PLANTING-DENSITY OPTIMIZATION STUDY FOR TOMATO FRUIT SET AND YIELD BASED ON FUNCTIONAL-STRUCTURAL MODEL GREENLAB

Lili Yang[1], Yiming Wang[1,*], Qiaoxue Dong[1]
[1] *College of Information and Electrical Engineering, China Agricultural University, Beijing, P. R. China 100083*
[*] *Corresponding author, Address: College of Information and Electrical Engineering, China Agricultural University, 100083, Beijing, P. R. China, Tel: +86-010-62737824, Fax: +86-010-62737842, Email:ym_wang@263.net*

Abstract: Quantification of tomato's fruit-sets depends on the level of competition for assimilate in different environment, and this paper presented some results of fruit yield and quality (fruit size) in response to environment（mainly respect to and planting-density and light）. Some experiments had been carried out to find the relationship between growth rules of tomato and plant densities A structural-functional model GREENLAB has been developed to simulate it. The results show that increasing plant density results in an increment of biomass production on a ground area but in a reduction of single plant fresh weight. To find rules between organ sink and source relationship, calibrations were made based on the target data of different plant density in the model. Environmental conditions were introduced into the model checking the influence on Q/D over plant growth period and fruit set ratio. It is found that changing the Q/D ratio in some critical periods can be used to optimize fruit set and yield of greenhouse tomato.

Keywords: tomato, structural-functional model, fruit set, sink and source, yield and quality.

1. INTRODUCTION

In spite of rapid developments in recent years, greenhouse environment control and cultivated management practices in China are still lower than in developed countries. This results particularly in lower yield and inferior quality of Chinese products as compared to the standards of international market (Heuvelink,2005). The development of tools, which allow optimizing greenhouse climate and management practices in order to maximise yield and quality are thus highly desirable and encouraged.

Crop growth models coupled with greenhouse climate represent the most promising approach to fulfil these objectives. Concerning tomato, several authors have proposed mechanistic models predicting growth and development through a set of equation describing the main physiological functions involved in carbon balance (TOMGRO: Jones et al.,1991; TOMSIM: Heuvelink,1999). These models have demonstrated their ability to simulate productivity and yield in various conditions but present the main drawback of being rather complicated to use in optimization procedure. The mathematical model GREENLAB (Guo et al.,2006) is a structural-functional model, which describes the plant architecture at the organ level, simulates resource dependent plasticity of this architecture and allows to computing plant geometry. Contrary to the previous attempts this model is particularly designed to be used in optimization. It has been shown that relative strength of fruits influences both yield and quality (Guichard et al.,2001), yield and quality was considerably affected by planting density and light conditions. In the current version, fruits are described as a whole at the truss scale. In this study the GREENLAB-Tomato model will be parameterized for different homogenous planting densities.

2. MATERIALS AND METHODS

2.1 Experimental design

The studies are based on experiments and measurements on tomato (Solanum Lycopersicum L.,'ZhongZa 9'). Plants were grown in regularly spaced 7-L pots in solar green house at the Chinese Academy of Agricultural Science in Beijing（39.55N, 116.25E）.Two experiments are designed. The first experiment (exp1) intends to verify potential growth assumption, the secondary experiment (exp2) studies the relationship between tomato growing conditions in green house and fruit set, the environment condition respects to light mainly.Exp1 was repeated twice with same density

（3plants/m2） in autumn of 2006 and spring of 2007,we pruned fruits and left the first fruit set from the first truss in 2006,the first fruit set from the second truss in 2007.Exp2 was repeated twice in spring of 2007 and autumn of 2007 with four densities (Table 1) each, no irrigation and fertilization stress, plots of 30 plants were surrounded by two rows of guard plants, when a plant was destructively harvested, it was replaced by a comparable plant in order not to disturb the light distribution among the plants, detailed topological observation were made throughout the development of the plants. Additionally, meteorological data (PAR, temperature, humidity stored by Galileo-LPS 2000 Data-logger) to parameterize the model and number of flower buds initiation, flowers, fruit sets (Φ>10mm) to characterize fruit development were recorded during growth and development of plant.

Table 1. plant density treatment design

treatment	plants/m^2
High density (hd)	11
High-intermediate density(md1)	6
Intermediate density(md2)	3
Low density(ld)	1

2.2 Model description

There are two biological laws used in GREENLAB model, Firstly, the organs production of plants are linked proportionally to the sum of temperatures, the thermal time relates to a new metamer named as “growth cycle”. Secondly, the biomass production is linearly correlated with the water transpiration (Potential Evapotranspiration: PET)(FAO guidelines; Allen et al.,1998). Main equations of GREENLAB:

The ith cycle total matter production is

$$Q(i)=\frac{E(i)S_p}{r_1r_2}\left(1-\exp\left(-r_2\frac{\sum_{j=1}^{n(i)}S_j}{S_p}\right)\right) \tag{1}$$

Where: Q(i) is the matter production during the cycle i, E(i) is growth potential during the ith growth cycle, Sp is the projection surface of one plant, r1 is blade resistance, r2 is a competition factor, leaf overlapping effect on PET, $\sum_{j=1}^{n(i)}S_j$ is total leaves surface at ith growth cycle.

$$E(i)=0.91*PET(i) \tag{2}$$

Where: PET(i) is Potential Evapotranspiration at ith growth cycle, used FAO-radiation Equation, 0.91 is an optimized parameter.

