Res. on Crops **15** (1) : 248-253 (2014) DOI : 10.5958/j.2348-7542.15.1.035
With one figure
Printed in India

Comparative study on different simulation models of flue-cured tobacco LAI variation under salinity condition

YAMING ZHAI[1]*, CHENGLI ZHU[1], LIHUA CHEN[1] AND MAOMAO HOU[1]

Key Laboratory of Efficient Irrigation-Drainage and
Agricultural Soil-Water Environment in Southern China
(Hohai University), Ministry of Education, Nanjing-210 098,China
**(e-mail : 332155763@qq.com)*

(Received : December 2013)

ABSTRACT

In order to simulate the dynamic changes of flue-cured tobacco leaf area index (LAI) and predict the tobacco yield under different salinity and fertilizer levels, a field experiment with six treatments for flue-cured tobaccos was carried out at a plastic sheet covered greenhouse in south China, and three models including the linear model, exponential model and crop growth model were used to simulate the tobacco LAI dynamic changes varying with days after transplanted. Results showed that the dynamic change of LAI presented a single-peak curve, and the changes of LAI could be divided into three stages, including the slower growth period, the acceleration period and the recession period. The linear simulation model, exponential simulation model and the crop growth model could well simulate the dynamic changes of flue-cured tobacco LAI, with the correlation coefficient of 0.8738~0.9027, 0.9964~0.9985 and 0.9924~0.9972, respectively; the linear model had the same parameter number as the exponential simulation model, but the simulation accuracy of which was poorer than that of exponential simulation model. Although the crop growth model had more parameters to fit, most of the parameters had practical significance and were conducive to provide useful information for the LAI simulations and predictions. In general, the exponential model and the crop growth model were more satisfactory in simulating the dynamic changes of LAI since they possessed the better simulation precision, and the deciders could consider using the crop growth model or the exponential model according to the actual requirement : if the more comprehensive information of tobacco LAI was needed, the crop growth model should be the first choice; and if the simpler calculation process and shorter calculation time were required, then the exponential simulation model could be firstly taken into consideration.

Key words : Fertilizer, flue-cured tobacco, leaf area index, salinity, simulation

INTRODUCTION

Soil salinization is a significant and increasing problem in many areas (Chen *et al.,* 2010; Guo *et al.,* 2013), not also in costal areas and perennial cultivated dry lands, but also found in the greenhouse soils during recent years (Zhang Jie and Shao, 2012). In the south of China, the situation was extremely serious, unreasonable field management and superfluous chemical fertilizer application resulted in a large area of soil salinization, part of the greenhouses could not germinate the crops if not timely treated. Throughout the basic studies on the relationship between soil salinity and crop growth, most of which focused on the crops such as sunflower (Karimi *et al.,* 2013), corn (Khodarahmpour, 2012), canola (Saeedipour, 2012), broccoli (Smith *et al.,* 2010), tomato (Yurtseven *et al.,* 2005), rice (Gay *et al.,* 2010), date palm (Tripler *et al.,* 2011), cotton (Zhang *et al.,* 2012) and so on, while there were rare reports on how soil salinity affected the growth and development of flue-cured tobaccos, particularly on how the flue-cured tobacco LAI changed with days after transplanted under different salinity and fertilizer levels.

Leaf area index (LAI) is the important parameter and index for the studies in the fields of agronomy, forestry, ecology and meteorology (Demarez *et al.,* 2008; Ryu *et al.,* 2010; Olivas *et al.,* 2013). For the researches on flue-cured

[1]College of Water Conservancy and Hydropower Engineering, Hohai University, Nanjing-210 098, China.

tobaccos, LAI was especially important since tobacco leaves were the main harvest. However, basic studies on flue-cured tobacco LAI were often ignored, and relevant reports on the simulation and prediction of flue-cured tobacco LAI were scarcer. In this study, the flue-cured tobaccos were treated with different salinity and fertilizer levels, and several models were introduced to simulate the dynamic changes of tobacco LAI varying with days after transplanted. The objective was to (1) understand how the soil salinization affected the growth of flue-cured tobacco LAI under different fertilizer levels; (2) discover the fitting accuracy, merits and demerits of the chosen models according the calculations and (3) propose the preferable model with better simulation precision and higher practical value.

