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Sweet Pepper Biomass Production and Partitioning as Affected by Different Shoot and Root-zone Conditions

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Abstract: Three greenhouse experiments on sweet pepper plants were carried out to investigate the effect of manipulating three root zone conditions namely volumetric Water Content (WC), Electrical Conductivity (EC) and minimum root zone temperature independently from each other on biomass production and partitioning of sweet pepper plants. Interactions of WC with fruit load and EC with climate were also investigated. Treatments were in Exp. I, two water content levels, High 80% (HWC) and low 50% (LWC) with an EC 3.0±0.5 mS cm^{-1}; in Exp. II, High EC (HEC) 6.5 mS cm^{-1} and low (LEC) 2.5 mS cm^{-1} both under normal (HET) or suppressed transpiration (LET) and in Exp. III, heated (18°C) or non heated nutrient solution (control). Under treatments of Exp. I, two fruit load treatments, Normal Fruit Load (NFL) and Manipulated Fruit Load (MFL) were applied. Dry matter production was not affected by reducing water content treatments in the root zone. While HEC reduced dry matter production under control condition (HET), manipulation of greenhouse climate (LET) mitigated this negative effect and dry matter production was not different than LEC treatment. In addition, raising nutrient solution minimum temperature increased significantly dry matter production. Total plant fresh weight followed the same pattern of dry matter production. No significant differences were observed in dry matter partitioning as affected by all treatments although there was a tendency for more dry matter partitioned to the stems due to lower fruit number in MFL or high incidence of blossom-end rot in HEC treatment. Partitioning between leaves and stems followed allomatric relationship while partitioning to the fruits seemed to follow the principle of sink strength.

Key words: Sweet pepper, *Capsicum annuum* L., salinity, water content, root zone temperature, biomass production, partitioning, electrical conductivity

INTRODUCTION

The ongoing water scarcity worldwide necessitates the careful use of this resource. Due to a growing competition from other sectors and the rapid increase in population, agriculture will have to do less with fresh water and do more with marginal quality water. Reduction in irrigation regimes and/or using low quality water is some of those options to increase production efficiency. This may lead to unfavorable growth conditions such as temporarily drought and/or salinity build up resulting in reduction in total plant biomass production. Protected cultivation enables for manipulation of growth conditions, root and shoot conditions, which increase production efficiency. Many studies investigated the effect of different irrigation frequencies on the growth and production of field crops[1-4] as well as greenhouse crops[5]. These studies reported negative effect of long irrigation intervals on general plant growth parameters and production. Salinity may also build up in soilless cultivation closed systems as a result of nutrient accumulation and/or of using poor quality water[6,7]. Salinity stress commonly affects negatively plant growth of vegetables such as tomato[8,9] and sweet pepper[10-12]. Bruggink *et al.*[13] mentioned that it should be possible to improve plant growth by adapting the salinity level in relation to the rate of transpiration, thus diminishing water deficits in the plant at high transpiration. The other way round was mentioned to be also possible where tomato crop growth and yield under salinity condition could be improved by manipulating greenhouse climate (transpiration rate)[14-18]. However, there is little known

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about the response of sweet pepper crop grown under different salinity levels to greenhouse climate manipulation[11].

Another option for the grower to improve plant growth is to manipulate root zone temperature. In practice, potential transpiration increases suddenly at sunrise while water uptake may be delayed because of the low nutrient solution temperature since water uptake was reported to be improved by warming up the nutrient solution[19-22]. However, these researchers have used 24 h/day heated nutrient solution. In countries like Egypt or regions like the Mediterranean, daytime temperature is high enough that there is no need to heat the nutrient solution during the day. On the other hand, during nighttime, nutrient solution temperature may drop as a result of a drop of greenhouse air temperature (commonly unheated plastic house). Therefore, heating the nutrient solution during nighttime may be enough.

This study was intended to investigate different approaches of manipulating root zone conditions with or without shoot environment aiming at improving plant biomass production using sweet pepper crop as a test plant.

MATERIALS AND METHODS

Three Experiments I, II and III were carried out using sweet pepper crop (*Capsicum annuum* L.) and each focused on one of the factors in the root environment namely, Water Content (WC), Electrical Conductivity (EC) and minimum Root Zone Temperature (RZT), respectively. Plants in Exp. I and II were grown in Rockwool slabs in controlled climate glasshouses in The Netherlands and in Exp. III plants were grown in Nutrient Film Technique (NFT) in unheated plastichouse in Egypt. Plants in Exp. I and II were trimmed to two first order branches while those in Exp. III were grown un-trimmed as a standard practices in both sites.

