Effect of Water Stress on Sweet Pepper (*Capsicum annuum* L.) Yield

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Abstract
Sweet pepper (*Capsicum annuum* L.) plants were grown using split-roots technique under water stress levels viz. normal (N), mild (MS) and severe stress (SS) in glasshouse at Nottingham University under daily mean temperature of 25°C. This investigation was concerned with examining the effect of water stress on vegetative canopy without any reduction in yield. Water stress was achieved by means of soil moisture sensor; alternatively by maintaining one root fully irrigated and the other root stressed until soil moisture, 0.40-0.50 m³.m⁻³, 0.30-0.40 m³.m⁻³, 0.20-0.25 m³.m⁻³ are reached for N, MS, SS respectively. In general, over all plant sizes in terms of vegetative growth such as shoot, leaf and stem fresh and dry weight showed highly significant differences (P<0.001) among treatments with reduction in water stress. The fruit fresh weight was not significantly reduced by water stress. Also, fruits dry matter percentage was not significant. Water stress usually plays important role in determining fruit size and its development. Additionally, high incidence of blossom-end rot (BER) was found associated reduction in water stress level.

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1. Introduction

Sweet pepper is classified as *Capsicum annuum* L. known commonly as bell pepper and belongs to the Solanaceae family. It is a biennial that is cultivated as annual herb that grows over 1 meter in height. Sweet pepper is an important economics horticulture species and has a vast number of varieties and. The crop requires warmth temperature, sunny days, humidity and humus rich soil to optimise the quality of fruits used spice. It is considered one of the major pepper species and vegetables crops grown in the world. It can be eaten as raw and cooked, both immature and mature. Sweet peppers are very good sources of vitamin C, A and Calcium (Monselise, 1986). Pepper is originated in Mexico and neighbouring area of Central America. Water stress commonly reduces growth and photosynthesis. However, water stressed plants often accumulate organic solutes and maintenance of these may require increasing respiratory activity. The organic solutes and other molecules maybe used as osmoregulatory compounds that would be actively compartmentalised, perhaps at considerable expense to plant growth. Plant water potential is a measure of water stress which may be complicated by changes in the component potentials (osmotic and turgor) and by changes in crop physiology (Jones H.G., Tardieu F., 1998).

Osmotic potential under stress leads to maintenance of turgor at lower water potential providing mechanism whereby plant adapt to water stress conditions. A split roots system has been developed to study the effect of water stress signals from the roots on growth at normal water status (Simonneu and Habib, 1994). The root subjected to water stress can result in massive accumulation of abscisic acid (ABA) (Davies, et al., 1994), which is considered to be the chemical which is most likely involved in root-to-shoot signalling. ABA plays a significant role in regulating vegetative growth (leaf and shoot) because the reduction in leaf area leads to reduction in photosynthesis. A spilt root technique has been employed in Australia to
control the vegetative growth of grape; the aim was reduction in use of resources such as water, land and labour. Surprisingly, this technique did not affect the yield but improve the quality. (Dry et al., 1995) and Fuller, 1997) described the results from experiments where grape vine vigour was substantially reduced without any yield penalty under split root drying, and at the same time efficiency of water use and quality of fruits significantly improved.

This investigation has the following hypothesis: “By Stressing one part of the root system and maintaining the other part unstressed, the vegetative growth will be reduced without any remarkable reduction in fruit yield”.

The stress signals are expected to reduce vegetative growth. Therefore, this work was investigated and evaluated under the context of the effects of three levels of water stress on sweet peppers (Capsicum annuum L.) by means of split root technique on growth parameters (shooting, leaf and stem fresh and dry weight) to find how this correlation between drought and yield results.

