al.*, (2007).

$$PIW = \frac{Y}{IW}$$

Where: PIW; productivity of irrigation water (kg m^{-3}),
Y; Yield (sum yields of 1st and 2nd harvest, kg), and
IW; Applied Irrigation water (m^3).

Economic evaluation

The economics were studied during the entire course of the experiment regarding the current inputs and outputs prices. Economic evaluation of interaction between irrigation scheduling regimes and chitosan foliar spraying treatments as described by Cimmyt (1988).

Statistical analysis

The statistical analysis of variance on the resulted data was made by COSTAT and the difference between means for evaluating the significance were analyzed as split plot design, and compared the means using Duncans' Multiple Range Test as described by Snedecor and Cochran (1990).

RESULTS AND DISCUSSION

Growth and Yield attributes

Growth attributes viz. shoot length, tillers number per plant, fresh and dry biomass per plant were responded to the diverse irrigation scheduling regimes and seasonal differences as the values of all studied parameters of the herb in the second experimental season were higher than those of the first one . As shown in Table (2), all above mentioned growth parameters significantly fluctuated among irrigation scheduling coefficient treatments, all were declined with decreasing irrigation scheduling coefficient in the two experimental seasons, the tallest lemongrass and the maximum number of tillers per plant were resulted under irrigation scheduling coefficients of 1.00 and 0.85 CPE in both experimental seasons. Tillers number per plant was clearly increased under irrigation at 0.85 CPE and 1.00 CPE with non-significant variations in between excluding the 2nd harvest in the 1st season as the tillers number increase was related to the elevation of irrigation levels and lemongrass age. Also, the highest values of fresh and dry biomass resulted from plants irrigated at 1.00 and 0.85 CPE, whereas the lowest ones resulted from those under 0.70 and 0.55 CPE. By decreasing irrigation scheduling coefficient from 1.00 to 0.55 CPE significantly decreased the shoot length, tillers number per plant, fresh and dry biomass particularly at the lower regime 0.55 CPE that decreased shoot length, tillers number per plant, fresh and dry biomass by about 24.9, 28.5; 33.3, 26.0; 62. 8, 65.5 and 61.5, 63.8% in respective of the first and second harvests in the 1st experimental season while, 26.8, 31.3; 39.8, 40.3; 66.0, 70.0 and 65.6, 69.6 respectively, in the 2nd one. Thus, the increments of shoot length and tillers number per plant under optimized irrigation leads to increasing of fresh biomass per plant as adequately water from the soil assistances in preserving good substrate for photosynthetic processes closing to growth enhancement as photosynthetic processes that increase affects cell number and cell enlargement. Growth and performance decline by water stress has been recognized, growth dropping was resulted due to soil osmotic potential decrease thus, water uptake was reduced as the plant growth are very linked to water flow and stomatal resistance and the hormonal balance between root and shoot was greatly altered due to water changes affecting metabolism and growth (Ben-Asher *et al.*, 2006). Also, the shoot length and biomass were negatively affected due to irrigation schedule as limiting soil moisture, nutrient uptake, and photosynthesis and its products (Lakpale *et al.*, 2007; Rahdari *et al*., 2012) and due to water stress particularly at suboptimal circumstances as it influences biochemical activities, production of substrates affecting growth (Yamiv and Palevitch, 1982; Ali *et al*., 2014). These results agree with those results of Singh *et al* (2016) and Mirzaie *et al* (2020 a)who mentioned that water deficit increase leads to reduction plant height and shoot dry weight of lemongrass plants.

Table 2. Average of shoot length (cm), tillers number per plant and both fresh and dry biomass (g/plant) of lemongrass (*Cymbopogon citratus* (DC.) Stapf) as a function of irrigation scheduling regime, chitosan foliar spray and their interaction under sandy soil for the 1st and 2nd harvest in both experimental seasons (2018 and 2019).

Irrigation scheduling regime (CPE coefficients)	Shoot length (cm)									
	First season 2018									
	First harvest					Second harvest				
	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average
IR_1(1.00 CPE)	66.43d	67.21d	73.87a	75.18a	70.67a	71.55e	71.78de	74.12bc	77.10a	73.64a
IR_2(0.85 CPE)	62.41f	64.46e	70.22c	71.85b	67.24b	69.97e	71.49e	73.58cd	75.89ab	72.73a
IR_3(0.70 CPE)	59.37g	59.88g	62.15f	61.57f	60.74c	59.96h	63.02g	63.46fg	65.26f	62.93b
IR_4(0.55 CPE)	49.89i	50.14i	54.00h	53.90h	51.98d	51.14j	51.60j	54.39i	55.10i	53.06c
Average	59.53c	60.42b	65.06a	65.63a		63.16d	64.47c	66.39b	68.34a	
	Second season 2019									
IR_1(1.00 CPE)	68.89d	70.41c	77.26b	78.89a	73.86a	71.99d	72.66d	78.25c	79.14c	75.51b
IR_2(0.85 CPE)	68.90d	68.92d	80.04a	79.90a	74.44a	72.00e	72.00d	83.04b	84.25a	77.82a
IR_3(0.70 CPE)	59.68g	61.22f	62.57e	62.06ef	61.38b	59.79h	61.30g	63.61f	65.09e	62.45c
IR_4(0.55 CPE)	50.44i	50.73i	53.96h	53.98h	52.28c	49.49l	50.96k	54.72j	56.32i	52.87d
Average	61.98c	62.82b	68.46a	68.71a		63.32d	64.23c	69.91b	71.20a	
Irrigation scheduling regime (CPE coefficients)	Tillers number per plant									
	First season 2018									
	First harvest					Second harvest				
	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average
IR_1(1.00 CPE)	13.73d	13.89cd	14.57bc	14.81b	14.25b	14.26c	15.78b	16.85a	17.03a	15.98b
IR_2(0.85 CPE)	13.80d	14.05bcd	16.98a	16.98a	15.45a	15.53b	15.99b	17.34a	17.10a	16.49a
IR_3(0.70 CPE)	11.46fg	11.51fg	12.00ef	12.34e	11.83c	11.70ef	11.70ef	12.16de	12.45d	12.00c
IR_4(0.55 CPE)	9.16j	10.11i	10.53hi	11.09gh	10.22d	10.55g	10.64g	10.64g	11.42f	10.81d
Average	12.04b	12.39b	13.52a	13.81a		13.01c	13.53b	14.25a	14.50a	
	Second season 2019									
IR_1(1.00 CPE)	15.60b	15.60b	16.43a	16.39a	16.01a	15.82b	15.90b	16.92a	16.92a	16.39a
IR_2(0.85 CPE)	15.56b	15.61b	16.35a	16.37a	15.97a	15.84b	15.89b	17.07a	16.92a	16.43a
IR_3(0.70 CPE)	12.41d	12.79d	12.79d	13.55c	12.89b	13.03d	13.88c	13.91c	13.93c	13.69b
IR_4(0.55 CPE)	9.39f	9.60f	10.50e	10.89e	10.10c	9.44g	10.60f	11.46e	11.61e	10.78c
Average	13.24b	13.40b	14.02a	14.30a		13.53c	14.07b	14.84a	14.85a	
Irrigation scheduling regime (CPE coefficients)	Fresh biomass (g/plant)									
	First season 2018									
	First harvest					Second harvest				
	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average
IR_1(1.00 CPE)	188.62d	190.12d	208.59b	212.18a	199.88a	205.18e	222.50d	231.77c	236.18b	223.91a
IR_2(0.85 CPE)	180.31e	188.58d	206.18c	208.99b	196.02b	196.13f	204.34e	250.14a	236.20b	221.70a
IR_3(0.70 CPE)	127.00i	129.15h	135.12g	141.33f	133.15c	140.25i	140.77i	162.04g	154.17h	149.31b
IR_4(0.55 CPE)	70.20m	78.61l	89.24j	87.00k	81.26d	70.73l	80.12k	89.57j	90.05j	82.62c
Average	141.53d	146.62c	159.78b	162.38a		153.07d	161.93c	183.38a	179.15b	
	Second season 2019									
IR_1(1.00 CPE)	218.30e	224.19d	245.88b	238.25c	231.66b	249.00f	260.08e	237.07b	265.16d	261.83a
IR_2(0.85 CPE)	219.05e	224.08d	250.74a	245.00b	234.72a	236.78h	245.23g	277.16a	270.75c	257.48b
IR_3(0.70 CPE)	125.86i	136.18h	140.85g	160.37f	140.82c	141.28l	145.20k	166.41i	154.28j	151.79c
IR_4(0.55 CPE)	74.18l	74.22l	87.06j	80.65k	79.03d	74.73o	80.95n	89.70m	89.93m	83.83d
Average	159.35c	164.67b	181.13a	181.07a		175.45d	182.87c	201.59a	195.03b	
Irrigation Scheduling regime (CPE coefficients)	Dry biomass (g/plant)									
	First season 2018									
	First harvest					Second harvest				
	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average
IR_1(1.00 CPE)	62.11e	63.03d	70.05b	71.73a	66.73a	68.07e	74.93d	77.18c	79.14b	74.83a
IR_2(0.85 CPE)	59.79f	61.84e	69.16c	70.44b	65.31b	65.72f	67.55e	85.85a	79.50b	74.66b
IR_3(0.70 CPE)	42.33i	42.95i	44.27h	48.85g	44.60c	46.22i	46.65i	53.79g	51.07h	49.43c
IR_4(0.55 CPE)	23.90l	26.12k	28.18j	27.84j	26.51b	24.62m	26.81l	28.70k	29.77j	27.48d
Average	47.03d	48.49c	52.92b	54.72a		51.16d	53.99c	61.38a	59.87b	
	Second season 2019									
IR_1(1.00 CPE)	73.07d	75.31c	83.08b	81.42b	78.22a	85.27d	87.13c	89.55b	87.89c	87.46a
IR_2(0.85 CPE)	73.68cd	75.13c	85.90a	82.37b	79.27a	80.07f	82.56e	91.68a	88.46bc	85.69b
IR_3(0.70 CPE)	40.70h	44.66g	47.27f	52.98e	46.40b	48.11i	49.54i	56.04g	51.67h	51.34c
IR_4(0.55 CPE)	25.15j	25.18j	27.89i	26.99i	26.30c	25.90l	27.46kl	29.03jk	29.10j	27.87d
Average	53.15c	55.07b	61.04a	60.94a		59.84d	61.67c	66.58a	64.28b	

