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Abstract: 【Objective】 In order to quantify the yield formation of protected tomato, 【Method】 the field experiments on varieties and fertilizer were conducted in 2009 and 2010, and cultivars: (B1) American mole 1 (early maturing), (B2) Chaoshijifanqiedawang (late maturing), and (B3) American 903 (medium maturing) were adopted; The models of dry matter production and yield formation for protected tomato were built by analyzing the relationships between yield and the number of fruit letting and the mean fruit weight, between yield and biomass and the economic coefficient at harvest, and between the mean fruit weight and economic coefficient and biomass of different varieties and fertilizer levels in accordance with the theory of yield formation. Independent experiments data was used to validate the models. 【Result】 The results showed that root mean squared error (RMSE), mean absolute error (X_{de}), and the determined coefficient (R^2) between the simulated and measured values of dry matter production was 363.135kg/ha (n=63), 79.016kg/ha, and 0.900, respectively, and RMSE, X_{de}, and R^2 between the simulated and measured values of yield based on yield components was 186.842g per plant (n=36), -1.069g per plant, and 0.854, respectively, and RMSE, X_{de}, and R^2 between the simulated and measured values of yield based on economic coefficient was 137.302g per plant (n=27), 21.170g per plant, and 0.785, respectively.【Conclusion】 It indicated that the dry matter production and yield formation under different varieties and fertilizer levels for protected tomato could be well simulated by these models.

Key words: protected tomato; dry matter production; yield formation; biomass; economic coefficient; models

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1. Introduction

Crop growth models are one of the powerful tools to support the optimum regulation for production environment and cultivation management of the protected crops, and tomato is one of the main protected crops [1]. So, it has an important role in the digital regulation management of protected tomato production to build yield formation models. Nowadays, there have been many reports on the yield formation models of field crops, however, the research of protected crops is not more [2-4], and the most reports about tomato yield were research on the relationships between yield formation and environmental factors in cultivation physiology and cultivation practice. For example, Song et al. [5] researched the tomato yield formation rules and its correlation to the environmental factors in modern greenhouse, Liu et al. [6] studied effects of soil moisture stress on greenhouse tomato yield and its formation under drip irrigation, Chen [7] built the simulation models of relationship between individual plant yield and physiological development time. However, the models were with more empirical, less mechanistic. Ni et al. [8] established the models of greenhouse tomato dry matter partition and yield prediction based on relationships between partitioning coefficient and harvest index and product of radiation by quantity of heat, and tested by various varieties, substratum, and sites, which had high precision and less parameters. Yang [9] studied the influence of growth environments on tomato fruits yield using the functional structural plant models, GreenLab, based on source-sink relationship with greenhouse environment factors such as temperature, humidity, light intensity, and so on. These models were more suitable for protected greenhouse, but less suitable for the environments of plastic shed. The objective of this research was to simulate protected tomato yield formation under various varieties and fertilization levels based on yield components factors and economic index, build protected tomato dry matter production and yield formation simulation models in accordance with the principle of yield formation, and provide a theoretical basis for growth and yield prediction as well as cultivation management and environment regulation of protected tomato.

2. Materials and Methods

2.1 Materials

This study used 3 tomato cultivars representing wide variation in maturing characteristics, and they are: (B1) American mole 1 (early maturing, determinate growth type, good disease resistance, growth period 100～110days), (B2) Chaoshijifanqiedawang (late maturing, sub-determinate growth type, super large fruit type, growth period 109～119days), and (B3) American 903 (medium maturing, determinate growth type, strong growth, growth period 106～116days).