2. Literature Review

There are five domesticated species that belong to capsicum genus, which are Capsicum annuum var. annuum, Capsicum baccatum var pendulum, Capsicum pubescens, Capsicum chinense and Capsicum frutescens (Monslise, 1986). Peppers are dicotyledonous and tropical perennials usually grown as annual crops. Peppers are erect growing; the branch height is between 0.5-1.5m (Rubatzky et al., 1997). Generally, the leaves of pepper have different sizes, shapes and colours depending on genotypes. They are simple, entire and symmetrical. Pepper is self-pollinated although out crossings can occur. Pepper is berry with short thick peduncle, which varies in shape colour and pungency.

Pepper is a warm season crop that requires about the same growing condition of tomatoes; high yield and good quality fruits are produced in long frost free season. The optimum temperature for pepper growing is between 16-32°C as fruit set does not occur if the mean temperature is below 16°C or above 32°C (Bosland and Votava, 1999). Pepper grows well in a well-drained, medium sand or loamy deep soil, having pH of 7-8.5, that holds moisture and has some organic matter. Irrigation is essential for pepper production, particularly during growing season. Peppers are known to be sensitive to moisture stress at flowering and fruit set. In addition, they are reports that Blossom-End Rot (BER) could result when plants are stressed at a time when young fruits are developing rapidly.

Water stressed plants generally produce pungent pods. Water stress results from withholding of water supply and it leads directly to changes in the physical environment of the crop and these changes may subsequently affect crop physiology. As growing medium is dried, its water potential decreases and so does its hydraulic conductivity. Therefore, it is more difficult for plants to absorb water and consequently the plant water potential tends to decreases which may directly affect the physical aspects of some physiological process such as turgor pressure in the cells which plays a very important role in the process of leaf expansion (Johnson, 1981). Loss of turgor can cause leaves to wilt and subsequently decreases light interception and reduces photosynthesis rate. However, under this condition it is likely that stomatal closure will have a greater effect upon photosynthetic rate than wilting. Decreases in leaf expansion and stomatal closure restrict photosynthesis and also slow down dry matter accumulation. This reduction in assimilate supply may affect many physiological processes including the differentiation and expansion of new tissue.

2.1. Water stress on plant growth

Water stress affects practically every aspect of vegetative growth, modifying anatomy, morphology, physiology and biochemistry. In general, moderate water stress inhibits vegetative growth particularly leaf expansion (Turner and Begg, 1981). Leaf area; cell size and intercellular volume are usually decreased (Sobrado and Tuner, 1986). Cutinisation, hairiness, vein density, stomatal frequency and thickness of entire leaves are usually increased (Kramer, 1983). Decrease in leaf area resulting from water stress has an effect on light interception and photosynthesis. Water stress also leads to reduction in closure of stomata (gas exchange), which reduces the dry matter and hence reduction in activity of the protoplasmic machinery (Hale and Orcutt, 1987). Leaves under stress often show a decrease in starch content, which is usually accompanied by increase in sugar content. Also, water stress causes considerable hydrolysis of protein and is accompanied by increase in amino acids.

2.2. Split root system

When water is withheld from the plant it produces abscisic acid (ABA) in its roots, which is transported to leaves. The surface of a well-watered leaf contains stomata through which plant takes up the gases it needs for photosynthesis and loses water to atmosphere. Wilkinson and Davies (1999) found that during drought the ABA sent to the leaves by the roots induces a reduction in pore aperture so that the plant retains more water and it remains turgid and functional despite the lack of water at the roots. Additionally, ABA in the leaves...
and shoots reduces their growth (Davies and Zhang, 1991). It is very difficult to control the point at which the soil is dry enough to cause the production of enough ABA/root singles to close stomata and reduce growth at which the plant is still receiving enough water to maintain the turgidity of its shoots. Wilting plants grow too slowly for commercial viability and produce unsightly lesions, or even die.