IR_1 Irrigation regime at 1.00 of cumulative pan evaporation, CPE), IR_2: Irrigation regime at 0.85 CPE, IR_3: Irrigation regime at 0.70 CPE and IR_4: Irrigation regime at 0.55 CPE)

In view of the chitosan foliar application in Table (2), the mean comparison showed that all levels of chitosan stimulated the growth under all irrigation scheduling coefficient treatments and the top averages of previous growth parameters were resulted at 100 and 150 ppm chitosan in the two experimental seasons compared to the least ones that were achieved at un treated plants. The enhancement of plant growth under chitosan effect may be owing to optimum conditions of irrigation water that be adjusted by chitosan anti-transpirant so water and available minerals uptake increase by adjusting cell osmotic pressure, also scavenging activities of reactive oxygen species were improved as capability of plants to be tolerant to various stresses is associated with antioxidants detoxify ROS likewise, the increase of enzymatic activities of N metabolism and photosynthesis (Guan *et al.* 2009; Mondal *et al.*, 2012; Ibrahiem and Mohsen, 2015; Anusuya and Sathiyabama,2016; Chakraborty *et al.*, 2020). These findings were in harmony with those of Farouk and Ramadan 2012 on cowpea and Pirbalouti *et al.* 2017on basil who stated that foliar chitosan at 250 mg L^{-1} and 0.2-0.4 gL^{-1} respectively, under drought stress positively affected growth traits.

As for the effect of the interaction between the irrigation scheduling treatments and chitosan application, data in Table (2) revealed that the previous growth traits were significantly affected. Chitosan foliar spraying of 100 or 150ppm under irrigation treatments of 0.85 CPE or 1.00 CPE in both harvests in the experimental seasons gave the supreme averages of shoot length. The maximum number of tillers/plant resulted from lemongrass plants irrigated with 0.85 CPE and applying 100 or 150 ppm chitosan in the 1st harvest, while, in the 2nd harvest during the 1st experimental season plants sprayed with 100 or 150 ppm chitosan under both irrigation treatments of 1.00 or 0.85 CPE gave the superlative average of tillers number and at the same irrigation treatment with the same levels of chitosan spray (100 and 150ppm) for both harvests in the 2nd experimental season. Correspondingly, fresh and dry biomass was significantly increased under interaction treatment of either irrigation at 100 or 0.85 CPE with applied chitosan at 100 or 150ppm for all harvests in both seasons. All growth traits affected when chitosan gradually increased from 50 to 100 or 150 ppm, it is worthy to state that the highest growth values were achieved under irrigation coefficient of 1.00 and 0.85 with application 100 and 150 ppm chitosan over all irrigation scheduling while, the lowest ones were attained from plants irrigated at 0.55 CPE. It is well-intentioned to state that water deficiency causes reduction for all growth traits due to water stress negatively effects on photosynthetic processes, availability of nutrients and plant water relatives accordingly plant water potential could be increased by antitranspirant affecting all metabolic processes that are important for plant growth such as photosynthesis (Win *et al.*,1991). Also, antitranspirants minimize water loss through transpiration besides, solar radiation increase and optimize soil moisture (Thakuria *et al.*, 2004). An adequately sunshine is necessary for enrichment oil yield (Kress, 2007). With reference to the positive effect on plant growth due to molecular signals of chitosan as growth stimulants and improve immune system of the plant as declared by Hadwiger *et al.*, 2002 and Nge *et al.*, 2006. Also, it gives available amino compounds and photosynthetic rates increase culminating in plant growth as evidenced by Khan *et al.*, 2002. Additionally, it increases water and available minerals uptake as mentioned by Guan *et al.*, 2009. Moreover, chitosan acts on the gene expression affecting genomes of nucleus and chloroplast as reported by Chamnanmanoontham *et al.* 2014. These findings support the present results that foliar applications of chitosan improved growth under limited irrigation and in agreement with results of Javan *et al.*, 2013 on soybean; Safaei *et al.*, 2014 on black cumin; Malekpoor *et al.*, 2016 on basil ; Ahmad *et al.* 2019 on peppermint; Zou *et al.*, 2017 on wheat and Khalil and Badr Eldin., 2021on grapevines.

Correlation between the results showed in Table (2) and those set up in Table (3) in which lemongrass yield per fed led us to conclude that fresh and dry yield per fed was reduced with a decrease in irrigation scheduling regimes and clearly lessening in fresh and dry yield per fed was achieved under 0.55 CPE that decreased the fresh and dry yield per fed by about 64.6 and 63.2% in the 1st experimental season, respectively and 68.1 and 67.6% in the 2nd one. On the other hand, the highest fresh or dry lemongrass yield per fed was obtained from plants irrigated either 1.00 CPE or 0.85 CPE in both experimental seasons. Fresh and dry yield per fed of grass plants under spraying of chitosan showed significantly variations. The greatest yield per fed was gotten under foliage spray chitosan at 100 and 150 ppm under all irrigation regimes. The stimulatory effect of optimum conditions of irrigation and the foliar spraying with chitosan on fresh and dry yield may be due to the effect that was previously mentioned in the case of growth parameters of herb as the increase in these parameters reflected on yield per fed. The upshots showed that the interaction treatment (1.00 CPE+ chitosan 150 ppm) and (0.85 CPE+ chitosan 100 ppm) recorded the highest fresh and correspondingly dry yield per fed in both harvests during 1st experimental season compared to the other interactions while, the interaction treatment (0.85 CPE+ chitosan 100 ppm) gave the utmost yield per fed in both harvests in the 2nd experimental season.

Chitosan also promoted improvements in fresh and dry weight, the pronounced effect on plant growth and yield could be explained on the basis of the optimum irrigation water and foliar application of anti-transpirant chitosan improved the metabolic activities closing in enhancement growth as reported by Iriti *et al.*, 2009 and Javan *et al.*,2013 who said that foliar application of antitranspirant increased yield due to increasing water potential of plants causing leaves relative humidity increased additionally, antitranspirants improved metabolic activity and synthesis of protein. Lemongrass yield in the 2nd experimental season was greater than that of the 1st one due to more appropriate environmental conditions. In this concern, similar results were obtained regarding irrigation regimes by Chakraborty *et al.* (2010) on *Cymbopogon flexuosus*, Also, bio stimulant chitosan application to tolerate water deficit was mentioned by Katiyar *et al.*, 2015; Malekpoor *et al.*, 2016; Rabelo *et al.* 2019 ; Farouk and EL-Metwally, 2019; Moolphuerk and Pattanagul, 2020; and Fouda *et al.*, 2021.

Plant analytical determinations

Essential oil (EO)

Results in Table (4) exhibited that the essential oil (EO) percentage and yield per plant and per fed considerably varied under irrigation regimes and chitosan spray in both harvests for two experimental seasons. The increase in yield of the plants was accompanied with the decrease in EO percentage under water stress and the response to the stress is mainly related to many factors such as other environmental conditions, plant species and stress intensity. The percentage of EO gradually decreased by increasing irrigation scheduling coefficients and meantime, to obtain improved oil yield, it should be maintain soil moisture comparing to irrigation deficiency. The increase in EO under water stress may be attributed to favored conversion photosynthetic compounds into secondary metabolites such as oil and alkaloids compared to primary ones such as fats and carbohydrates as mentioned by Morales *et al.*, 1993. The increase in irrigation level up to optimum irrigation scheduling coefficient of 0.85 CPE causes oil yield per plant and consequently per fed increments for both harvests in the studied years while, the oil yield under more increase in irrigation level declined whereas by decreasing irrigation level to 0.55 CPE the oil yield was extremely reduced. Remarkable increase in EO yield under 0.85CPE is due to the herbage yield increments. Contrariwise, the decrease in oil yield per plant and per fed were noted under irrigation coefficients of 0.70 and 0.55 CPE due to negatively effects of water stress on EO production that related to the photosynthesis process against the respiration. These findings were in coincided with Singh *et al*., 2000 and Tesfaye *et al*., 2017 who stated that water have emotional impact on both mass and quality so, it is necessary to optimize the irrigation for obtaining fresh herbs and essential oils.

Table 3. Average of the herbage and dry yield (ton fed^{-1}) of lemongrass (*Cymbopogon citratus* (DC.) Stapf) as a function of irrigation scheduling regime, chitosan foliar spray and their interaction under sandy soil for the 1st and 2nd harvest in both experimental seasons (2018 and 2019).

