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Modelling Yield Response and Water Use to Salinity and Water Relations of Six Pepper Varieties

Gülüzar Duygu SEMIZ[a*], **Cansu ŞENTÜRK**[b], **Ahmet Cengiz YILDIRIM**[a], **Elifnaz TORUN**[a]

[a]*Department of Farm Structures and Irrigation, Agricultural Faculty, Ankara University, Ankara, TURKEY*

[b]*Republic of Turkey Ministry of Agriculture and Forestry, General Directorate of Agricultural Research and Policies, Ankara, TURKEY*

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Corresponding Author: Gülüzar Duygu SEMIZ, E-mail: semiz@ankara.edu.tr
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ABSTRACT

Better understanding of crop yield response under salinity and water deficit conditions is essential to meet food need under the circumstance of population growth and climate extremities. It has been well known that plant species response differently under stress conditions. Recent studies show that these different responses occur not only among species but also in different varieties within the same species. The aims of the study are to examine and to compare yield, yield response factors (k_y), salinity thresholds, biomasses, and water productivity responses of six varieties of pepper plant (Sürmeli-Hot, Yalova, BT016-Hot, BT 016, BT Ünsal, BT Demok) under salinity conditions. In another experiment under the same conditions (location, time, growth media etc.), water deficit was applied to two of these six varieties (BT Ünsal and BT Demok) separately, and their responses to salinity and water deficit conditions were compared. The experiment was carried out in containers. The amount of irrigation water was determined manually by weighing each container. Water deficit treatments were consisted of meeting 120, 100, 70 and 50% of soil water depleted from field capacity. Water salinity levels were 0.25 (control), 2, 4 and 6 dS m^{-1}. There was no difference in yield under non-stress and excessive stress conditions, but the yield difference was as high as 38.9% under moderate stress conditions. Varietal differences were also observed for water productivity. Salinity threshold values vary between 0.89 and 1.83 dS m^{-1}. Yield response factor (k_y) were high for all varieties under salinity. Comparing the k_y values obtained under water deficit and salinity experiments, sensitivity to salinity induced water stress was found higher than that of applied water deficit itself. Using salinity (Model 1) and water deficit (Model 2) data set of two varieties, two models were created plotting relative yield and water potentials (osmotic potential + matric potential) and compered their predications statistically. Statistically better predictions were obtained from Model 2.

Keywords: Irrigation, Stress response modelling, Relative yield, Yield response factor, Salinity tolerance, Water deficit

1. Introduction

Beginning in the 1960s and 70s, the "Green Revolution" lead dramatic increase in total global food production. In this period, the world has witnessed extraordinary productivity increase. While agricultural land has increased by only 30%, grain production has tripled during this period (Wik et al. 2008). This productivity increase is generally attributed to the development of productive crop varieties and management practices (Allen et al. 1998), but a significant part of this increase is related to increasing in irrigated areas. Irrigated lands have higher productivity and economic returns per unit area compared to non-irrigated lands. Globally, irrigated lands are estimated to account for 15% of the cultivated area yet produce between 30% and 40% of the world's food needs (Ghassemi et al. 1995; Postel 1999). While the annual increase in irrigated areas was 1.5% by the time "Green Revolution", it is reported that this rate is 0.6% in 1998-2030 (UNESCO 2009). In arid regions, the effect of irrigation is generally much greater. On the other hand, arid and semi-arid regions are the most effected lands by water scarcity and salinization. Scientists have been drawing attention on food security questions raised by climate extremities, population growth, water, and land degradations etc. (Kiremit & Arslan 2016). Fifty years ago, this problem was overcome to some extent, but the next fifty years will be more difficult. Due to the limited conditions in all aspects, careful use of lower quality and quantity of water has vital importance for upcoming years. The issues underlined above show that it is more important than ever to carry out studies on salt and drought sensitive plants that cannot be grown without irrigation in arid and semi-arid regions. Many scientists have repeatedly stated that water stress and salinity are the most important abiotic stresses limiting plant growth and yield (Wang et al. 2003; Saleem et al. 2020; Alam et al. 2021; Heydari et al. 2021; Atiya et al. 2022). Therefore, understanding, selecting, and developing crops with high osmotic tolerance may provide a solution to the problem (El-Beltagy & Madkour 2012).

Economically and nutritionally important solanaceae vegetables such as pepper, eggplant, and tomato etc., occupied 39% and 66% of horticultural production globally and in Europe, respectively. Solanaceae family members are also utilized as model crops for several traits (Sharma et al. 2017). Pepper (*Capsicum annuum*) production recently increased from 17 to 36 million tons with 35% increase in cultivated area (Tripodi & Kumar 2019; López-Serrano et al. 2021). Pepper plants were considered very sensitive to drought and sensitive to salinity stress (Ayers & Westcot 1989; De Pascale et al. 2003) but some other studies reported response variations to salinity and drought (Aktaş et al. 2006; Kurunç et al. 2011; Semiz et al. 2014; Ünlükara et al. 2015). Plant genetic resources help breeders developing varieties adapting to those different climatic conditions, but more knowledge about unexplored resources is required. Pre-breeding research, to first identify and then characterize those resources for all crops, will need to be at the center of the next research and innovation projects (Economidis et al. 2010).

To counterbalance the predicted increase in the world population to up to nine billion people by 2050 and the related expected impact of climate change, science must produce the knowledge on more productive water use and understand plant response to drought and salinity via plant water use models. Forecasts based on the integration of crop yield models for water stress associated with climate change will be more important than ever for sustainable production and food security. Crop yield models would lead us to make better decision to increase yields and productivity in a sustainable way and adapting crops to match the effects of changes in the environment. Reports of salt tolerance for crops were mostly based on relatively few studies, sometimes just one. However, overall varietal differences were not reported in these databases (Suarez et al. 2021). Suarez et al. (2021) also pointed out the difficulties in comparisons salinity-yield response data in consequence of nonstandard experimentation procedure.

