Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 117 No. 1 (2016) 45–56

urn:nbn:de:hebis:34-2016010549546 ISSN: 2363-6033 (online); 1612-9830 (print) – website: www.jarts.info

Effects of shoot pruning and inflorescence thinning on plant growth, yield and fruit quality of greenhouse tomatoes in a tropical climate

Johannes F. J. Max [a,∗], Lilian Schmidt [b], Urbanus N. Mutwiwa [c], Katrin Kahlen [b]

[a] *Institute for Plant Nutrition, Leibniz University Hannover, Hannover, Germany*
[b] *Center of Viticulture & Horticulture, Department of Vegetable Crops, Geisenheim University, Geisenheim, Germany*
[c] *Biosystems and Horticultural Engineering Section, Institute for Biological Production Systems, Leibniz University Hannover, Hannover, Germany (Present affiliation: Biomechanical and Environmental Engineering Department, College of Engineering and Technology, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya)*

Abstract

The combined effects of shoot pruning (one or two stems) and inflorescence thinning (five or ten flowers per inflorescence) on greenhouse tomato yield and fruit quality were studied during the dry season (DS) and rainy season (RS) in Central Thailand. Poor fruit set, development of undersized (mostly parthenocarpic) fruits, as well as the physiological disorders blossom-end rot (BER) and fruit cracking (FC) turned out to be the prevailing causes deteriorating fruit yield and quality. The proportion of marketable fruits was less than 10 % in the RS and around 65 % in the DS. In both seasons, total yield was significantly increased when plants were cultivated with two stems, resulting in higher marketable yields only in the DS. While the fraction of undersized fruits was increased in both seasons when plants were grown with a secondary stem, the proportions of BER and FC were significantly reduced. Restricting the number of flowers per inflorescence invariably resulted in reduced total yield. However, in neither season did fruit load considerably affect quantity or proportion of the marketable yield fraction. Inflorescence thinning tended to promote BER and FC, an effect which was only significant for BER in the RS. In conclusion, for greenhouse tomato production under climate conditions as they are prevalent in Central Thailand, the cultivation with two stems appears to be highly recommendable whereas the measures to control fruit load tested in this study did not proof to be advisable.

Keywords: assimilate partitioning, blossom-end rot, fruit cracking, fruit load, heat stress, *Solanum lycopersicum* L., source-sink relationship, Thailand

---

Abbreviations:

BER:	blossom-end rot
cv:	cultivar
DS:	dry season
FC:	fruit cracking
GH:	greenhouse
PE:	polyethylene
RS:	rainy season
VPD:	vapour pressure deficit
WAT:	weeks after transplanting

1 Introduction

Tomato (*Solanum lycopersicum* L.) is the most widely grown vegetable crop in the world (FAOSTAT, 2015). Mainly due to temporarily unfavourable climatic conditions (Kleinhenz *et al.*, 2006; Max & Horst, 2009), high insect pest infestation pressure and associated vectored plant viruses (Nguyen *et al.*, 2009; Maboko *et al.*, 2011), and fungal diseases (Heine *et al.*, 2011) tomato fruit yield is generally much lower in tropical lowlands as compared to temperate climates (Muhammad & Singh, 2007; Max *et al.*, 2009). Among abiotic stressors, heat stress has been identified as a major factor limiting the productivity of tomato crops in tropical and

---

[∗] Corresponding author
Present address: Center of Applied Biology, Dept. of Soil Science and Plant Nutrition, Geisenheim University, von Lade Str. 1, D-65366 Geisenheim Germany
Email: Johannes.Max@hs-gm.de

subtropical climates (Allakhverdiev *et al.*, 2008; Abdelmageed & Gruda, 2009a,b). The tissues most sensitive to temperatures above the optimum, which is reported to be in the range of 21–27 °C for tomatoes (Abdul-Baki & Stommel, 1995; Sato *et al.*, 2000), include the photosynthetic apparatus (in particular Photosystem II) (Allakhverdiev *et al.*, 2008) and reproductive organs (Snider *et al.*, 2012). Both, photosynthetic performance and development of reproductive organs directly or indirectly affect the source-sink-relationship and thus assimilate partitioning among plant organs. According to Heuvelink (1995), temperature is the most important climatic factor influencing dry matter partitioning in crops. In greenhouse tomato grown under the prevailing hot and humid climate conditions of Central Thailand, relative biomass allocation to fruits of indeterminate tomato cultivars was observed to be markedly lower than reported for temperate climate zones (Kleinhenz *et al.*, 2006; Max & Horst, 2009). In previous trials at the same site, poor fruit set, high numbers of undersized and parthenocarpic fruits and, moreover, the physiological disorders blossom-end rot (BER) and fruit cracking (FC) (Liebisch *et al.*, 2009; Max & Horst, 2009) were identified as the most important factors causing deterioration of fruit quality and hence reduction of marketable yields (Mutwiwa *et al.*, 2008). BER and FC might also be influenced by source-sink relationships (Bertin, 2005).

Simple and inexpensive methods to manipulate the sink-source interaction in tomato plants are measures to control the number of stems and the fruit load of individual trusses, i.e. shoot pruning and inflorescence thinning. It is widely accepted that assimilate partitioning among sinks mainly depends on the strength of the sinks themselves and that source strength and assimilate availability are - unless light is limiting - only of minor importance in this regard (Heuvelink, 1995; Ho, 1996). During the reproductive growth stage, the fruits represent the strongest sinks among the organs of tomato plants (Cockshull & Ho, 1995). Reducing the number of fruits per truss decreases the overall sink strength of the generative organs as well as the competition for assimilates between individual fruits within the truss. The sink strength of individual fruits, on the other hand, increases at the same time. Accordingly, the final dry weight and size of tomato fruits increases with lower numbers of fruits per truss (DeKock *et al.*, 1982; Heuvelink, 1997; Adams *et al.*, 2001; Fanasca *et al.*, 2007) and, moreover, results of e.g. Hesami *et al.* (2012) suggest that fruit quality may be improved in response to reduced fruit loads. Inflorescence thinning may, thus, be an option for optimizing the assimilate partitioning between the fruits and to decrease the number of undersized fruits. Moreover, manipulating the source sink relationship may alter the proportion of sap-influx into the fruits via phloem or xylem. Since BER is assumed to be caused by a local Ca-deficiency in the distal fruit half (Ho & White, 2005) and the transport of Ca is almost exclusively confined to the xylem (Clarkson, 1984) this may exert an influence on BER incidence as well.