Exp. I consisted of two volumetric water content treatments, High (HWC) 80% and Low (LWC) 50%. WC and EC were monitored online by two dielectric water content sensors. Irrigation was triggered by signals from the sensors. EC in the two treatments was kept at 3.0±0.5 mS cm^{-1} by switching the irrigation automatically from nutrient solution with EC 3.0 mS cm^{-1} to a nutrient solution with EC 1.0 mS cm^{-1} whenever the EC in the root zone was above 3.0 mS cm^{-1}.

Exp. II consisted of two EC levels in the root zone namely High EC (HEC) 6.5 mS cm^{-1} and Low EC (LEC) 2.5 mS cm^{-1} and both were under two different greenhouse climates. First greenhouse was controlled according to the standard Dutch practice and used as control (HET) and the second greenhouse (LET) was set to 25% less ventilation opening compared to the control to have lower Vapor Pressure Deficit (VPD). In addition, if necessary, humidication was applied in the second greenhouse to suppress transpiration not to exceed 0.15 l $plant^{-1}$ h^{-1}.

Exp. III consisted of two treatments, unheated nutrient solution (control) and heated nutrient solution by setting minimum nutrient solution temperature to 18°C.

In addition, for the interest of studying the interactive effect of sink strength with water content in the root zone on dry matter production and partitioning, Exp I included two fruit manipulation treatments. Manipulated Fruit Load (MFL) by allowing only two flowers per plant per week to develop to fruits and Normal Fruit Load (NFL) by allowing all possible flowers to set and develop to fruits. Both of the two fruit treatments were under the two water treatments.

Crop measurements: In Exp. I, fresh and dry weights of all plant organs were measured in destructed samples which were carried out once a month for NFL and every two months for MFL treatment. Two plants per replicate were taken out in every sample (6 plants per treatment). Plants next to destructed samples were not included in any measurements. In Exp. II destructed samples were taken every two weeks starting from the generative stage and each consisted of three plants for each treatment for determining dry matter production. Destructed samples were taken once a month in Exp. III.

Exp. I and II were arranged in a split plot design with climate treatment as main plot and EC as the sub-main in Exp I meanwhile, Water content in the root as main plot and fruit load treatment as sub-main. Exp. III was arranged in a Complete Randomized Block Design.

RESULTS

Total plant fresh weight was slightly higher only during the warm periods in HWC and this resulted in 6% difference between the two water treatments (Fig. 1A). On the other hand, total plant fresh weight was significantly reduced by HET-HEC in the time that LET-HEC had the same fresh weight when compared to LEC under the two climate conditions (Fig. 1B). Total plant fresh weight increased also by heating up the nutrient solution (Fig. 1C).

There was a minor difference between the treatments of water content concerning total plant dry matter production (Fig. 2A). Meanwhile, total plant dry weight was significantly reduced by HET-HEC. LET-HEC had almost the same dry matter production compared to LEC