2.2 Methods

The experiments were conducted in plastic shed with 80m long, 9.8m width, and horse liver soil (the total nitrogen, 0.239 g/Kg; total phosphorus, 1.297 g/Kg; available phosphorus, 202 mg/Kg; and pH, 6.344 in pre-planting in soils) at Suoshi village in Nanjing from July to October of 2009 and from March to June of 2010. The experiments was a split plot design with three whole-plot treatments arranged in a randomized complete block design with three blocks and three sub-plot treatments. The whole-plot factors were the fertilizer levels: A1 (CK: 1/2 F_N), A2 (Normal: F_N), and A3（High fertilizer:

3/2 F_N), and the sub-plot factors were varieties (B1, B2, and B3), with 3 replications and 27 plots (2.96×4.6m^2). F_N was the normal fertilizer level: compound fertilizer (N:P:K=16%:16%:17%) 750 kg·ha^{-1}, in that 40 percent of this fertilizers was basal, 60 percent was top dressing applied in early fruit stage and maximum fruit number stage. The planting density was 3-4 plants/m^2, and the other cultivation practices were the same as the conventional high yield field.

2.2.1 Data Acquisition

After planting, the representative samples were taken every 7d from seedling to flowering and every 14d during fruit period. Three representative plants selected in each treatment were separated into organs after determining fruits number, dried in 30 min. at 105℃, then at 80℃ until reaching a constant weight, measured using a 0.001 g electro-level, and leaf area was determined by method of dry weight.

HOBO-H8 was placed in three different positions in the plastic shed to collect environment elements automatically every 10 s, including air temperature, relative humidity and dew point, the absolute humidity, and light intensity, etc. In that average values every 15 minutes were recorded.

At the main growth period of tomato, ECA-PB0402 was used in measuring photosynthetic rate (including CO_2 concentrations, relative humidity (RH), canopy temperature (TC), leaf temperature (TL), net photosynthetic rate (Pn), and photosynthetically available radiation (PAR), etc.) of the top three leaves on plants tagged in each treatment around midday. According to the data, light response curve was made, and the max photosynthetic rate value (Pmax) was confirmed.

2.2.2 Data treatments

In this study, Excel.2007and SigmaPlot V 10.0 were used to analysis experimental data. The experiment data in 2009 were applied to model establishment and parameter determination, and the experiment data in 2010 were applied to model verification.

2.2.3 Model verification

Simulation values were calculated using Visual C++6.0, and model precision was verified using root mean squared error (RMSE), mean absolute error (X_{de}), the determined coefficient (R^2), and 1:1 plotting between measured values and simulated values. If X_{de} and RMSE were smaller and R^2 was larger, the simulated values were better agree with measured values, i.e. the deviation between simulated values and measured values was smaller, and simulation results of model were more accurate and reliable. The calculation formula of RMSE and X_{de} can be expressed as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(OBS_i - SIM_i)^2}{n}}$$

$$de = |OBS_i - SIM_i|$$

$$X_{de} = \frac{\sum de}{n}$$

where OBS_i is measured values, SIM_i is simulated values, de is absolute error, and n is sample numbers.

3 Results

3.1 Model Description

3.1.1 Dry matter production simulation of protected tomato

3.1.1.1 The calculation of leaf photosynthetic rate

The leaf photosynthetic rate was expressed by negative exponential model [10-13]:

$$Pg = P_{max} \times \left[1 - e^{\left(\frac{-\varepsilon \times PAR}{P_{max}}\right)}\right] \quad (1)$$

where Pg is leaf photosynthetic rate in kg $CO_2 \cdot ha^{-1} \cdot h^{-1}$, Pmax is single leaf maximum photosynthetic rate in kg $CO_2 \cdot ha^{-1} \cdot h^{-1}$, with the ranges from 20 to 50 kg $CO_2 \cdot ha^{-1} \cdot h^{-1}$ at the weak light and usual carbon dioxide concentration in greenhouse, and it was 37 kg $CO_2 \cdot ha^{-1} \cdot h^{-1}$ in accordance with the observation data. ξ is the initial slope of photosynthesis-light responsive curve, called initial light utilized efficiency in kg $CO_2 \cdot ha^{-1} \cdot h^{-1}/J \cdot m^{-2} \cdot s^{-1}$, in other words, at the early stage of leaf received light, the quantity of carbon dioxide fixed by unit area leaf in ha when it absorbed $1 J \cdot m^{-2} \cdot s^{-1}$ PAR at unit time in h, and it was always regarded as a constant under the weak light of greenhouse [10, 14, 15]. ξ equals to 0.40 kg $CO_2 \cdot ha^{-1} \cdot h^{-1}/J \cdot m^{-2} \cdot s^{-1}$ [16], and PAR is photosynthetically active radiation in this paper in $J \cdot m^{-2} \cdot s^{-1}$.

