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Leaf Area Estimation of the Sugar Beet (*Beta vulgaris* L.) at Different Irrigation Regimes

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Abstract

Leaf area estimation is an important measurement for most physiological and agronomic studies. The aim of this study was to determine the leaf area estimation of the sugar beet (*Beta vulgaris* L.) at different irrigation regimes under field conditions. The study was carried out in split plots in randomized blocks with three replications in 2012-2013, and measurements were taken from leaf parameters, such as length (L) and width (W), petiole length, and the total number of leaf per a sugar beet. The linear (linear, polynomial, and exponential) and non-linear (Logistic, Richards, and Gompertz) methods were used to estimate leaf area measurements. As a result, the non-linear models at the level of each of three irrigation levels had a higher explanation ratio than the linear models. Among these non-linear models, logistic model can be used in the best estimation of leaf area of sugar beet grown at different irrigation regimes.

Key words: Irrigation; leaf area, linear, non-linear models, sugar beet

Farklı Sulama Rejimlerinde Şeker Pancarı Yaprak Alanı Tahmini

Özet

Yaprak alanı tahmini pek çok fizyolojik ve agronomik çalışmalar için önemli bir ölçümdür. Bu çalışmanın amacı tarla koşullarındaki farklı sulama rejimlerindeki şeker pancarının (*Beta vulgaris* L.) yaprak alanı tahminini belirlemektir. Deneme 2012-2013 yılında üç tekerrürlü olarak tesadüf blokları deneme desenine göre yürütülmüştür ve ölçümler yaprak parametreleri olarak uzunluk (L), genişlik (W), yaprak sapı uzunluğu ve şekerpancarı başına toplam yaprak sayısı alınmıştır. Yaprak alanı ölçümleri tahmininde doğrusal (lineer, polinom, üstel) ve doğrusal olmayan (Lojistik, Richards ve Gompertz) yöntemler kullanılmıştır. Araştırma sonucu olarak, her üç sulama seviyelerindeki doğrusal olmayan modeller, doğrusal modellerden daha yüksek bir açıklama oranına sahiptir. Doğrusal olmayan modeller arasında lojistik model farklı sulama rejimlerinde yetiştirilen şeker pancarı yaprak alanının en iyi tahmininde kullanılabilir.

Anahtar kelimeler: Sulama, yaprak alanı, doğrusal, doğrusal olmayan modeller, şeker pancarı

Introduction

Leaf area is an important variable for most physiological and agronomic studies involving plant growth, light interception, plant protection measures, photosynthetic efficiency, evapotranspiration, response to fertilizers and irrigation, and yield potential (Smart 1974, 1985; Williams 1987; Williams and Martinson 2003; Blanco and Folegatti 2005; Kumar 2009). Leaf size depended on position on the stem and was influenced by sowing date, nitrogen fertilizer rate, plant population, the development of crop water stress, and climatic factors (Milford et al., 1985). An accurate leaf area measurement plays a key role in understanding crop growth and its environment.

However, leaves may have complex shapes making leaf area determination more difficult, time consuming, and subject to larger errors (Tsialtas and Maslaris, 2008). In addition to this, it is not possible to make successive measurements of the same leaf and plant canopy is also damaged, which cause problems to other measurements of the experiment. Thus, for many crop species, non-destructive, easily applied models were developed for leaf area (LA) estimation based on simple measurements of leaf parameters such as length and width or some combinations of these parameters (Tsialtas and Maslaris, 2008). Sustainability of the leaves affect crop growth and bio-productivity, thus, leaf area measurements assume a great importance in plant growth studies (Igathinathane et al. 2006).

In addition, irrigation program can be made depending on the growth of plant cover. In this case, when the crop cover percentage increased, the amount of irrigation water is also increased. Because the initial growth periods of plants are in the spring months, plant water consumptions are less than the hot summer months depending on the climatic factors such as high temperature, high wind and low humidity. Moreover, the plant cover percentage shows a progressive reduction toward to harvest time. The leaf area varies up to the last harvest from the seed sowing and it is increased up to the plant's most mature period, then decrease until the harvest period. Therefore, irrigation scheduling considering the plant cover (leaf area) growth is proposed by many researchers (Tsialtas and Maslaris, 2005, 2007, 2008; Igathinathane et al., 2006; Karadavut, 2009; Cemek et al., 2011,). Leaf area, as in all the plants, is also one of the features in the sugar beet plants that should be measured as an important indicator of growth and development in the sugar beet plants. Furthermore, leaf growth and development are also known to be the most important determinants of yield.