Irrigation scheduling regime (CPE coefficients)	Herbage yield (ton fed^{-1})									
	First season 2018									
	First harvest					Second harvest				
	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average
IR$_1$(1.00 CPE)	2.654c	2.678c	2.927ab	2.971a	2.81a	2.879e	3.120d	3.246c	3.312b	3.14a
IR$_2$(0.85 CPE)	2.516d	2.633c	2.890b	2.931ab	2.74b	2.757f	2.867e	3.506a	3.314b	3.11a
IR$_3$(0.70 CPE)	1.780f	1.813f	1.910e	1.982e	1.87c	1.967i	1.969i	2.271g	2.160h	2.09b
IR$_4$(0.55 CPE)	0.976i	1.115h	1.253g	1.210g	1.14d	0.989l	1.139k	1.255j	1.267j	1.16c
Average	1.98c	2.06b	2.25a	2.27a		2.15d	2.27c	2.57a	2.51b	
	Second season 2019									
IR$_1$(1.00 CPE)	3.059c	3.142c	3.445ab	3.340b	3.24a	3.490d	3.646c	3.830ab	3.714c	3.67a
IR$_2$(0.85 CPE)	3.072c	3.141c	3.513a	3.428ab	3.29a	3.322e	3.436d	3.892a	3.798b	3.61b
IR$_3$(0.70 CPE)	1.766f	1.911e	1.973e	2.250d	1.98b	1.980h	2.041h	2.335f	2.163g	2.13c
IR$_4$(0.55 CPE)	1.011i	1.035hi	1.218g	1.157gh	1.11c	1.077k	1.179j	1.257i	1.261i	1.19d
Average	2.23c	2.31b	2.53a	2.54a		2.47d	2.58c	2.83a	2.73b	
Irrigation scheduling regime (CPE coefficients)	Dry yield (ton fed^{-1})									
	First season 2018									
	First harvest					Second harvest				
	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average
IR$_1$(1.00 CPE)	0.858cd	0.887c	0.985ab	1.014a	0.94a	0.956d	1.051c	1.088bc	1.110b	1.05a
IR$_2$(0.85 CPE)	0.839d	0.867cd	0.970b	0.989ab	0.92a	0.921d	0.949d	1.204a	1.117b	1.04a
IR$_3$(0.70 CPE)	0.591f	0.602f	0.621f	0.686e	0.63b	0.650f	0.653f	0.755e	0.719e	0.69b
IR$_4$(0.55 CPE)	0.328h	0.370g	0.401g	0.395g	0.37c	0.340i	0.379hi	0.407gh	0.421g	0.38c
Average	0.65d	0.68c	0.74b	0.77a		0.71d	0.75c	0.86a	0.84b	
	Second season 2019									
IR$_1$(1.00 CPE)	1.022d	1.070c	1.166ab	1.141b	1.10a	1.197bc	1.222bc	1.256ab	1.233ab	1.23a
IR$_2$(0.85 CPE)	1.039cd	1.064cd	1.206a	1.153b	1.12a	1.125d	1.157cd	1.291a	1.240ab	1.20a
IR$_3$(0.70 CPE)	0.573g	0.625f	0.666f	0.746e	0.65b	0.677f	0.697f	0.789e	0.727ef	0.72b
IR$_4$(0.55 CPE)	0.350i	0.355hi	0.397h	0.383hi	0.37c	0.319h	0.390g	0.411g	0.414g	0.40c
Average	0.74c	0.78b	0.86a	0.85a		0.84b	0.87b	0.94a	0.90a	

As regards foliar spraying chitosan, data in Table (4) showed remarkable variances in the EO percentage, oil yield per plant and per fed in the two harvests for both years. The previous traits were gradually increased at all levels of chitosan in particular at 100 and 150 ppm chitosan with non-significant differences in between compared with the control treatments. These results provide indication for chitosan promising effects in increasing stress tolerance of lemongrass.

The percentage of EO, oil yield per plant and per fed were significantly enhanced in response to a fundamental interaction between the irrigation scheduling coefficients and chitosan application as indicated in Table (4). The combination treatments (0.85 CPE with 100 ppm chitosan spray) and (1.00 or 0.85 CPE with 100 ppm chitosan spray) enhanced the percentage of EO in the 1st and 2nd harvest, respectively through the 1st experimental season. However, the combination treatment (0.85 CPE with 150 ppm chitosan) in the 1st harvest and the same irrigation treatment 0.85 CPE with 100 ppm foliar spray in the 2nd one through the 2nd experimental season. The combination treatment of 1.00 CPE with chitosan spraying at 150 ppm increased oil yield per plant and per fed by 29.4 and 33.2%, respectively in the 1st harvest in the 1st experimental season while, the interaction treatment of 0.85 CPE with 100 ppm chitosan exhibited its auspicious effect by 49.9 and 50.2% in the 2nd harvest in the 1st experimental season. Likewise, plants irrigated with 0.85 CPE and chitosan foliage spraying at 100 ppm for both harvests in the 2nd experimental season attained the utmost increase by about 31.5 and 49.2% on oil yield per plant in respective of 1st and 2nd harvests and by about 35.5 and 54.4% for two harvests, respectively on oil yield per fed compared to unsprayed plants at the same irrigation scheduling. Accordingly, the percentage of EO and lemongrass oil yield quality was in relation to climatic conditions, distillation state and plant age as stated by Penka, 1978. These discoveries may be in line for that increasing of lemongrass growth and yield attributing to chitosan application so directly interrelated increase in EO production and photosynthetic activity due to optimize the irrigation level and water stress tolerance by chitosan application as previously mentioned thus, appropriate levels 100 or 150 ppm chitosan foliage spray under 1.00 or 0.85 CPE realized the maximum herbage and oil yield per fed for both harvests in the two experimental seasons. Results were in accordance with those Bistgani *et al*., 2017 who reported that under mild stress, applied chitosan at 400 μ L per liter gave the maximum EO yield of thymus due to the adversely effect of stress on yield and oil was reduced by chitosan that acts on osmotic adjustment increase and lipid peroxidase decrease so leads to cell membranes integrity enhancement.

Essential oil (EO) chemical composition

Data listed in Table (5) clarify of GC analysis by which major components that represented 73.40 to 98.86 % of lemongrass oil component were recognized as neral, geranial, myrcene, limonene, α-Terpinolene, citronellal, and Cis- Carveol. Geranial (citral- a) as the main component then citral-b was the second one thus citral is the major component signified 64.2 to 84.33 % of the oil. The obtained data in agreement with Shahi *et al*., 2005 and Rabbani *et al*., 2006. Citral was elevated by increasing chitosan level under all irrigation scheduling treatments particularly at 100 and 150ppm.Under irrigation coefficient 1.00 CPE interacted with 100 ppm chitosan or 0.85CPE interacted with 150 ppm recorded the highest content of citral (84.33 and 84.17%, respectively) while, the lowest content was attained under 0.70 CPE interacted with 50ppm (64.2%). The highest content of myrcene and limonene were attained under the combination treatment of 1.00CPE with 50ppm chitosan spray whereas, α-Terpinolene, citronellal, and Cis- Carveol resulted from plants sprayed with 100, 50 and 50 ppm chitosan, respectively under irrigation of 0.70 CPE.

Table 4. The essential oil (EO) percent, oil yield/ plant (ml) and oil yield /fed (L) of lemongrass (*Cymbopogon citratus* (DC.) Stapf) as a function of irrigation scheduling regime, chitosan foliar spray and their interaction under sandy soil for the 1st and 2nd harvest in both experimental seasons (2018 and 2019).