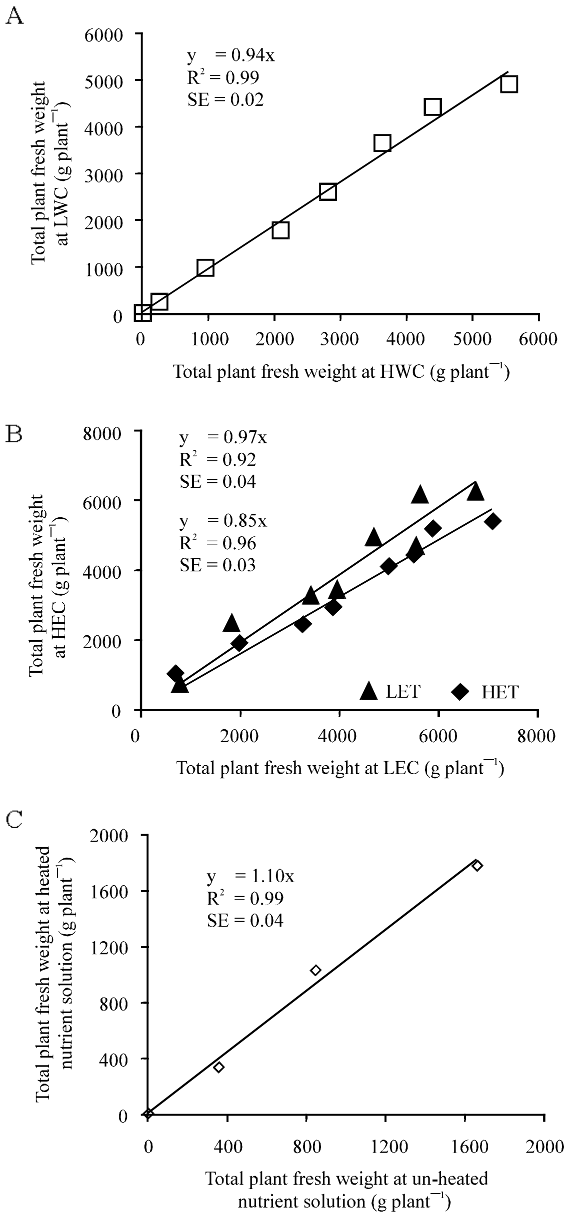

Fig. 1: Total plant fresh weight (g $plant^{-1}$) of sweet pepper plants grown in Low Water Content (LWC) versus High Water Content (HWC) in the root zone (A), High EC (HEC) versus Low EC (LEC) nutrient solution under the two climate conditions low transpiration (LET) and High transpiration (HET)(B) and heated nutrient solution versus un heated nutrient solution (C)

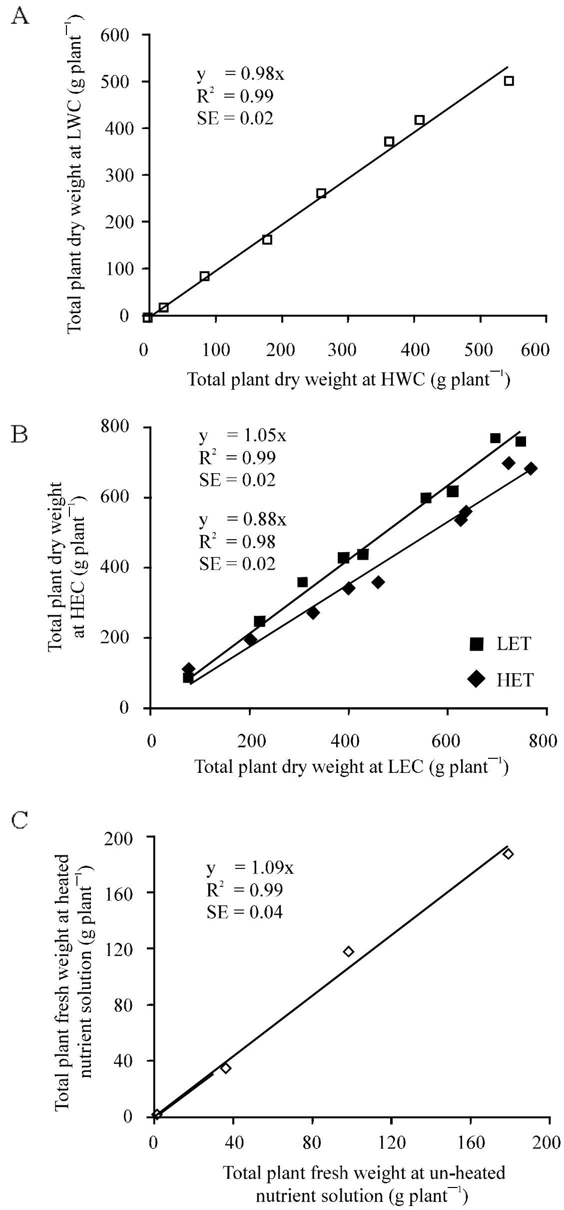

Fig. 2: Total plant dry weight (g $plant^{-1}$) of sweet pepper plants grown in Low Water Content (LWC) versus High Water Content (HWC) in the root zone (A), High EC (HEC) versus Low EC (LEC) nutrient solution under the two climate conditions low transpiration (LET) and High transpiration (HET)(B) and heated nutrient solution versus un heated nutrient solution (C)

(Fig. 2B). It was clear that dry matter production responded positively to the heating treatment (Fig. 2C).

In order to analyze how the reduction in dry matter production by HET-HEC was brought about, a validated