The "split-root system" is used to reduce plant water requirements without affecting shoot turgidity. The roots of the plant can be divided into two either in two separate pots or bags or in a pot containing a plastic barrier between the halves of soil. Only one half of the soil is watered while the other is left to dry. The roots in the drying side produce the chemical signals required to close stomata and reduce water loss, which can also reduce leaf and stem growth (Wilkinson and Davies, 1999). Roots in the wet side take up enough water to keep the plant turgid. This technique breaks the link between water stress (soil drying) and restriction of water supply to shoots. For instance, one of the split roots techniques involves pressuring the roots of the intact plants to counterbalance the declining water potential of the soil as it dries (Davies et al., 1994). This technique will sustain shoot water relationships of drought plants in the state comparable with those of well-watered plants but despite this, growth and stomatal conductance of the plant with roots in the drying soil are still restricted. Split root signals reduce the stomatal conductance, leaf gas exchange and suppressed leaf expansion (Davies and Zhang, 1991) and this reflects on the final net photosynthesis rate.

Several investigations have used split root systems in different crops. For example, growing grapevines for wine with split root system results in reduction of transpiration and vegetative growth with no yield penalty (Fuller, 1997). Also, Shaozhong et al. (1998) found that by growing maize with split root system, there was great improvement in water use efficiency and production of comparable biomass yield with those under well water controls.

ABA is well known to accumulate to high concentration in plant tissues experiencing water deficit. This has led to much speculation that ABA is involved in the regulation of growth at lower water potentials (Davis, et al., 1986). The work of Zhang et al., (1990) demonstrates that ABA plays a significant role in the root to shoot communication of effects of soil drying. They illustrated that the root system can sense soil drying effectively by producing signals such as shoot physiology (Davies and Zhang, 1991). These signals are chemical in nature and are mainly involved in elevating ABA concentration in the xylem (Zhang and Davis, 1991; Khalil and Grace, 1993). Therefore, plants can save water by reducing vegetative growth.

3. Materials and Methodology

Experiment was carried out at Nottingham University, Sutton Bonington Campus, Loughborough, UK. The name of the cultivar used in this experiment was CUZCO (F1 Hybrid). The 24 days old uniform seedlings of sweet pepper were picked out individually and transplanted to grow into 10cm diameter plastic pots containing pot and bedding compost, which is used for potting and growing on bedding medium term pot plant throughout the year. The average temperature in the glasshouse was 22.6°C, the plants were usually under natural lighting condition. The seedlings were immediately irrigated by basic solution (Table 1). Twenty-four days later when the third of the true leaves were about 1cm long (Plate 1), the seedlings were transplanted into polythene plastic bags (28cm X 26cm). The bags filled with pot and bedding compost and roots were divided into two bags as split system (Plate 2). After that plants were arranged in the glasshouse at daily main temperature of 25°C.

<table>
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<tr>
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The experiment was laid randomised block design with the glasshouse compartment. There were three blocks and three treatments of water stress viz. normal, mild and severe. The experiment examined the effects of three levels of water stress on sweet pepper (Capsicum annuum) in terms of fruit production by using split root system. These treatments were normal stress (NS), control =0.4 – 0.50 m³.m⁻¹, mild stress (MS) = 0.30 -0.40 m³.m⁻¹ and sever stress (SS)= 0.20 - 0.25 m³.m⁻¹. After 80% of plants attained to flowering, the treatments were imposed.
All the plants in split root system were irrigated until same level of moisture (normal). The plants belonged NS were maintained to be in this level of moisture for both roots during the experiments while treatments were kept with one half of the roots at normal moisture and dried the other until 0.30 -0.40 m$^3$.m$^{-3}$ for MS treatment and 0.20 - 0.25 m$^3$.m$^{-3}$ for SS treatment. This method was repeated continually until the end of the experiment (53 days after treatments). The two flowers were allowed to develop fruits in each plant and remove the rest of them continually during the experiment. Our target was one fruit, therefore, the first fruit developed for each plant and treatment was marked and noted their development every 5 days in terms of size (length and diameter). Simultaneously, the second fruit was noted for its development as a standby to the first in the event of any loss to the first target fruit.