Irrigation scheduling regime (CPE coefficients)	EO (%)									
	First season 2018									
	First harvest					Second harvest				
	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average
IR_1(1.00 CPE)	0.88g	0.90f	0.97c	0.99b	0.93b	0.89g	0.98e	1.08a	1.03b	0.99b
IR_2(0.85 CPE)	0.91ef	0.92de	1.01a	0.93d	0.94a	0.93f	1.03b	1.07a	1.04b	1.02a
IR_3(0.70 CPE)	0.92de	0.93d	0.98bc	0.92de	0.93b	0.92f	0.99de	1.01c	1.00cd	0.98c
IR_4(0.55 CPE)	0.74j	0.76i	0.78h	0.78h	0.77c	0.75j	0.76ij	0.79h	0.77i	0.76d
Average	0.86d	0.88c	0.94a	0.91b		0.87d	0.94c	0.98a	0.96b	
	Second season 2019									
IR_1(1.00 CPE)	0.88g	0.94e	0.99c	0.97d	0.95c	0.93f	1.02d	1.09b	1.04c	1.02b
IR_2(0.85 CPE)	0.92f	0.99c	1.03b	1.06a	1.00a	1.04c	1.04c	1.12a	1.08b	1.07a
IR_3(0.70 CPE)	0.94e	0.95e	0.98cd	0.97d	0.96b	0.93f	0.99e	1.00e	1.00e	0.98c
IR_4(0.55 CPE)	0.74i	0.75i	0.79h	0.78h	0.77d	0.72i	0.76h	0.80g	0.79g	0.77e
Average	0.87c	0.91b	0.95a	0.95a		0.91d	0.95c	1.00a	0.98b	
Irrigation scheduling regime (CPE coefficients)	EO yield/ plant (ml)									
	First season 2018									
	First harvest					Second harvest				
	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average
IR_1(1.00 CPE)	0.555c	0.578c	0.688ab	0.718a	0.63a	0.617d	0.750c	0.847b	0.827b	0.76a
IR_2(0.85 CPE)	0.554c	0.580c	0.708a	0.668b	0.62a	0.623e	0.706c	0.934a	0.839b	0.78a
IR_3(0.70 CPE)	0.398e	0.407e	0.443d	0.458d	0.43b	0.433g	0.472fg	0.566de	0.522ef	0.50b
IR_4(0.55 CPE)	0.178g	0.200fg	0.222f	0.219f	0.20c	0.126i	0.206h	0.229h	0.231h	0.20c
Average	0.42c	0.44b	0.52a	0.52a		0.45d	0.53c	0.64a	0.60b	
	Second season 2019									
IR_1(1.00 CPE)	0.653g	0.723ef	0.841bc	0.807cd	0.75b	0.697g	0.910d	0.992b	0.937c	0.88a
IR_2(0.85 CPE)	0.690fg	0.761de	0.907a	0.887ab	0.81a	0.701g	0.871f	1.046a	0.894e	0.87b
IR_3(0.70 CPE)	0.390j	0.433ij	0.473i	0.525h	0.45c	0.456k	0.486j	0.579h	0.534i	0.51c
IR_4(0.55 CPE)	0.140l	0.192k	0.222k	0.212k	0.19d	0.190o	0.214n	0.238l	0.232m	0.21d
Average	0.47c	0.53b	0.61a	0.60a		0.51d	0.62c	0.71a	0.65b	
Irrigation scheduling regime (CPE coefficients)	EO yield /fed (L)									
	First season 2018									
	First harvest					Second harvest				
	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average
IR_1(1.00 CPE)	7.77d	8.33c	9.92ab	10.35a	9.09a	8.63e	10.82c	12.21b	11.93b	10.89a
IR_2(0.85 CPE)	7.75d	8.36c	10.11a	9.63b	8.96a	8.72e	10.18d	13.10a	12.10b	11.02a
IR_3(0.70 CPE)	5.50f	8.86f	6.38e	6.60e	6.08b	6.06i	6.80h	8.00f	7.53g	7.09b
IR_4(0.55 CPE)	2.49h	2.88gh	3.18g	3.15g	2.92c	2.60l	2.97k	3.30j	3.33j	3.05c
Average	5.87c	6.35b	7.39a	7.43a		6.50d	7.69c	9.15a	8.72b	
	Second season 2019									
IR_1(1.00 CPE)	9.14h	10.43f	12.13c	11.64d	10.83b	9.40h	13.12d	14.30b	13.51c	12.58a
IR_2(0.85 CPE)	9.60g	10.97e	13.01a	12.79b	11.59a	9.77g	12.56f	15.08a	12.89e	12.57a
IR_3(0.70 CPE)	5.46l	6.24k	6.82j	7.57i	6.52c	6.38l	7.00k	8.35i	7.70j	7.35b
IR_4(0.55 CPE)	2.58p	2.77o	3.20m	3.06n	2.90d	2.66o	3.09n	3.43m	3.34m	3.13c
Average	6.69c	7.60b	8.79a	8.76a		7.05d	8.94c	10.29a	9.36b	

Table 5. The major essential oil (EO) constituents (%) of lemongrass (*Cymbopogon citratus* (DC.) Stapf) as influenced by the interaction of irrigation scheduling regime chitosan foliar spray under sandy soil in the 2nd harvest in the 2nd experimental season.

EO content Treatments	(%)	Myrcene	Limonene	α-Terpinolene	Citronellal	Neral	Geranial	Cis-Carveol
1.00 CPE	C_{50ppm}	13.09	0.57	0.96	1.91	29.95	41.97	0.14
	C_{100ppm}	11.12	0.55	1.10	1.62	35.00	49.33	0.13
	C_{150ppm}	11.11	0.49	1.03	1.79	32.89	50.14	0.09
0.85 CPE	C_{50ppm}	7.14	0.52	1.11	2.00	30.17	39.98	0.18
	C_{100ppm}	10.75	0.52	1.07	1.98	35.63	48.07	0.15
	C_{150ppm}	11.03	0.50	0.98	2.07	34.21	49.96	0.11
0.70 CPE	C_{50ppm}	5.35	0.40	1.12	2.13	29.60	34.60	0.20
	C_{100ppm}	5.84	0.37	1.13	1.96	31.75	34.62	0.17
	C_{150ppm}	7.16	0.33	1.08	2.08	33.94	35.14	0.13

Our results confirmed earlier report on *Origanum vulgare* by Yin *et al*., 2011 as applied chitosan elevated total terpenes and probably acts as effective inducer for production of secondary metabolites. These results are in harmony with Singh *et al*., 2000; Bistgani *et al*., 2017 and Mukarram *et al*., 2021 who proved the results that chitosan at 120 mg/l increase biosynthesis of EO by upregulating of geraniol dehydrogenase enzyme essential for reversible transfiguration between citral and geraniol.

Stomatal transpiration rate

As shown in Table (6), stomatal transpiration rate of lemongrass significantly declined with lessening irrigation water as the irrigation at 1.00 CPE recorded the maximum transpiration rate in both harvest for two experimental seasons while the lowest values of transpiration rate were gotten at 0.55 CPE. These findings may be due to the physiological responses under irrigation water limited conditions to become accustomed to drought as a diminution in irrigation water causes a stomatal closure that in relation to limiting the loss of water vapor and a transpiration rate (De Sen *et al*., 2007).

A significant reduction in transpiration rate and decrease water loss by the plant was commenced by chitosan spraying particularly 100 and 150 ppm levels. Accordingly, elevation of chitosan levels mitigated the effects of irrigation water deficit so, increasing water retention under water deficiency. These results may be owing to chitosan act as antiperspirant under agricultural stress, improves water-deficient plants to enhance water retention, it has a potential effect in drought tolerance by inducing of defense and moderates the environmental effects, also increase water deployment of the soil by decreasing of evapotranspiration. Foliar spraying of chitosan acts as antitraspirant causes fully or partially stomatal closure so transpiration reduction (Bittelli *et al*., 2001; Iriti *et al*., 2009), it reduces stomatal apertures that is the main factor in the diffusion conductance of leaves (Karimi *et al*., 2012; Khalil and Badr Eldin, 2021). The stomata regulate the diffusion processes as the stomatal pore opening alteration causes the regulation of the CO_2 entrance to the leaf and release of water vapor. As per the stomatal aperture decrease, the resistance to diffusion increases so transpiration rate decrease as mentioned by Larcher, 1980. These findings are concord with those stated by Mahmoud *et al*., 2017 on basil as transpiration rate declined under water shortage in addition resistance of drought by chitosan as mentioned by Dzung *et al*., 2011 on coffee.

Table 6. Stomatal transpiration rate (μg H_2O $cm^{-2}s^{-1}$) of lemongrass (*Cymbopogon citratus* (DC.) Stapf) as a function of irrigation scheduling regime, chitosan foliar spray and their interaction under sandy soil for the 1st and 2nd harvest in both experimental seasons (2018 and 2019).

Irrigation scheduling regime (CPE coefficients)	Stomatal transpiration rate (μg H_2O $cm^{-2}s^{-1}$)									
	First season 2018									
	First harvest					Second harvest				
	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average	C_0	C_{50ppm}	C_{100ppm}	C_{150ppm}	Average
IR_1(1.00 CPE)	5.39a	5.27b	4.52d	4.31e	4.87a	5.22a	5.00b	4.60c	4.23e	4.76a
IR_2(0.85 CPE)	5.02c	4.51d	4.19f	4.03g	4.44b	4.99b	4.57d	4.21f	4.06g	4.46b
IR_3(0.70 CPE)	3.02k	3.05j	3.09i	3.12h	3.07c	3.00k	3.05j	3.11l	3.13h	3.07c
IR_4(0.55 CPE)	2.13n	2.14mn	2.16m	2.19l	2.15d	2.18o	2.21n	2.24m	2.26l	2.22d
Average	3.89a	3.74b	3.49c	3.41d		3.85a	3.71b	3.54c	3.42d	
	Second season 2019									
IR_1(1.00 CPE)	5.28a	5.00b	4.41d	4.28f	4.74a	5.25a	4.96b	4.55d	4.24f	4.75a
IR_2(0.85 CPE)	4.92c	4.37e	4.26fg	4.24g	4.45b	4.85c	4.30e	4.21fg	4.18g	4.39b
IR_3(0.70 CPE)	2.97j	3.04i	3.07i	3.13h	3.05c	3.08j	3.12i	3.15i	3.20h	3.13c
IR_4(0.55 CPE)	2.11l	2.13l	2.14l	2.18k	2.14d	2.20m	2.22lm	2.25kl	2.28k	2.24d
Average	3.82a	3.64b	3.47c	3.46c		3.84a	3.65b	3.54c	3.48d	

Lemongrass yield-water relatives

1- Applied irrigation water (IW or AW):

Data in the Table (7) and Fig. (2) illustrated that the amount of applied water to lemongrass crop under drip irrigation system for two experimental seasons. The treatments of irrigation were the irrigation scheduling treatments (different of irrigation quantities treatments) and spray treatments didn't have any effect on seasonal AW. The highest values for total AW were obtained under 1.00 of CPE treatment are 4669.56 m^3 fed^{-1} (111.18 cm) and 4918.62 m^3 fed^{-1} (117.11 cm) in the 2018 and 2019 experimental seasons, respectively. While, the lowest values were under 0.55 of CPE treatment are 2609.88 m^3 fed^{-1} (62.14 cm) and 2747.64 m^3 fed^{-1} (62.47 cm) in respective of the 2018 and 2019 experimental seasons. The seasonal of AW increased by the cumulate higher coefficient of CPE (the applied a higher quantity of AW). These results are in agreement by Ram *et al*., (2006) and Mahmoud *et al*., (2017). Generally, the total values of AW can be progressive in order 1.00 CPE > 0.85 CPE > 0.70 CPE > 0.55 CPE, respectively.