In commercial greenhouse tomato production, indeterminate tomato cultivars are predominantly cultivated with one main stem only and axillary shoots are customarily removed on a regular basis (Navarrete & Jeannequin, 2000; Maboko *et al.*, 2011). In high- and mid-latitude regions cultivation with two stems is associated with yield reductions particularly during periods when light is limiting, e.g. early and late stages of the growing season. Compared to temperate climate zones, radiation available for plant growth is much greater and incident angle of the sunlight is much less important in the tropics. Accordingly, there is some evidence that under tropical climate conditions cultivating indeterminate tomato plants with two stems may increase fruit yield per plant as compared to plants grown with single stems (Kleinhenz *et al.*, 2006; Rahmatian *et al.*, 2014). Kleinhenz *et al.* (2006) attributed this to an increased interception of photosynthetically active radiation and thereby maximized carbon assimilation and propagated double stemmed cultivation as a “premium measure to improve tomato fruit biomass under hot tropical conditions”. Additionally, the existence of a secondary stem may influence assimilate availability, i.e. source strength. Continuous stem pruning throughout the cultivation period generally shifts the partitioning of photoassimilates between sink and source and thus controls growth (Osorio *et al.*, 2014). A balanced partitioning of assimilates between the fruits may reduce fruit cracking.

The objective of this study was to examine the effects of trimming indeterminate growing tomato plants to either one or two shoots, as well as reducing the fruit load by restricting the number of flowers to either five or ten per inflorescence under the tropical climate conditions of Central Thailand. A main focus in this regard was the quantity of undersized fruits and the incidences of BER and FC, which - in previous trials at the same site (e.g. Kleinhenz *et al.*, 2006; Mutwiwa *et al.*, 2008; Liebisch *et al.*, 2009; Max & Horst, 2009) - were identified to represent the major causes determining the proportion of non-marketable fruits. On the basis of the results of this study, recommendations for commercial greenhouse tomato production in Central Thailand and areas with similar climatic features could be improved.

2 Materials and methods

2.1 Experimental site and greenhouse specifications

The experiments were carried out in an experimental greenhouse (GH) of the "Protected Cultivation Project" on the campus of the "Asian Institute of Technology" (AIT), situated 44 km north of Bangkok in Khlong Luang, Pathum Thani, central Thailand, (14° 04' N, 100° 37' E, altitude 2.3 m above sea level). There are two distinct seasons in Central Thailand: the rainy season, lasting from May to October in average years and the dry season from November to May, of which the latter can be divided in a cooler dry season (Nov.–Feb.) and a hot dry season (Mar.–May). Average daily mean temperatures and average monthly precipitation are 26,5 °C and 27 mm, 29,6 °C / 97 mm and 28,3 °C / 210 mm during the cool dry, hot dry and rainy season, respectively (Kleinhenz *et al.*, 2006).

The experiments for this study were conducted during the rainy season ("RS") 2006, from 9th May to 17th August 2006 and during the dry season ("DS") 2006/2007 (1st November 2006 to 2nd April 2007). The east-west oriented GH had the following dimensions: length: 20.0 m, width: 10.0 m, height: 6.4 m to the ridge and 3.8 m to the gutter. GH-roof and lower sidewalls were clad with an UV-absorbing polyethylene (PE) film ("Wepelen™, 200μ, thermic diffused, "anti-dust" / "anti-fog", FVG, Dernbach, Germany). GH-floors were covered with a white plastic mulch (Silo plus™, FVG, Dernbach, Germany). The total area of GH ventilation openings was 228 m^2. All ventilation openings (side walls, gables and 0.8 m high vents underneath the roof ridge) were covered with 52-mesh ("52 holes per inch" = ~20.5 holes per cm in both, warp and weft, directions) UV-absorbing insect-proof screens (Bionet™, Klayman Meteor Ltd, Petah Tikva, Israel). The GH was additionally equipped with two exhaust fans (∅ 1 m, capacity 550 $m^3\,min^{-1}$) installed at the eastern gable end. Fan operation was controlled automatically with a threshold temperature of 30 and 33 °C for the first and second fan respectively.

2.2 Experimental design and treatments

In both seasons the statistical design was a completely randomized 2-factorial (2-2) scheme. Of a total of 100 plants, each 50 plants were trimmed to either one or two shoots. The inflorescences of each one half of every shoot trimming treatment were thinned to either 5 or 10 flowers per inflorescence, resulting in the following treatment combinations:

a) 1 shoot / 5 flowers per inflorescence (herein after referred to as "1S5F")
b) 1 shoot / 10 flowers per inflorescence ("1S10F")
c) 2 shoots / 5 flowers per inflorescence ("2S5F")
d) 2 shoots / 10 flowers per inflorescence ("2S10F")

The 25 plants of every treatment were randomly distributed within three (RS) or two (DS) GH-rows. Plants of the side rows were excluded from data collection and sampling in order to minimize any unwanted effect possibly resulting from the plant's position neighbouring the sidewalls.

2.3 Cultural practices

Seeds of the heat-tolerant, indeterminate growing F_1 hybrid tomato (*Solanum lycopersicum* L.) cultivar (cv) FMTT260 (AVRDC, Shanhua, Taiwan) were sown in peat moss on 25th April 2006 (RS) and 18th October 2006 (DS) and kept in an evaporative cooled nursery GH for two weeks. On 9th May 2006 (RS) and 1st November 2006 (DS) plants were transplanted to the experimental GH at a density of 1.5 plants m^{-2} using white 10 L plastic pots filled with a local commercial potting mix (Dinwondeekankasat, Ayutthaya, Thailand; textural classes: 30 % sand, 39 % silt and 31 % clay; containing 28 % organic matter; pH 5.3). Substrates were treated with Trichoderma 10 days prior to sowing and transplanting, respectively. Each one half of the plants was cultivated with either one or two shoots, for the latter the first side shoot, which emerged from the first node below the first truss of the primary shoot, was not removed but allowed to develop into a secondary stem. All shoots were trained using a high wire growing system (for details see Kleinhenz *et al.*, 2006) and laid down according to necessity. In each one half of the plants of both shoot pruning treatments the number of flowers per inflorescence was reduced to either 10 or 5 flowers per truss by manually cutting off supernumerary flowers beginning from the distal end of each inflorescence. The number of flowers / fruits per truss was repeatedly controlled and readjusted as necessary. Side shoots of all plants were removed twice every week and senescent leaves were regularly removed up to the oldest fruit carrying truss after the first harvesting. Insect pests were controlled by alternately spraying of Cypermethrin™ (2 ml L^{-1}), Abamectin™ (1.5 ml L^{-1}) or Spinosad™ (1.5 ml L^{-1}) on a weekly basis (RS) or on survey (DS). After harvesting commenced only Spinosad™ was applied. Mancozeb™ (4 ml L^{-1}) was sprayed against fungal diseases three times in the RS and twice in the DS. Fertigation was applied by single drippers with an average emitter flow rate of 33 ml min^{-1} and an average leachate of 25 % of the supply. Fertigation frequency was automatically controlled based on the solar radiation integral and varied between 6 to 10 irrigation cycles per day. In addition, the duration of the dripper intervals was regularly adjusted according to plant age from 1 minute in the beginning to 9 minutes at the end of the cultivation period. The average composition of the nutrient solution was (in mM): N 7.4, P 0.8, K 5.9, Ca 3.1, Mg 0.7, S 1.7, Na 1.8 and (in μM): B 6.0, Fe 4.2, Cu 5.3, Mn 3.8, Mo 1.1, Zn 1.4. Set EC was 1.5 and 1.8 mS cm^{-1} prior to and after the first harvest respectively, maintaining the same element ratio. Set pH was 5.5. The experiments were ended on 17th August 2006 (RS) and 2nd April 2007 (DS). Due to the rapidly progressing deterioration of the overall condition of the plants during the final third of the trial, the experiment RS 2006 had to be ended after 13 weeks already resulting in a markedly shorter cultivation period as compared to the DS experiment.