The use of a mathematical equation to estimate leaf area as a function of plant parameters that can be more easily measured should be a feasible alternative to direct measurement of leaf area (Ma et al., 1992). Some researchers indicated mathematical relationships between leaf parameters and leaf area for several plants (Ramos et al., 1983; Sharrett and Baker 1985; Dwyer and Stewart 1986; Lieth et al., 1986; NeSmith, 1991; Karadavut et al., 2010). The various leaf area estimation models for many crop species in horticulture and field experiments have been developed in agronomical and physiological studies by researchers. A leaf area estimation model for the sugar beet grown at different irrigation regimes is still lacking despite some studies on sugar beets (Květ and Marshall 1971; Tsialtas and Maslaris 2005, 2007, 2008; Lemaire et al. 2008; Albayrak and Yüksel 2009; Cemek et al., 2011). The aim of the current study is to estimate leaf area for sugar beets (*Beta vulgaris* L.) for different irrigation regimes under field conditions using the linear and non-linear methods.

Materials and Methods

Experimental site

The experiments were conducted during the growing seasons of 2012-2013 under field conditions at the Çukurçayır in Kırşehir Centrum, Turkey. Geographically, the experimental site called Çukurcayır is situated at a 36°42´ and 39°16´ N latitude, 31°14´ and 34°26´ E longitude and 1017 m altitude.

The area has a typical continental climate. Winters are hard and cold, and summers are hot and dry. The area is located in with a long term (1970-2012) annual average temperature 11.4°C and total annual rainfall of 384.4 mm for the April and October growing season (Kırşehir Regional Meteorology Station 2013). The soil texture is silty-clay-loam (SCL). The pH was 7.52–7.61 between depths of 0.3 and 0.9 m. The average value of organic matter, available phosphorus, and available potassium range from 1.10 to 1.99%; 52 to 168 kg ha^{-1}; 333 to 1056 kg ha^{-1}, respectively, at a 0.3-0.9 m soil depth (Kiymaz and Ertek, 2015).

Experimental design

The Isella sugar beet variety was used as the experimental material. Seeds were sown at 1.5–2 cm depths using a five-row mechanic beet seeder. The experiment design was a split plot in randomized blocks with three replications and the size of each plot was 2.25 m in length x 9 m in width (20.25 m^2). Seed sowing was performed on April 1, 2012 and 2013, taking into account the sowing program of the Kırşehir Sugar Factory in region. According to the results of the soil analysis, a compound of fertilizer of NPK (12–30–12% N, P_2O_5, K_2O) and nitrogen were applied before seeding at a rate of 50 kg ha^{-1} and 160 kg ha^{-1}, respectively. The remaining the amount of nitrogen was applied to the experimental plots in the form of ammonium sulfate (21% N) in two parts on June 28 and July 25 in 2012. Irrigation consisted of one irrigation rate at 7-day intervals and three plant-pan coefficients ($K_{cp}1$: 0.5; $K_{cp}2$: 0.75; and $K_{cp}3$: 1.00) and applied with a drip irrigation system.

Measurements

Irrigation was administered at seven-day intervals. Measurements started after three days after the first irrigation, and then measurements were taken after three days every irrigation at 10-day intervals and continued until final irrigation.

Total leaf measurements were taken twelve times (June 24, July 2, 8, 22, and 29, August 5, 12, 19, and 26, September 2, 9, and 16).

Three plants randomly were selected per plot. All of the nine plants were measured from three replication plants on the same leaves in the middle of each plot. The leaf area and petiole length were measured using a planimeter and the tape measure, respectively. The measurements of leaf parameters were maximum length (L) and maximum width (W), petiole length, and the total number of leaf per a sugar beet. The number of leaves in each plot was counted by hand. All leaf parameters are expressed in cm, except total leaf number per sugar beet.

Models

In the study, the linear (linear, polynomial, and exponential) and the non-linear models (logistic, Richards, and Gompertz models) were used. The linear models were given by Equations (1), (2), and (3) and the non-linear models were given by Equations (4), (5), and (6) as the following equations (Draper and Smith, 1998; Karadavut, 2009).