3.1.1.2 The calculation of canopy photosynthesis

Canopy photosynthesis is the total photosynthesis of all plant leaves on unit area. According to the research of Goudriaan [13, 17], Gauss Integral was applied to compute the canopy photosynthesis rate in this paper, and it can be calculated as follows:

$$LGUSS_i = DIS_i \times LAI \; (i = 1,2,3) \quad (2)$$

$$L_i = PAR \times k \times e^{(-k \times LGUSS_i)} \quad (3)$$

$$Pg_i = P_{max} \times \left[1 - e^{\left(\frac{-\varepsilon \times L_i}{P_{max}}\right)}\right] \quad (4)$$

$$Pg_t = \sum (Pg_i \times WT_i) \times LAI \quad (5)$$

$$DTGA = Pg_t \times DL \quad (6)$$

where $LGUSS_i$ is canopy depth of gauss layer, DIS_i is distance coefficient of gauss integral (table 1), LAI is leaf area index, i is layer number of canopy layers, L_i is the quantity of PAR of arriving the i^{th} layer, k is the extinction coefficient of canopy (it equals to 0.8[16] in this paper), Pg_i is the instantaneous photosynthesis rate of the i[th] layer in kg $CO_2 \cdot ha^{-1} \cdot h^{-1}$, Pg_t is the instantaneous photosynthesis rate of all canopy at the time of t in kg $CO_2 \cdot ha^{-1} \cdot h^{-1}$, WT_i is weight of gauss integral (table 1), DTGA is the total photosynthetic amount of one day in kg$CO_2 \cdot ha^{-1} \cdot d^{-1}$, and DL is day length in h.

Table 1. The Gaussian weight and distances for the method of 3 points [16]

i	1	2	3
DIS_i	0.1127	0.5000	0.8873
WT_i	0.2778	0.4444	0.2778

3.1.1.3 The simulation of protected tomato leaf area index (LAI)

The protected tomato LAI continuously increased with the adding of biomass in accordance with the data in 2009, and it's changes like as power function (Fig.1).

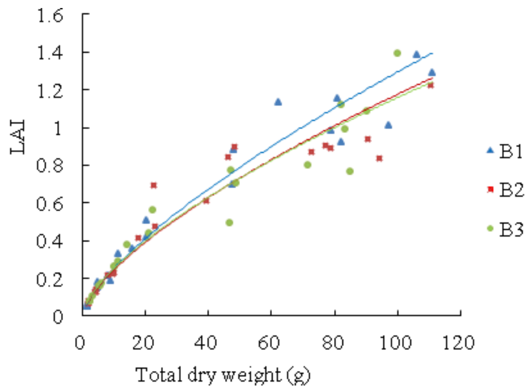

Fig.1. The relationship between leaf area index and biomass for different varieties

The figure 1 showed: LAI of B1, B2 and B3 continuously increased as a power function with the raising of per plant biomass, and during growth and development of B2 (late maturing) and B3 (medium maturing), the changes in LAI were almost the same, B2 was appreciably higher than B3, and the two obviously lower than B1(early maturing). With the further raising of biomass, LAI of three protected tomato varieties also tended to stable.

According to the relationship between LAI and per plant biomass of protected tomato, the changes in LAI with the per plant biomass of different protected tomato varieties can be expressed as follow:

$$LAI = a_1 \times DW^{b_1} \tag{7}$$

where a_1 and b_1 are parameters, and DW is total dry matter weight of per plant. All parameters and its statistical test are showed in table 2.