2.4 Data acquisition

Temperature and relative humidity inside the GH were monitored with two aspirated psychrometers (sensors: sheathed type K [NiCr-Ni] thermocouples, ∅: 0.5 mm, BGT, Hannover, Germany) installed in the centre of either the front or the rear half of the GH, 1.8 m above the floor. One identical sensor was used to monitor outside temperature and humidity. Global radiation was measured with a pyranometer (each one sensor per GH and outside) type CM11/14 (Kipp and Zonen, Delft, The Netherlands) positioned in the centre of the GH, 2.5 m above the floor. Data were sampled every 15 s, transferred to a data-logger (BGT, Hannover, Germany) and recorded as mean values every 5 minutes. All sensors were calibrated prior to the start of the experiment. Plant height and number of clusters of five randomly selected plants per treatment-combination were manually rated on a weekly basis. Plant height was measured from the substrate surface to the tip of the primary shoot. Fruits were picked twice a week starting from 10 weeks after transplanting (WAT) in the RS and 9 WAT in the DS. Fruits of every individual plant were harvested separately and divided into the following yield categories:

a) Marketable yield (healthy fruits > 50 g per fruit)
b) BER-affected fruits (all fruits with visible symptoms of BER, regardless fruit weight, size, or symptom intensity)
c) Cracked fruits (all fruits with visible cracks, regardless fruit weight, size, or symptom intensity)
d) Undersized fruits (all fruits < 50 g, except BER-affected or cracked fruits, mostly parthenocarpic fruits)
e) Other non-marketable fruits (misshapen or disease affected fruits).

The fruits of each yield fraction were weighed separately. In the DS fruits of all categories were additionally counted while in RS only healthy, BER-affected and cracked fruits were counted. As in both seasons only few misshapen or disease infected fruits were found, this fraction was considered to be negligible.

2.5 Statistical analysis

Statistical analysis was conducted with SAS Version 8e (SAS, 2001, SAS Institute Inc., Cary N.C., USA). SAS's "GLM"-procedure was used to perform analysis of variance (ANOVA) and subsequent mean separation by least significant difference (LSD) test. Percentages and data which were not normally distributed were transformed to their arcsin or square root prior to the statistical analysis and results were retransformed to the scale of the original data afterwards. Except where explicitly mentioned, the interaction between the main experimental factors (Number of shoots × number of flowers per inflorescence) was not significant.

3 Results

3.1 Climatic conditions

The averages of global radiation, daytime air temperature and relative humidity (corresponding vapour pressure deficit [VPD] values in parentheses) inside the GH during the course of the experiment were 137.8 W m^{-2}, 31.7 °C and 75.8 % (1.2 kPa) in the RS and 265.8 W m^{-2}, 32.2 °C and 60.9 % (2.3 kPa) in the DS. Night-time temperatures and relative humidity (VPD) averaged 28.2 °C and 90.7 % (0.4 kPa) in the RS and 25.5 °C and 81.2 % (0.6 kPa) in the DS. The profile of the average weekly daytime means of global radiation, air temperature and relative humidity is shown in Fig. 1.

3.2 Plant growth

While no effect of the shoot-trimming on average plant height was observed in the RS, the primary shoot of plants with one shoot grew taller than that of plants with two shoots in the second half of the DS (Fig. 2, left). However, in the last three weeks of DS, coinciding

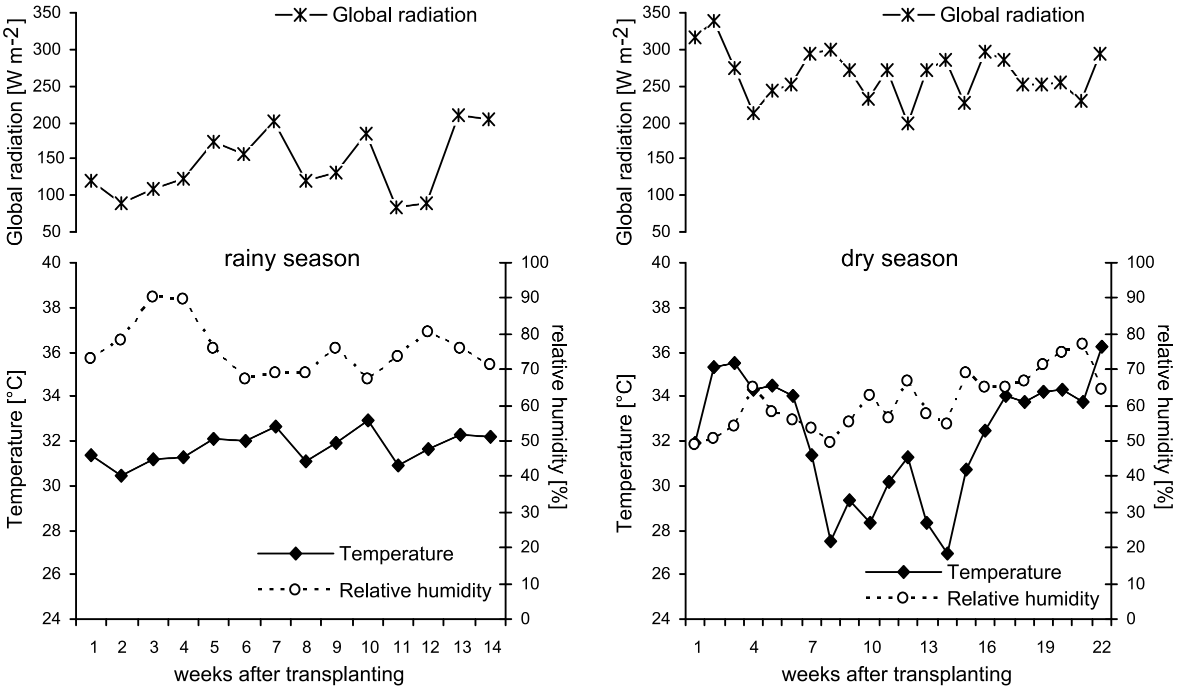

Fig. 1: *Weekly means of daily global radiation, daytime air temperature and relative humidity inside the greenhouse during the rainy season 2006 (graphs on the left side) and the dry season 2006/2007 (graphs on the right side) in central Thailand. Temperature and relative humidity values are means of each two sensors. Global radiation was recorded with one sensor.*

