Two instead of Three Leaves between Tomato Trusses: Measured and Simulated Effects on Partitioning and Yield

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Abstract

Commercial tomato cultivars initiate three leaves between trusses. It is expected that in a cultivar with only two leaves between trusses assimilate partitioning towards the fruits and therefore yield would be favored. However, a lower number of leaves on the plant reduces leaf area index (LAI) and may therefore reduce light interception and total biomass production, affecting yield negatively. The effect of the number of leaves between trusses was investigated in a simulation study and a greenhouse experiment. In the photosynthesis-driven model TOMSIM, two leaves per truss were simulated by reducing the sink strength of each vegetative unit by 1/3. Seven fruits per truss were assumed. Reduced vegetative sink strength increased partitioning to the fruits over a whole season from 66% to 74%. However, yield increased only marginally (1.5%), as average LAI decreased from 2.4 to 1.7 m^2 m^{-2} and hence total biomass production was reduced by 9.5%. To avoid this reduction in total biomass production, the removal of old leaves was delayed by 2 weeks. This resulted in an average LAI of 2.3 m^2 m^{-2}, identical total biomass production, and yield improved compared to the control with 12.8%. In the greenhouse experiment, control plants (no leaf pruning) and plants where the second leaf of each vegetative unit was weekly removed when it was only 1-3 cm long, were grown. To compensate for a decrease in LAI, pruned plants were also grown at 3.8 plants m^{-2}. All plants were pruned to 6 fruits per truss. Leaf pruning increased partitioning to the fruits, averaged over the period from 18 February to 20 May, from 57% to 61%. Average LAI was 2.9, 2.4 and 3.6 m^2 m^{-2} for control, leaf pruning and leaf pruning & increased density, respectively. Leaf pruning significantly reduced total biomass by 11% whereas fruit yield was hardly affected. Leaf pruning & increased density unexpectedly resulted in only 58% of dry matter allocated to the fruits. Increasing density increased biomass and fruit yield per m^2 by 29% and 17%, respectively. It is concluded, based on simulation results and experimental data, that a tomato cultivar with 2 instead of 3 leaves between trusses would improve yield, when combined with measures to keep LAI sufficiently high.

INTRODUCTION

In general, commercial tomato cultivars initiate three leaves between two successive trusses and around 10 leaves before the appearance of the first truss (De Koning, 1994). Heuvelink (1999) presents a model for indeterminate tomato crop, where within the plant, individual fruit trusses and vegetative units (three leaves and stem internodes between two successive trusses) are distinguished, and where the initiation rate of new vegetative units and trusses is only dependent on temperature. Daily available biomass is distributed among the total number of sinks per plant, according to their relative sink strength, which is defined as their potential growth rate, relative to the total sink strength of all sinks together (Heuvelink, 1996). It is expected that the reduction of the number of leaves per vegetative unit within a plant will reduce the total vegetative sink strength and hence favor biomass partitioning to the fruits and the fruit yield.

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However, a lower number of leaves on the plant reduces leaf area index (LAI) and may therefore reduce light interception and total biomass production, affecting yield negatively. This adverse effect could be compensated for when assimilate supply is not limited by keeping LAI sufficiently high. Therefore, we hypothesize that in a tomato cultivar with only two leaves between successive trusses assimilate partitioning towards the fruits and therefore yield would be favored, if LAI is kept sufficiently high.

The objective of this study is to investigate the effect of two, instead of three leaves between two successive trusses on dry matter distribution and yield in tomato, in both a simulation study and a greenhouse experiment. Trusses were pruned to constant numbers of fruits per truss, to prevent indirect effects of source strength on dry matter distribution, through flower and/or fruit abortion. To reach the same LAI as in a cultivar with three leaves between trusses and hence counteract negative effects of leaf pruning on total biomass production, delayed leaf removal (in the simulation study) or increased plant density (in the greenhouse experiment) was adopted alternatively.