Table 2. Analysis of variance for LAI models and its coefficient test

Varieties	Correlation coefficient	F	a1	b1
B1	0.984**	439.226**	0.067**	0.630**
B2	0.971**	262.439**	0.083**	0.554**
B3	0.971**	234.101**	0.058**	0.650**

Note: *P<0.05 and **P<0.01, the follows were as the same.

3.1.1.4 The calculation of respiration

Respiration includes maintenance respiration and growth respiration generally. The former is the energy needed by living organism maintaining its normal biochemical and physiological process, and it can be computed by formula (8) in accordance with the research of Spitters et al. [17]. The later is the energy needed by organic matter synthesis, plant growth as well as metabolism consumption in plant, in other words, it is partial photosynthesis consumed in the process of carbon dioxide translating into CH_2O, and it is considered at the formula (9) for calculating dry matter increment.

$$Rm = Rm(T_{25}) \times W \times 2^{\frac{T-25}{10}} \tag{8}$$

where Rm is consumption of plants maintenance respiration in kg $CH_2O \cdot ha^{-1} \cdot d^{-1}$, Rm ($T_{25}$) is the maintenance respiration coefficient at 25℃ (it equals to 0.015 kg $CH_2O \cdot kg^{-1}DM \cdot d^{-1}$ [17] in this paper), W is the total dry matter weight in kg $DM \cdot ha^{-1}$, and T is daily average temperature in ℃.

3.1.1.5 The calculation of dry matter production

Dry matter increment can be expressed as follow:

$$\Delta W = \frac{30/44 \times DTGA - R_m}{ASRQ} \times F(N) \tag{9}$$

where ΔW is dry matter increment in kg $DM \cdot ha^{-1} \cdot d^{-1}$, ASRQ is the conversion coefficient which is from CH_2O to dry matter (it equals to 1.43 kg $CH_2O \cdot kg^{-1}DM$ [17] in this paper), 30/44 is the molecular weight conversion coefficient which is from CO_2 to CH_2O, DTGA is daily total photosynthate in kg $CO_2 \cdot ha^{-1} \cdot d^{-1}$, F(N) is nitrogen influencing factor, and it can be computed as follows [18-19]:

$$F(N) = (SN + CKN + RFN \times CURN)/TNP \tag{10}$$

$$SN = Nc \times \gamma \times H \times \left(\frac{1-\delta_{2mm}}{100}\right) \times 10^{-1} \tag{11}$$

$$CURN = (NBY - NCK)/RFN \tag{12}$$

where SN and Nc are the 0-30cm topsoil total nitrogen storage in $g \cdot m^{-2}$ and content in $g \cdot kg^{-1}$, respectively; CKN is the nitrogen rate of CK in $kg \cdot ha^{-1}$ (it equals to 60 $kg \cdot hm^{-2}$ in this paper), RFN is nitrogen rate in $kg \cdot ha^{-1}$ (it includes high nitrogen level and normal nitrogen level), the compound fertilizer amount of high fertilizer, CK, and the normal levels is 1125 $kg \cdot ha^{-1}$, 375 $kg \cdot ha^{-1}$, and 750 $kg \cdot ha^{-1}$, respectively (nitrogen rate is 180 $kg \cdot ha^{-1}$, 60 $kg \cdot ha^{-1}$, and 120 $kg \cdot ha^{-1}$, respectively), TNP is nitrogen requirement of high yield level (it equals to 189.321 $kg \cdot ha^{-1}$ in this paper). γ is the bulk density (1.3 $g \cdot cm^{-3}$), H is the thickness (30 cm), and δ 2mm is the <2mm fraction (%) of soil. CURN is nitrogen use efficiency (%). NBY and NCK is the nitrogen absorbed by tomato plant at the RFN and CK levels in $kg \cdot ha^{-1}$, respectively.