Linear model is given by Equation (1)

$$Y = a + bX \qquad (1)$$

Polynomial model is given by Equation (2)

$$Y = a + bX + cX^2 \qquad (2)$$

Exponential model is given by Equation (3)

$$Y = aX^b \qquad (3)$$

Non-linear models as following equations:

Logistics growth model is given by Equation (4)

$$Y = a/(1 - be^{-ct}) \qquad (4)$$

Richards growth model is given by Equation (5)

$$Y = a(1 \pm be^{-ct})^d \qquad (5)$$

Gompertz growth model is given by Equation (6)

$$Y = ae^{-be^{-ct}} \qquad (6)$$

Where a is an asymptote value, b refers to size of values of the leaf in the period in which they begin to grow, c is net growth ratio, d is inflexion point. Comparison of models were made with determination of coefficient (R^2).

Statistical analyses

Statistica 6.0 statistical program was used to estimate the parameters of all the models with Marquardt iterative method (Douglas and Donald, 1998; Karadavut, 2009).

Results and Discussion

In this study, leaf area of sugar beet can be estimated from linear and non-linear growth models. The regression analysis results obtained from these models presented in Table 1, 2, and 3. The models used to estimate the leaf area of the sugar beets is given in Table 1. Considering the models in Table 1, the exponential model is more successful among the linear models; the logistic model is more successful among the non-linear models.

Considering the irrigation levels, the exponential model with the coefficient of determination R^2= 0.884 in the level irrigation of I_1 were included ahead of the linear and polynomial models. Considering the non-linear models, the coefficient of determination of the logistic model had an explaining level (R^2 = 0.902) and it was determined to be better than the Richards and Gompertz models.

Looking at the irrigation level of I_2, the exponential model with R^2 = 0.884 an explanation rates has an estimated leaf area better than the linear and polynomial model.

When the non-linear model is evaluated, the logistic model has R^2 = 0.930 with explanation rate in the leaf area estimation more successful compared to the Richards and Gompertz models. In the irrigation level of I_3, there was no significant change according to other two irrigation levels in terms of estimation of leaf area in the linear model. In non-linear models, Gompertz model has a better estimate ratio with R^2 = 0.919 than logistic model (R^2 = 0.916).

While in the irrigation level of I1, linear models are shown estimation success with R^2 = 0.867, non-linear models showed estimation success (R^2 = 0.890). In the irrigation level of I_2 linear models estimated R^2 = 0.874, while a non-linear model estimated R^2 = 0.908. In the irrigation level of I_3, linear models estimated R^2 = 0.880, while is a non-linear models showed R^2 = 0.909, a prediction success.

While the model considered all of the irrigation levels, the linear models estimated R^2 = 0.873, and non-linear models estimated R^2 = 0.902. If the linear model is selected according to these results in the estimation of leaf area of the sugar beet plant, the exponential model that results that should be preferred. However, the logistic model should be primarily preferred in the non-linear model. However, the R^2 values obtained from all the irrigation levels of the non-linear models are higher from the R^2 values in the linear model. Non-linear models showed leaf area estimation to be a more successful prediction. In the present study, the leaves of sugar beets grown under full irrigation conditions had explanation by both non-linear and linear models.

Table 1. The parameter values and comparisons of models for leaf area (LA, cm^2) estimation of sugar beet