MATERIALS AND METHODS

Experimental Site

The experiments were carried out in a plastic sheet covered greenhouse in the Vegetables and Flowers Institute of Jiangning (latitude 31°43' N, longitude 118°46′E), Nanjing, China. The average annual rainfall is about 1106.5 mm, with the rainy season from the end of June to the middle of July, and the average annual temperature is about 15.7°C and average humidity is about 81%. Soil characters of the experimental fields were : 14.43 g/kg, bulk density 1.36 g/cm^3, field capacity 28% and total nitrogen 1.3 g/kg.

Experimental Design

The field experiments lasted from April 15 to August 15, 2012, which corresponded to one growth season of flue-cured tobaccos. Flue-cured tobacco cultivar K 326 was chosen as the plant material, tobacco seedlings were elaborately cultivated in seedling trays and transplanted into the experimental fields when they grew 4~6 expanded leaves. The experiments were divided into several lysimeters which were made of cement and bricks, with each lysimeter area of about (4 × 2) m^2. Twelve tobacco plants with transverse spacing of 1.0 m and longitudinal spacing of 0.5 m were planted in one lysimeter, and the same field management was conducted among the 12 tobacco plants during their whole growth seasons. Simply, one lysimeter corresponded to one treatment, and each treatment made three repetitions.

The experiments set two salinity levels and three fertilizer levels, there were six treatments in total. T_1 : surface soil EC (electrical conductivity) 5.98 ms/cm, N fertilizer amount 60 kg/hm^2; T_2 : Surface soil EC 5.98 ms/cm, N fertilizer amount 90 kg/hm^2; T_3 : Surface soil EC 5.98 ms/cm, N fertilizer amount 120 kg/hm^2; T_4 : surface soil EC 3.26 ms/cm, N fertilizer amount 60 kg/hm^2; T_5 : surface soil EC 3.26 ms/cm, N fertilizer amount 90 kg/hm^2 and T_6 : surface soil EC 3.26 ms/cm, N fertilizer amount 120 kg/hm^2. The flue-cured tobacco plants were irrigated with 500 mm waters; irrigation amount of root-extending stage, vigorous stage and maturity stage accounted for 30, 40 and 30% of the total amount, respectively, and the time interval of irrigation was seven days. Flue-cured tobacco dedicated inorganic fertilizers (N : P_2O_5 : K_2O=1 : 2 : 3) were applied according to the proportion of basal dressing : topdressing=7 : 3, the latency time of topdressing was 26 days after transplanted.

Measurements

Six flue-cured tobaccos from one treatment were chosen randomly for the measurements, the maximum leaf length and width of the tobaccos were measured every seven days after transplanted, and the tobacco LAI was calculated by :

$$LAI = \sum_{i=1}^{n} \left(\frac{\pi \times L_i \times W_i}{4}\right) \Big/ S$$

Where, LAI was the leaf area index of single plant; n was the leaf number; L_i was the maximum length (m) of the i^{th} leaf; W_i was the maximum width (m) of the i^{th} leaf and S was the land area (m^2) occupied by single plant.

Data Analysis

MATLAB 7.1 was used to calculate the parameters of LAI simulation models.

RESULTS AND DISCUSSION

Dynamic Changes of Flue-cured Tobacco LAI

Fig. 1 shows the dynamic changes of

tobacco LAI with different treatments. The changes of LAI could be divided into three stages, 14d~42d : slower growth period; 42d~77d: acceleration period and 77d~104d : recession period. During the recession period, the decreasing trend of LAI was similar among the treatments due to the picking of maturity leaves. Salt stress had significant effects on the growth of flue-cured tobacco leaves, the growing vigour of tobacco leaves in T_4, T_5 and T_6 was better than that in T_1, T_2 and T_3, especially in the acceleration period. Under the same salinity level, different fertilizer application also affected the growth of tobacco leaves significantly; the tobacco LAI had a positive relationship with N application under lower salinity condition, however, under higher salinity condition, the excess N application could not promote the growth of tobacco leaves, instead, the tobacco. LAI decreased obviously with superfluous N application; this result was similar to the earlier study conclusions (Hou *et al.,* 2012a; Hou *et al.,* 2012b) which suggested that excessive N application restrained the development of tobacco leaves and decreased the dry matter accumulation of overground parts of flue-cured tobacco plants.