Yield potential of a crop means the maximum yield obtained under non stress conditions in a particular location (equal solar energy, air temperature, longitude etc.). Where the environmental conditions are equal, the yield difference among varieties is a result of their genetical factors (Watson 1952; Sinclair et al. 2005; Prado et al. 2018). Capacity building in terms of standard methods, modelling, and comparable data features on measuring yield potentials under increasing stress conditions, need to be discussed thoroughly. Biotechnology and genetic tools/methods for breeding have been gained tremendous acceleration but salinity and drought resistant crop breeding are relatively slow. The reason for this is generally expressed as the complex response of plants under stress conditions (Kumar et al. 2020; Godoy et. al. 2021). This statement may be true but is it sufficient? The partial results of our study surprisingly revealed the importance of the magnitude of the stress. The method of the applied stress is also important to be comparable real word condition. The method applied water deficit studies on plant (sometimes called drought) need to be comparable to field condition. For example, reporting the results should be referred depleted water from field capacity (FC), not continuous drought or keeping soil water at some % of FC which are not practical. In terms of salinity, utilized salts to prepare saline water should be scrutinized as well. For example, using only NaCl salt would lead infiltration problems then resulting in water stress in the root zone and this situation could be underestimated. Or specific ion toxicity occurs, which may be incorrectly thought of as the osmotic effect of salinity (Grattan & Grieve 1992; Munns & Tester 2008; Semiz & Suarez 2019). Navarro et al. (2002) reported that the use of salt in irrigation water was more harmful than NaCl salts in irrigation water on pepper plants than Na_2SO_4 at the same electrical conductivity (EC) levels. These issues, which have not been emphasized much, need to be discussed in the scientific arena. More comparative studies are needed on these issues. The methodical problems listed above are for modelling and pre-breeding studies. Practical approaches used in plant physiology studies are not criticized.

In arid and semi-arid areas, irrigation has become even more dependent on poorer quality and deficit quantity water. Moreover, differences in resistance to drought and salinity between varieties, which were not covered extensively before, have become more important than before. Demonstrating the tolerance differences among varieties with the help of models will provide technical support to the primary users in economic planning and irrigation programming. In addition, the method followed here is especially recommended for plant breeding as it gives comparable results in selecting drought- and salinity-resistant varieties.

The aim of the study are to (1) determine and compare biomass and fruit yield of six pepper plant varieties under increasing salinities (2) determine and compare the response of increasing water deficit levels of two pepper plant varieties (3) modelling plant-water-soil salinity relations under salinity and water deficit conditions (4) compare the model outputs for water salinity and water deficit (5) suggest and discuss the importance of methodology on pre-breeding and stress tolerance modelling studies. Thus, our research outputs will contribute to the agricultural sciences by developing models that make adaptive yield estimation for primary users and planners in their own fields, as well as discussing and making recommendations for methods used for breeding salinity and drought tolerant plants.

2. Material and Methods

Pepper (*Capsicum annuum*) seedlings (standard and registered) were purchased Atatürk Horticultural Central Research Institute and Bursa Seed Company, Turkey. The list of varieties and registered names are shown in Table 1. Pepper seeds were sown in seedling viols in a greenhouse in April 2018, in Ankara. The greenhouse mean temperatures were 10-15 °C at night and 20-25 °C daytime. When the pepper seedling reached three-true leaf stage, the seedlings were transferred to the experimental containers in May 2018. The containers had been well-watered with tap water (0.25 dS m^{-1}) for two weeks to provide good establishment. Then, the experiment was initiated in accordance with the treatments.

Table 1- Registered and standard varieties used in the experiment

Plant abbreviation	Variety	Maintainer
YS	Sürmeli- Hot	Atatürk Horticultural Central Research Institute, Turkey
YT	Yalova	Atatürk Horticultural Central Research Institute, Turkey
KC	BT 016- Hot	Bursa Seed, Turkey
KT	BT 016	Bursa Seed, Turkey
HT	BT Ünsal	Bursa Seed, Turkey
GT	BT Demok	Bursa Seed, Turkey

Salinity-water use-yield relations of 6 pepper varieties and deficit water applications-water use-yield relations of HT and GT varieties were determined. For this purpose, fresh and biomass yield, evapotranspiration (Semiz et al. 2014), soil osmotic (Allison et al.1954) and matric potentials (Saxton & Rawls 2006), water productivity (Allen et al. 1998), salinity threshold and slope values (Maas & Hoffman 1977), yield response functions (Stewart & Hagan 1973) were examined.

The experimental setup was completely randomized factorial design with three replications, totally 96 containers. The experiment was conducted 350 mm in diameter and 300 mm in depth containers, in Ankara University Faculty of Agriculture, Department of Farm Structures and Irrigation experimental area, Ankara, Turkey. The soil was top layer of an agricultural land (30 cm of surface soil). Air dried soil were sieved (4 mm). The soil texture was sandy clay loam (Bouyoucos 1951). Experimental soil media was consisted of 1:0.5:0.5, soil: peat (Klasmann TS 1): perlite. Initial soil extract salinity, EC_e and pH_e were 0.255 dS m^{-1} and 7.49, respectively. To provide free drainage conditions, 5 cm thick gravel was filled at the bottom of the containers. Each container was filled with 11 kg of air-dried soil media. Randomly selected 6 containers used to evaluate the weight at field capacity. These 6 containers initially saturated with tap water and covered to prevent evaporation. The containers were weighed again immediately after drainage had stopped and the average weight was taken as the weight at field capacity (Ünlükara et al. 2010; Semiz et al. 2012). At the beginning of the study, the weight of each lysimeter at field capacity was known, Evapotranspiration (ET) could be calculated based on the weight lost between consecutive irrigations (as detailed by Semiz et al. 2014). The amount of irrigation water to be applied was calculated as follows (Eq. 1):

$$\mathrm{AW} = \frac{\frac{(\mathrm{W_{fc}} - \mathrm{W})}{\rho_\mathrm{w}}}{1 - \mathrm{LF}} \quad \text{(Eq. 1)}$$

Where; AW is applied water (L): W_{fc} and W; are the weight of each lysimeter at field capacity and the weight of each lysimeter just before irrigation: (g); respectively: ρ_w ; unit weight of water (1000 g L^{-1}) and LF is the leaching fraction, which is not applicable for water deficit treatments.

