Dynamic Simulation on Canopy Light Distribution and Dry Matter Accumulation of Natural Colored Cotton in Alar Reclamation Area of Xinjiang

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Abstract: Based on Ross's theory of optical radiation transmission and full consideration of influences of vertical distribution of canopy leaf area and leaf inclination angle distribution of colored cotton on the light distribution, the Gaussian 5-point distance was used to divide the canopy into 5 layers on basis of the leaf area index. The leaf inclination angle on each layer was divided into 6 equal parts by 15°. The types of radiation in canopy, spatial distribution of light radiation, as well as diurnal variation with solar hour angles were quantified in detail. After comprehensively considering influences of temperature, physiological age and other factors on photosynthesis and respiration, the canopy light distribution, photosynthetic production and dry matter accumulation of colored cotton were simulated with strong mechanistic and physiological & ecological significance. The colored cotton samples sown on April 16, 2019 were used to verify the model. The RMSEs of simulated and measured canopy *PAR* values at Beijing time 10:00, 12:00, 14:00 and 16:00 on July 30 were 58.2, 64.1, 43.4 and 39.7 μmol·m^{-2}·s^{-1}, respectively. The RMSE of simulated and observed values of the dry matter accumulation above ground was 412.6 kgDM·hm^{-2}, reflecting the good predictability of the model.

Key words: Canopy light distribution, colored cotton, dry matter accumulation, extinction coefficient, photosynthetic production.

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1. Introduction

Natural colored cotton (hereinafter referred to as "colored cotton") is a collective name for colored cottons grown naturally. It is a new type of textile raw material used in the cotton industry that can omit the bleaching and dyeing process. Its significant effects of energy-saving and emission reduction are consistent with the tendency of protecting the ecological environment and pursuing a low-carbon life [1]-[3]. Located in the upper reaches of the Tarim River where the Aksu River, the Hotan River and the Yarkand River jointly meet, the Alar reclamation area of Xinjiang has an annual sunshine duration over 2900 hours and an average annual solar radiation ranging from 133.7kcal/cm^2 to 146.3kcal/cm^2. Thanks to the unique natural conditions, Alar reclamation area has become an important production base of colored cotton in China.

Photosynthesis is an inherent driving force for the growth of crops, therefore, accurately simulating the accumulation of cotton photosynthetic products is quite essential for the prediction of the economic yield of cottons, which is also a major part of the cotton growth model. The present crop photosynthesis models can be roughly divided into two types. For the first type, models have strong mechanisms but also involve many parameters difficult to be obtained accurately, so these models are seldom applied in practice [4]-[8]; for the second type, models are relatively simple. During the calculation of the photosynthetic production force, the daily total radiation quantity is often multiplied by a conversion coefficient, without considering the diurnal variation process of the extinction coefficient. In some cases, the diurnal variation of the photosynthetic radiation is calculated using the Gaussian integral method [9]-[12]. The light intensity distribution in the crop canopy varies greatly with the depth of the leaf area. Moreover, the extinction coefficient and the radiation conditions also change during the day. Therefore, it is necessary to quantify the radiation types in the canopy and their spatial distributions in detail in the research on photosynthesis models. Based on Ross's radiation theory [13], Yu and Liu, *et al.* [14]-[16] established the radiation transfer model and the photosynthesis model of rice canopy and maize canopy with the consideration of the leaf area index vertical distribution and the leaf inclination angle spatial distribution, showing relatively high accuracy.

To address problems existing in present photosynthesis models, this paper learns from previous methods used to study the crop canopy light transmission and distribution models. In addition, this paper also focuses on the combination of mechanism and practicality based on the radiation theory of Ross to simulate the light radiation transmission and biomass production of colored cotton canopy in Alar reclamation area, laying a solid foundation for the research on the dynamic simulation models of dry matter accumulation and distribution in colored cotton canopy.