Irrigation Level	Linear model	Regression equation	R^2	Non-linear model	Regression equation	R^2
I_1	$Y = a + bX$	$Y = -68{,}514 + 26{,}8X$	0.842	$Y = a/(1 - be^{-ct})$	$Y = 32{,}167/(1 + 1{,}926e^{-0{,}416t})$	0.902
	$Y = a + bX + cX^2$	$Y = 30{,}16 + 1{,}351X + 0{,}714X^2$	0.876	$Y = a(1 \pm be^{-ct})^d$	$Y = 30{,}24(1 - 1{,}418e^{-0{,}217t})^{1{,}272}$	0.884
	$Y = aX^b$	$Y = 3{,}158X^{1{,}487}$	0.884	$Y = ae^{-be^{-ct}}$	$Y = 30{,}548e^{-1{,}069e^{-0{,}154t}}$	0.886
Average of R^2			0.867	Average of R^2		0.890
I_2	$Y = a + bX$	$Y = -51{,}317 + 30{,}4X$	0.857	$Y = a/(1 - be^{-ct})$	$Y = 34{,}642/(1 + 1{,}884e^{-0{,}507t})$	0.930
	$Y = a + bX + cX^2$	$Y = 32{,}156 + 1{,}406X + 0{,}651X^2$	0.881	$Y = a(1 \pm be^{-ct})^d$	$Y = 29{,}512(1 - 1{,}168e^{-0{,}176t})^{1{,}316}$	0.904
	$Y = aX^b$	$Y = 4{,}064X^{1{,}067}$	0.884	$Y = ae^{-be^{-ct}}$	$Y = 36{,}166e^{-1{,}684e^{-0{,}216t}}$	0.892
Average of R^2			0.874	Average of R^2		0.908
I_3	$Y = a + bX$	$Y = -56{,}142 + 34{,}12X$	0.862	$Y = a/(1 - be^{-ct})$	$Y = 30{,}068/(1 + 1{,}554e^{-0{,}488t})$	0.916
	$Y = a + bX + cX^2$	$Y = 34{,}916 + 1{,}426X + 0{,}665X^2$	0.883	$Y = a(1 \pm be^{-ct})^d$	$Y = 28{,}516(1 - 1{,}624e^{-0{,}316t})^{1{,}603}$	0.893
	$Y = aX^b$	$Y = 3{,}894X^{1{,}306}$	0.896	$Y = ae^{-be^{-ct}}$	$Y = 35{,}017e^{-1{,}044e^{-0{,}184t}}$	0.919
Average of R^2			0.880	Average of R^2		0.909
General means of R^2			0.873	General means of R^2		0.902

R^2: Coefficients of determination

Table 2. The parameter values and comparisons of models for petiole length (cm) estimation of sugar beet

Irrigation Level	Linear model	Regression equation	R^2	Non-linear model	Regression equation	R^2
I_1	$Y = a + bX$	$Y = 16{,}32 + 3{,}416X$	0.762	$Y = a/(1 - be^{-ct})$	$Y = 11{,}506/(1 - 1{,}926e^{-0{,}416t})$	0.824
	$Y = a + bX + cX^2$	$Y = 15{,}62 + 2{,}884X + 0{,}916X^2$	0.778	$Y = a(1 \pm be^{-ct})^d$	$Y = 18{,}41(1 + 2{,}427e^{-0{,}316t})^{0{,}416}$	0.817
	$Y = aX^b$	$Y = 17{,}561X^{2{,}427}$	0.774	$Y = ae^{-be^{-ct}}$	$Y = 15{,}124e^{-2{,}611e^{-0{,}722t}}$	0.822
Average of R^2			0.771	Average of R^2		0.821
I_2	$Y = a + bX$	$Y = 17{,}88 + 3{,}862X$	0.813	$Y = a/(1 - be^{-ct})$	$Y = 18{,}894/(1 + 2{,}226e^{-0{,}811t})$	0.915
	$Y = a + bX + cX^2$	$Y = 14{,}17 + 2{,}167X + 1{,}088X^2$	0.806	$Y = a(1 \pm be^{-ct})^d$	$Y = 20{,}156(1 - 2{,}024e^{-0{,}547t})^{0{,}662}$	0.906
	$Y = aX^b$	$Y = 16{,}842X^{1{,}988}$	0.810	$Y = ae^{-be^{-ct}}$	$Y = 21{,}246e^{-1{,}994e^{-0{,}816t}}$	0.907
Average of R^2			0.809	Average of R^2		0.909
I_3	$Y = a + bX$	$Y = 21{,}544 + 2{,}611X$	0.756	$Y = a/(1 - be^{-ct})$	$Y = 15{,}142/(1 + 2{,}544e^{-0{,}422t})$	0.877
	$Y = a + bX + cX^2$	$Y = 18{,}662 + 2{,}171X + 1{,}806X^2$	0.762	$Y = a(1 \pm be^{-ct})^d$	$Y = 16{,}417(1 - 2{,}671e^{-0{,}442t})^{0{,}717}$	0.851
	$Y = aX^b$	$Y = 19{,}721X^{1{,}776}$	0.771	$Y = ae^{-be^{-ct}}$	$Y = 14{,}981e^{-2{,}074e^{-0{,}553t}}$	0.867
Average of R^2			0.763	Average of R^2		0.865
General means of R^2			0.781	General means of R^2		0.865