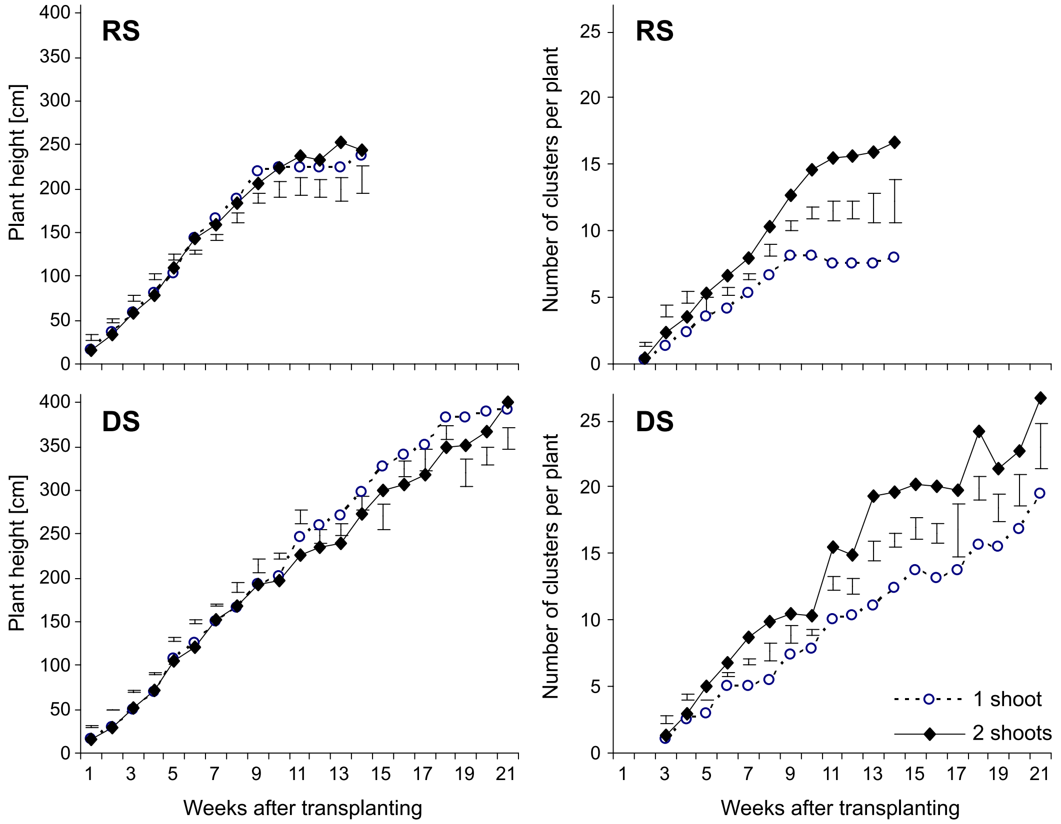

Fig. 2: *Average height and number of clusters per plant of greenhouse grown tomato plants trimmed to either one or two shoots during the rainy season 2006 (RS) and the dry season 2006/2007 (DS) in Central Thailand. Data points are means of each 10 randomly selected plants. Error bars indicate LSD*$_{(0.05)}$ *(LSD-test,* $\alpha < 0.05$*, n=10).*

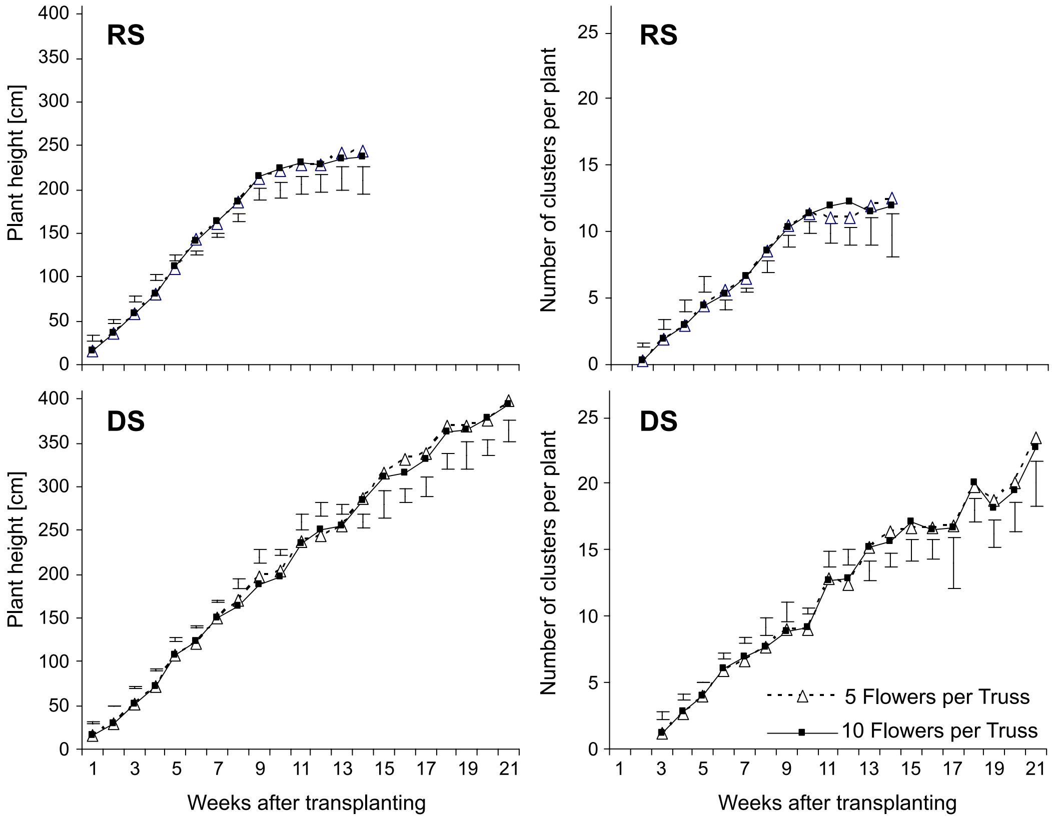

Fig. 3: *Average height and number of clusters per plant of tomato plants grown in greenhouse during the rainy season 2006 (RS) and the dry season 2006/2007 (DS) in Central Thailand. Inflorescences were pruned to either 10 or 5 flowers per truss. Data points are means of each 10 randomly selected plants. Error bars indicate* $LSD_{(0.05)}$ *(LSD-test,* $\alpha < 0.05$*, n=10).*

with a steep temperature increase (Fig. 1), the growth of the primary shoot of plants with one shoot slowed down, whereas the reverse was true for plants cultivated with two shoots (Fig. 2, left). In both seasons, from 5 WAT onwards the number of clusters was significantly higher when plants were cultivated with two shoots (Fig. 2, right).

The reduction of the number of flowers per inflorescence did not influence plant height or the number of trusses per plant (Fig. 3). However, compared to the DS, longitudinal growth as well as truss formation was distinctly restrained during the RS, particularly during the harvesting period (Figs 2 and 3).