Productivity of irrigation water (PIW)

Productivity of irrigation water depended on herb yield (PIW_h), productivity of irrigation water depended on dry yield (PIW_d) and productivity of irrigation water depended on oil yield (PIW_o) were presented data in Fig (3 & 4 and 5). General direction in this study, PIW values for the applied water treatment 0.85 of CPE was the highest compared with the other treatments. This may be due to the higher fresh yield, dry yield or oil yield caused PIW increase. The highest values found for 0.85 CPE and 100 ppm spray treatment in 2018 and 2019 experimental seasons under PIW (PIW_h , PIW_d and PIW_o) while, the lowest values were with 0.55 of CPE and 0 spray treatment (control). Under same study, the mean values of PIW_h, PIW_d and PIW_o under different of irrigation quantities treatments and spray treatments can be descended in order 0.85 CPE >1.0 CPE > 0.70 CPE >0.55 CPE and foliar spraying chitosan at $C_{100\ ppm}$ > $C_{150\ ppm}$ > $C_{50\ ppm}$ > C_0 in both experimental seasons. A decline in the mean values of PIW_h, PIW_d and PIW_o under 0.55 CPE and zero chitosan in comparison with other treatments in 2018 and 2019 seasons may be due to decreasing quantity of applied water and decreasing lemongrass yield (herb, dry and oil yield).

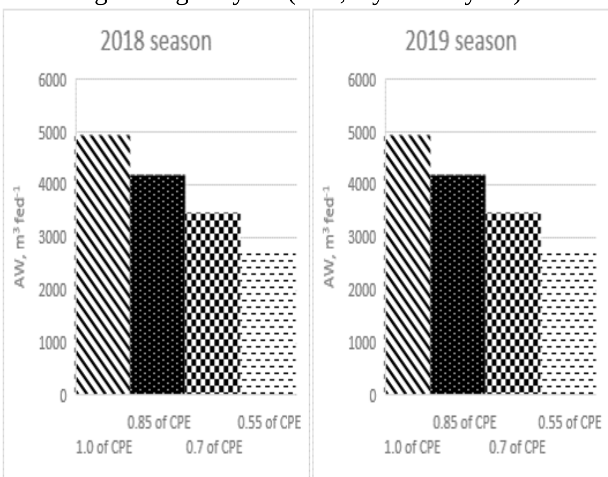

Fig. 2. Seasonal applied irrigation water (AW, m^3fed^{-1}) for lemongrass plant as a function of irrigation scheduling regime.

Table 7. The monthly and seasonal applied irrigation water (AW) for lemongrass plant as affected by irrigation scheduling treatments for 2018 and 2019 experimental seasons.

Month	No. of irrigations	1.00 CPE	0.85 CPE	0.70 CPE	0.55 CPE
First season 2018					
		Aw, cm			
Mar.	Planting	2.20	2.20	2.20	2.20
Apr.	14	16.52	14.04	11.56	9.09
May	16	20.48	17.41	14.34	11.26
June	11	17.6	14.96	12.32	9.68
July	14	21.84	18.56	15.29	12.01
Aug.	15	23.1	19.64	16.17	12.71
Sep.	8	9.44	8.02	6.61	5.19
Seasonal	78	111.18	94.83	78.49	62.14
Second season 2019					
		AW, cm			
Mar.	Planting	2.23	2.23	2.23	2.23
Apr.	14	16.52	14.04	11.56	9.09
May	16	20.16	17.14	14.11	11.09
June	11	16.06	13.65	11.24	8.83
July	14	24.36	20.71	17.05	13.40
Aug.	15	26.10	22.19	18.27	14.36
Sep.	8	11.68	9.93	8.18	6.42
Seasonal	78	117.11	99.89	82.64	65.42

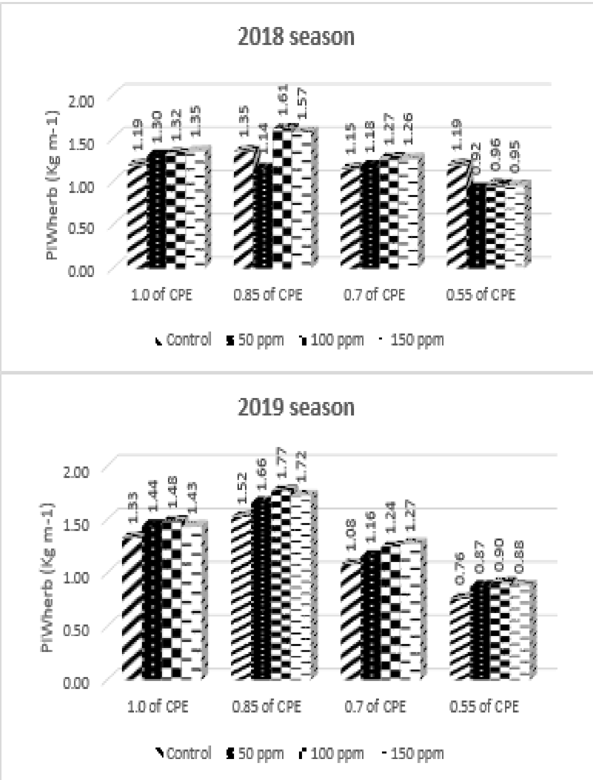

Fig. 3. Effect of applied water and spray treatments on productivity of applied water depended on herb yield (PIW_{herb}, kg m^{-3}).

Economic evaluation

The target of the study is the best treatment gave the highest oil yield. The results in Table (8) showed that the maximum net return and water return were recorded with all spray treatments under irrigation 0.85 CPE followed by 1.00 CPE and 0.7 CPE irrigation compared to 0.55 CPE irrigation treatments. Generally, all spray treatments under 0.85 of CPE irrigation gave the highest values of the studied economic criteria mainly due to the criteria lemongrass yield. Net return and water return can be descended in order $C_{100ppm} > C_{150ppm} > C_{50ppm} > C_0$ spray treatments under different irrigation treatments, respectively, during the two seasons. The irrigation treatment 0.55 CPE with different spray treatments was not economic because the all values were negative caused in the costs of the production higher than net return.

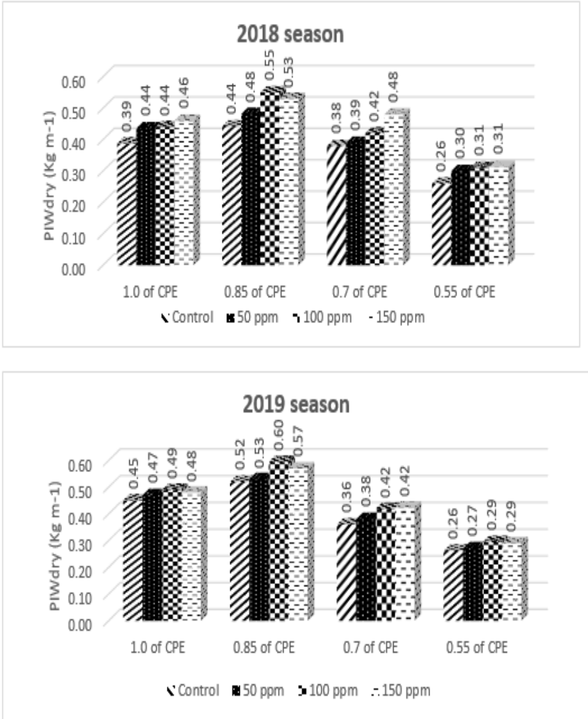

Fig. 4. Effect of applied water and spray treatments on productivity of applied water depended on dry yield (PIW_{dry}, kg m^{-3}).

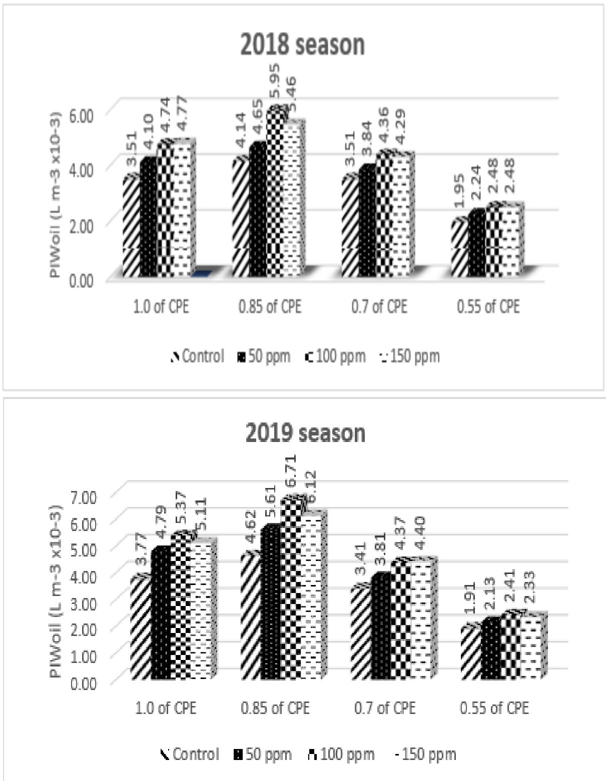

Fig. 5. Effect of applied water and spray treatments on productivity of applied water depended on oil yield (PIW_{oil}, L m^{-3}) in 2018 and 2019 seasons.