R^2: Coefficients of determination

Table 3. The parameter values and comparisons of models for a total of leaf number per a sugar beet estimation of sugar beet

Irrigation Level	Linear model	Regression equation	R^2	Non-linear model	Regression equation	R^2
	$Y = a + bX$	$Y = 9{,}141 + 2{,}744X$	0.821	$Y = a/(1 - be^{-ct})$	$Y = 10{,}342/(1 - 1{,}404e^{-0{,}284t})$	0.926
I_1	$Y = a + bX + cX^2$	$Y = 10{,}192 + 2{,}651X + 0{,}877X^2$	0.836	$Y = a(1 \pm be^{-ct})^d$	$Y = 9{,}846(1 + 2{,}070e^{-0{,}426t})^{0{,}181}$	0.910
	$Y = aX^b$	$Y = 11{,}196X^{2{,}986}$	0.832	$Y = ae^{-be^{-ct}}$	$Y = 8{,}472e^{-2{,}113e^{-0{,}507t}}$	0.881
Average of R^2			0.829	Average of R^2		0.905
	$Y = a + bX$	$Y = 8{,}76 + 2{,}168X$	0.851	$Y = a/(1 - be^{-ct})$	$Y = 11{,}476/(1 + 1{,}907e^{-0{,}944t})$	0.944
I_2	$Y = a + bX + cX^2$	$Y = 10{,}075 + 2{,}084X + 1{,}110X^2$	0.863	$Y = a(1 \pm be^{-ct})^d$	$Y = 10{,}560(1 - 1{,}914e^{-0{,}612t})^{0{,}481}$	0.928
	$Y = aX^b$	$Y = 9{,}061X^{1{,}812}$	0.861	$Y = ae^{-be^{-ct}}$	$Y = 11{,}627e^{-2{,}011e^{-0{,}715}}$	0.905
Average of R^2			0.859	Average of R^2		0.925
	$Y = a + bX$	$Y = 10{,}312 + 2{,}178X$	0.862	$Y = a/(1 - be^{-ct})$	$Y = 10{,}696/(1 + 2{,}152e^{-0{,}513t})$	0.911
I_3	$Y = a + bX + cX^2$	$Y = 9{,}294 + 2{,}311X + 1{,}911X^2$	0.871	$Y = a(1 \pm be^{-ct})^d$	$Y = 9{,}611(1 - 2{,}334e^{-0{,}518t})^{0{,}606}$	0.904
	$Y = aX^b$	$Y = 10{,}381X^{1{,}644}$	0.866	$Y = ae^{-be^{-ct}}$	$Y = 10{,}084e^{-1{,}996e^{-0{,}483t}}$	0.887
Average of R^2			0.866	Average of R^2		
General means of R^2			0.856	General means of R^2		0.927

R^2: Coefficients of determination

Many researchers have also reported that leaf area can be estimated by linear measurements such as leaf width and leaf length in the following plants: Cucumber (Robbins and Pharr 1987; Blanco and Folegatti 2005), grape (Elsner and Jubb 1988; Uzun and Çelik 1999), onion (Gamiely et al., 1991), cherry (Demirsoy and Demirsoy 2003), peach (Demirsoy et a., 2004); chestnut (Serdar and Demirsoy 2006), faba bean (Pekşen 2007), French bean (Rai et al., 1990), Broad bean (Odabaş 2003), sunflower (Rouphael et al., 2007), and rose (Rouphael et al., 2010), orange (Arias et al., 1989 and Ramkhelavan and Brathwaite, 1990), coconut (Mathes et al., 1990), coffee (Antunes et al., 2008) and sugar beet (Tsialtas and Maslaris 2008). However, they not use non-linear models. Different from these studies, non-linear models were used in our study. In the estimation of leaf area of linear models has been provided the successful results. However, non-linear models revealed more fit performance than the linear models.