Irrigation waters were applied in accordance with salinity levels and the percentage of total water needs, manually. Each container was weighed at 3–4-day intervals. ET was determined by weighting each container thus each plant received a different quantity of water based on their actual water consumption during the previous time interval. Irrigation water amounts were selected 120, 100, 70 and 50% of depleted water from field capacity. Thus, only 70% or 50% of the evapotranspiration being met, the water deficit was created. Irrigation water salinity levels were 0.25 (tap water), 2, 4 and 6 dS m^{-1}. Saline irrigation water was prepared using Na_2SO_4, NaCl, $CaCl_2$, $MgSO_4$ salts to mimic natural saline conditions and not to lead additive specific ion toxicity rather than the salinity (Grattan & Grieve 1992). The SAR value was kept below 5 because in addition to salinity, infiltration problems would not arise and the negative effect of Na and/or Cl as specific ions would not interfere with the salinity effect (Ayers & Westcott 1994). SAR (sodium adsorption ratio, defined as $Na^+/((Ca^{2+}+Mg^{2+})/2)^{0.5}$ where concentrations are expressed in m mol L^{-1}). The EXTRACTCHEM model (Suarez & Taber 2012) was used to calculate the amount of salt to be dissolved in tap water.

At the end of the experiment, soil samples were collected from each container, air dried, sieved 4 mm, saturated for 24 h, extracted and then salinities were measured (Allison et al.1954). The salt tolerance model (Eq. 2) proposed by Maas and Hoffman (1977) was applied to determine threshold and slope values (relative yield decrease per unit increase in salinity for each variety).

$$\mathrm{Y_r} = 100 - \mathrm{b}(\mathrm{EC_e} - \mathrm{EC_{e\,treshold}}) \quad \text{(Eq. 2)}$$

Where: Y_r; relative yield: % EC_e; soil salinity beyond the threshold value dS m^{-1}: $EC_{e\ threshold}$; threshold soil salinity dS m^{-1}: b; slope value which is the % yield loss per unit increase in electrical conductivity of the saturated soil extract beyond the threshold value.

The following equations (Eq. 3, 4, 5 and 6) proposed by Saxton & Rawls (2006) were used to determine the matrix (MP) and osmotic potential (OP).

$$\Psi_{(1500-33)} = \Psi_\Theta = \mathrm{A}(\Theta)^{-\mathrm{B}} \quad \text{(Eq. 3)}$$

$$\mathrm{A} = \exp(\ln 33 + \mathrm{B}\ln\Theta_{33}) \quad \text{(Eq. 4)}$$

$$\mathrm{B} = \left(\frac{\ln(1500)-\ln(33)}{\ln(\Theta 33)-\ln(\Theta 1500)}\right) \quad \text{(Eq. 5)}$$

$$\Psi_o = 40\mathrm{EC}_e \quad \text{(Eq. 6)}$$

Where, tension at moisture Ψ_Θ (matric potential) is in kPa; 33 kPa moisture is Θ_{33}; A and B are coefficients of moisture-tension: %v; 1500 kPa moisture is Θ_{1500}: %v; Ψ_o is the osmotic potential in kPa; and EC_e is the electrical conductance of a saturated soil extract at 25° C in dS m^{-1}.

The total matric and osmotic potential values for each treatment was plotted against their relative yield values. Then, regression equations were created namely Model 1 and Model 2. The data used for Model 1 and Model 2 were salinity and water deficit experimental results of HT and GT varieties, respectively. Next, using Model 1 and Model 2 outputs and measured relative yields were plotted against predicted versus observed relative yields for the rest of 6 varieties.

Two-way ANOVA and Bonferroni (1936) multiple range test were performed using SPSS 19.0 (SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1. Fruit and biomass yield

The interaction of genotypes and water amount was found statistically significant at P<0.005 significance level (Table 2). GT and HT had similar fruit yield, where water requirement was fully met (100% and 120%). The fruit yield difference was only occurred at moderately water deficit condition (70%) with 12.1% higher yield of GT. At 50% of water requirements are met, both genotypes had similar fruit yield. It is worth mentioning here that in this study, free drainage conditions are provided. Thus, there were similar amount of water in the root zone for both 100% and 120% treatments. This result shows that both genotypes give similar fruit yields under optimum conditions. At the moderately water deficit condition (where 70% water requirement met), genotypic difference may have arisen thus more fruit yield decline occurred in HT genotype. At the excessive water deficit condition (where 50% water requirement met), the fruit yield declines were similar in both genotypes, 60% and 59% for GT and HT, respectively. These findings suggested that it is also important to select the magnitude of the water deficit to find out genotypic response to water deficit. Kurunç et al. (2011) reported 33.7 and 40.4% yield reduction for bell pepper, where 70 and 50% water requirement met, respectively. They also reported no yield difference between the treatments of 145% and 100% water requirement met.