The total biomass on any day can be computed by initial dry matter and daily dry matter increment, ΔW , and the formula was follow:

$$Biomass_{i+1} = Biomass_i + \Delta W \tag{13}$$

where $Biomass_{i+1}$ is the total dry matter of the $(i+1)^{th}$ day in kg DM·ha^{-1}, $Biomass_i$ is the total dry matter of the i^{th} day in kg DM·ha^{-1}.

3.1.2 Yield formation models for protected tomato

3.1.2.1 The model of yield formation for protected tomato based on the method of yield component

The yield formation of protected tomato can be determined by per plant fruit number and mean fruit weight. Therefore, the model of yield formation for protected tomato can be expressed as follow:

$$Y = FN \times MFW \tag{14}$$

where Y is per plant yield, FN is per plant fruit number, and MFW is mean fruit weight.

(1) The model of per plant fruit number for protected tomato

Individual plant fruit number (FN) is the result of balance between per plant potential fruit number (PFN) and per plant fruit abscission number (DFN). Therefore, it can be computed as follow:

$$FN = PFN - DFN \tag{15}$$

where PFN can be estimated by per plant flower number (FLN) and the ratio of FN to total flower number per plant (PFLN), and the formula is as follow:

$$PFN = FLN \times PFLN \tag{16}$$

where FLN can be estimated by per plant bud number (BN) and the ratio of PFLN to total bud number per plant (PBN), PFLN can be computed by FN and per plant maximum flower number (FLNMAX), and FLNMAX is a variety parameter. Therefore, FLN and PFLN can be computed respectively as follows:

$$FLN = BN \times PBN \tag{17}$$

$$PFLN = FN/FLNMAX \tag{18}$$

where BN can be decided by varieties and environment factors, and PBN can be computed as follow:

$$PBN = FLN/BNMAX \tag{19}$$

where BNMAX is per plant maximum buds number, can be regarded as a variety parameter.

It has been analyzed in the other paper because of its complexity.

(2) The model of mean fruit weight for protected tomato

The protected tomato mean fruit weight continuously increased with the raising of biomass in accordance with the data in 2009, and it’s increasing was the same as a power function (Fig.2).

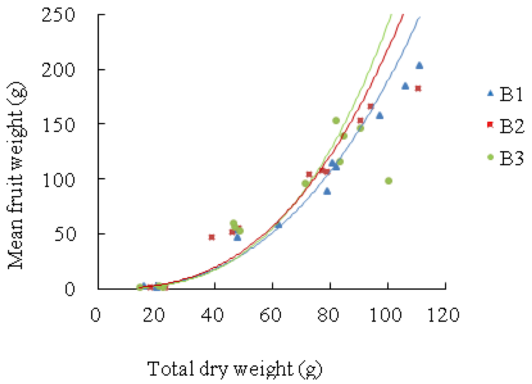

Fig.2. The relationship between mean fruit weight and biomass for different varieties

The figure 2 showed: when per plant biomass of B1, B2, and B3 all achieved about 14g, it started to set fruit, and changes in mean fruit weight of three varieties with per plant biomass were basically similar, and the same as a power function. However, the growth rate and extreme value were different obviously, all in all, medium maturing B3>late maturing B2>early maturing B1, the maximum mean fruit weight of B1 and B2 were similar (about 200g), and all higher than B3 (about 160g).

According to the relationship between mean fruit weight and per plant biomass of protected tomato, the changes in mean fruit weight with the per plant biomass of different protected tomato varieties can be expressed as follow:

$$MFW = a_2 \times DW^{b_2} \tag{20}$$

where DW is dry weight in per plant, it is computed section 3.1.2.2, a_2 and b_2 are all parameters. All parameters and its statistical test are showed in table 3.