3.2.1 *Fruit yield and quality*

The duration of the cultivation period and thus that of the production period (the time in which ripe tomatoes were harvested) was much shorter in the RS (14 weeks / 5 weeks; cultivation period in the greenhouse / harvesting period, respectively) than in the DS (21 / 12). Both shoot pruning and inflorescence thinning exerted a strong influence on average fruit weight during the DS but not in the RS. In the DS average fruit weight was significantly increased when plants were grown with only one shoot and on trusses with only five flowers as compared to plants with two shoots or 10 flowers per inflorescence, respectively. Consequently, the biggest fruits were harvested in 1S5F while those in 2S10F were smallest (Table 1). In the RS the trend for the shoot trimming treatments (but not for flower-pruning) was the same, but the differences were not significant. BER affected fruits tended to be smaller than average fruits in both seasons whereas the size of cracked fruits was above average in the DS but below average in the RS (Table 1).

Total cumulative fruit yield was almost ten-fold lower in the RS than in the DS (Table 2). In part, this was a result of the shorter harvesting period but even when expressed as average weekly yield, the quantity of fruits harvested during the RS was distinctly smaller as compared to the DS. Averaged across all treatments mean weekly total yield per plant was 347 g in the DS but only 108 g in the RS. In terms of marketable yield the difference between the seasons was even more striking: While weekly marketable yield per plant averaged 234 g (across all treatments) in the DS, it was only 10 g per plant in the RS. In both seasons - particularly pronounced in the RS - undersized (predominantly

Table 1: *Average weight [g per fruit] of fruits of different categories harvested from tomato plants pruned to one or two shoots and subjected to inflorescence thinning to either 5 or 10 flowers per inflorescence in a greenhouse experiment in Central Thailand during the rainy season 2006 and the dry season 2006/2007.* †

Treatment combination	*Average fruit weight (g per fruit)*				
	average across all yield fractions	*Fruit category*			
		marketable	*undersized*	*BER-affected*	*cracked*
Rainy Season 2006					
1 shoot / 5 flowers	71.6	-.-	-.-	36.3	58.7
1 shoot / 10 flowers	68.3	-.-	-.-	26.0	56.5
2 shoot / 5 flowers	60.8	-.-	-.-	30.6	49.0
2 shoot / 10 flowers	65.9	-.-	-.-	25.8	49.5
Dry Season 2006/2007					
1 shoot / 5 flowers	56.3 ^{a}	80.8 ^{a}	29.1 ^{a}	45.9	75.9
1 shoot / 10 flowers	49.1 ^{bc}	76.0 ^{b}	27.3 ^{ab}	54.4	75.8
2 shoot / 5 flowers	51.4 ^{b}	69.8 ^{c}	27.5 ^{ab}	44.2	53.1
2 shoot / 10 flowers	45.3 ^{c}	65.9 ^{c}	26.5 ^{b}	45.7	53.3

† Means followed by different letters are significantly different between treatments (LSD-test, $\alpha < 0.05$, n=25, data on fruit weight of marketable as well as undersized fruits were only collected during the dry season).

parthenocarpic) fruits constituted the largest portion of non-marketable yield (Table 2, Fig. 4). BER incidence was considerably higher in the DS than in the RS, where it was only of marginal importance. In contrast FC was more prevalent in the RS as compared to the DS (Table 2, Fig. 4).

Except for BER incidence the treatment-effects were more pronounced in the DS. In both seasons average cumulated total yield was significantly higher when plants were grown with two stems, regardless whether weight or number of fruits were considered. In the DS also the marketable yield fraction was significantly increased in the double-stem treatment whereas no influence of shoot-pruning on marketable yield was observed in the RS. Double-stemmed cultivation resulted in significantly greater quantities of undersized fruits in the rainy as well as the dry season. However, the percentages (proportion of total yield, w/w) did not differ significantly between the shoot-pruning treatments. The percentage (w/w) of BER-affected fruits was significantly lower in plants cultivated with two stems than in those with only one main stem in both seasons. During the RS the difference between the treatments was only significant for the weight of BER-affected fruits. Weight, number and percentage (w/w) of cracked fruits were significantly reduced by cultivating the plants with two stems during the DS.

Truss thinning resulted in reduced total yields in both seasons. Marketable yield fraction, however, was not affected by reducing the fruit load per truss. In the DS the proportion (% w/w) of marketable yield was even significantly increased in the treatment in which the number of flowers was restricted to five flowers per inflorescence.

Greater fruit loads per truss led to significantly increased amounts of undersized fruits in both seasons. When expressed as percentages the difference between the truss-thinning treatments were only found to be significant in the DS. The quantity and proportion of fruits affected by BER was significantly increased by more intense inflorescence thinning in the RS but not in the DS, where this effect was only visible as a slight trend. Inflorescence thinning exerted hardly any influence on the incidence of fruit cracking (Table 2, Fig. 4).

In both seasons cumulative total fruit yield of tomato plants was the more reduced the more plant development was manipulated either by the applied shoot pruning or inflorescence thinning treatments (Fig. 4). In the rainy season, however, the increment in total yield was almost entirely due to increasing quantities of undersized fruits, while marketable yield remained unaffected by the treatments and generally on an extremely low level.

In the DS tomato cultivation with two stems significantly increased marketable yield whereas the intensity of inflorescence thinning had no effect on marketable yield regardless whether inflorescences of plants with one or two stems were treated (Fig. 4).

Table 2: *Average weight (W, g per plant) and number (No) of fruits per plant and percentages [w/w] of individual non-marketable fruit classes (BER: Blossom-end rot, FC: fruit cracking) harvested from tomato plants pruned to one or two shoots and subjected to inflorescence thinning to either 5 or 10 flowers per inflorescence in a greenhouse experiment in Central Thailand during the rainy season 2006 (RS, production duration: 5 weeks) and the dry season 2006/2007 (DS, production duration: 12 weeks).* †

			Fruit category												
Treatment	*Total yield*		*marketable*			*undersized*			*BER*			*FC*			
	W	*No*	*W*	*No*	*%*	*W*	*No*	*%*	*W*	*No*	*%*	*W*	*No*	*%*
Rainy Season 2006 (harvesting period: 5 weeks)															
1 shoot	463	7.1	41	–	9.2	337	–	71.7	14.6	0.6	3.2	72.2	1.3	15.9
2 shoots	618	9.9	54	–	8.6	491	–	79.1	10.6	0.6	1.8	62.7	1.2	10.5
Effect	**	**	n.s.	–	n.s.	**	–	n.s.	*	n.s.	***	n.s.	n.s.	*
5 flowers	490	8.0	47	–	9.8	358	–	72.1	14.9	0.7	3.1	72.4	1.3	15.0
10 flowers	590	9.0	49	–	8.1	470	–	78.7	10.3	0.5	1.9	72.5	1.1	11.4
Effect	*	n.s.	n.s.	–	n.s.	*	–	n.s.	**	*	**	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	–	n.s.	n.s.	–	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Dry Season 2006/2007 (harvesting period: 12 weeks)															
1 shoot	3807	73.3	2481	31.5	64.2	972	35.1	25.9	248	5.2	6.3	107	1.6	3.6
2 shoots	4530	94.9	3133	46.2	68.8	1146	42.8	25.6	220	5.4	4.9	32	0.5	0.7
Effect	***	***	***	***	**	**	***	n.s.	n.s.	n.s.	*	***	***	***
5 flowers	3947	47.1	2796	37.6	70.4	823	29.5	21.4	254	6.0	6.2	75	1.1	2.1
10 flowers	4390	94.1	2817	40.1	62.7	1295	48.5	30.1	214	4.6	5.0	64	1.0	2.3
Effect	**	***	n.s.	n.s.	***	***	***	***	n.s.	n.s.	n.s.	n.s.	n.s.	*
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

† *: $\alpha < 0.05$, **: $\alpha < 0.01$, ***: $\alpha < 0.001$, n.s.: not significant, LSD-test, n=25.