Table 2- Yield, biomass, ET, and WP statistical results under water deficit conditions

Applied Water		*120%*	*100%*	*70%*	*50%*	
Yield g plant^{-1}	GT	116.3 A a	115.2 A a	86.2 A b	46.2 A c	90.97 A
	HT	112.4 A a	111.8 A a	75.8 B b	46.7 A c	86.68 B
	Mean	114.34 a	113.50 a	80.99 b	46.45 c	
ET, mm	GT	350.0 B a	304.5 B b	259.0 A c	164.50 A d	269.50 B
	HT	381.1 A a	322.6 A b	273.6 A c	178.6 A d	288.98 A
	Mean	365.54 a	313.56 b	266.29 c	171.50 d	
Biomass, g plant^{-1}	GT	8.20 A a	8.32 A a	5.33 A b	3.20 A c	6.288 A
	HT	7.36 B a	7.58 B a	4.88 B b	2.98 A c	5.625 B
	Mean	7.780 a	7.950 a	5.005 b	3.090 c	
WP, kg m^{-3}	GT	4.70 A b	5.35 A a	4.71 A b	3.98 A c	4.684 A
	HT	4.18 B b	4.90 B a	3.92 B b	3.72 B	4.180 B
	Mean	4.441 b	5.126 a	4.314 b	3.848 c	

A ↓ Vertical comparisons of means; a→ Horizontal comparisons of means
Water amount P< 0.005, genotype P>0.005, genotype x WD P<0.005

Interaction of water amount and genotypes were found significant on biomass production. Biomass productions of both genotypes showed similar trend as continuous reductions in biomass yield under moderate and excessive water deficit conditions and did not differ under full irrigations. Comparing full irrigations, GT's biomass reductions were 32.4% and 61.1% at 70 and 50% treatments and HT's biomass reductions were 34.6% and 60.1% at 70 and 50% treatments, respectively.

Comparing genotypes, genotypic variations have arisen at full irrigation and moderate water deficit treatments. Biomass yields of GT were 10.2, 9.0 and 8.0% higher than HT under 120, 100 and 70% treatments respectively and statistically similar under 50% treatment. Unlike the fruit yield, genotypic differences occurred in biomass yield under no and moderate water stress.

Salinity experiment (increasing salinity with 20% regular leaching) revealed some genotypic variations (Table 3) as well. Genotype and salinity levels interaction was found statistically significant on biomass and fruit yield ($P<0.005$). In irrigation with control water (non-saline), genotypes had statistically similar fruit yields. Increasing salinity levels caused to decrease in economical yield for all genotypes, in different rate. At 2 dS m^{-1} salinity level, YT (103.0 g) and KC (105.5 g) genotypes had the similar (statistically) highest fruit yields. The fruit yield reductions by genotypes were 0.08%, 21.4%, 18.7% and 32.5% for KT, YS, HT, and GT, respectively. At 4 dS m^{-1} salinity levels KC (87.4 g) had the highest fruit yield. The fruit yield reductions by genotypes were 0.07%, 17.0%, 21.1%, 34.1% and 38.9% for YT, KT, YS, HT, and GT, respectively. At 6 dS m^{-1} salinity levels YT (55.5 g) had the highest fruit yield. The fruit yield reductions by genotypes were 0.19%, 20.9%, 21.1%, 22.7% and 31.7% for KC, KT, YS, HT, and GT, respectively. De Pascale et al. (2003) utilized sea salts diluting in irrigation water on the Laser variety (pepper) and reported a yield reduction of 46% at a salinity level of 4.4 dS m^{-1}. The authors also reported that 8.5 dS m^{-1} salinity level and non-irrigated (drought) treatments showed similar plant-water relations. Salinity in the root zone causes excessive ion accumulation and high osmotic and matric stress in plants. Thus, a decrease in growth and development occurs. This results in lower soil matrix potential and leads to drought conditions, i.e., conditions that cause physiological limitation for plant growth (Munns & Tester 2008; Abrar et al. 2020).

Table 3-Yield, biomass, ET, and WP statistical results under salinity conditions.

Irrigation Water Salinity (dS m^{-1})		*0.25*	*2*	*4*	*6*	*Mean*
Yield g plant^{-1}	YS	110.5 A a	82.1 C b	69.0 C c	43.9 B d	76.37 C
	YT	114.6 A a	103.0 AB b	79.5 B c	55.5 A d	88.17 A
	KC	116.6 A a	105.5 A b	87.4 A c	45.1 B d	88.64 A
	KT	114.0 A a	96.1 B b	72.5 BC c	42.9 B d	81.38 B
	HT	112.4 A a	84.9 C b	57. 6 D c	37.9 BC d	73.18 C
	GT	116.3 A a	70.5 D b	53.4 D c	35.2 C d	68.84 D
	Mean	114.04 a	90.34 b	69.91 c	43.42 d	
Biomass g plant^{-1}	YS	8.14 B a	8.22 B a	7.03 AB a	4.30 B b	6.92 B
	YT	12.21 A a	12.23 A a	7.07 AB b	5.84 A b	9.34 A
	KC	11.00 A a	10.34 A ab	8.31 A b	7.06 A b	9.18 A
	KT	11.08 A a	10.11 A a	7.11 AB b	6.98 A b	8.82 A
	HT	7.36 C a	3.87 D b	3.51 C b	3.33 B b	4.52 C
	GT	8.20 B a	6.54 C ab	5.16 B b	3.51 B c	5.85 B
	Mean	9.67 a	8.52 b	6.37 c	5.17 d	
ET, mm	YS	403 A a	372 A b	341 A c	246 B d	340 AB
	YT	407 A a	373 A b	336 AB c	289 A d	351 A
	KC	389 A a	346 AB b	309 B c	277 A d	330 B
	KT	374 AB a	360 AB b	309 B c	238 B d	320 B
	HT	381 A a	341 B b	284 BC c	203 C d	302 C
	GT	350 B a	289 C b	255 C c	206 C d	275 D
	Mean	383 a	347 b	306 c	243 d	
WP, kg m^{-3}	YS	3.88 B a	3.12 C bc	2.87 C cd	2.54 A d	3.212 C
	YT	4.00 B a	3.91 AB a	3.35 B b	2.72 A c	3.602 AB
	KC	4.24 AB a	4.31 A a	4.00 A a	2.30 A b	3.821 A
	KT	4.32 AB a	3.77 B b	3.32 BC c	2.56 A d	3.601 A
	HT	4.18 B a	3.53 BC b	2.87 C c	2.64 A c	3.413 B
	GT	4.70 A a	3.45 BC b	2.97 C c	2.421 A d	3.493 B
	Mean	4.221 a	3.681 b	3.280 c	2.530 d	

