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Estimation of Growth Curve Parameters for Pepper (*Capsicum annuum cv. Kapija*) Under Deficit Irrigation Conditions

Kısıtlı sulama koşulları altında biberin (*Capsicum annuum cv. Kapija*) büyüme eğrisi parametrelerinin tahmini

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Anahtar Sözcükler:

Büyüme modelleri, tahminleme, su stresi, biber (*Capsicum annuum cv. Kapija*)

ÖZET

Bu çalışma, kısıtlı sulama koşulları altında farklı büyüme eğrisi modellerini kullanarak biber bitkisinin (*Capsicum annuum cv. Kapija*) büyüme eğrisi parametrelerini tahmin etmek için yürütülmüştür. Bitki boyu, bitki x-x ve y-y çapı ve klorofil okumaları 12 hafta boyunca bitkideki büyümeyi tahmin etmek için ölçülmüştür. Bitki boyu ve çapı için en uygun modeller Linear, Gompertz ve Logistik model ve klorofil okumaları için Linear, $W(t)=A.t^B exp(-k.t)$, $W(t)=A(1-B^t)$ modeller uygun bulunmuştur. Biber bitkisinin boy, x-x ve y-y çapı için belirtme katsayıları (R^2) %99.1-99.9 arasında ve klorofil okumaları için %38.8-82.8 arasında değişmiştir. Biberin büyüme dönemi boyunca klorofil okumaları değerleri sürekli olarak artmadığı için, R^2 değerleri diğer modellere göre daha düşük çıkmıştır.

Key Words:

Growth models, estimation, water stress, pepper (*Capsicum annuum cv. Kapija*)

ABSTRACT

This study was conducted to estimate growth curve parameters for pepper (*Capsicum annuum cv. Kapija*) by using different growth curve models under deficit irrigation conditions. Plant height, plant x-x and y-y diameter and chlorophyll readings (ChRs) were measured to estimate plant growth during 12 weeks. Use of Linear, Gompertz and Logistic models for plant height and diameter, and the linear, $W(t)=A.t^B exp(-k.t)$, $W(t)=A(1-B^t)$ models for ChRs were found to be best for pepper under deficit irrigation. R^2 values for x-x and y-y diameters were in between 99.1% and 99.9%, and for ChRs 38.8-82.8%. Since ChRs values were not continually increased throughout the growth period, R^2 values for ChRs were less than other models.

INTRODUCTION

Pepper (*Capcicum annuum cv. Kapija*) is the second main vegetable crop produced in the Çanakkale Province, Turkey (CTIM, 2009). In recent years, pepper plantation rate has been affected by farmer preferences based on the water deficit in Çanakkale. Growth is a fundamental property of all living organisms (Lawrence and Fowler, 2002). Growth can be defined as an increased height, diameter and size within a certain time frame in plants (Yıldızbakan, 2003). There are many factors that affect plant growth such as extreme temperature, light, flooding, drought, insect predation, and various pathogens including viruses, fungi and bacteria etc. (Abeles et al. 1992; Glick et al. 2007).

There are many harvest and yield estimation methods in the determination of plant growth in field conditions. Fruit size is one of the most important parameters was used to develop models for yield predictions for different plants (Jenni et al., 1997; Estrada-Luna et al., 2001; Ngouajio et al., 2003; Riga and Anza., 2003). Researchers were used the Relative Growth Rate (RGR) equations to calculate RGR by dividing the difference in Ln-transformed plant weight by the time difference between two harvests. It is reported that this formula may not provide accurate results since plant weight changes is not linear throughout the growth period (Poorter and Lewis, 1986). Riga and Anza (2003) were used the relative growth rate equation (RGR) for measurements of fruit size. They also point that in order to use this formula, harvesting needs to be done in a certain period. Ngouajio et al. (2003) found a rapid and nondestructive method to determine the bell pepper's fruit volume. With this simple model the size of fruit was calculated.

In addition, there are several different growth models were used to predict PGR such as Linear, Gompertz, von Bertalanffy, Birch, Michaelis-Menten, Logistic and Richard's equations (Werker and Jaggard, 1997; Yıldızbakan, 2003; Glick et al., 2007; Damgaard and Weiner, 2008).

Since pepper is an important plant in Turkey, projection of future growth rate is critical. Pepper is produced during summer when there is little rainfall in Turkey. To produce marketable pepper in Turkey, irrigation is necessary during the growth period. The main objective of this study was to determine the kapija pepper's growth rate by using linear and nonlinear growth models using ChRs, plant height, x-x and y-y diameters under deficit irrigation conditions in the field.