The theta probe (soil moisture sensor, type ML2x Delta-Devices, Ltd) measures volumetric soil moisture content ($\theta$) which is the ratio between the volume of water present and the total volume of the sample. This is a dimensionless parameter, expressed either as a percentage (% vol.) or a ratio (m$^3$.m$^{-3}$). Thus 0.0 m$^3$.m$^{-3}$ corresponds to a completely dry soil and water gives a reading of 1.0 m$^3$.m$^{-3}$. The moisture was measured daily by Theta Probe. This measurement gives an indication of the level of water stress in each partial root separately. In addition, according to this measurement it can be determined when, which plant (only one half of the roots) and how many times it should be irrigated.

### 3.1. Water stress practice

The roots of each plant are divided into two separate plastic bags with a barrier between the two halves of medium. Only one half of the medium is watered (basic solution) to a normal level (i.e. no water stress), whilst the other is left to dry until it reach those levels of stress the dry half is irrigated until the normal levels.

### 3.2. Growth measurement

Periodic non-destructive measurements were carried out on the same plants to monitor the effect of the treatment on shoots, leaf number and fruit (length and diameter). Also, destructive analyses were carried out at the end of the experiment to find out any possible correlation between the treatments and plant parameters in terms of fresh and dry weight of roots (in addition to volume), shoots, leaves and fruits.

Cyclic non-destructive measurements were carried out on the same plants to monitor the effect of the water stress levels on the vegetative parameters. The shoot height and leaf number were measured every three weeks since plants were transplanted. In addition, fruit development in terms of length and diameter was measured every five days after fruit become greater than 1cm in length.

Number of leaves on the plant which were longer than 1cm were counted and totalled to determine effects on leaf initiation. Also, shoot height was recorded as the distance between the cotyledon and the apex for all the plants regularly every three weeks. Fruit expansion in terms of length and diameter was measured weekly by means of electronic callipers.

Destructive sampling, vegetative and reproductive parameters were measured and analysed to illustrate whether any significant relationship existed between these parameters and treatments. Plants were partitioned into leaves, stems and fruits. The leaf number, total leaf area meter (Delta T Devies) and shoot height were recorded. Also, fresh weight for both leaves and shoots and fruits were taken and dried in the oven for 48h at 82°C to measure moisture % and dry matter weights.

The experiment was arranged as randomised block design. Statistical analysis of variance was carried out to examine any interaction between treatments in respect of vegetative and productive development.

### 4. Results and Discussion

The objective of this study was to investigate the effects of three levels of water stress N, MS and SS on sweet pepper (Capsicum annuum L.). Stress was applied by means of a split root technique. Vegetative growth and fruit yield in terms of fresh and dry weight were determined. Therefore it aims to find how the split-root technique correlates with drought and vegetative and yield results. Thus, by stressing one part of the root system and maintaining the other part unstressed, the vegetative growth will be reduced without any remarkable reduction in fruit yield.

It is well known that water deficits can reduce the number of growing points and hence the leaves produced. For instance Steinberg, et al., (1990) noted that production of a new growing points in peach was rapidly reduced by water deficit and completely stopped under watering regime of 25% of the control.

The finding of this experiment show that leaf growth and final leaf number were more severely reduced by water stress. It was clear among all of the treatments. On the other hand, the leaf number was significantly reduced in severe stress treatment.
at 42 (P<0.05), 63 (P<0.05) and 75 (P=0.01) days after treatment.

**Figure 1:** The effect of water stress on peppers vegetative growth

Leaf growth was severely reduced with increasing water deficit (Metcalfe, et al., 1990), which was slower along with drying soil even when leaf turgor was maintained by use of split root system. The water supplied below the actual need results in leaf number per plant being much smaller for dry treatment than the wet treatment. This is due to plant adoption so stressed condition.