Table 8. Effect of irrigation scheduling regime (CPE coefficients) and chitosan spray treatments on economic evaluation and water return for lemongrass.

Treatments		Productivity ($L\ fed.^{-1}$) Oil	water applied ($m^3\ fed.^{-1}$)	Total seasonal return ($LE\ fed.^{-1}$)	Variable Costs ($LE\ fed.^{-1}$)	Total costs ($LE\ fed.^{-1}$)	Net return (NR) ($LE\ fed.^{-1}$)	Water return ($LE\ m^{-3}$)
First season 2018								
1.00 CPE	C_0	16.4	4669.56	65600	34805	43805	21795	4.67
	C_{50ppm}	19.15	4671.56	76600	34920	43920	32680	7.00
	C_{100ppm}	22.3	4670.56	89200	34935	43935	45265	9.69
	C_{150ppm}	22.28	4669.99	89120	34960	43960	45160	9.67
0.85 CPE	C_0	16.47	3982.56	65880	34780	43780	22100	5.55
	C_{50ppm}	18.54	3983.44	74160	34860	43860	30300	7.61
	C_{100ppm}	23.68	3980.99	94720	34985	43985	50735	12.74
	C_{150ppm}	21.73	3981.6	86920	34955	43955	42965	10.79
0.70 CPE	C_0	11.56	3296.58	46240	34520	43520	2720	0.83
	C_{50ppm}	12.66	3300.85	50640	34535	43535	7105	2.15
	C_{100ppm}	14.38	3296.5	57520	34590	43590	13930	4.23
	C_{150ppm}	14.13	3290.5	56520	34695	43695	12825	3.90
0.55 CPE	C_0	5.09	2609.88	20360	34235	43235	-22875	-8.76
	C_{50ppm}	6.85	2610	27400	34290	43290	-15890	-6.09
	C_{100ppm}	6.48	2611.98	25920	34305	43305	-17385	-6.66
	C_{150ppm}	6.48	2619.75	25920	34310	43310	-17390	-6.64
Second season 2019								
Treatments		Productivity (L fed.-1) oil	water applied ($m^3\ fed.^{-1}$)	Total seasonal return ($LE\ fed^{-1}$)	Variable Costs ($LE\ fed.^{-1}$)	Total costs ($LE\ fed.^{-1}$)	Net return (NR) ($LE\ fed.^{-1}$)	Water return ($LE\ m^{-3)}$)
1.00 CPE	C_0	18.54	4918.62	70452	35010	44010	26442	5.38
	C_{50ppm}	23.55	4920.6	89490	35045	45445	44045	8.95
	C_{100ppm}	26.43	4970.55	100434	35110	44110	56324	11.33
	C_{150ppm}	25.15	4916.25	95570	35085	44085	51485	10.47
0.85 CPE	C_0	19.37	4195.38	73606	34980	43980	29626	7.06
	C_{50ppm}	23.53	4197.57	89414	35010	44010	45404	10.82
	C_{100ppm}	28.16	4190.68	107008	35150	44150	62858	15.00
	C_{150ppm}	25.68	4200	97584	35095	44095	53489	12.74
0.70 CPE	C_0	11.84	3470.88	44992	34525	43525	1467	0.42
	C_{50ppm}	13.24	3478.8	50312	34560	43560	6752	1.94
	C_{100ppm}	15.17	3469.98	57646	34630	43630	14016	4.04
	C_{150ppm}	15.24	3475.68	57912	34635	43635	14277	4.11
0.55 CPE	C_0	5.24	2747.64	19912	34260	43260	-23348	-8.50
	C_{50ppm}	5.86	2750.44	22268	34275	43275	-21007	-7.64
	C_{100ppm}	6.63	2741.64	25194	34305	43305	-18111	-6.61
	C_{150ppm}	6.4	2751.58	24320	34300	43300	-18980	-6.90

CONCLUSION

Considering limited availability of water resources in agricultural sectors in combination with higher air temperature and huge climatic alterations, it is obligatory to save water by wise use of water consumptive use and adapt to the changes by actively antiperspirant chitosan acting as a bio stimulant with worth in productivity as it is more relevant for lemongrass under extreme situations. Chitosan act as antiperspirant, it has a potential effect in drought tolerance without influencing the agronomic yield. Also, it moderates the environmental effects thus it is a sustainable and clean alternative. Overall, it can be concluded that under the study situations the judicious training is irrigation of lemongrass plants at 0.85 CPE with foliar spraying chitosan at 100 ppm level three weeks intervals starting four weeks after transplanting and clogged two weeks before each harvest for enriching yield determinations, oil yield and quality in addition to transpiration rate was reduced. On the other side both applied irrigation water and water consumptive use were condensed while irrigation water productivity was increased. Additionally, greater economic return within this agro climatic area particularly in relation to the oil which is the most sought product of the lemongrass.

REFERENCES

Ahmad A. and Viljoen A. (2015). The in vitro antimicrobial activity of *Cymbopogon* essential oil (lemon grass) and its interaction with silver ions. Phytomedicine, 22(6): 657- 665.

Ahmad B., Jaleel H., and Shabbir A. (2019). Concomitant application of depolymerized chitosan and GA3 modulates photosynthesis, essential oil and menthol production in peppermint (*Mentha piperita* L.). Sci Hortic (amsterdam) 246:371–379.

Ali M.H., Hoque M.R., Hassan A.A. and khair A. (2007). Effects of deficit irrigation on yield, water productivity and economic returns of wheat. Agricultural water management, 92 (3): 151-161.

Ali Q., Ali A., Waseem M., Muzaffar A., Ahmad S., Ali S., Bajwa K.S., Fareed Awan M., Samiullah T.R., Nasir I. and Husnain T. (2014). Correlation analysis for morphophysiological traits of maize (*Zea mays* L.). Life Science Journal, 11(12): 9-13.

Aly A.I., Farrag F.R.M. and Mohammed N.F. (2019). Enhancing eggplant productivity through irrigation scheduling regime and foliar spray with chitosan concentrates. Zagazig J. Agric. Res., 46 (6B):2183-2192.

Anusuya S. and Sathiyabama M. (2016). Effect of Chitosan on Growth, Yield and Curcumin Content in Turmeric under Field Condition. *Biocatal. Agric. Biotechnol. 6*, 102–106.

Babarinde A., Ogundipe K., Sangosanya K.T., Akintola B.D. and Hassan A.O. (2016). Comparative study on the biosorption of Pb (II), Cd (II) and Zn (II) using Lemon grass (*Cymbopogon citratus*): kinetics, isotherms and thermodynamics. International J. of New Chemistry, *2*(8): 234-239.

Ben-Asher J., Tsuyuki I; Bravdo B.A. and Sagih M. (2006). Irrigation of grapevines with saline water. I. Leaf area index, stomatal conductance, transpiration and photosynthesis. Agr. Water Manag. 83(1-2): 13–21.

Bistgani Z.E., Siadat S.A., Bakhshandeh A. Pirbalouti A.G. and Hashemi M. (2017). Interactive effects of drought stress and chitosan application on physiological characteristics and essential oil yield of *Thymus daenensis* Celak. The Crop Journal, 5(5): 407-415.

Bittelli M., Flury M., Campbell G.S. and Nichols E.J. (2001). Reduction of transpiration through foliar application of chitosan. Agricultural and Forest Meteorology 107:167–175.

Boukhatem M.N., Ferhat M.A., Kameli A., Saidi F, Kebir H.T.(2014). Lemon grass (*Cymbopogon citratus*) essential oil as a potent anti-inflammatory and antifungal drugs. Libyan Journal of Medicine, 9(1): 25431.

C.A.A.E.S (2014). Lemongrass. Egyptian Ministry of Agriculture and Land Reclamation.

Chakraborty H., Sethi R. R., Brahmanand P. S., Mandal K. G., Singandhupe R. B. and Kumar A. (2010). Effect of irrigation regimes and nitrogen levels on herbage and oil yield, oil quality, nutrient uptake and economics of lemongrass (*Cymbopogon flexuosus*) in a sandy loam soil of Orissa. Indian Journal of Agricultural Sciences, 80 (8): 713–18.

Chakraborty M., Hasanuzzaman M., Rahman M., Khan M.A.R., Bhowmik P., Mahmud N.U., Tanveer M., and Islam T. (2020). Mechanism of Plant Growth Promotion and Disease Suppression by Chitosan Biopolymer. *Agriculture* 10, 624.

Chamnanmanoontham N., Pongprayoon W., Pichayangkura R. (2014). Chitosan enhances rice seedling growth via gene expression network between nucleus and chloroplast. Plant Growth Regul, 75:101–114.

Chinese H., Huang J., Zhang X. Chen Y., Yang J., and Hei L. (2005). Allelopathic effects of (*Cymbopogon citratus*) volatile and its chemical components. Ying Yong Sheng Tai Xue Bao, 16 (4):763-767.

Cimmyt D.F. (1988). From Agronomic Data to Farmer Recommendation: An Economic Work Book: 31- 33.

De Sen J. O., Zaidan H.A. and Castro P. R. (2007). Transpiration and stomatal resistance variations of perennial tropical crops under soil water availability conditions and water deficit. Braz. Arch. Biol. Technol., 50 (2): 225-230.

Dzung N.A., Khanh V.T.P. and Dzung T.T. (2011). Research on impact of chitosan oligomers on biophysical characteristics, growth, development and drought resistance of coffee. Carbohydr. Polym., 84: 751–755.