J aged organ at plant ith cycle biomass increment is

$$\Delta q_o(i,j)=\frac{P_o\cdot f_o(j)}{D(i)}\cdot Q(i-1) \tag{3}$$

Where: $\Delta q_o(i,j)$ is j aged organ o(o=internode, blade, petiole, fruit, root, layer) at ith growth cycle increased biomass, Po is organ sink, fo(j) is organ sink variation function(beta law), $\sum_{j=1}^{i} f_o(j)$ =1, i is organ expansion duration.

Demand of plant at ith growth cycle is

$$D(i)=\sum_{o=b,p,e,f} P_o.\sum_{j=1}^{i} f_o(j) \tag{4}$$

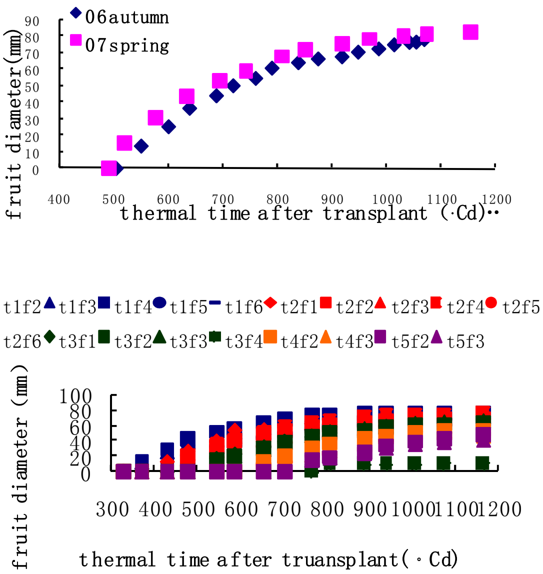
Where: D(i) is plant demand at ith growth cycle

In model parameters are divided two groups: directly measurable group and hidden group, first group like organs geometry, function time of leaves, organ's expansion time etc, second group calibrated from directly measurable one like: Po, fo, r1, r2. Some target files got by destructed experiment in several growth stages for all the organs are used to multi-fitting to get hidden parameter, The sink strength of the blade(Pblade) is set to 1 as a reference.

3. RESULTS AND DISCUSSION

3.1 At same density, individual fruits display a determinate growth, all fruit have same potential sink strength

Potential growth is defined by the growth which would be realized if no factor is limiting, that is, when assimilate supply is higher than or equal to assimilate demand (Bertin, 1995). Fig.1 shows that at same density individual fruit growth curves is similar between exp1 and exp2, individual fruits are likely to display a determinate growth, different source did not result in different final maximum fruit growth biomass, and the final fruit size may reach a extreme, while fruit abortion favor assimilation distribution towards the vegetative plant parts (Marcelis, 2004), not fruit. Fig.2 shows that delay between set remains constant. The delay between position of the truss on the stem and position of the fruit within the truss result in gradient of attract biomass ability. It is to say at one density every fruit behave the same but at different moments. This means same sink, same expansion time and expansion rule but different apparition time, so a single set of sink parameters is able to represent all fruit for one density.



(b)

Fig 1: fruit diameter development with one fruit per plant in exp1(a) and with all fruits reserved in exp2(b) in same density(3p/m ^{2})
tx is truss number on stem above cotyledon , fy is fruit number from base on one truss, absence is no fruit on this position.

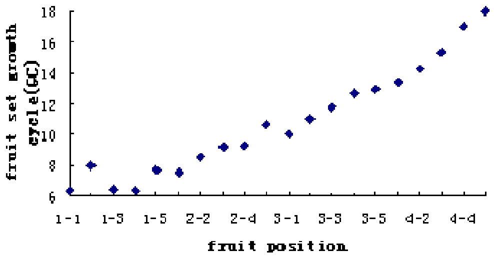


Fig 2: The fruits set growth cycle in each trusses

3.2 Multi-fitting results on the hidden parameters for different density

Where: Ppetiole ,Pinternode , Pfruit are organ sink of the petiole, the internode and the fruit , bblade , bpetiole , binternode , bfruit are parameter b of extension beta-law function for each organ type, another function parameter a is constrained to 2.Fit results show that the sink of organs changes with density increase, For fruit, the higher the density is, the lower the sink will be, while for internode, the result is reverse. This is consistent with the observation: in high density, the internode is longer than in low density, but the fruit is smaller.