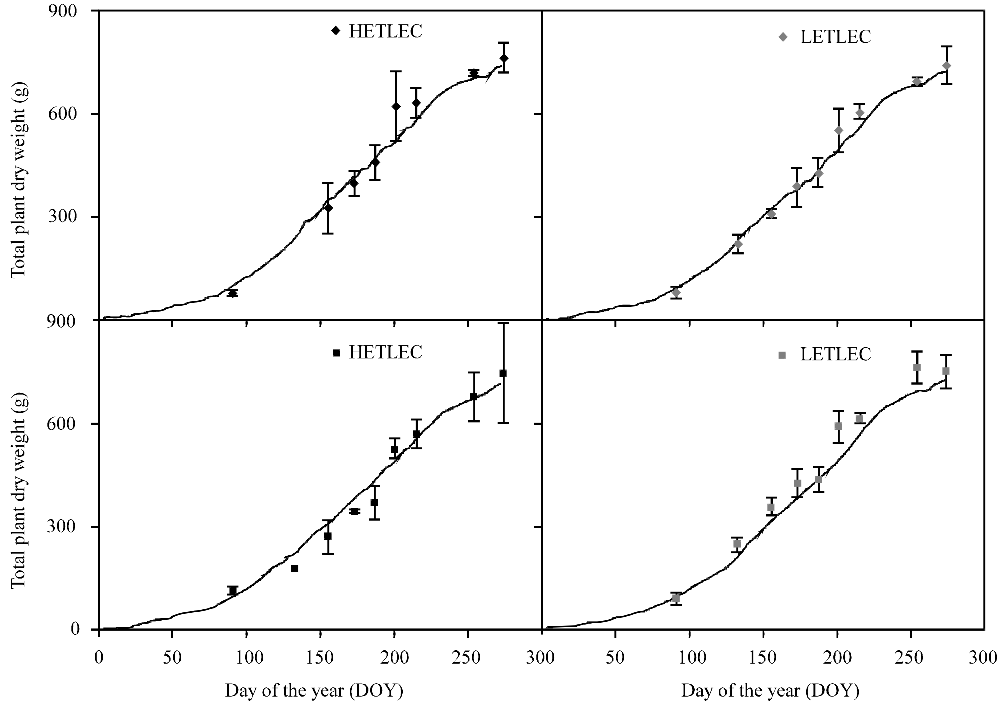

Fig. 3: Actual (symbols) and simulated (lines) total plant dry matter production (g plant^{-1}) of sweet pepper plants grown under the four combinations of EC levels and climate conditions. Error bars are twice standard error

Table 1: Dry matter of different plant organs (fraction of total plant dry weight) of sweet pepper plants under different root and shoot conditions

Experiment No.	Treatments	Leaves	Stems	Fruits
I	HWC-MFL	15.70	30.59	53.71
	HWC-NFL	14.18	27.24	58.58
	LWC-MFL	13.54	26.83	59.62
	LWC-NFL	12.54	25.85	61.25
LSD 5%		N.S	N.S	N.S
II	HET-LEC	11.19ab	21.87	66.9
	HET-HEC	11.39ab	22.40	66.2
	LET-LEC	9.44b	19.33	71.2
	LET-HEC	12.82a	20.99	66.2
LSD 5%		2.93	N.S	N.S
III	Heated nutrient solution	15.84	20.75	63.41
	Un-heated nutrient solution	20.1	25.63	55.27
LSD 5%		N.S.	N.S.	N.S.

NS = non significant

explanatory crop growth model developed by Gijzen[23] was used. Simulation results show that the model can predict plant dry matter production very well under different conditions (Fig. 3). There were also some differences among the treatments in their simulation results. These differences among the treatments were brought about mainly by differences in Leaf Area Index (LAI). LAI was introduced as an input in the model. The smaller LAI in HET-HEC was the main reason for the lowest dry matter production by the crop. As there was no provision in the model for the effect of EC, resulting differences in calculated production were caused by differences in climate and LAI. Within a greenhouse, (high and low EC) differences can only come from LAI. Modeled differences were slightly smaller than real ones (about 5%). Hence, some other effect (stomatal conductance) plays a role. Indeed a sensitivity analysis of the model revealed that a reduction of 15% in maximum stomatal conductance (g_{max}) may result in the 5% remaining of the observed reduction in total dry matter production.

Dry matter partitioning: Dry Matter (DM) partitioning to the fruits was the highest fraction and averaged more than 60% in all experiments meanwhile leaves had the lowest fraction of plant dry weight (Table 1). Although differences in partitioning to different parts were non significant almost in all treatments, plants under HEC had a tendency for higher dry matter partitioning to the stems compared to plants under LEC treatments. Similarly, plants with Manipulated Fruit Load (MFL) tended to partition more assimilates to the stems compared to NFL plants. However, the partitioning relationship between leaves and stems was linear all the time for all the treatments in all experiments (Fig. 4).