This investigation found that leaf area was particularly affected by water stress i.e. severe stress that was a much lower than other treatments, which was in agreement with other studies. For instance, leaf growth is very sensitive to water stress, particularly leaf expansion, which if affected can affect leaf area by the senescence and death of leaves during all phases of growth. Severe stressed treatments decreased leaf expansion which in turn limits the develop of transpiration surface during water stress. This modification relates to hormones in the plant such as ABA (Davies and Zhang, 1991). Recently, it has been widely accepted that roots in drying soil produces chemical signals moving from the roots to shoots to regulate physiology and development such as restricted leaf expansion and reduced stomatal conductance (Davies et al., 1994; Peter, 1997; Shoazhong et al., 1998). It appears that water stress inhibits vegetative growth particularly leaf expansion (Turner and Begg, 1981) and subsequence leaf area which results in reduction of cell size and intercellular volume (Sobrado and Tuner, 1986).

Fresh weights of both leaf and stem were significantly different between the three treatments (P<0.01). Fresh weight was found decreased considerably with increasing water stress. Also increasing water stress markedly reduced shoot height. The differences in shoot height between the three treatments become most notable 75 days after treatment application in giving highly significant differences (p<0.001) in the final shoot height per plant between treatments. This data indicates that the performance of sweet pepper is likely to better under irrigated treatment condition than under water stress condition. Obviously, an increase in plant size is associated with increase in plant weight.

Availability of water increases leaf and stem expansion you due to increase in cell growth. There is an immediate effect on cell expansion due to inadequate turgor pressure to maintain the growth of cell wall when plants are subjected to water stress. Rudich and Luchinsky (1986) demonstrated the plant mechanism that develop the capacity for plastic stretching. They also explained that turgor pressure presents the “physical driving force” which brings about an irreversible growth of the cell by means of hydrostatic pressure applied to the primary wall. Additionally, decrease in plant water potential was found to be associated with a decline of turgor. A decrease in the osmotic potential of the cell, which is fundamental for turgor, take place later during water stress and results in inhibition of enlargement and final growth.

Dry weight of both leaf and stem were also significantly different between three treatments (P<0.01). Day (1981) pointed that while reducing the area of the photosynthesis tissue, water stress also affects the process of the photosynthesis itself. Water stress limits photosynthesis in tomato mainly by increasing resistance to gas through the stomata, which close to reduce transpiration under stress condition. The rate of the leaf photosynthesis is limited by the rate at which it can assimilate CO₂ from the atmosphere and reduce it to carbohydrates (Azam-Ali et al., 1993). Evidence that carbon dioxide is a limiting resource for crop production is indicated by studies on effects on elevated carbon dioxide concentration in dry matter formation (Kimbell, 1983). Our results among the treatments showed the relationship between shoot dry weight and leaf area. For all treatments, there were positive relationships between the increase in leaf area and stem dry weight per plant. On other word, the increase in leaf area leads to increase in dry weight per plant.

Salter (1958) noted that neither water stress nor fruit load in tomato appeared to influence the growth rate of individual fruits during the growth period; however, the fruit size is reduced by water stress, which is a result of a shorter fruit growth period. Water stress affects the timing and amplitude of fruit diameter fluctuations (Chongren et. al., 2000). Much data is available to substantiate the fact that the fruit yield as well as size of the crop grown under water stress condition are
There was no significant treatment effect on fruit weight, length or diameter (Fig. 2). This result was supported by Petter (1997) who reported that grapes can achieve more fruits per liter of water applied using partial drought with split root system and no reduction in yield. The outcome of this investigation showed that there was a positive relationship between leaf area and fruit fresh weight.

**Figure 2: The effect of water stress on peppers fruit**

Increasing water stress markedly reduced shoot height. The differences in shoot height between the treatments become more notable 75 days after treatments application and gave highly significant differences (P<0.01) in the final shoot height/plant. Also, there was a substantial difference in both fresh and dry weight of stem in reaction to the water stress levels, which was highly significant (P<0.01). Normal stress gave the highest fresh and dry weights followed by MS and SS in sequence. The highest stem dry matter percentage was produced at SS treatment followed by MS and NS that accounted for 21.4%, 20.03% and 19.2%, respectively. These differences were significant at (P<0.05).

The fruit fresh weight was not significantly reduced by water stress. Also, fruits dry matter percentage was not significant. Water stress usually plays important role in determining fruit size and its development.

**References**


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