MATERIAL AND METHOD

Study Area and Research Design

This research was conducted during the growing season of 2009 at the Dardanos Agricultural Experimental Station of Çanakkale Onsekiz Mart University, Çanakkale, Turkey. The location of the experimental area is showed in Figure 1. The soil is mostly clay-loam in the research area. Some physical soil parameters used for the study are presented in Table 1.

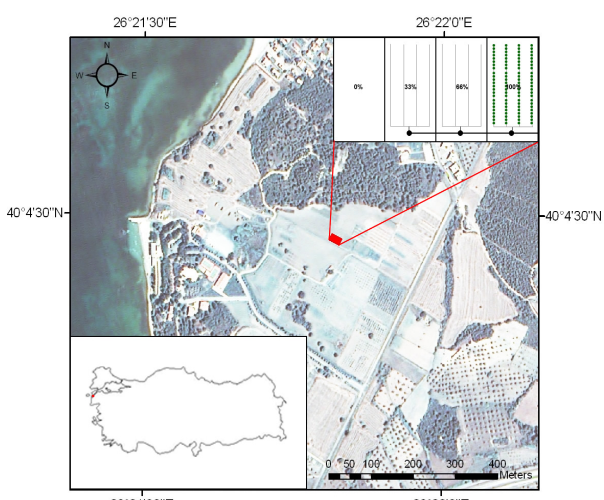

Figure 1. The location of the field experiment (Komsat satellite image (1 m))

Table 1. Some physical characteristics of soil in the study area

Soil Depth (cm)	Texture Class	Bulk weight (gr/cm^3)	Field Capacity	Wilting point	Available Water Holding Capacity
			Pv (%)	Pv (%)	d (mm)
0-30	CL	1.30	40.30	22.39	53.73
30-60	SCL	1.53	34.14	18.97	45.52
60-90	SL	1.67	28.61	15.89	38.15
Total (0-90)					137.40

Soil moisture levels were measured and all treatments were given field capacity by initial irrigation. The soil water content in plots was determined by gravimetrically in the soil layers 0-30, 30-60 and 60-90 cm during growing period. The experimental field was divided into three replications as per field capacity 100% (S1), 66% (S2), 33% (S3) and 0% (S4), respectively. S1 irrigation treatment was applied to consume available soil moisture in the root zone (0-90 cm) for a 7-day interval. S2; 66% of applied water to S1, S3; 33% of applied water to S1 and S4 treatment was not irrigated except that first irrigated. Row and within row spacings were 0.70 and 0.33 m, respectively. There were 32 plants in each plot with a gap of 2.5 m width between each plot to prevent water movement among the treatments. The main and manifold pipes have 75 mm diameter and 6 atm operating pressure were used. The plots were irrigated by drip irrigation. Laterals which 16 mm diameters were laid in each plant row and inline emitters which discharge rate of 4 l h^{-1} and a dripper spacing of 0.33 m intervals. The system was operated at 100 kPa during growing season. The control unit of the system has a pump, control valves, disk filters, and water counter. The plots were fertilized on May 14, 2009 with the $N_{15}P_{15}K_{15}$ type of fertilizer as 5 kg da^{-1}.

Evapotranspiration for each treatment was calculated according to the water balance method (Doorenbos and Kassam 1979):

$$ET = I + P - Dr - Rf \pm \Delta S \quad (1)$$

where, ET : evapotranspiration, I : irrigation water applied during the growth period, P: rainfall during the growth period, Dr : amount of drainage water, Rf :amount of runoff, Δs: change in the soil water content determined by gravimetric sampling

Plant Measurements

Plant height, plant x-x and y-y diameter and chlorophyll readings (ChRs) were measured to determine weekly plant growths. Pepper was planted on May 16, 2009 and harvested on September 29,

2009. First measurement was conducted in June 6, 2009 and ended in August 29, 2009. In each plot, 10 plants were selected for measurements. Total 120 plants were continually measured throught the study in each measurement time. Plant height, x-x and y-y diameters were measured by tape, and ChRs were aquired using Field Scout CM-1000 chlorophyll meter from the same plant between 11:00-14:00 hours in each measurement day. Plant height was measured from the soil surface to the terminal point and plant diameter was measured over terminal point towards x-x and y-y.