Ehlert P.A.D., Blank A.F., Blank M.F.A., Paula J.W.A., Campos D.A., and Alviano C.S. (2006). Hydrodistillation time for extraction of essential oil from seven medicinal plant species. Revista Brasileira de Plantas Medicinais, 8(2):79-80.

Ekpenyong C. E., Akpan E. E., and Daniel N. E. (2014). Phytochemical constituents, therapeutic applications and toxicological profile of *Cymbopogon citrates* stapf (DC) leaf extract. J. Pharmacogn. Phytochem, 133–141.

Ertek A. (2011). Importance of pan evaporation for irrigation scheduling and proper use of crop-pan coefficient (*K*cp), crop coefficient (*K*c) and pan coefficient (*K*p). African Journal of Agricultural Research, 6(32): 6706- 6718.

FAO (2015). Water Use. Food and Agriculture Organization of the United Nations. http://www.fao.org/aq-uastat/en/overview/ methodology/water-use/

Farouk S. and Ramadan A. A. (2012)**.** Improving growth and yield of cowpea by foliar application of chitosan under water stress. Egyptian J. of Biol., 14(1): 14-26.

Farouk S. and EL-Metwally I.M. (2019). Synergistic Responses of Drip-Irrigated Wheat Crop to Chitosan and/or Silicon under Different Irrigation Regimes. Agric. Water Manag. , 226, 105807.

Fouda S. E.E., El-Saadony F.M.A., Saad A.M., Sayed S.M., El-Sharnouby M., El-Tahan A. M., and El-Saadony M. T.(2021). Improving growth and productivity of faba bean (*Vicia faba* L.) using chitosan, tryptophan, and potassium silicate anti-transpirants under different irrigation regimes. Saudi Journal of Biological Sciences xxx (xxxx) xxx.

Guan Y. J., Hu J., Wang X., and Shao C. (2009). Seed priming with chitosan improves maize germination and seedling growth in relation to physiological changes under low temperature stress. J. ZhejiangUniv. Sci., 10(6): 427–433.

Hadwiger L.A., Klosterman S.J. and Choi J.J. (2002). The mode of action of chitosan and its oligomers in inducing plant promoters and developing disease resistance in plant. In: Suchiva, K. S. Chandrkrachang, P. Methacanon and M.G. Peter (Eds.) Advances in Chitin Science. Bangkok: 452-457.

Han X., and Parker T. L. (2017). Lemongrass (*Cymbopogon flexuosus*) essential oil demonstrated anti-inflammatory effect in pre-inflamed human dermal fibroblasts. Biochimie Open, 4: 107–111.

Hidangmayum A., Dwivedi P., Katiyar D., and Hemantaranjan A. (2019). Application of chitosan on plant responses with special reference to abiotic stress. Phys. Mol. Biol. Plants 25(2): 313–326.

Ibraheim S.K.A. and Mohsen A.A.M. (2015). Effect of chitosan and nitrogen rates on growth and productivity of summer squash plants. Middle East J. Agric. Res., 4 (4): 673- 681.

Iriti M., Picchi V., Rossoni M., Gomarasca S., Ludwig N., Gargano M., and Faoro F. (2009). Chitosan antitranspirant activity is due to abscisic acid-dependent stomatal closure. Envionmental and Experimental Botany, 66 (2), 493-500.

Jackson M.I. (1973). Soil Chemical Analysis. prentice Hall of India private, LTD New Delhi, P.187.

Jain H.C., Mehta S., Mehtani S., Singh G., Mukherjee T., Doreswamy R. and Sharma D. (1994). Report of the workshop on Information Management for the medicinal and aromatic plants industry. J. Sci. Ind. Res., 53(1): 43-46.

Javan M., Tajbakhsh M. and Mandoulakani B.A. (2013). Effect of antitranspirants application on yield and yield components in soybean (*Glycine max L.*) under limited irrigation. Journal of Applied Biological Sciences 7 (1): 70-74.

Karimi S., Abbaspour H., Sinaki J.M., and Makarian H. (2012). Effects of water deficit and chitosan spraying on osmotic adjustment and soluble protein of cultivars castor bean (*Ricinus communis* L.). J. Stress Physio. Bio., 8(3): 160-169.

Katiyar D., Hemantaranjan A., Singh B., Bhanu N.A. (2014). A future perspective in crop protection: chitosan and its oligosaccharides. Adv Plants Agric. Res. 1:06.

Katiyar D., Hemantaranjan A., Singh B. (2015). Chitosan as a promising natural compound to enhance potential physiological responses in plant: a review. Indian J Plant Physiol., 20(1):1–9. DOI: 10.1007/s40502-015-0139-6

Kaya M., Mujtaba M., Bulut E., Akyuz B., Zelencova L., Sofi K. (2015). Fluctuation in physicochemical properties of chitins extracted from different body parts of honeybee. Carbohydr Polym.,132: 9–16.

Khalil H.A. (2015). Morphological and physiological performance and drought resistance improvement of pomegranate seedlings by mycorrhizal inoculation. Journal of Plant Production 6: 2145–2162.

Khalil H.A. and Badr Eldin R.M. (2021). Chitosan improves morphological and physiological attributes of grapevines under deficit irrigation conditions. Journal of Horticultural Research, 29(1): 9–22.

Khalil H.A. and El-Ansary D.O. (2020). Morphological, physiological and anatomical responses of two olive cultivars to deficit irrigation and mycorrhizal inoculation. European Journal of Horticultural Science 85(1): 51–62.

Khan W.M., Prithiviraj B., and Smith D.L. (2002). Effect of foliar application of chitin and chitosan oligosaccharides on photosynthesis of maize and soybean. Photosynthetica 40: 621–624.

Klute A.C. (1986). Water retention: laboratory Methods. In: A. koute (ed), Methods of Soil Analysis, part1 2nd ed. Agron. Monogr.9, Ame. Soc. Agron. (ASA), Madison, Wisconsin, U.S.A: 635 – 660.

Korenblum E., Goulart F. R. D. V., Rodrigues I. D. A., Abreu F., Lins U., Alves P. B., *et al*. (2013). Antimicrobial action and anti-corrosion effect against sulfate reducing bacteria by lemongrass (*Cymbopogon citratus*) essential oil and its major component, the citral. AMB Exp. 3(1):44.

Kress H. (2007). Henriette's Herbal Home Page. Inc. available at www. henriettesherbal.com.

Kumoro A.C., Wardhani D. H., Retnowati D. S., and Haryani K. (2020). A brief review on the characteristics, extraction and potential industrial applications of citronella grass (*Cymbopogon nardus*) and lemongrass (*Cymbopogon citratus*) essential oils. International Conference on Chemical and Material Engineering (ICCME 2020).

Lakpale R., Shrivastava G. K., and Tripathi R. S. (2007). Effect of irrigation schedule on growth, yield and economics of spice crops. Indian J. Agric. Sci., 77(3): 410-415.

Larcher W. (1980). Physiological plant ecology. Springer-Verlag, Berlin.

Mahmoud M.A., Shala A.Y., and Rashed N.M. (2017). The mutual effect of irrigation scheduling and foliar spray of silica nanoparticles on basil plant. J. Plant Production, Mansoura Univ., 8 (12):1303 – 1313.

Malerba M., and Cerana R. (2016). Chitosan Effects on Plant Systems. Int. J. Mol. Sci., 17, 996.

Malekpoor F., Pirbalouti G. A., and Salimi A. (2016). Effect of foliar application of chitosan on morphological and physiological characteristics of basil under reduced irrigation. Res. on Crops, 17 (2):354–359.

Mirzaie M., Ladanmoghadam A. R., Hakimi L., and Danaee E. (2020 a). The Plant growth promoting rhizobacteria (PGPR) improve plant growth, antioxidant capacity, and essential oil properties of lemongrass (*Cymbopogon citratus*) under water stress. Iranian Journal of Plant Physiology, 10 (2): 3155-3166.

Mirzaie M., Ladanmoghadam A. R., Hakimi L., and Danaee E. (2020b). Water stress modifies essential oil yield and composition, glandular trichomes and stomatal features of lemongrass (*cymbopogon citratus* l.) inoculated with arbuscular mycorrhizal fungi. J. Agr. Sci. Tech., 22(6): 1575-1585.

Mondal M.M.A., Malek M., Puteh A.B., Ismail M.R., Ashrafuzzaman M., and Naher L., (2012). Effect of foliar application of chitosan on growth and yield in okra. Australian J.Crop Sci. 6(5), 918–921.

Moolphuerk N., and Pattanagul W.(2020). Pretreatment with different molecular weight chitosans encourages drought tolerance in rice (*Oryza sativa* L.) seedling. Not. Bot. Horti. Agrobot. Cluj Napoca , 48, 2072–2084.

Morales C., Cusido R.M., Palazon J., and Bonfill M. (1993). Response of *Digitalis purpurea* plants to temporary salinity. J. Plant Nutr 16: 327-335.

Mukarram M., Masroor M., and Khan A., Francisco M. U., and Corpas J. (2021). Irradiated chitosan (ICH): an alternative tool to increase essential oil content in lemongrass (*Cymbopogon flexuosus*). Acta Physiologiae Plantarum 44:2

Nge K.L., New N., Chandrkrachang S., and Stevens W.F. (2006). Chitosan as a growth stimulator in orchid tissue culture. Plant Science, 170:1185-1190.