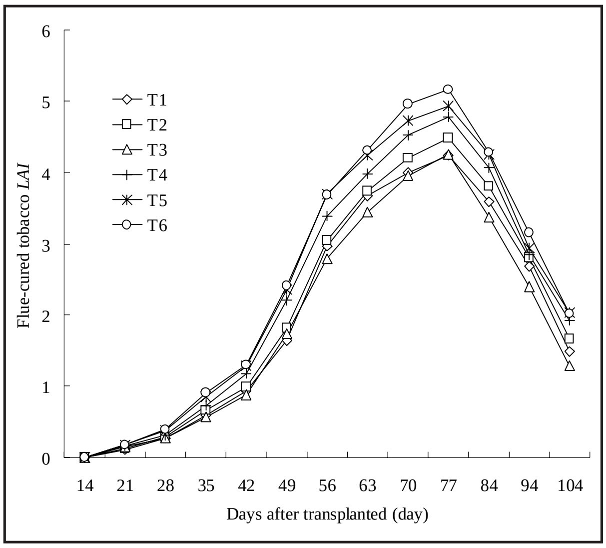

Fig. 1. Dynamic changes of tobacco LAI varying with days after transplanted.

LAI in 77 days after transplanted reflected the growth vigour of tobacco leaves most visually, which also reflected the eventual yield of flue-cured tobacco. LAI of T_6 was the highest, recording as 5.16, followed by T_5, indicating that lower salinity level combining with higher N application was beneficial for the increasing of LAI, while whether the higher N application of 120 kg/hm^2 was conducive to the quality improvement of tobacco leaves, still needed a further exploration.

Linear Model

The relationship between tobacco LAI (y) and days after transplanted (x) established by the linear models followed the formula :

$$y=ax^2+bx+c$$

The simulation models and the corresponding correlation coefficient are shown is Table 1, there were three parameters in the simulation model, and the models achieved a satisfactory result with the correlation coefficient at 0.8738~0.9027. The simulation result of T_3 was comparatively poorer, with the correlation coefficient of 0.8738; T_5 obtained the highest correlation coefficient of 0.9027. No obvious differences of correlation coefficient were detected among other treatments.

Exponential Model

Similar to the linear model, the exponential simulation model also had three parameters, and the relationship between tobacco LAI (y) and days after transplanted (x) established by the exponential models followed the formula :

$$y=\exp(ax^2+bx+c)$$

Table 2 gives the exponential simulation models and their correlation coefficient, from the table it was discovered that the simulation effects of exponential models were considerably well, the correlation coefficient of which reached a pretty high value of 0.9964~0.9985, indicating a high fitting accuracy.

Crop Growth Model

The mathematic model proposed by Qin *et al.* (2008) and Zhou *et al.* 2013) was used to simulate the dynamic changes of tobacco LAI, the relationship between tobacco LAI (g) and days after transplanted (t) established by the crop growth models followed the formula :

$$g=g_M(1+(1-\beta)e^{-\alpha(t-t)})^{-1}+g_0(1-\beta)$$

Table 1. Linear simulation models and their correlation coefficient

Treatment	Simulation models	Correlation coefficient
T_1	y = -0.0012 x^2 + 0.1733 x - 3.2444	0.8830
T_2	y = -0.0012 x^2 + 0.1792 x - 3.3454	0.8883
T_3	y = -0.0012 x^2 + 0.1724 x - 3.2073	0.8738
T_4	y = -0.0013 x^2 + 0.1948 x - 3.5908	0.8981
T_5	y = -0.0014 x^2 + 0.2069 x - 3.7730	0.9027
T_6	y = -0.0014 x^2 + 0.2123 x - 3.8790	0.9012

Table 2. Exponential simulation models and their correlation coefficient

Treatment	Simulation models	Correlation coefficient
T_1	y = exp (-0.0012 x^2 + 0.1866 x - 5.5823)	0.9984
T_2	y = exp (-0.0012 x^2 + 0.1826 x - 5.4054)	0.9985
T_3	y = exp (-0.0012 x^2 + 0.1797 x - 5.3285)	0.9964
T_4	y = exp (-0.0012 x^2 + 0.1760 x - 5.0721)	0.9981
T_5	y = exp (-0.0012 x^2 + 0.1726 x - 4.8572)	0.9979
T_6	y = exp (-0.0012 x^2 + 0.1729 x - 4.8395)	0.9982

Where, g_M is the total fresh biomass increment; g_0 is the original fresh biomass of the clove; α and β are the fast growth constants; τ is the time point for the biomass increase to reach the half maximum.