Statistical Analysis

Twenty-one different growth models were fitted to week-plant height, week-diameters (x-x and y-y) and week- ChRs in order to describe the growth of peppers under different irrigation practices (S1, S2, S3 and S4). However, Linear (Eq.3), Gompertz (Eq.4) and Logistic (Eq.5) models were chosen to describe week-plant height, week-x-x and y-y diameter while the other models (Eq.6 and Eq.7) were chosen to describe week-ChRs, since those models were found to be more effective than the other models. Statistical analysis was performed on 30 plants. NCSS statistical package program was used to analyze the data (Hintze, 2001). Statistical significance of the model parameters were determined using 95% asymptotic confidence intervals.

In the comparison of effectiveness of models, R^2, mean square error (MSE), Jp statistic and AIC were used (Akaike, 1969; Hocking, 1976; Schwarz, 1978; Gage and Tyler, 1985; Lamare and Mladenov, 2000).

In order to test the effect of treatments, 120 individual growth curves were fitted using the linear, Gompertz and logistic model. Each parameter for the individual growth curves was then subjected to one-way analysis of variance, using the following model to test the effect of treatment:

$$Y_{ijk} = \mu + \alpha_i + \varepsilon_{ijk} \quad (2)$$

where, Yijk is a growth curve parameter, μ is the overall mean, αi is the fixed effect of treatment (i=1, 2, 3, 4) and εijk is the random error term distributed as N(0, σ2) (Mendes et al., 2007).

The arithmetic mean of plant height, ChRs, x-x and y-y diameter for all periods was used for the estimation of average growth functions.

Linear, Gompertz and Logistic model (Equation 3, 4 and 5) were used for plant height and diameter and other models were used for ChRs are defined as:

Linear model: $$W(t)=\beta_0+\beta_{1t}+\varepsilon \quad (3)$$

Gompertz model: $$W(t)=A\exp(-B.\exp(-k.t)) \quad (4)$$

Logistic model: $$W(t)=A/(1+B\exp(-kt)) \quad (5)$$

$$W(t)=A.t^B \exp(-k.t) \quad (6)$$

$$W(t)=A(1-B^t) \quad (7)$$

where, W(t): is the expected value of the characteristic at week t,

A : is the maximum value of the characteristic at maturity or limiting size of the plant

when time (t)→∞,

B : is the growth rate constant or integration constant,

K : is the coefficient of relative growth or maturing index (where a smaller value of k indicated late maturing, and a larger value of k indicates early maturing)

β_0 : is the intercept or regression constant,

β_1 : is the slope or regression coefficient,

ε : error term

RESULTS

Irrigation dates and the amount of applied irrigation water in each week are presented Table 2. The amount of total irrigation water, rainfall, the change of soil moisture content (ΔS) and seasonal evapotranspiration are presented in Table 3.

Table 2. Irrigation dates and applied irrigation water amounts

Treatments	16.05.09	25.06.09	02.07.09	09.07.09	16.07.09	23.07.09
S1	30	27	13	76	51	48
S2	30	18	8	50	34	32
S3	30	9	4	25	17	16
S4	30	0	0	0	0	0
	30.07.09	06.08.09	13.08.09	20.08.09	27.08.09	03.09.09
S1	66	52	57	50	48	49
S2	43	34	38	33	31	32
S3	22	17	19	16	16	16
S4	0	0	0	0	0	0

Table 3. Total irrigation water, rainfall, ΔS and seasonal ET

Treatments	Total Irrigation Water (mm)	Rainfall (mm)	ΔS (mm)	Seasonal Evapotranspiration (mm)
S1	567	185	103	855
S2	383	185	110	678
S3	207	185	99	491
S4	30	185	118	333

Table 4. Growth models and statistical parameters for plant height

Variables	Treatments	Model	Parameter Estimates			Confidence interval		R^2	MSE	Jp	AIC
			A	B	k	Lower %95 C.L	Upper %95 C.L				
Plant Height	S1	Logistic	57.66	4.13	0.40	55.67(A) 3.58 (B) 0.35 (C)	59.65(A) 4.69 (B) 0.44 (C)	0.997	0.81	2.06	0.06
	S2	Logistic	51.08	3.95	0.43	49.63(A) 3.42 (B) 0.38 (C)	52.54(A) 4.48 (B) 0.47 (C)	0.997	0.59	1.84	-3.69
	S3	Gompertz	59.38	0.26	2.53	57.16(A) 0.23 (B) 2.35 (C)	61.61(A) 0.28 (B) 2.71 (C)	0.998	0.38	1.63	-9.11
	S4	Gompertz	58.45	0.21	2.53	56.10(A) 0.19 (B) 2.33 (C)	60.81(A) 0.23 (B) 2.74 (C)	0.999	0.21	1.46	-16.27