Table 3. Analysis of variance for the mean fruit weight models and its coefficient test

Varieties	Correlation coefficient	F	a_2	b_2
B1	0.952^{**}	378.588^{**}	$1.321\times10^{-3*}$	2.579^{**}
B2	0.908^{**}	779.857^{**}	$3.785\times10^{-4*}$	2.903^{**}
B3	0.923^{**}	53.586^{**}	$1.102\times10^{-3*}$	2.649^{**}

3.1.2.2 The model of yield formation for protected tomato based on economic coefficient method

Economic coefficient was a vital standard to measure crop yield, and tomato yield simulation model based on economic coefficient method was expressed as follow:

$$Y = DW \times EC \tag{21}$$

where Y is yield per plant, DW is biomass per plant and EC represents economic coefficient per plant at harvest.

(1) The per plant biomass model for protected tomato

The formation of biomass per plant was the joint action of photosynthesis and respiration of protected tomato. And its model could be expressed as follow:

$$DB_{i+1} = DB_i + \Delta DW \tag{22}$$

where DB_{i+1} and DB_i were total dry weight per plant in the $(i+1)^{th}$ day and the i^{th} day, respectively, ΔDW is increment of dry weight per plant. In that the harvest date of protected tomato in 2010 field trials was from 2 to 6 July.

(2) The calculation of per plant economic coefficient for protected tomato

Economic coefficient per plant is an important index for crop production. It can be calculated as follow:

$$EC = Y/DW \tag{23}$$

where EC is economic coefficient per plant, Y is mean yield per plant and DW is biomass per plant at harvest. Economic coefficient per plant of treatments showed in table 4. According to table 4, B3 had a higher economic coefficient per plant than B1 and B2 under different fertilizer levels. As the raising of fertilizer rate, the highest economic coefficients of B1 and B2 can be gained at medium fertilizer levels, while B3 was at high fertilizer level.

Table 4. The economic coefficient of different treatments in 2009

Treatments	A1B1	A1B2	A1B3	A2B1	A2B2	A2B3	A3B1	A3B2	A3B3
Economic coefficient	12.840	11.576	18.424	15.710	12.366	16.879	12.992	10.780	19.671

3.2 Model verification

3.2.1 The model verification of population dry matter production for protected tomato

3.2.1.1 The model verification of population dry matter production for protected tomato

The population dry matter production model was verified by independent data in 2010 (Fig.3). The figure 3 showed: RMSE, X_{de}, and R^2 of between the measured and simulated values for protected tomato population dry matter were 363.135kg/ha (n=63), 79.016kg/ha, and 0.900, respectively. The correlation coefficients (r) was 0.949 ($r_{0.01\ (61)}$ =0.322) with 0.01 significant level. Therefore, the measured values agree well with the simulated values.

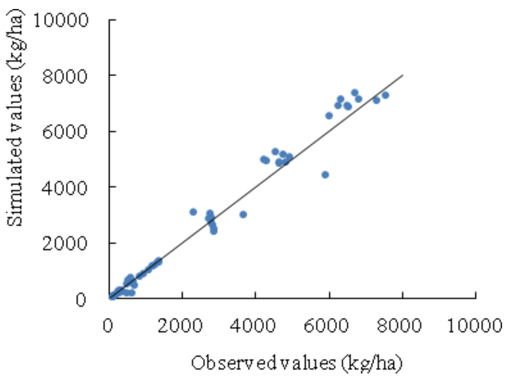

Fig.3. The 1:1 plotting comparison between observed and simulated total dry weight for protected tomato population

3.2.1.2 *The model verification of LAI for protected tomato*

The leaf area index model was verified by independent data in 2010 (Fig.4). The figure 4 showed: RMSE, X_{de}, and R^2 of between the measured and simulated values for LAI of different protected tomato B1, B2, and B3 were 0.144 (n=24), 0.051, and 0.868; 0.109 (n=24), 0.048, and 0.912; 0.137 (n=24), 0.051, and 0.894, respectively. The correlation coefficients (r) were 0.932 ($r_{0.01\ (22)}$ =0.517), 0.955 ($r_{0.01\ (22)}$ =0.517), and 0.946 ($r_{0.01\ (22)}$ =0.517) with 0.01 significant level, respectively. Therefore, the measured values agree well with the simulated values.