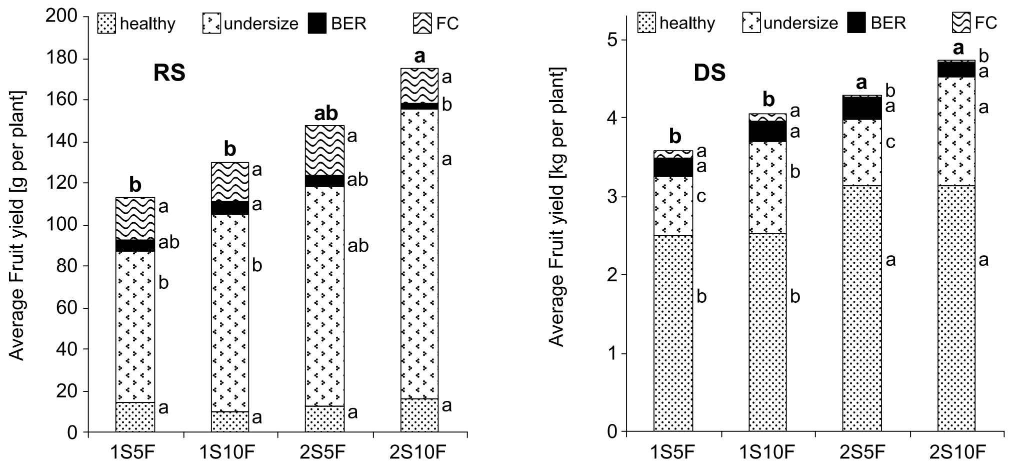

Fig. 4: *Cumulated fruit yield of tomato plants trimmed to one or two shoots (S) and subjected to inflorescence thinning to either 5 or 10 flowers (F) per inflorescence in a greenhouse experiment in Central Thailand during the rainy season 2006 (RS) and the dry season 2006/2007 (DS). Different letters above and beside the bars indicate significant differences between the treatments in total yield or in individual yield fractions, respectively (LSD-test, $\alpha < 0.05$, n=25, note that yield quantity per plant is given in g for the RS and in kg for the DS).*

4 Discussion

Although the daytime air temperatures in the dry season (DS) and rainy season (RS) were of similar magnitude (Fig. 1) when averaged across the entire respective experimental period the duration of the period during which a tomato crop could be reasonably cultivated inside the greenhouse was much shorter in the RS (14 weeks) as compared to the DS (21 weeks, Fig. 3). In part, this was probably due to lower solar irradiation, higher relative humidity (RH) and thus lower VPD in the RS which limited plant growth as well as total and marketable fruit yield in comparison to the DS (Table 2, Fig. 4). Moreover, during the RS the daily means of daytime air temperature continuously ranged between 30 and 32 °C whereas during the course of the DS the temperature profile alternated strongly with very hot periods at their beginning and end, but comparably low temperatures between 7 and 16 WAT (Fig. 1). This cooler period coincided with flowering and fruit set in the first trusses and eventually resulted in higher total and marketable fruit yields from the respective clusters. However, the most decisive difference regarding temperature profiles between the seasons was probably the lower night-time air temperatures during the DS which were additionally accompanied by lower RH. The observation of distinctly decreased numbers of marketable fruits during the RS is in line with results of Peet & Bartholemew (1996) as well as Willits & Peet (1998) who – although temperature level generally was much lower as in our experiments – reported significant yield reductions when night-time temperatures particularly during fruit set exceeded 21 °C as compared with control treatments where temperature at night was kept below 20 °C. The fact that in our experiments parthenocarpic fruits constituted the major share of the non-marketable yield fraction, particularly in the RS appears to corroborate the assumption that reduced pollen fertility entailed by a lack of pollination was the main reason for poor fruit set and eventually the very low marketable yield. As compared to the dry season, distinctly lower total fruit yields accompanied by simultaneously increased proportions of the non-marketable yield fractions during the rainy season were likewise observed in previous experiments (Kleinhenz *et al.*, 2006; Max *et al.*, 2009; Max & Horst, 2009). Similarly, results of Hernández *et al.* (2014) demonstrate that seasonal influences do not only influence yield quantity but also the quality of the harvested tomato fruits.

Furthermore, in accordance with results of Kleinhenz *et al.* (2006) who found the percentage of total biomass distributed to tomato fruits to be much lower in Central Thailand than reported for temperate climates, our results suggest that inhibited allocation of photoassimilates into the fruits, due to low sink strength might have been another important reason for the very low total yield observed particularly in the RS: The additional reduction of the generative sink-strength imposed by the truss-thinning treatments invariably lead to smaller quantities of tomato fruits, indicating that not the competition for assimilates between individual trusses but the cumulative sink strength of all clusters present at a time was decisive for yield formation. In previous (e.g. Liebisch *et al.*, 2009; Max *et al.*, 2009) as well as in experiments conducted in parallel (Max & Horst, 2009), where the number of fruits per cluster was not manipulated, total yield was always higher as in this study. Further reducing the fruit load by restricting the number of flowers to 5 flowers per truss further decreased total fruit yield compared to the treatments with 10 flowers per truss, a finding similarly reported for other indeterminate growing tomato cultivars by e.g. Heuvelink (1997) and Adams & Valdés (2002). The result that, in the tropical climate of Central Thailand, double stem cultivation led to increased total yields in both seasons (whereof in the RS only the quantity of undersized fruits was increased) point into the same direction: Apparently, double stem cultivation is associated with an increase in assimilate availability due to greater leaf area in combination with significantly higher numbers of trusses (Fig. 2) per plant and thus increased overall generative sink strength. Under tropical and subtropical climates similar results were reported for other indeterminate (Kleinhenz *et al.*, 2006) and semi-determinate (Hesami *et al.*, 2012) tomato cultivars as well as for cherry tomato (Charlo *et al.*, 2006). In contrast, for commercial greenhouse tomato production in temperate climates, however, single stem production is common since – particularly during periods with low solar irradiation – double stem cultivation alike increased planting densities may decrease light interception to undesirable low levels entailed by reduced assimilate availability and dry matter allocation to the fruits (Heuvelink, 1995; Adams *et al.*, 2001; Navarrete & Jeannequin, 2000).