Table 5. Growth models and statistical parameters for plant x-x diameter

Variables	Treatments	Model	Parameter Estimates			Confidence interval		R^2	MSE	Jp	AIC
			A	B	k	Lower %95 C.L	Upper %95 C.L				
Plant x-x diameter	S1	Logistic	50.21	4.46	0.26	43.81 (A) 3.85 (B) 0.21 (C)	56.62 (A) 5.06 (B) 0.31 (C)	0.994	0.87	2.12	0.88
	S2	Logistic	49.89	4.58	0.26	43.32 (A) 3.96 (B) 0.21 (C)	56.47 (A) 5.19 (B) 0.31 (C)	0.994	0.82	2.07	0.22
	S3	Logistic	53.13	4.25	0.22	43.58 (A) 3.60 (B) 0.17 (C)	62.68 (A) 4.90 (B) 0.26 (C)	0.994	0.66	1.91	-2.37
	S4	Linear	11.60	2.28	-	10.49 (A) 2.13 (B)	12.69 (A) 2.43 (B)	0.991	0.64	1.81	-3.54

Table 6. Growth models and statistical parameters for plant y-y diameter

Variables	Treatments	Model	Parameter Estimates			Confidence interval		R^2	MSE	Jp	AIC
			A	B	k	Lower %95 C.L	Upper %95 C.L				
Plant y-y diameter	S1	Logistic	45.38	4.45	0.30	42.05 (A) 3.93 (B) 0.26 (C)	48.70(A) 4.98 (B) 0.34 (C)	0.996	0.53	1.78	-5.17
	S2	Logistic	42.88	3.85	0.27	38.25 (A) 3.31 (B) 0.22 (C)	47.52(A) 4.39 (B) 0.33 (C)	0.993	0.75	1.99	-0.98
	S3	Logistic	49.48	4.01	0.23	42.09 (A) 3.48 (B) 0.18 (C)	56.87(A) 4.545(B) 0.28 (C)	0.994	0.64	1.80	-2.86
	S4	Logistic	39.53	2.74	0.27	36.47 (A) 2.42 (B) 0.22 (C)	42.60(A) 3.06 (B) 0.32 (C)	0.994	0.46	1.71	-6.77

The amount of total irrigation water in S1, S2, S3 and S4 treatments were found to be 567, 383, 207 and 30 mm, respectively. Also, seasonal ET was changed between 333-855 mm.

The Linear, Gompertz and Logistic models for plant height and x-x, y-y diameter and the linear, W (t)=A.t^B exp(-k.t), W (t)=A(1-B^t) models for ChRs were chosen to describe time-characteristics relation in plants. These growth models were found to be more effective than the other growth models such as Weibull, Monomolecular, Richards and

Von Bertalanffy in the preliminary analysis. When R^2 values only are considered, almost all of the models fit the height, diameters (x-x, y-y) and ChRs. In addition, when all factors (R^2, MSE, Jp statistic and AIC) were taken into consideration, the appropriate model was selected for all treatments (Table 4, 5, 6 and 7). The most appropriate model has the highest R^2 and the lowest MSE, Jp statistic and AIC values.

Table 7. Growth models and statistical parameters for ChRs in plant

Variables	Treatments	Model	Parameter Estimates			Confidence interval		R^2	MSE	Jp	AIC
			A	B	k	Lower %95 C.L	Upper %95 C.L				
ChRs in Plant	S1	$W(t)=A(1-B^t)$	210.02	0.46	-	185.86 (A) 0.22 (B)	234.17 (A) 0.70 (B)	0.388	899.44	900.61	83.43
	S2	Linear	148.15	7.18	-	118.33 (A) 3.13 (B)	177.97 (A) 11.23 (B)	0.609	472.79	473.96	75.72
	S3	$W(t)=At^B.exp(-k.t)$	126.89	0.53	0.07	88.90 (A) 0.12 (B) -0.01 (C)	164.88 (A) 0.94 (B) 0.14 (C)	0.699	524.62	525.87	77.69
	S4	$W(t)=At^B.exp(-k.t)$	131.49	0.67	0.11	103.88 (A) 0.38 (B) 0.05 (C)	159.10 (A) 0.96 (B) 0.16 (C)	0.828	268.71	269.96	69.67

Growth in height, diameters (x-x, y-y) and ChRs of plants were affected significantly by applied irrigation conditions. While Gompertz growth model was appropriate for growth definition in that plant height at S4 and S3 irrigation conditions, logistic model was appropriate at S1 and S2 irrigation conditions (Table 4). Estimated growth model with both growth parameters were observed to be statistically significant ($p<0.05$). Plant heights (58.45 and 59.38 cm) in ripening period of plants at S4 and S3 irrigation conditions were higher than (51.08 and 57.66 cm) was estimated for plants at S2 and S1 irrigation conditions. Also, growth rates of plants (2.53 and 2.53) were found to be higher under S3 and S4 treatments. Therefore, plants grown under these conditions were expected to reach mature plant height rapidly.