A ↓ Vertical comparisons of means; a→ Horizontal comparisons of means
Salinity P< 0.005, genotype P<0.005, genotype x Salinity P<0.005

Biomass yield for six cultivars under increasing salinity levels showed also different responses (Table 3). At control salinity level, highest-mean biomass yield (statistically similar) was 11.43 g $plant^{-1}$ for YT, KC and KT cultivars. Biomass yield strongly affected both salinity levels and genotypes. YS and GT genotypes had 8.17 g $plant^{-1}$ mean biomass yield (statistically similar) but increasing salinity levels affected GT more strongly than YS. Comparing to control treatment, biomass yield reductions were 20, 37, and 57.2% for GT at 2, 4, and 6 dS m^{-1}. There was no statistical difference in biomass productions of YS at control, 2 and 4 dS m^{-1} salinity levels but there was 47.2% yield reduction at 6 dS m^{-1} salinity level. The lowest biomass yield at control treatment was observed in HT genotype with 7.36 g $plant^{-1}$ and a sharp biomass yield decrease occurred at 2 dS m^{-1} with 47.4%. Interestingly, there was no furthered biomass yield decrease under increasing salinity levels for HT. Baath et al. (2017) reported that biomass productions of 5 pepper cultivars decreased under increasing salinity conditions up to 5 dS m^{-1} salinity level. At the control treatment (120% water application rate and 0.25 dS m^{-1} salinity level), the six genotypes gave similar fruit yield responses, indicating that genotypic variations on crop yield potentials under optimal conditions were not significant. Rameshwaran et al. (2016) stated that under water or salinity stress conditions, biomass/yield differences among varieties were higher. Ficiciyan et al. (2021) also reported similar fruit yield responses under full irrigation and variable responses under drought treatments of 15 sweet pepper varieties. These results indicated genotypic variations in both biomass and fruit yields occurred at moderate salinity level. These results strengthen our hypothesis that genotypes of peppers may response variable to moderate stress but similarly response to excessive and non-stress condition. Other outcome of the current study is that it is important to carefully assign the salinity and drought stress levels to reveal genotypic differences when selecting candidate lines for breeding.

3.2. Water use and productivity

Irrigation water was applied in accordance with individual plant water requirements, meaning that each plant received water according to own stress response. Evapotranspiration rate decreased with decreasing water amount applied, in accordance with the nature of the treatments. The treatment of 100% and 120%, where water requirement fully met, water consumption was higher HT than GT (Table 2). The treatment of 70% and 50%, where water requirement partially met, both genotypes were in the same statistical group. Water productivity (WP) was higher in GT than HT under excessive, moderate, and non-stress conditions. The highest WP (5.35 kg m^{-3}) was observed in GT at 100% of water requirement met and, the lowest (3.72 kg m^{-3}) in HT at 50% of water requirement met.

ET reduced with increasing salinity levels for six pepper cultivars. ET reductions is directly proportional to salinity induced water use stress (Table 3). Under control treatment (0.25 dS m^{-1}), the lowest ET (350 mm) was observed in GT genotype, and rest of the genotypes were at the same statistical group. Under control treatment (non-saline), although KC, KT and GT at the same statistical group, the highest WP was observed in GT (4.70 kg m^{-3}) but decreased sharply under moderate and excessive salinity treatments. Except KC, WPs of each genotype continually decreased with increasing salinity level, statistically. WP of KC decreased only at excessive saline condition. Rameshwaran et al. (2016) investigated two pepper cultivars under different water regimes and salinity levels. They reported that increasing salinity level and water deficit caused reductions in WP, but they did not report varietal differences. Varietal differences in WPs were reported for different water regimes such as for wheat van den Boogard et al. (1997); for peanut Bhatnagar-Mathur et al. (2007), Ratnakumar et al. (2009) and Devi et al. (2009); for pepper Erwin et al. (2019). Erwin et al. (2019) stated that differences in water use properties among pepper varieties are higher than previously reported.

3.3. Crop stress modelling

Under optimal conditions, plant ET is maximum (ET_m), and the relative yield (RY_m) is 100% (Vaux & Pruitt 1983). Under abiotic stress conditions, ET and RY decrease by different rates related the magnitude of the environmental stresses and the plant type or variety (Suarez et al. 2021). It has been suggested different approaches to predicting or modelling RY under stress conditions. First approach is estimating the relationship between ET and RY reductions (Doorenbos & Kassam 1979; Vaux & Pruitt 1983). Second approach is establishing a relation which directly estimates RY under quantitative measures of the stress, in our study matric and/or osmotic potentials. Both approaches were adopted, and their predictions were analysed.

First approach includes soil extract salinity-relative yield and water deficit-relative yield estimations. Ayers & Westcot (1989) salinity threshold and slope modelling are used to determining and forecasting yield reduction under saline conditions. Ayers & Westcot (1989) reported 1.5 dS m^{-1} pepper salinity threshold. The method proposed by Ayers & Westcot (1989) was adopted, and similar but variable results were found. Graphical models and outputs are shown in supplementary files-S2 and Table 4, respectively. The most sensitive genotype was found to be KT with a slope value of 13.5% and a threshold of 0.89 dS m^{-1}. The most resistant genotype was GT with 1.83 dS m^{-1} threshold with 13.9% slope value. These variable responses to salinity are suggesting that it is important to select not only crop species but also its variety. Reporting crop response to salinity suggested and standardized by Ayers & Westcot (1989) are of great important since outputs of this approach are comparable and applicable to directly economical and water management decisions. No publications were found addressing salt tolerance modelling of different pepper varieties under this standard approach. Most pepper salinity tolerance studies solely NaCl was used as salinity agent such as Aktaş et al. (2005), Chartzoulakis & Klapaki (2000) Penella et al. (2015) and Giorio et al. (2020) and so on.