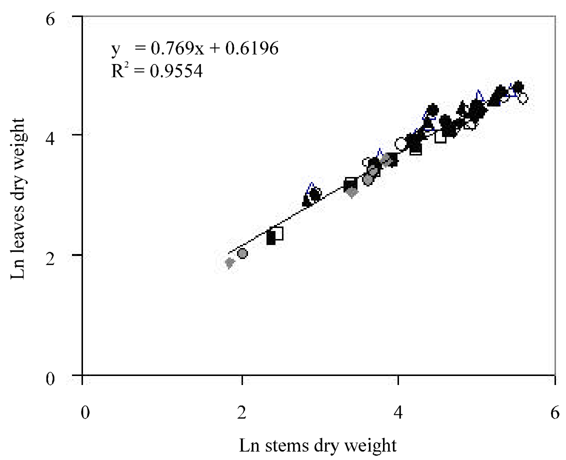

Fig. 4: Relationship between dry weights of leaves and stems (transformed to natural logarithm) for all treatments in all experiments. Triangles are low EC and circles are high EC, blank is high transpiration and black is low transpiration. Squares are normal fruit load and diamonds are manipulated fruit load, blank is low water content and black is high water content. Gray circles are heated nutrient solution and gray diamonds are unheated nutrient solution

DISCUSSION

The non significant difference in dry matter production under water content treatments in the root environment can be explained on the basis that plants were not under any degree of water stress. As yield is the main fraction of biomass production and it was not affected by the treatments[24], difference in total plant dry weight was not expected. In addition, it was reported that if the canopy is already complete, mild water stress should have little or no effect on biomass production rate[25]. On the other hand, under different EC conditions, the improvement in plant total dry matter production under LET-HEC compared to HET-HEC maybe due to the improvement in plant water relations which reflected on net photosynthesis. With severe water stress, stomatal opening and photosynthesis per unit leaf area are reduced[25]. Plant growth and production is a function of the relationship between dry matter production (photosynthesis) and water content (related to water uptake and transpiration) in plant tissue[26,27]. The two components of this relationship, dry matter and water, are interdependent[28] and very much affected by conditions during growth such as solar radiation and EC in the root zone (or the irrigation water). Reduction in plant dry matter production has been reported to be caused by high EC in the root zone[10-12,29]. This reduction was also noticed in the data of this study. However, as with other crops such as tomato[14,16-18], reducing vapor pressure deficit of the greenhouse resulted in mitigating the negative effect of HEC. Since VPD of the greenhouse and EC of the root zone affect the same state variable of plant water status, this mitigation is brought about by improving plant water relations. Zabri *et al.*[11] mentioned that leaf conductance and area were the causes of the reduction in dry matter production caused by HEC. The data of this study show that both of these two parameters are affected by the imposed conditions (HEC and VPD). However, the main accurate measurable factor that was more affected is leaf area. The small reduction in g_{max} calculated by the sensitivity analysis of the model show that actual stomatal conductance is even smaller to be measured with a fair degree of accuracy by any current existing devices. Prediction of leaf area development is still a weak feature of crop growth models[30] and that is the reason for giving it as an input to crop growth models as in many other studies[31,32].

Dry matter production was also improved by heating the nutrient solution. This was reported earlier for many crops[33] as well as for pepper[34]. The latter explained this increment based on a higher photosynthesis. Under the same greenhouse conditions, photosynthesis is a function of leaf area and stomatal conductance. Leaf area was found to be higher under the heating treatment in this study. In addition, data in literature indicate that stomatal conductance increased when root zone temperature increased[35].

Partitioning between leaves and stems follows always an allometric relationship[36]. The latter found the allometric relationship to be constant under different shoot conditions of temperature and plant densities. The same was also observed here under all the experimental treatments of root zone environment. On the other hand, partitioning to the fruits always follows sink strength of generative parts[31,36,37]. The sink strength of generative parts depends on number of fruits and sink strength of each fruit. The sink strength of individual fruit depending mainly on age and temperature[36]. Since EC may affect both the number of growing fruits on the plant and the incidence of BER, sink strength may also be affected by EC. This may or may not, depending on the degree of EC effect, influence dry matter partitioning. EC does not affect DM partitioning in tomato with exception of very high level of EC (EC= 17 mS cm^{-1})[38] and this is what have been observed also in sweet pepper during this work. The tendency for more allocation of dry matter to the stems in HEC and MFL treatments can be due to the lower fruit sink strength, compared to that observed in the LEC and

NFL treatments, respectively. Indeed higher partitioning to the stems with the lower number of fruits has been observed in earlier study[39].

CONCLUSIONS

It can be concluded that total dry matter production is not affected by reducing water content in the root zone to 50% if the water potential can be controlled. Under conditions of over-abundant supply of water, effect of changing the EC in the root zone does not appear until a threshold of transpiration is reached. Limiting the minimum nutrient solution temperature from falling below a certain degree, has a positive advantage on plant fresh and dry matter production. Root zone conditions do not seem to have a direct effect on dry matter partitioning. The effect of root environment on dry matter partitioning may come through the effect on fruit sink strength.

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