While linear growth model was appropriate for plant x-x diameter at S4 irrigation conditions, logistic model was appropriate at S1, S2 and S3 irrigation conditions (Table 5). Plant x-x diameter (53.13 cm) in ripening period at S3 irrigation conditions were higher than (11.60, 49.89 and 50.21 cm) was estimated for plants at S4, S2 and S1 irrigation conditions. Moreover, growth rates of plants were changed between 0.22 and 0.26 under all treatments. Therefore, plants grown under all treatments were expected to reach mature plant x-x diameter similarly.

Logistic growth model was appropriate for plant y-y diameter under all irrigation conditions (Table 6). Plant y-y diameter (49.48 cm) in ripening period at S3 irrigation conditions higher than (39.53, 42.88 and 45.38 cm) was estimated for plants at S4, S2 and S1 irrigation conditions. Also, growth rates of plants (0.30) were found to be higher under the S1 irrigation conditions. Plants x-x and y-y diameters were found to be same results with regard to growth rates of plants.

Linear, Eq.6 and Eq.7 growth models were fit for ChRs. While Eq.6 was appropriate for ChRs of S3 and S4 treatments, Eq. 7 fitted ChRs at S1 treatments. Besides, linear growth model fitted at S2 irrigation conditions (Table 7). Plant ChRs (210.02 and 148.15) in ripening period of plants at S1 and S2 irrigation conditions were higher than (126.89 and 131.49) was estimated for plants at S3 and S4 irrigation conditions. While R^2 for height, x-x diameter y-y diameter was changed between 99.1% and 99.9%, R^2 for ChRs was changed between 38.8% and 82.8%.