Table 4- Ayers and Westcot (1989) and Stewart and Hagan (1973) model outputs

Plant variety	*Threshold (dS m^{-1}) and slope (%)*	*Yield Response Function (k_y)*
YS	1.51 and 13.5	1.70
YT	1.43 and 12.8	1.73
KC	1.55 and 16.2	1.75
KT	0.89 and 13.5	1.78
HT	1.12 and 13.8	1.56
GT	1.83 and 13.9	1.83
HT-WD	-	1.39
GT-WD	-	1.35

Stewart & Hagan (1973) proposed yield response function model, to predicting relative decrease of crop yield under water deficit conditions. Yield response functions of crops are beneficial modelling since they give important sense of water use and yield predictions under non-standard conditions. The model procedure was first proposed to determine yield response to water deficit but later it has been also implemented on water use modelling under saline conditions (Khataar et al. (2018) for bean and wheat; Kurunç et al. (2011) for bell pepper; Düzdemir et al. (2009) for cowpea). Yield response functions (ky) were determined for all genotypes under salinity and for HT and GT genotypes under water deficiency conditions. Graphical models and outputs are shown S1 and Table 4, respectively. All varieties were found very sensitive to water deficit caused by salinity. The most sensitive and the most resistant varieties were GT with 1.83 and HT with 1.56 k_y values, respectively. Under water deficit conditions, on the contrary to salinity, GT and HT gave similar responses, 1.35 and 1.39 k_y values, respectively. Those results indicated that both varietal responses occur under salinity and, GT and HT are more sensitive to water deficit caused by salinity. In other words, salinity induced ET reduction was found more pronounced (or severe) than water deficit itself. No studies reporting and comparing salinity and water deficiency conditions for different varieties were found in the same experiment. Kurunç et al. (2011) examined and compered k_y values under salinity and water deficit for a bell pepper variety. Although their findings are not compatible to our study, they reported that salinity and drought effected bell pepper yield response similarly. Qiu et al. (2017) reported that under increasing salinity level k_y value of hot pepper was 1.65.

Githu & Goodwin (2020) stated that studies on physiological feature needed to carry along with yield-water response functions to provide a better knowledge of crop response. They also pointed out the difficulty in put into practice the results from different studies. Apparently, more modelling and standardized studies need to be carried out.

To establish the second approach (quantitative relationship), soil osmotic and matric potentials were calculated, as detailed in the Allison et al. (1954) and Saxton & Rawls (2006), respectively. Since only the HT and GT varieties were exposed to water deficit, the datasets were used under salinity and water deficit (separately) to construct the models (Figure 1).The total water potential (OP+MP) was considered as a quantitative stress measurement. Two different models were created, the results of which were combined for HT and GT. Model 1 and Model 2 represent salinity and water deficit experimental results, respectively. Then, in order to examine whether any model would (statistically) predict relative yield better, both models were applied to the entire dataset for 6 varieties. Some comparative statistical analyses are shown in Table 5. In addition, a graphical presentation was prepared to demonstrate the accuracy of the estimates. The lines of x=y represent perfect predictions and dots represents prediction via models.

Figure 1 clearly shows that Model 2 produces more reliable predictions than Model 1. Comparative statistical analyses also showed that Model 2 has better predictions than Model 1. The reason of the better predictions of Model 2 might be pepper yield's being relatively more sensitive to MP under these ranges of MP and OP. Since salinity experimental results were used in Model 1, MP's relative impact on OP+MP value was lower. Similarly, relative impact of MP on MP+OP was more since water deficit experimental results were used.

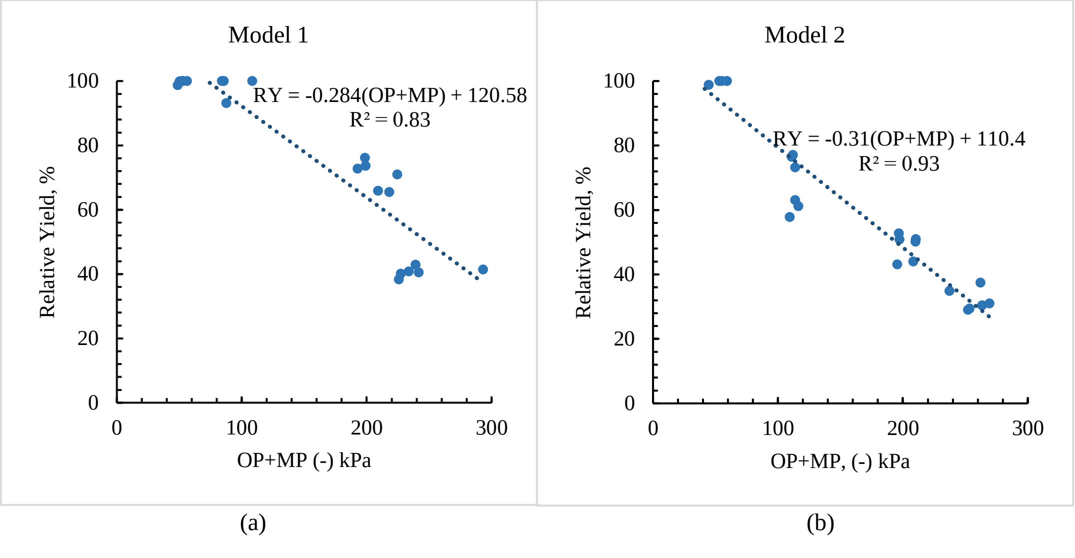

Figure 1- (a) Saline treatment data set (b) Water deficit treatments data set used