Table2. hidden parameters for different density

parameter	LD	MD1	HD
$Q(0)$	0.08	0.08	0.08
$P_{petiole}$	0.6	0.7	0.8
$P_{internode}$	0.5	0.6	0.8
P_{fruit}	14	13	11
b_{blade}	2.3	2.2	2.4
$b_{petiole}$	2.2	2.7	2.6
$b_{internode}$	1.8	2	1.9
b_{fruit}	4	8	9

3.3 Different yield in different plant density result from environmental conditions action on Q/D

Increasing plant density results in an increase of biomass production on a ground area but in a reduction of single plant fresh weights（Fig.3）. Environmental conditions act on Q/D on plant growth（Fig.4）, the number of developing fruits is the overall result of the flowering rate, the number of flowers initiated per truss and the incidence of abortion of flower buds, flowers and fruits (Koning, 1994).To find rule between Q/D during critical periods and initiation bud number, flowering rate, fruit set rate, calibration is done on data of different plant densities in the model (Table 3,4,5).

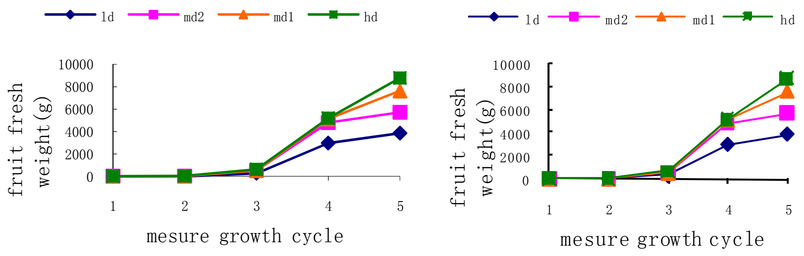


Fig. 3: tomato fruit fresh weight on one plant and one centiare in different density

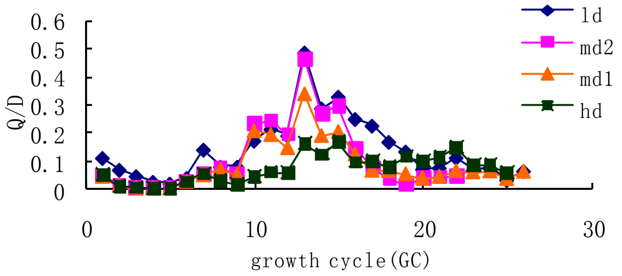


Fig.4: Q/D ratio over the plant growing period

Table 3: Q/D during GCs of bud initiation and the number of initiated flower buds

treatment	Q/D	Init Flower buds per truss
ld	0.09	6.1
md2	0.07	6
md1	0.04	5.8
hd	0.02	5.7

Table 4: average Q/D of GCs between 50% bud emergence and 50% flowering with flowering rate

treatment	Q/D	flowers	Flower rate
ld	0.29	5.8	95%
md2	0.29	5.8	96%
md1	0.21	5.5	95%
hd	0.1	5.1	89%

Table5: average Q/D of GCs between 50% flowering and 50% fruit set with fruit set rate

treatment	Q/D	Fruits per truss	fruit set
ld	0.29	4.4	75%
md2	0.17	4.2	72%
md1	0.15	3.7	67%
hd	0.11	2.8	55%

To contrast the Q/D of GCs of bud initiation with the number of initial flower buds, we average Q/Ds values during this period which last several GCs from the first flower bud emergence on one truss to the number of flower bud being stable for four densities each. Result showed that increasing density tends to reduce initial bud number (though difference is not distinct). This is consistent with the trend of average Q/D of GCs during bud initiation (Table 3). We define average Q/D of GCs between 50% bud emergence and 50% flowering as flowering rate, average Q/D of GCs between 50% flowering and 50% fruit set as fruit set rate. Table 4 and table 5 show reductions in average Q/D of corresponding GCs could be related to the decrease of flowering rate and fruit set rate.

4. CONCLUSION

Individual fruits display a determinate growth, so a single set of sink parameters is able to represent all fruits in same density, there are gradients for one organ sink parameter in different densities. GREENLAB-Tomato model can represent it.

Density reflects different environment factors, increasing densities strongly reduce individual plant biomass, the initial bud number, flowering rate, fruit set rate. In high density, the fruit is smaller than in low density, but the leaf and internode are bigger. This can be explained by competition for assimilation among organs: the change of Q/D ratio in critical periods may change the ratio between vegetative growth and reproductive growth, which can be done through optimizing greenhouse climate control. Greenlab can fit the resource-dependent phenotypic plasticity induced by plant spacing and light availability

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