Thus, strategies aiming at increasing the productivity of tomato plants under climatic conditions as those prevailing in Central Thailand should consider measures to shift the sink-source ratio in favour of the sinks. This could include measures to increase pollination success (e.g. by bumble bees), targeted removal of parthenocarpic fruits, the application of artificial growth regulators, and greenhouse cooling to generally improve pollination and fruit set.

Generally, compared to the fraction of undersized fruits, BER and FC incidences were only of minor importance in reducing the marketable yield fractions in both seasons. However, besides the enormous differences between dry and rainy season regarding the quantities of undersized fruits as well as total and marketable yields, also marked seasonal influences on the incidences of the physiological disorders blossom-end rot (BER) and fruit cracking (FC) were evident. While BER occurrence was higher in the DS than in the RS, the opposite was true for FC, which was almost negligible during the DS whereas it contributed significantly to the share of non-marketable fruits in the RS. During the RS an increase in RH towards the harvesting period (Fig. 1) resulted in increased fractions of cracked fruits, as this was shown to be caused by large differences in water potentials between leaves and fruits (Lara *et al.*, 2014). The incidence of BER in the RS was only 50 % of that in the DS (Table 2), which could be attributed to the higher solar irradiation during the DS, since, according to Hanssens *et al.* (2015), “high light decreases xylem contribution to fruit growth in tomato”.

The effects of the treatments on BER incidence were more pronounced during the RS whereas they exerted a stronger influence on FC during the DS. Reducing the number of flowers per inflorescence significantly increased quantity and percentage of BER-affected fruits in the RS, an effect which was only visible as a trend in the DS (Table 2). It was shown earlier that truss thinning leads to increased BER incidences (DeKock *et al.*, 1982). A probable reason for this observation is that the increased sink strength of individual fruits in trusses may shift the balance between sap-influxes via xylem and phloem towards increased phloem influx and thus to decreased relative Ca^{2+} import into the fruits via the xylem.

Cultivating the plants with only one shoot resulted in higher quantities (significant only for the RS) as well as significantly higher percentage shares of BER affected fruits as compared to double stem cultivation in both seasons (Table 2) a result similarly reported by Hesami *et al.* (2012). It could be speculated on several factors, such as more balanced distribution of water and assimilates within the plant (Kim *et al.*, 2014) which may individually or interactively cause this effect. For example, in double stem plants the relative assimilate partitioning to leaves and fruits is shifted in favour of the fruits (Kleinhenz *et al.*, 2006) which may influence the relation between leaf and fruit transpiration possibly entailing increased relative influxes of xylem sap and thus Ca^{2+} to the fruits, hence decreased BER incidence. A higher “self-shading effect” within the canopy of individual double stem plants may further enhance this effect. However, for an actually reasonable explanation of this finding certainly more detailed studies would be required. The same is true for the observation that FC incidence was significantly increased by trimming the plants to one shoot in both seasons. This could be attributed to increased assimilate and water influxes to the fruits via the phloem. Even when the overall photosynthetic activity is reduced, each of the remaining fruits receives more assimilates which enhances fruit growth (Rahmatian *et al.*, 2014), thus the weight of individual fruits is higher (Table 1), and so is, eventually, the probability of fruit cracking (Max & Horst, 2009). Even though the sink strength of individual fruits is considered to increase when the number of fruits in one cluster is reduced, no significant effect of inflorescence thinning on the incidence of FC was observed.

5 Conclusion

Our results clearly demonstrate that a production of greenhouse tomato with the cultivation practices currently available and applied in a semi-humid tropical monsoon climate is only reasonable during the dry season. For that period of the year, the causal connection between temperature profiles and yield data indicate that adjusting the scheduling of crop production period to the temperature profile of the DS, i.e. moving the time of sowing and transplanting forwards to the later weeks of the RS, offers opportunities to prolong the production period and hence yield quantity as well as the quality of a major proportion of the harvested fruits. When cooling facilities (e.g. evaporative cooled nursery greenhouses) are available, the production period could be further prolonged by 2–4 weeks. To enable a successful production during the rainy season, however, profound improvements and development of novel techniques and production strategies are required. To ensure the economic viability of such newly developed systems assessments of the cost-effectiveness and profitability are indispensable for respective future studies.

Clearly, for tomato production in climates resembling that of Central Thailand, pruning tomato plants to one stem - independent of seasonal influences - is neither beneficial for yield nor for fruit quality. Thus, as earlier proposed by Kleinhenz *et al.* (2006) it is recommended to grow tomato with two stems as this strongly increases yield and, moreover, reduces the incidences of FC and BER. Inflorescence thinning on the other hand did not appear to be an appropriate measure to increase total marketable yield. Blossom removal to numbers less than 10 flowers per truss, thus, cannot be recommended. For the identification of the optimal fruit load further research would be required.

Acknowledgements

This work was supported by the German research foundation (Deutsche Forschungsgemeinschaft – DFG) within the framework of “Forschergruppe FOR 431”. We thank Songthum Deeaum and Sopana Yule for their technical support.

References

Abdelmageed, A. H. A. & Gruda, N. (2009a). Influence of high temperatures on gas exchange rate and growth of eight tomato cultivars under controlled heat stress conditions. *European Journal of Horticultural Science*, 74 (4), 152–159.

Abdelmageed, A. H. A. & Gruda, N. (2009b). Performance of different tomato genotypes in the arid tropics of Sudan during the summer season. II. Generative development. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 110 (2), 147–154.

Abdul-Baki, A. A. & Stommel, J. R. (1995). Pollen viability and fruit set of tomato genotypes under optimum- and high-temperature regimes. *HortScience*, 30 (1), 115–117.

Adams, S. R. & Valdés, V. M. (2002). The effect of periods of high temperature and manipulating fruit load on the pattern of tomato yields. *Journal of Horticultural Science and Biotechnology*, 77 (4), 461–466.

Adams, S. R., Valdés, V. M., Cave, C. R. J. & Fenlon, J. S. (2001). The impact of changing light levels and fruit load on the pattern of tomato yields. *Journal of Horticultural Science and Biotechnology*, 76 (3), 368–373.

Allakhverdiev, S. I., Kreslavski, V. D., Klimov, V. V., Los, D. A., Carpentier, R. & Mohanty, P. (2008). Heat stress: An overview of molecular responses in photosynthesis. *Photosynthesis Research*, 98 (1-3), 541–550.

Bertin, N. (2005). Analysis of the Tomato Fruit Growth Response to Temperature and Plant Fruit Load in Relation to Cell Division, Cell Expansion and DNA Endoreduplication. *Annals of Botany*, 95 (3), 439–447.

Charlo, H. C. O., Castoldi, R., Ito, L. A., Fernandes, C. & Braz, L. T. (2006). Productivity of cherry tomatoes under protected cultivation carried out with different types of pruning and spacing. *Acta Horticulturae*, 761, 323–326.