Table 5- Comparative statistical analyses for predicted and observed relative yield

Statistical Analyse	*Salinity-Model 1*	*Water Deficit-Model 2*
Mean Absolute Deviation	11.88	5.57
Mean Squared Error-Deviation	183.39	48.41
Root Mean Square Error	13.54	6.96
Mean Absolute Percentage Error	16.26	9.63
Mean Error	11.82	-2.22
Mean Percentage Error	16.08	-5.28
Correlation	0.95	0.95

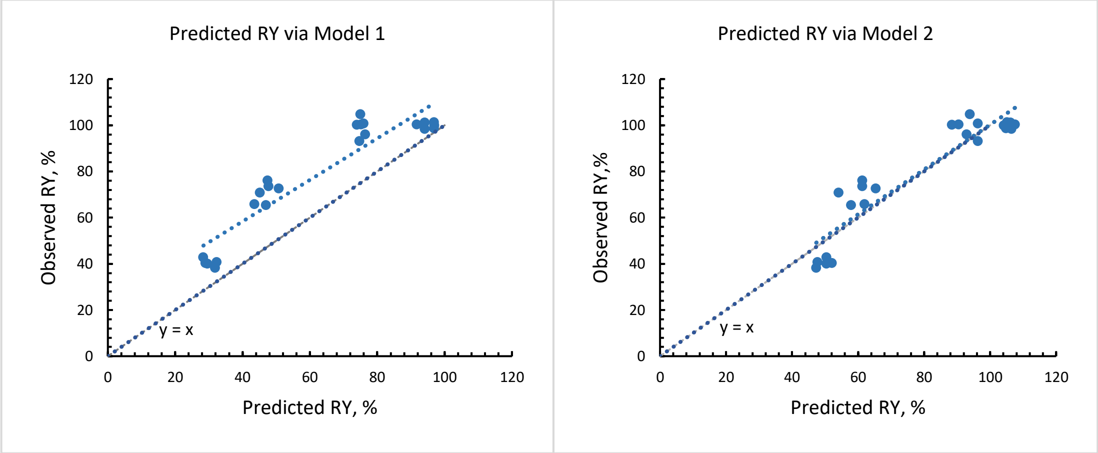

Figure 2- Predicted versus observed relative yields for six varieties

4. Conclusions

The fruit yields of GT and HT varieties showed similar responses under non-water stress and excessive water stress conditions, but GT had higher yield under moderately water stress condition. Under control treatment, no yield differences were observed between the varieties, but increasing salinity levels caused a larger difference in yield responses. The yield difference observed as high as 38.9% and as low as 0.08% at 4 dS m^{-1} salinity level. These results clearly demonstrated the yield response under salinity were varietal. GT had higher water productivity than HT variety under both non-water stress and water deficit conditions. Varietal differences have also arisen for WP under salinity condition, except the highest salinity level. The crop stress model was examined for each variety. Salinity threshold values ranged 1.83 and 0.89 dS m^{-1}. This large difference suggests the importance of variety selection under low water quality conditions. Yield response functions were determined under both salinity and water deficit. Higher sensitivity was found in the water use-yield relationships under salinity stress than under water stress conditions. This result may indicate that pepper is more sensitive to salinity induced water stress, or that the water stress caused by salinity is higher than the applied water deficit itself. Two models were created for HT and GT variants using the water deficiency treatment and salinity treatment dataset. Total soil potentials (osmotic + matric potentials) were determined and plotted against the relative yield of HT and GT varieties. Both models were applied to predict RY for the rest of the cultivars. Then, predicted and observed RY were cross-checked and their results evaluated statistically. Interestingly, statistically better estimates were found generated through Model 1 using data based on water deficit. This might be the result of higher water stress sensitivity under saline conditions.

As a conclusion, it is aimed to reveal varietal differences by proposing standardized studies on salinity and water deficit in the same experiment and to benefit the practical use of the models.