Table 2 presented the results of estimation of leaf length petiole of the sugar beet plants grown in different irrigation level. When Table 2 is examined, in the irrigation level of I_1, polynomial model explains R^2= 0.778 and was placed ahead of the linear and exponential models. In the non-linear model, with an explanation amount R^2 = 0.824, made better estimates according to the logistic and Richards model.

Linear models in the irrigation level I_2 with amount of explanation R^2= 0.813 ranked ahead of the polynomial and exponential models. The logistic model was ranked ahead with an amount of explanation R^2 = 0.915 compared to other models. In the irrigation level I_3, the exponential model with an explanation of the degree R^2 = 0.771 was better compared to the other models. The logistic model was ranked ahead of the others with an explanation of R^2 = 0.877 among non-linear models.

Generally, when all models showed the different descriptions of success of the linear model for each irrigation level, the non-linear models revealed stability. Compared to models based on irrigation levels, while the linear models had the amount of explanation of R^2= 0.771 in the irrigation level I_1, the non-linear models had the amount of explanation R^2= 0.821. The linear models had an amount of explanation R^2= 0.809 in the irrigation level I_2, and non-linear models had an explanation R^2 = 0.909. All models in the irrigation level I_2 showed higher amounts of explanation. The reason for this may be due to the sufficient stem growth in plants with irrigation level I_2.

All models on irrigation level I_3 declined in the coefficient of determination compared to irrigation level I_2. This supported our results. Considering this, all irrigation levels in terms of non-linear models with R^2 = 0.865 are shown to better explain linear models (R^2 = 0.781). Accordingly, the estimation stem length of the sugar beet can be said to be more appropriate to use non-linear models.

Models and the amount of explanations used to estimate the total numbers of leaves per sugar beet plant, which are grown in different irrigation levels, are given in Table 3. When examining Table 3, the function of the polynomial from the linear models in irrigation level I_1 had a R^2 = 0.836 explanation ratio. The logistic model from the non-linear models had a value of R^2 = 0.926, which was ranked ahead of the Richards and Gompertz models.

While the polynomial model in irrigation level I_2 had an explanation ratio R^2= 0.863, the logistic model in the non-linear models were ranked ahead with an explanation of ratio R^2 = 0.944. As the polynomial model in the irrigation level I_3 had the highest ratio of explanation with R^2=0.871, the logistic model among the non-linear models ranked ahead of the other models with R^2 = 0.911.

When the irrigation levels are examined, in irrigation level I_1, the linear models had an average rate of explanation of R^2 = 0.829, which remained below the non-linear models with an explanation ratio of R^2= 0.905. The linear models in irrigation level I_2, with average R^2 = 0.859 and R^2 = 0.925 explanation explaining ratios, remained below the ratio of non-linear models. Similar results were observed in irrigation level I_3. While linear the regression explanation rate was R^2 = 0.866, non-linear models were determined as R^2 = 0.900.

When the average of all irrigation levels were evaluated, the non-linear models with an explanation ratio of R^2= 0.910 had the better explanation rates compared to the linear models (R^2 = 0.851). While the explanation of the average according to irrigation levels in the linear models showed an increase, depending on the irrigation level, the non-linear models in irrigation level I_2 had the highest amount of explanation.

While polynomial model (R^2= 0.856) made the best explanation in all three irrigation levels in linear models, the logistic regression model in non-linear models at the level of each of the three irrigation levels had the most significant explanation rates (R^2 = 0.927).

According to the results, it would be more useful to estimate the total number of leaves of the sugar beet using non-linear models. The logistic model has also been shown to increase the success of the definition of the preferred model among applied models. In our study, non-linear models containing other variables give a considerably better prediction than linear models.

Conclusions

In the current study, the study aimed to determine the leaf area estimation of the sugar beet (*Beta vulgaris* L.) at different irrigation regimes under field conditions using the linear and non-linear methods. Non-linear models at each of the three levels of irrigation have had a higher explanation ratio than the linear models. In terms of irrigation levels, leaf area estimation observed the highest rate explanation in irrigation level I_3. The irrigation level of I_2 had the highest petiole length and total number of leaves than two of the model groups. Providing a better explanation of the non-linear model of sugar beet irrigation will help maintain optimal irrigation. Thus, the efficiency of agronomic practices in sugar beet cultivation should increase.

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