MATERIALS AND METHODS

Simulation Study

The growth, development and yield of a greenhouse tomato crop is simulated using the photosynthesis-driven model TOMSIM (Heuvelink, 1999). In TOMSIM crop growth results from daily crop gross assimilation rate minus maintenance respiration rate, multiplied by a conversion efficiency. Dry matter partitioning is simulated based on sink strengths of plant organs. Two leaves per truss were simulated by reducing the sink strength of each vegetative unit by 1/3. The simulation started at the flowering of the first truss (10 January) and continued until 7 September. Lowest, old leaves from a vegetative section were removed one week before fruits on the corresponding truss above the section were harvest-ripe. Seven fruits per truss were assumed. Temperature was 20°C, CO_2 concentration was 340 ppm and plant density was 2.5 plants m^{-2}. To avoid the reduction in total biomass production, leaf removal was delayed by 2 weeks (so leaves from a vegetative section were removed one week after the corresponding truss was harvest-ripe). This would compensate for the reduction of average LAI and therefore of total biomass production resulting from the reduced vegetative sink strength.

Greenhouse Experiment

On 24 December 2002, seeds of an indeterminately growing round tomato cultivar *Lycopersicon esculentum* Mill. ‘Capita’ (De Ruiter Seeds, Bergschenhoek, The Netherlands) were sown in trays filled with a commercial potting soil and trays were placed in a 12.8 m x 12 m compartment of the multispan Venlo-type glasshouse of Unifarm (Wageningen, The Netherlands, latitude 52°N). About 2 weeks later, plants were transplanted into rockwool cubes (10 cm x 10 cm x 6 cm), placed on benches and irrigated with an ebb-flood system with a standard nutrient solution (Sonneveld and Straver, 1989). When the first truss reached anthesis (18 February 2003), plants were transferred to another greenhouse compartment, where they were grown on rockwool slabs, placed in containers, and irrigated by a trickle irrigation system, using the same standard nutrient solution (EC: 2.5 dS m^{-1}). Shoots were trained according to the high-wire system (Van de Vooren et al., 1986). The experiment ended on 20 May 2003.

The greenhouse was heated by heating pipes installed just above ground level, fed by a central boiler, temperature setpoint was 18°C (ventilation: 20°C) day and night, and CO_2 concentration setpoint was 350 ppm, when CO_2 concentration dropped below the setpoint, pure CO_2 was supplied. Glasshouse temperature was measured by PT500 elements (Jumo, Fulda, Germany) and recorded every 5 minutes by a commercial VITACO computer system (Hoogendoorn, Vlaardingen, The Netherlands). The 24-h average glasshouse air temperature over the whole growing period was 19.0°C. Fertilization and control of insects and diseases were conducted as described by Moerman et al. (1986). Flowers were pollinated three times a week with the aid of an ‘electric bee’.

The experiment had a randomised block design with three blocks. Each block was divided into three plots, respectively, for three treatments: (1) Control: plants were grown at a density of 2.5 plants m^{-2} (0.8 m between and 0.5 m within-row distance) and no leaf pruning; (2) Leaf pruning: plants were grown at a density of 2.5 plants m^{-2} and leaves were pruned by weekly removal of the second leaf of each vegetative unit between two successive trusses when it was only 1-3 cm long; (3) Leaf pruning & increased density: leaves were pruned as in treatment (2) but plants were grown at higher density of 3.8 plants m^{-2} (0.8 m between and 0.33 m within-row distance), resulting in the same number of leaves per m^2 as in the control.

All plants were pruned to 6 fruits per truss, trusses were initially pruned to seven flowers, and if all of these flowers set the most distal fruit was subsequently removed. From each plot, periodically (every 20-29 days), 2 plants were selected at random for destructive measurements. These plants were surrounded by guard plants. On one of these two guard plants for each selected plant, a side shoot was kept to maintain stem density and to minimize disturbance of light distribution in the crop by destructive measurements. Fresh and dry weights (ventilated oven at 105°C for 15 h for leaves and stems and 30 h for fruits) of leaves (including petioles), stems, individual fruit trusses (including peduncles), removed leaves, picked fruits, and leaf area (LI-COR Model 3100 Area Meter, Lincoln, USA) were determined for each plant. Leaves below the lowest truss still on the plant were removed 8 times (leaves of each vegetative unit were periodically removed each time, except for leaves of the first vegetative unit which were removed in two steps) during the experiment. Fruits were picked two times a week when they reached stage 7 (CBT color scale). Shoot length, total number of visible trusses (> 0.5 cm) and total number of visible leaves (> 0.5 cm) were also recorded. Due to culture in rockwool slabs, measurements on the root system were not feasible.