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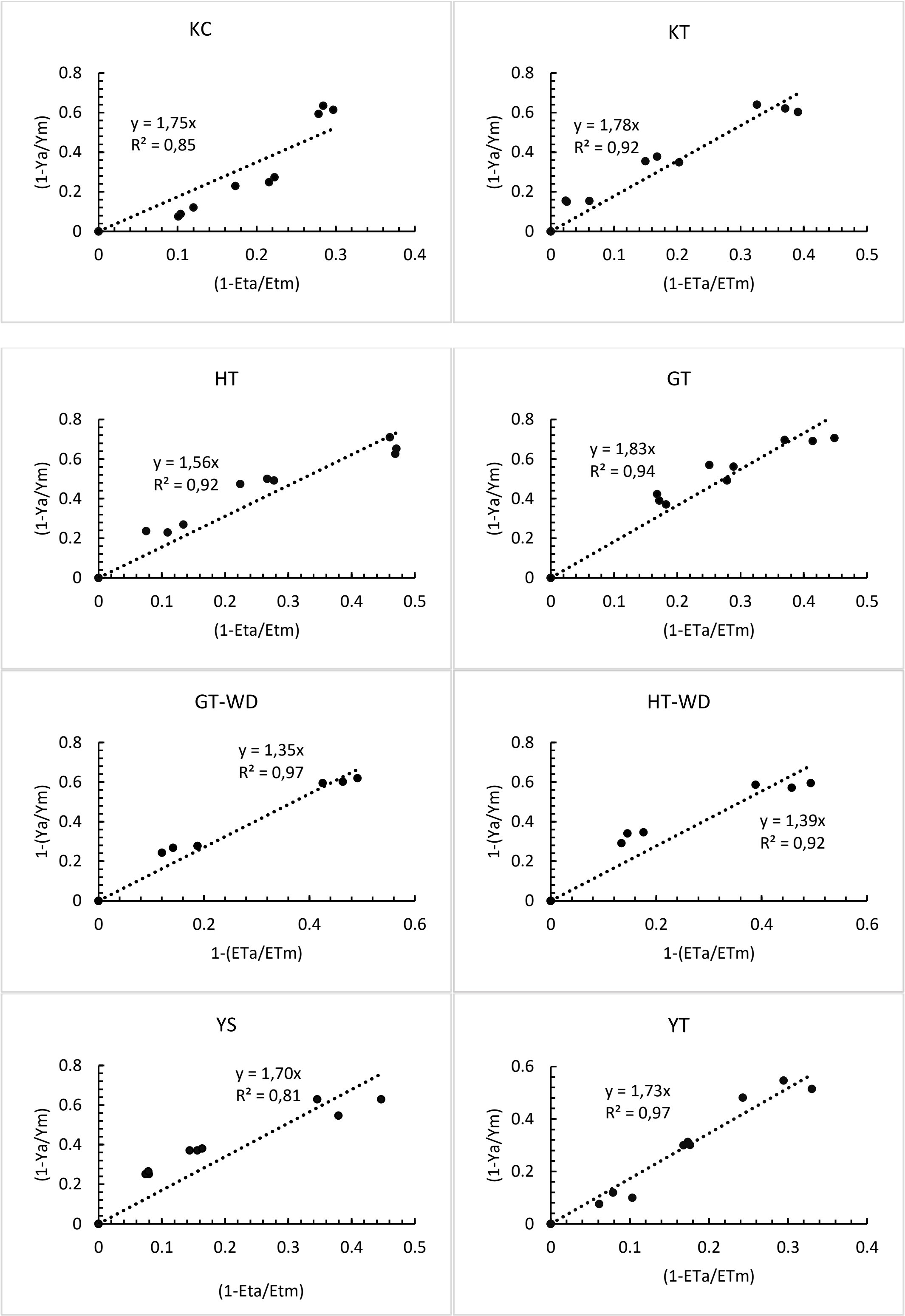
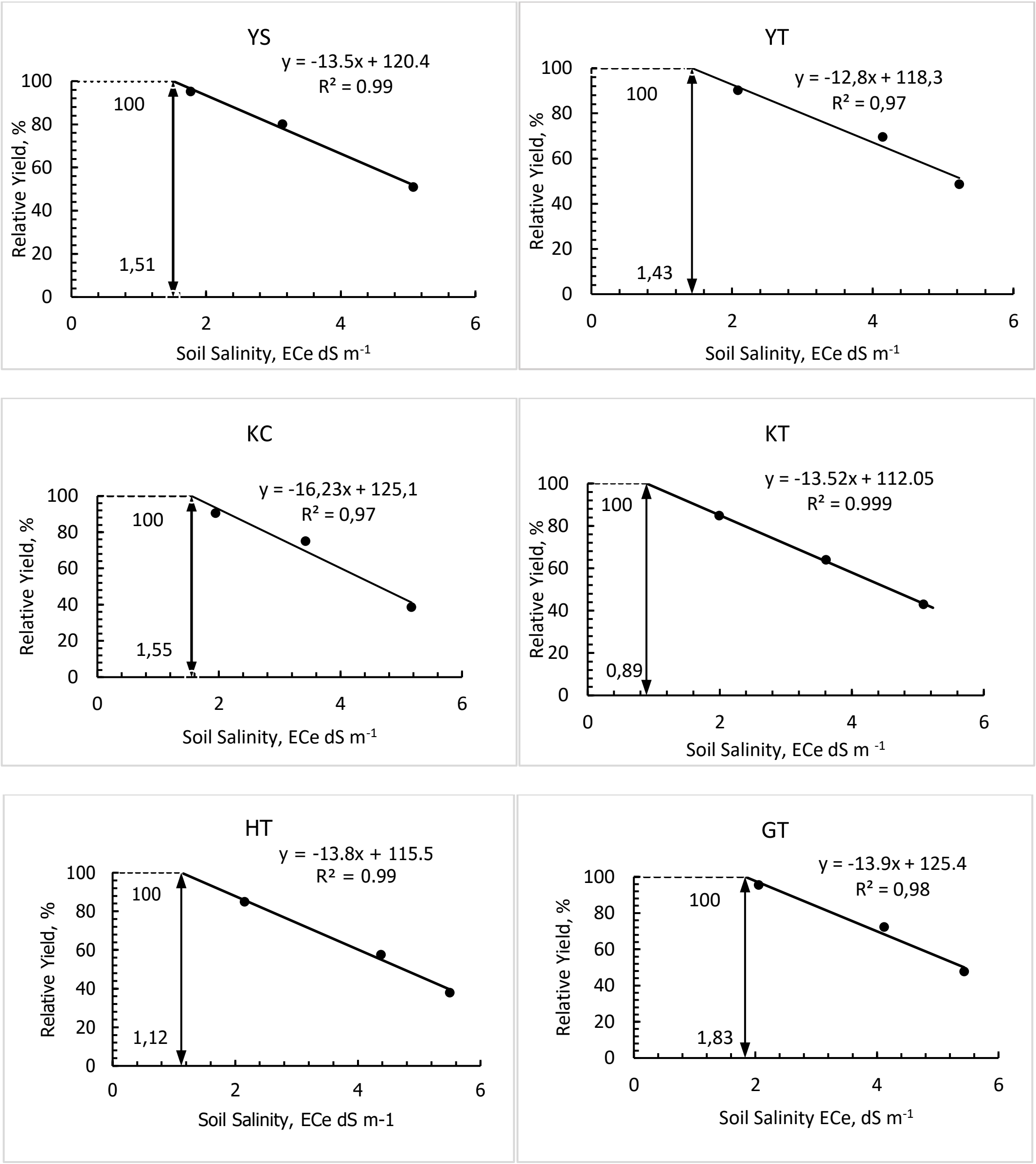
SUPPLEMENTARY



S 1- Yield response functions model for each variety



S 2- Salt tolerance models for each variety