Oliveira P. D. L., de Oliveira K. A. R., dos Santos Vieira W. A., Câmara M. P. S. and de Souza E. L. (2018). Control of Anthracnose caused by Colletotrichum species in Guava, Mango and Papaya using synergistic combinations of chitosan and *Cymbopogon citratus* (DC ex Nees) Stapf essential oil. Int. J. Food. Microbiol., 266: 87-94.

Orabi S.A., Talaat I.M., Balbaa L.K., Abdalla A.E. (2015). Influence of pyridoxine and spermine on lemongrass (*Cymbopogon citratus*) plants. NUSANTARA BIOSC- IENCE, 7(2):139-143.

Pandey P., Verma M.K., De N. (2018). Chitosan in agricultural context- A review. Bull. Env. Pharmacol. Life Sci., 7 (5): 87-96.

Penka M. (1978). Influence of irrigation on the contents of effective substances in official plants. Acta Horticulturae, 73:181-189.

Pirbalouti A.G., Samani M. R., Hashemi M., and Zeinali H. (2013). Salicylic acid affects growth, essential oil and chemical compositions of thyme (*Thymus daenensis* Celak.) under reduced irrigation. Plant Growth Regul. 72: 289-301.

Pirbalouti A.G., Malekpoor F., Salimi A., Golparvar A. (2017). Exogenous application of chitosan on biochemical and physiological characteristics, phenolic content and antioxidant activity of two species of basil (*Ocimum ciliatum* and *Ocimum basilicum*) under reduced irrigation. Sci Hortic 217:114–122.

Rabbani S.I., Devi K., Khanam S., and Zahra N. (2006). Citral, a component of lemongrass oil inhibits the clastogenic effect of nickel chloride in mouse micronucleus test system. Pak J. Pharm. Sci., 19 (2):108-113.

Rabelo V.M., Magalhaes P.C., Bressanin L.A. *et al* (2019). The foliar application of a mixture of semisynthetic chitosan derivatives induces tolerance to water deficit in maize, improving the antioxidant system and increasing photosynthesis and grain yield. Sci Rep, 9:1–13.

Rahdari P., Tavakoli S., and Hosseini S. M. (2012). Studying of salinity stress effect on germination, proline, sugar, protein, lipid and chlorophyll content in purslane (*Portulaca oleracea* L.) leaves. Journal of Stress Physiology & Biochemistry, 8(1): 182-193.

Rai R. K. (2017). Planning and Evaluation of Irrigation Projects chapter 12 – Irrigation Scheduling. Academic Press.385–412.

Ram D., Ram M. and Singh R. (2006). Optimization of water and nitrogen application to menthol mint (*Mentha arvensis* L.) through sugarcane trash mulch in a sandy loam soil of semi-arid subtropical climate. Bioresource Tec., 97:886– 893.

Robert A. (1995). Identification of Essential Oils by Gas Chromatography- Mass Spectrometry. Allurd Pub., U.S.A.

Safaei Z., Majid A., Yarahmadi M., Hossein A., Gholamhossein D. (2014). The Effect of different irrigation intervals and anti-transpiration compounds on yield and yield components of Black Cumin (*Nigella sativa*). Int. J. Adv. Biol. Biom. Res. 2014; 2(4):326-335.

Shahi A., Kaul M., Gupta R., Dutt P., Chandra S., Qazi G. (2005). Determination of essential oil quality index by using energy summation indices in an elite strain of *Cymbopogon citratus* (DC) Stapf [RRL(J)CCA12]. Flavour Frag. J., 20:118–121.

Singh S., Ram M., Ram D., Singh V.P., Sharma S., and Tajuddin (2000). Response of lemongrass (*Cymbopogon flexuosus*) under different levels of irrigation on deep sandy soils. Irrig. Sci., 20:15-21.

Singh M., Kumar J., Singh S., Singh V. P., and Prasad S.M. (2015). Roles of osmoprotectants in improving salinity and drought tolerance in plants: a review. Reviews in Environmental Science and Bio/Technology, 14(3): 407-426.

Singh R., Singh S., Sharma B., Kumar J., Soni M., and Agrahari P. (2016). Effect of irrigation and nitrogen on plant growth and stalk yield of lemongrass (*Cymbopogon flexuosos* S.). Tropical Plant Research 3(2): 460–462.

Snedecor G.W. and Cochran W.G. (1990). Statistical Methods. 7th Ed. Iowa State Univ. Press. Ames., Iowa, USA, p. 593.

Tesfaye H., Meskelu E., Mohammed M. (2017). Determination of optimal soil moisture depletion level for lemongrass (*Cymbopogon citratus* L.). Irrigat Drainage Sys Eng, 6: 2.

Thakuria R.K., Singh H., and Tejsingh S. (2004). Effect of irrigation and antitranspirants on growth and yield of spring sunflower (*Helianthus annus* L.). Annals of Agricultural Research, 25: 433-438.

Thangam R., Sathuvan M., Poongodi A., Sureshe V., Pazhanichamye K., Sivasubramanian S., *et al*. (2014). Activation of intrinsic apoptotic signaling pathway in cancer cells by *Cymbopogon citratus* polysaccharide fractions. Carbohydr. Polym. 107: 138–150. Doi: 10.1016/j.carbpol.2014. 02.039.

Win K., Berkowitz G.A. and Henninger M. (1991). Antitranspirant –induced increases in leaf water potential increase tuber calcium and decreases tuber necrosis in water stressed photato plants. Plant physiology, 96(1):116-12.

Yamiv Z., and Palevitch D. (1982). Effect of drought on the secondary metabolites of medicinal and aromatic plants. In: Atal C.K., Kapoor B.M.(eds) Cultivation and utilization of medicinal plants. CSIR, Jammu Tawi, India, pp 1-12.

Yin H., Fretté X.C., Chrestensen L.P., and Grevsen K. (2011). Chitosan oligosaccharides promote the content of polyphenols in Greek oregano (*Oreganum vulgare* ssp. hirtum). J. Agric. Food Chem., 60:136-143.

Zou P., Tian X., Dong B., Zhang C (2017). Size Effects of Chitooligomers with Certain Degrees of Polymerization on the Chilling Tolerance of Wheat Seedlings. Carbohydr. Polym., 160, 194–202.

تأثير الشيتوزان على نمو و محصول نبات حشيشة الليمون عند مستويات مختلفة من مياه الرى تحت ظروف التربة الرملية

جيهان فوزى أحمد مسعود[١] ، أحمد السيد دبور [١] و منى عبد الحليم محمد المنصورى[٢]

[١] قسم بحوث النباتات الطبية والعطرية -معهد بحوث البساتين -مركز البحوث الزراعية -الجيزة -مصر

[٢] قسم بحوث المقننات المائية والرى الحقلى -معهد الاراضى والمياه والبيئة -مركز البحوث الزراعية -مصر

أقيمت دراسة حقلية تحت ظروف التربة الرملية خلال الموسمين المتتاليين ٢٠١٨ و٢٠١٩ بهدف دراسة التأثير المتداخل بين جدولة الرى عند المستويات (١,٠٠- ٠,٨٥- ٠,٧٠- ٠,٥٥من البخر التجميعى لوعاء البخر القياسى) مع رش الشيتوزان كمادة مضادة للنتح بتركيزات (٠- ٥٠- ١٠٠- ١٥٠ جزء فى المليون) على قياسات النمو وناتج محصول حشيشة الليمون وكذلك الزيت الطيار بالإضافة إلى بعض العلاقات المائية والعائد الإقتصادى. أظهرت النتائج أن جدولة الرى عند المستويات ١,٠٠و ٠,٨٥ من البخر التجميعى لوعاء البخر القياسى أدى إلى الزيادة فى الوزن الطازج والجاف للعشب وبالتالى الناتج المحصولى طازج وجاف للفدان, بينما سجل انخفاضا فى كل قياسات النموالمختبرة وناتج المحصول, ناتج الزيت وكذلك معدل النتح عند المستويات ٠,٧٠ - ٠,٥٥من البخر التجميعى لوعاء البخر القياسى. بينت النتائج أن معاملات التداخل بين جدولة الرى عند المستويات ١,٠٠ أو ٠,٨٥ من البخر التجميعى لوعاء البخر القياسى مع الرش بالشيتوزان عند كل التركيزات أدت إلى زيادة معنوية فى ناتج الزيت العطرى للعشب و محصول الزيت للفدان ومحتوى الزيت من المكونات الفعالة فى كلا القرطتين للموسمين. خلصت النتائج إلى أن التفاعل بين جدولة الرى عند ٠,٨٥ من البخر التجميعى لوعاء البخر القياسى مع رش الشيتوزان بتركيزى ١٠٠ أو ١٥٠ جزء فى المليون سجل زيادة معنوية فى المحصول وانتاجية العشب من الزيت علاوة على محتوى الزيت من المكونات الفعالة وبالأخص النسبة المئوية من الستر ال. كما سجلت أفضل انتاجية لمياه الرى عند معاملة جدولة الرى عند ٠,٨٥ من البخر التجميعى لوعاء البخر القياسى مقارنة بباقى معاملات الرى الأخرى. وعليه يمكن التوصية باستخدام المقنن المائى الأمثل وجدولة الرى عند ٠,٨٥ من البخر التجميعى لوعاء البخر القياسى مع رش الشيتوزان بتركيز ١٠٠ جزء فى المليون كمادة مضادة للنتح بهدف تعظيم الناتج المحصولى والزيت لنبات حشيشة الليمون, العائد الاقتصادى والعائد من وحدة المياه وتحسين انتاجية مياه الرى تحت ظروف نقص المياه.