As is shown in Table 3, the correlation coefficient of crop growth model was also in a very high level reaching 0.9924~0.9972. g_M meant the theoretically maximum LAI increment, from the g_M value it was discovered that T_6 was the most promising treatment to achieve highest tobacco LAI, in other words, T_6 was most likely to obtain the highest flue-cured tobacco yield; T_5 followed T_6 closely, with the g_M value of 5.501; T_3 had the lowest g_M value of 4.563, indicating a relatively poorer increasing trend of LAI, this result further confirmed the above analysis that high salinity level combining with excess N application would impair the growth of flue-cured tobacco leaves.

Comprehensive Comparison of Three Simulation Models

The linear simulation model was the same type as the exponential simulation model, they both had three parameters, and the fitting of parameter fully complied with the original data structure. Although the linear simulation model obtained a high fitting accuracy with correlation coefficient of 0.8738~0.9027, the exponential simulation model appeared to be more effective on account of higher correlation coefficient value at 0.9964~0.9985, hence, the linear model was eliminated here, however, if the curve form of crop LAI was complicated, the linear simulation model could still be put into use by increasing the parameter number.

The crop growth model had the obvious advantages compared with the other two models, the parameters of which owned the practical significances, especially the g_M value, reflecting very useful information for the simulations and predictions, and the theoretically maximum LAI value would be easily gained by referring the parameters of g_0 and g_M. The disadvantage of the crop growth model in comparison with the exponential model was that the crop growth model had more parameters to fit, implying a relatively complex calculation process. Therefore, the deciders could consider using crop growth model or exponential model for the simulation according to the actual requirement. If the more comprehensive information was needed, the crop growth model should be the first choice;

Table 3. The main parameters and their values of the crop growth model

Treatment	g_0	g_M	α	β	τ	Correlation coefficient
T_1	-0.0788	4.625	0.1187	-0.1349	50.52	0.9939
T_2	-0.0631	5.013	0.1077	-0.6161	47.96	0.9960
T_3	-0.0941	4.563	0.1109	-0.6971	45.93	0.9944
T_4	-0.1525	5.194	0.1110	-0.0857	49.31	0.9972
T_5	-0.0577	5.501	0.1065	0.5431	58.73	0.9941
T_6	-0.0390	6.054	0.0958	0.5468	61.55	0.9924

if the simpler calculation process and shorter calculation time were required, then the exponential simulation model could be firstly taken into consideration.

CONCLUSIONS

Throughout the results of case analysis and model simulation, following conclusions could be obtained :

1. The dynamic change of LAI presented a single-peak curve, and the changes of LAI could be divided into three stages : 14d~42d was the slower growth period; 42d~77 d was the acceleration period and 77d~104d was the recession period. Salt stress had significant effects on the growth of flue-cured tobacco leaves, in this study, the growing vigour of tobacco leaves with lower salinity level was better than that with higher salinity level, especially in the acceleration period. Tobacco LAI had a positive relationship with N application under lower salinity condition; however, under higher salinity condition, the superfluous N application (120 kg/hm^2) impaired the growth of flue-cured tobacco leaves and obviously decreased the LAI value.
2. The correlation coefficient of linear simulation model, exponential simulation model and the crop growth model was 0.8738~0.9027, 0.9964~0.9985, and 0.9924~0.9972, respectively. The linear simulation model had the same parameter number as the exponential simulation model, but the simulation accuracy of which was poorer than that of exponential simulation model. The crop growth model had more parameters to fit, but most of the parameters had practical significances.
3. The exponential and the crop growth models were more satisfactory for simulating the dynamic changes of LAI since they possessed the better simulation precision. While they both had advantage and disadvantage, the deciders could consider using the crop growth model or the exponential model according to the actual requirement. If the more comprehensive information was needed, the crop growth model should be the first choice; if the simpler calculation process and shorter calculation time were required, then the exponential simulation model could be firstly taken into consideration.

ACKNOWLEDGEMENTS

This work was financed by Natural Science Foundation of Jiangsu Province (BK20130838), basic research funds of Hohai University (2012B00914), the funds of public welfare projects supported by the Chinese Ministry of Agriculture (200903001), and the creative funds for high school postgraduates of Jiangsu province (CXZZ13_0266).

REFERENCES

Chen, W., Hou, Z., Wu, L., Liang, Y., Wei, C. (2010). Evaluating salinity distribution in soil irrigated with saline water in arid regions of north-west China. *Agric. Water Manage.* **97** : 2001-08.