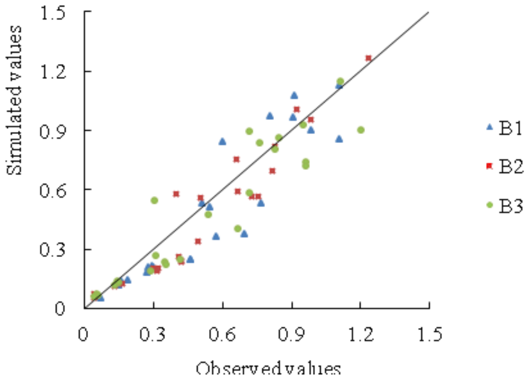

Fig.4. The 1:1 plotting comparison between observed and simulated LAI values

3.2.2 The model verification of yield formation for protected tomato

3.2.2.1 *The model verification of yield formation for protected tomato based on the method of yield component*

(1) The model verification of yield formation for protected tomato based on the method of yield formation

The yield formation model was verified by independent data in 2010 (Fig.5). The figure 5 showed: RMSE, X_{de}, and R^2 of between the measured and simulated values for protected tomato yield formation were 186.842g per plant (n=36), 1.069g per plant, and 0.854, respectively. The correlation coefficients (r) was 0.924 ($r_{0.01\ (34)}$ =0.424) with 0.01 significant level. Therefore, it had better consistency between the measured and the simulated values.

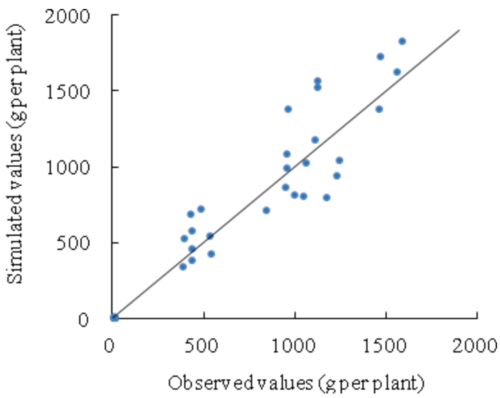

Fig.5. The 1:1 plotting comparison between observed and simulated Y values

(2) The model verification of mean fruit weight for protected tomato

The mean fruit weight model was verified by independent data in 2010 (Fig.6). The figure 6 showed: RMSE, X_{de}, and R^2 of between the measured and simulated values for mean fruit weight of different protected tomato B1, B2, and B3 were 10.308g (n=12), 3.806g, and 0.768; 9.434g (n=12), 0.625g, and 0.932; 8.402g (n=12), 0.524, and 0.819, respectively. The correlation coefficients (r) were 0.877 ($r_{0.01\ (10)}$ =0.517), 0.965 ($r_{0.01\ (10)}$ =0.517), and 0.905 ($r_{0.01\ (10)}$ =0.517) with 0.01 significant level, respectively. Therefore, it had better consistency between the measured and the simulated values.