RESULTS

Simulation Study

According to the model, reduced vegetative sink strength increased dry matter partitioning to the fruits, averaged over the whole 241 days, from 66% to 74% (Table 1). However, yield increased only marginally (1.5%), as average LAI decreased from 2.4 to 1.7 m^2 m^{-2} and hence crop growth rate decreased from 11.8 to 10.7 g m^{-2} d^{-1} and total biomass production was reduced by 9.5% (Table 1). Hence, as increased partitioning to the fruits was counteracted by reduced total biomass production and fruit yield was hardly influenced by reduced vegetative sink strength. Delayed leaf removal, where leaves from a vegetative section were removed one week after the corresponding truss was harvest-ripe, resulted in an average LAI of 2.3 m^2 m^{-2}. As this LAI is almost equal to the control treatment, the same total biomass production was simulated. Yield improved compared to the control (no reduced vegetative sink strength) with 12.8% (Table 1), as dry matter partitioning to the fruits was increased to 74%. Leaf pruning & delayed leaf removal resulted in improved yield because fruits were larger than in the control, whereas number of fruits harvested was not influenced.

Greenhouse Experiment

In control and both treatments each truss consisted of 6 fruits, which was the desired number. Leaf pruning by weekly removal of the second leaf of each vegetative unit between two successive trusses significantly reduced growth rate and therefore total dry matter production (Table 2 and Fig. 1), resulting from a reduction in average LAI (Table 2). Compared to the control, the total dry matter production in the leaf pruning treatment decreased by 11%, as average LAI decreased from 2.9 to 2.4 m^2 m^{-2}. However, fruit dry weight was hardly affected by leaf pruning (Fig. 1 and Table 2), because two instead of three leaves between trusses, increased the biomass allocation to the fruits (Table 2). Leaf pruning significantly increased the cumulative fraction to the fruits, averaged over the whole growth period of 92 days, from 57% to 61% compared to the control.

The reduction of dry matter production could be avoided by increased plant density, which resulted in a higher LAI (Fig. 1B and Table 2). A 50% increase in plant density, combined with leaf pruning, resulted in an average LAI of 3.6 $m^2 m^{-2}$ and in 29% higher biomass production compared to the control. Leaf pruning & increased density unexpectedly resulted in only 58% of dry matter allocated to the fruits. Increasing plant density from 2.5 plants m^{-2} to 3.8 plants m^{-2} decreased dry matter production and fruit yield per plant by 15% and 23%, respectively (Table 2).

Plant development was not influenced by leaf pruning and plant density. At the end of the experiment the number of visible trusses was 13.8, 14.2 and 14.0, and the final plant height was 350 cm, 349 cm and 350 cm for control, leaf pruning and leaf pruning & increased density, respectively. No influence of leaf pruning on the specific leaf area (SLA) was observed, however, increased density resulted in a higher SLA (data not shown). Improved yield in the combination of leaf pruning & increased density was the result of more fruits harvested per unit area, with a lower individual fruit weight compared to the control.

DISCUSSION

Both the simulation study and the greenhouse experiment supported the hypothesis that in tomato with two instead of three leaves between two successive trusses, assimilate partitioning towards the fruits is favored. At constant generative sink strength, leaf pruning, implemented as a 33% reduced vegetative sink strength in the simulation study, significantly decreased total biomass production, but hardly influenced fruit yield. Increased partitioning to the fruits when leaves were pruned was compensated by reduced total biomass production, resulting in the same yield as for the control. The difference in the fraction to the fruits between greenhouse experiment and simulation study mainly results from the number of fruits per truss (6 and 7 fruits per truss for greenhouse experiment and simulation study, respectively), as the generative sink strength is strongly dependent on the number of fruits per truss (Heuvelink, 1997). Another reason for a lower fraction in the experiment is the shorter cultivation period, i.e. 92 days instead of 241 days for the simulation study.