Demarez, V., Duthoit, S., Baret, F., Weiss, M. and Dedieu, G. (2008). Estimation of leaf area and clumping indexes of crops with hemispherical photographs. *Agric. and Forest Meteorol.* **148** : 644-55.

Gay, F., Maraval, I., Roques, S., Gunata, Z., Boulanger, R., Audebert, A. and Mestres, C. (2010). Effect of salinity on yield and 2-acetyl-1-pyrroline content in the grains of three fragrant rice cultivars (*Oryza sativa* L.) in Camargue (France). *Field Crops Res.* **117** : 154-60.

Guo, Y., Shi, Z., Zhou, L.-q., Jin, X., Tian, Y.-f., Teng, H.-f. (2013). Integrating remote sensing and proximal sensors for the detection of soil moisture and salinity variability in coastal areas. *J. Integrative Agric.* **12** : 723-31.

Hou, M. M., Shao, X. H., Chen, L. H., Chang, T. T., Wang, W. N. and Wang, Y. F. (2012a). Study on fertilizer N leaching, accumulation and balance in tobacco fields with N-15 tracing technique. *J. Food Agric. Environ.* **10** : 1284-89.

Hou, M. M., Shao, X. H., Chen, L. H., Chang, T. T., Wang, W. N., Yang, Q. and Wang, Y. F. (2012b). Study on nitrogen utilization efficiency of flue-cured tobacco with 15n tracing technique, 1st International Conference on Energy and Environmental Protection, ICEEP 2012, June 23, 2012 - June 24, 2012. Trans. Tech. Publications, Hohhot, China. pp. 520-24.

Karimi, S., Nasri, M. and Ghoshchi, F. (2013). Effects of zeolite application on yield components and yield of sunflower grown under water deficit stress. *Res. on Crops* **14** : 162-68.

Khodarahmpour, Z. (2012). Effect of salinity stress on germination indices of corn (*Zea mays* L.) hybrids. *Res. on Crops* **13** : 846-51.

Olivas, P. C., Oberbauer, S. F., Clark, D. B., Clark, D. A., Ryan, M. G., O'Brien, J. J. and Ordoñez, H. (2013). Comparison of direct and indirect methods for assessing leaf area index across a tropical rain forest landscape. *Agric. and Forest Meteorol.* **177** : 110-16.

Qin, F. F., Xu, H. L. and Ma, G. (2008). Garlic sprouts grown indoors at kitchen sites. *Med. and Arom. Plant Sci. and Biotechnol.* **2** : 117-22.

Ryu, Y., Sonnentag, O., Nilson, T., Vargas, R., Kobayashi, H., Wenk, R. and Baldocchi, D. D. (2010). How to quantify tree leaf area index in an open savanna ecosystem : A multi-instrument and multi-model approach. *Agric. and Forest Meteorol.* **150** : 63-76.

Saeedipour, S. (2012). Salinity tolerance of canola cultivars at germination and early seedling growth. *Res. on Crops* **13** : 123-27.

Smith, T. E., Grattan, S. R., Grieve, C. M., Poss, J. A. and Suarez, D. L. (2010). Salinity's influence on boron toxicity in broccoli. I. Impacts on yield, biomass distribution and water use. *Agric. Water Manage.* **97** : 777-82.

Tripler, E., Shani, U., Mualem, Y. and Ben-Gal, A. (2011). Long-term growth, water consumption and yield of date palm as a function of salinity. *Agric. Water Manage.* **99** : 128-34.

Yurtseven, E., Kesmez, G. D. and Ünlükara, A. (2005). The effects of water salinity and potassium levels on yield, fruit quality and water consumption of a native central anatolian tomato species (*Lycopersicon esculentum*). *Agric. Water Manage.* **78** : 128-35.

Zhang, D., Li, W., Xin, C., Tang, W., Eneji, A. E. and Dong, H. (2012). Lint yield and nitrogen use efficiency of field-grown cotton vary with soil salinity and nitrogen application rate. *Field Crops Res.* **138** : 63-70.

Zhang Jie, C. T. and Shao, X. (2012). Improvement effect of sub-surface drainage on secondary salinization of greenhouse soil and tomato yield. *Transactions of the CSAE* **28** : 81-86.

Zhou, Y. X., Zhen, S. C. and Zhai, Y. M. (2013). The application of EM-treated dairy effluent on the flue-cured tobacco irrigation. *J. Food Agric. Environ.* **11** : 960-64.