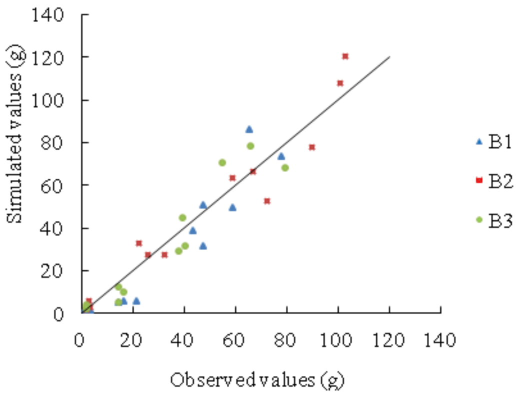

Fig.6. The 1:1 plotting comparison between observed and simulated MFW values

3.2.2.2 The model verification of yield formation for protected tomato based on the method of economic coefficient

The yield formation model based on the method of economic coefficient was verified by independent data in 2010 (Fig.7). The figure 7 showed: RMSE, X_{de}, and R^2 of between the measured and simulated values for protected tomato yield formation were 137.302g per plant (n=27), 21.170g per plant, and 0.785, respectively. The correlation coefficients (r) was 0.924 ($r_{0.01\ (25)}$ =0.487) with 0.01 significant level. Therefore, it had better consistency between the measured and the simulated values.

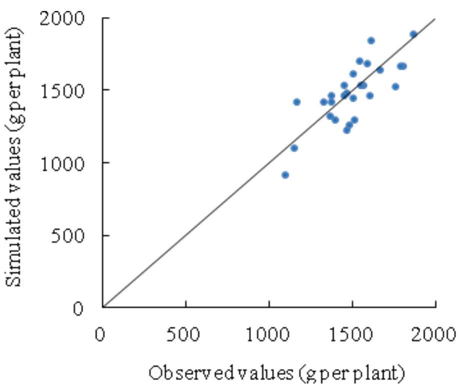

Fig.7. The 1:1 plotting comparison between observed and simulated Y values

4. Discussion

The yield of two kind of yield formation models were all theoretical yield in this paper, however, actual yield and theoretical yield had a certain difference because of the effects of environments factors such as light, temperature as well as water, and so on and the quality factors such as malformed fruit, disease fruit, pest fruit, cracked fruit as well as minimal fruit, and so on, and the actual yield was the sixty percent of theoretical yield. In addition, the actual LAI of protected tomato was smaller than simulated LAI because of the influence of planting density and artificial pruning, but the results of simulation were good. The yield formation models based on yield component factors and economic coefficient were built by analyzed the influence of varieties and fertilizer on yield formation of protected tomato. Compared with the results reported, it had a better mechanism, and simulated results. Moreover, the structure of plastic shed, genetic effect factors of tomato as well as environmental factors all affected the yield formation certainly. Lian et al. [20] researched the dynamic relationship between tomato yield formation and meteorological element in plastic shed, Fadhl [21] studied the heterosis of related traits and genetic effect of tomato yield, Han et al. [22] built the harvest date and yield prediction models of Brassica L.in planted in plastic shed covered with insect-proof screens. In addition, Diao et al. [23] simulated the yield formation of greenhouse sweet pepper using harvest index (it is a ratio of harvested fruit dry matter weight to total fruit dry matter weight). Further research should comprehensively considerate these factors, specially introduce temperature, light, soil water and so on in population dry matter production, establish the quantitative relationship between them and yield component factors, increase the feasibility and precision of models, and supply theoretical basis and technical support for cultivation management of protected tomato. In this paper, the phosphorus and potassium influencing factors were not studied because of the restricted of experiment conditions. Besides, the models established in this paper dealt with three varieties, and had a suitable environment, the results of these models was good, but the corresponding conditions would be used to verify and revise it if these models were applied to any other conditions.

5. Conclusions

The yield formation models based on yield component factors and economic coefficient were built respectively by analyzing the relationships among yield formation factors, varieties, and biomass as well as among yield and per plant biomass at harvest and per plant economic coefficient in accordance with rules of yield formation, and using the field experiment data of protected tomato in 2009 and 2010, and it included mean fruit weight model, per plant economic coefficient model, LAI model, dry matter production model, and so on. These models were verified using independent experiment data, the statistical analysis (RMSE, X_{de} and R^2) and 1:1 diagram all showed: the models could simulate the yield formation of different varieties and fertilizer levels well, and the X_{de} of yield formation based on economic coefficient larger than that of based on yield formation factors, while the RMSE and R^2 were all smaller than the later. Conclusively, the simulation results of yield formation model based on yield component factors was better than that of based on economic coefficient.

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