Clarkson, D. T. (1984). Calcium transport between tissues and its distribution in the plant. *Plant, Cell and Environment*, 7 (6), 449–456.

Cockshull, K. E. & Ho, L. C. (1995). Regulation of tomato fruit size by plant density and truss thinning. *Journal of Horticultural Science*, 70 (3), 395–407.

DeKock, P. C., Inkson, R. H. E. & Hall, A. (1982). Blossom-end rot of tomato as influenced by truss size. *Journal of Plant Nutrition*, 5 (1), 57–62.

Fanasca, S., Martino, A., Heuvelink, E. & Stanghellini, C. (2007). Effect of electrical conductivity, fruit pruning, and truss position on quality in greenhouse tomato fruit. *Journal of Horticultural Science and Biotechnology*, 82 (3), 488–494.

FAOSTAT (2015). Food and Agricultural commodities production / Commodities by regions. Food and Agriculture Organization of the United Nations (FAO) Statistics Division. URL `http://faostat3.fao.org/browse/rankings/commodities_by_regions/E` (last accessed: 03.03.2015).

Hanssens, J., De Swaef, T. & Steppe, K. (2015). High light decreases xylem contribution to fruit growth in tomato. *Plant, Cell and Environment*, 38 (3), 487–498.

Heine, G., Max, J. F. J., Führs, H., Moran-Puente, D. W., Heintz, D. & Horst, W. J. (2011). Effect of manganese on the resistance of tomato to *Pseudocercospora fuligena*. *Journal of Plant Nutrition and Soil Science*, 174 (5), 827–836.

Hernández, M., Espinosa, F. & Galindo, P. (2014). Tomato fruit quality as influenced by the interactions between agricultural techniques and harvesting period. *Journal of Plant Nutrition and Soil Science*, 177 (3), 443–448.

Hesami, A., Sarikhanikhorami, S. & Hosseini, S. S. (2012). Effect of Shoot Pruning and Flower Thinning on Quality and Quantity of Semi-Determinate Tomato (*Lycopersicon esculentum* Mill.). *Notulae Scientia Biologicae*, 4 (1), 108–111.

Heuvelink, E. (1995). Effect of temperature on biomass allocation in Tomato (*Lycopersicon esculentum*). *Physiologia Plantarum*, 94 (3), 447–452.

Heuvelink, E. (1997). Effect of fruit load on dry matter partitioning in tomato. *Scientia Horticulturae*, 69 (1-2), 151–159.

Ho, L. C. (1996). The mechanism of assimilate partitioning and carbohydrate compartmentation in fruit in relation to the quality and yield of tomato. *Journal of Experimental Botany*, 47 (special issue), 1239–1243.

Ho, L. C. & White, P. J. (2005). A Cellular Hypothesis for the Induction of Blossom-End Rot in Tomato Fruit. *Annals of Botany*, 95 (4), 571–581.

Kim, S. E., Lee, M. Y., Lee, M. H., Sim, S. Y. & Kim, Y. S. (2014). Optimal Management of Tomato Leaf Pruning in Rockwool Culture. *Horticulture, Environment, and Biotechnology*, 55 (6), 445–454.

Kleinhenz, V., Katroschan, K., Schütt, F. & Stützel, H. (2006). Biomass Accumulation and Partitioning of Tomato under Protected Cultivation in the Humid Tropics. *European Journal of Horticultural Science*, 71 (4), 173–182.

Lara, I., Belge, B. & Goulao, L. (2014). The fruit cuticle as a modulator of postharvest quality. *Postharvest Biology and Technology*, 87, 103–112.

Liebisch, F., Max, J. F. J., Heine, G. & Horst, W. J. (2009). Blossom-end rot and fruit cracking of tomato grown in net-covered greenhouses in Central Thailand can partly be corrected by calcium and boron sprays. *Journal of Plant Nutrition and Soil Science*, 172 (1), 140–150.

Maboko, M. M., Du Plooy, C. P. & Chiloane, S. (2011). Effect of plant population, fruit and stem pruning on yield and quality of hydroponically grown tomato. *African Journal of Agricultural Research*, 6 (22), 5144–5148.

Max, J. F. J. & Horst, W. J. (2009). Influence of nighttime electrical conductivity of substrate solution on fruit cracking and blossom-end rot of greenhouse tomato in the tropics. *Journal of Plant Nutrition and Soil Science*, 172 (6), 829–838.

Max, J. F. J., Horst, W. J., Mutwiwa, U. N. & Tantau, H.-J. (2009). Effects of greenhouse cooling method on growth, fruit yield and quality of tomato (*Solanum lycopersicum* L.) in a tropical climate. *Scientia Horticulturae*, 122 (2), 179–186.

Muhammad, A. & Singh, A. (2007). Yield of tomato as influenced by training and pruning in the Sudan savanna of Nigeria. *Journal of Plant Science*, 2 (3), 310–317.

Mutwiwa, U. N., Tantau, H. J., von Elsner, B. & Max, J. F. J. (2008). Effects of NIR-reflection Greenhouse Cooling on Blossom-end Rot and Fruit Cracking. *African Journal of Horticultural Science*, 1 (1), 33–43.

Navarrete, M. & Jeannequin, B. (2000). Effect of frequency of axillary bud pruning on vegetative growth and fruit yield in greenhouse tomato crops. *Scientia Horticulturae*, 86 (3), 197–210.

Nguyen, T. H. N., Borgemeister, C., Max, J. & Poehling, H.-M. (2009). Manipulation of Ultraviolet Light Affects Immigration Behavior of *Ceratothripoides claratris* (Thysanoptera: Thripidae). *Journal of Economic Entomology*, 102 (4), 1559–1566.

Osorio, S., Ruan, Y.-L. & Fernie, A. R. (2014). An update on source-to-sink carbon partitioning in tomato. *Frontiers in Plant Science*, 5, 516.

Peet, M. M. & Bartholemew, M. (1996). Effect of night temperature on pollen characteristics, growth, and fruit set in tomato. *Journal of the American Society for Horticultural Science*, 121 (3), 514–519.

Rahmatian, A., Delshad, M. & Salehi, R. (2014). Effect of grafting on growth, yield and fruit quality of single and double stemmed tomato plants grown hydroponically. *Horticulture Environment and Biotechnology*, 55 (2), 115–119.

Sato, S., Peet, M. M. & Thomas, J. F. (2000). Physiological factors limit fruit set of tomato (*Lycopersicon esculentum* Mill.) under chronic, mild heat stress. *Plant Cell and Environment*, 23 (7), 719–726.

Snider, J. L., Russo, V. M., Roberts, W., Wann, E. V. & Raper, R. L. (2012). Cultural and Environmental Factors Governing Tomato Production: Local Production under Elevated Temperatures. *HortScience*, 47 (8), 1022–1028.

Willits, D. H. & Peet, M. M. (1998). The effect of night temperature on greenhouse grown tomato yields in warm climates. *Agricultural and Forest Meteorology*, 92 (3), 191–202.