To avoid the reduction in biomass production resulting from leaf pruning, delayed leaf removal and increased plant density are two alternative ways to maintain LAI and hence total biomass production. Dry matter production and fruit yield were increased by 29% and 17%, respectively, by increased density, where LAI was increased from 2.4 to 3.6 $m^2 m^{-2}$ in the greenhouse experiment. However, it was unexpected that LAI for leaf pruning & increased density increased by 50% compared to that of the treatment of leaf pruning alone. Heuvelink (1996) reported an increase in average LAI of only 12% when plant density increased from 2.1 plants m^{-2} to 3.1 plants m^{-2}. In the simulation study, delayed leaf removal resulted in identical total biomass production and improved fruit yield with 12.8% compared to the control (no reduced vegetative sink strength) where LAI was increased from 1.7 to 2.3 $m^2 m^{-2}$ in the simulation study. In the model, source strength (assimilate supply) has no direct influence on biomass partitioning, which is based on Heuvelink (1999). Therefore, delayed leaf removal did not influence partitioning (Table 1). Hence, it was also expected that leaf pruning and leaf pruning & increased density would result in the same biomass partitioning. However, partitioning to the fruits was 61% and 58%, respectively; although not statistically significant, this difference was unexpected. On the one but last destructive harvest date, partitioning to the fruits was as expected 55% and 54%, respectively.

It is concluded, based on simulation results and experimental data, that a tomato cultivar with 2 instead of 3 leaves between trusses would improve yield, when combined with measures to keep LAI sufficiently high.

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Tables

Table 1. Average LAI, growth rate, total and fruit dry weight, and fruit fraction in the simulation study for three treatments.

Treatments	LAI (m^2 m^{-2})	Growth Rate (g m^{-2} d^{-1})	Total dry weight (g m^{-2})	Fruit dry weight (g m^{-2})	Fruit fraction (%)
Control	2.4	11.8	3190	2093	66
Leaf pruning	1.7	10.7	2887	2125	74
Leaf pruning & delayed leaf removal	2.3	11.8	3201	2362	74

Table 2. Average[1)] LAI, growth rate, total and fruit dry weight, and fruit fraction in the greenhouse experiment for three treatments.

Treatments	LAI (m^2 m^{-2})	Growth Rate (g m^{-2} d^{-1})	Total dry weight (g m^{-2})	Fruit dry weight (g m^{-2})	Fruit fraction (%)
Control	2.9 b	12.8 b	1210 b	668 a	57 a
Leaf pruning	2.4 a	11.4 a	1083 a	639 a	61 b
Leaf pruning & increased density	3.6 c	14.7 c	1395 c	781 b	58 ab

[1)]Means within a column, followed by different letters, are significantly different according to Student's t-test at P=0.05.

Figures

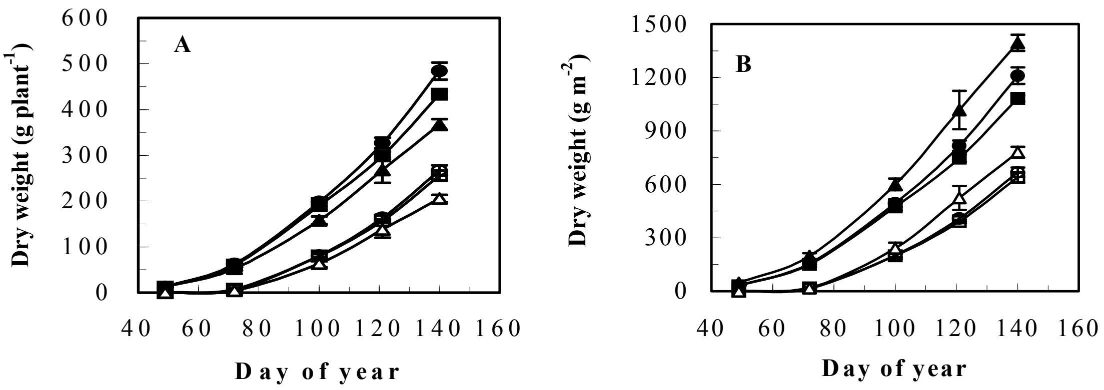

Fig. 1. Measured total (●, ■, ▲) and fruit (○, □, Δ) dry weight (A, per plant; B, per square meter) as a function of day of the year (Day 1 is 1 January) for tomato in three treatments: (●, ○) control, (■, □) leaf pruning and (▲, Δ) leaf pruning & increased density, respectively. Vertical bars indicate standard error of mean larger than symbols.