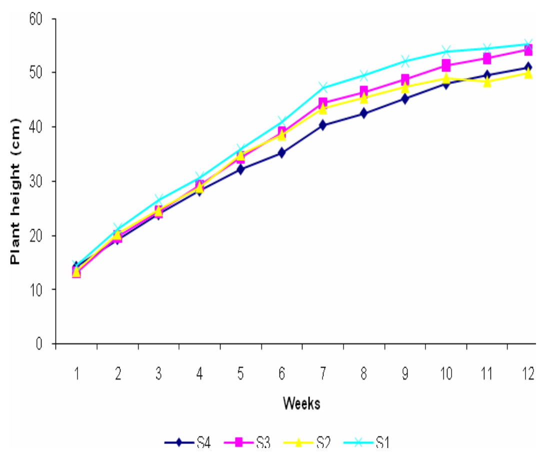

Figure 2. Growth curve for height during growth periods

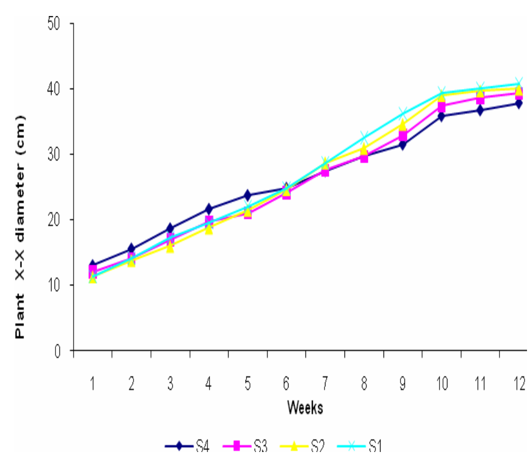

Figure 3. Growth curve for x-x diameter during growth periods

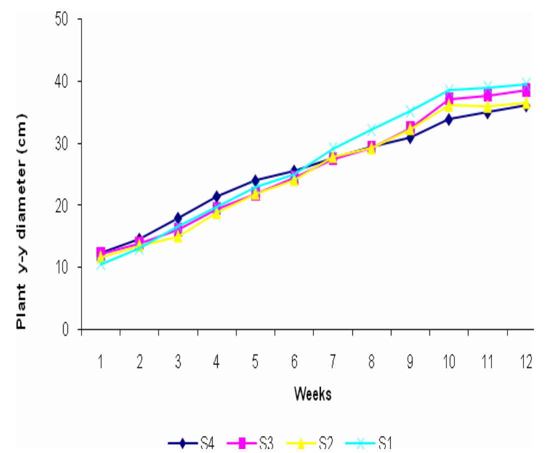

Figure 4. Growth curve for y-y diameter during growth periods

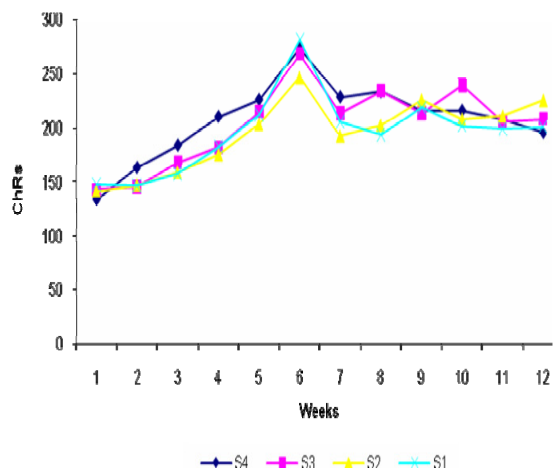

Figure 5. Growth curve for ChRs during growth periods

Growth curves of height, x-x and y-y diameter and ChRs are shown in Figure 2, 3, 4 and 5. Growth curves for height, x-x and y-y diameters are continuously increased. Plant height increased especially until the first seven weeks and then it was noticed that growth increased slowly (Figure 2). Non-irrigated and less irrigated plots (S3 and S4) increased more than S2 and S1 irrigated plots for x-x and y-y diameter until first six weeks, while fully irrigated and S2 plot increased more than less irrigated plots after six weeks (Figure 3 and 4). R^2 values for height, x-x and y-y diameters were higher than ChRs, since the ChRs values were not uniform but changed during the pepper's growth period (Figure 5). Although the growth of height and diameter of the plants constantly increased to a certain point during growth periods, ChRs values did not continually increased. ChRs values generally increased to the middle of the growth period and decreased slowly for each treatment.

DISCUSSION

Three models (Linear, Gompertz and Logistic) were found to be suitable to predict the growth rate using pepper's height and diameters in this study. However, logistic growth model highly explain the pepper growth rate than others. It was assumed that logistic growth model should be first used to estimate the plant growth rate using plant height and diameters.

In the determination of the plant growth, Birch and Richards models were used. Damgaard and Weiner (2008) suggested that the Birch model was explained better than the Richards model for individual plant growth. Werker and Jaggard (1997) tested three empirical models (Gompertz, Richards and Chanter) in sugar beet. They suggested that the Gompertz model was better than the other models for foliage dynamics of sugar beet. After investigating Table 4, 5, 6 and 7, the irrigation water restrictions affect the growth pattern except for y-y diameter. However, models using pepper's height, x-x diameter and ChRs were affected by water stress. R^2, MSE, jp, AIC values for each treatment are also found to be similar except ChRs. The highest ChRs values in growth period were seen in week-6. On the contrary, Demirel et al. (2009) reported that determination of the relationship among ChRs, yield and some quality parameters were affected by deficit irrigation (0%, 20%, 40%, 60%, 80%, 100%) in watermelon. They also demonstrated that relationship between ChRs and yield R^2 under different irrigation applications were found to be between 0.910 (0%) and 0.940 (100%). In this study, ChRs values and curves during growth periods differ than they found due to the different plant materials.

Pepper's height and diameter growth dramatically increased between week-1 and week-10. After week-10, height and diameter growth gradually increased. At week-12, plant growth was almost completed (Figure 2, 3 and 4). Important differences were not found that affect growth between irrigation treatments because of the falling rain during the development of the plants.

CONCLUSION

This study is demonstrated that plant height, x-x and y-y diameters increased during growth period as expected. However, ChRs did not constantly increase. It was found that Linear, Logistic and Gompertz growth models were appropriate to determine pepper growth rate using plant height and diameters. It was found that plant height, diameters (x-x, y-y) and ChRs were affected significantly by water stress. Since ChRs values did not continually increased or decreased during growth period, R^2 values for ChRs were lower than that plant height and diameters.

It was concluded that one-year data would be enough to determine the pepper growth rate using models. However, in order to predict the yield and quality parameters, at least two years data should be collected.

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