2. Materials and Methods

In 2019, field tests (80°38′ E, 40°32′ N) were conducted in Alar reclamation area with "New Color No. 4" as the test samples, which were planted on the sandy loam with a plant spacing of 0.12m and a row spacing of 0.30m. No water or fertilizer stress occurred in the field management. The GLZ-C device made in Zhejiang Top Clound-agri Technology Co., Ltd. was used to measure the photosynthetically active radiation (PAR) at the top of the canopy and inside the canopy at different heights. Other meteorological data was provided by local meteorological stations.

3. Model Description

3.1. Light Distribution of the Colored Cotton Canopy

Studies have showed that the radiation amount and incident angle of sunlight, the canopy structure, the spatial distribution and orientation of leaves greatly affect the light distribution in the crop canopy [17]-[20].

3.1.1. Total solar radiation

According to the Angstron equation [21], [22], the total amount of direct solar radiation and sky diffuse radiation on each unit area of the ground can be calculated by (1).

$$Q_1 = Q(0.23 + 0.48 * SunH/DayL) \tag{1}$$

In (1), Q_1 refers to the total solar radiation of the day (J·m^{-2}·d^{-1}), $SunH$ refers to the sunshine duration (h), and $DayL$ refers to the day length (h) (including 40 minutes of twilight), Q refers to the total daily astronomical radiation (J·m^{-2}·d^{-1}), which can be calculated by (2)-(8).

$$Q = 3600 * SC(DayL * SSIN + 24CCOS * \sqrt{1 - SSCC^2}/\pi) \tag{2}$$

$$SC = 1370(1 + 0.033\cos(2\pi * DOY/365)) \tag{3}$$

$$SSIN = \sin\phi * \sin(\delta) \tag{4}$$

$$CCOS = \cos\phi * \cos(\delta) \tag{5}$$

$$SSCC = SSIN/CCOS \tag{6}$$

$$\delta = -\sin^{-1}(\sin(23.45\pi/180) * \cos(2\pi * (DOY + 10)/365)) \tag{7}$$

$$DayL = 12(1 + 2\sin^{-1}(SSCC)/\pi) + 40/60 \tag{8}$$

SC(J·m^{-2}·d^{-1}) refers to the solar constant. $SSIN$, $CCOS$ and $SSCC$ are intermediate variables, δ refers to the solar declination, ϕ refers to geographic latitude, DOY refers to the number of days from January 1st.

3.1.2. Photosynthetically active radiation on top of the colored cotton canopy

The instantaneous photosynthetically active radiation intensity $PAR_1(t)$ (J·m^{-2}·s^{-1}) on the top of the colored cotton canopy can be determined by the total radiation Q_1 received on the day and the sinusoidal value $SINB(t)$ of the sun elevation angle [23], as shown in (9).

$$PAR_1(t) = 0.5Q_1 * SINB(t) * (1.0 + 0.4SINB(t))/DSINBE \tag{9}$$

Different values of solar time $Hour(t)$ (h) result in different sine values of the solar altitude angle, as shown in (10).

$$SINB(t) = SSIN + CCOS * \cos(2\pi * (Hour(t) + 12)/24) \tag{10}$$

$DSINBE$ can be used to correct the sun elevation angle, as shown in (11).

$$\begin{aligned} DSINBE = 3600(DayL * (SSIN + 0.4(SSIN^2 + 0.5CCOS^2)) + 12CCOS \\ * (2 + 3 * 0.4SSIN)\sqrt{1 - SSCC^2} \end{aligned} \tag{11}$$

According to atmospheric physics, the instantaneous atmospheric transmission coefficient $ATMTR$, the theoretical diffuse coefficient F, and the sky diffuse radiation coefficient $FRDF$ are respectively shown in (12), (13) and (14).

$$ATMTR = PAR_1(t)/(0.5SC * SINB(t)) \tag{12}$$

$$F = \begin{cases} 1.0 & ATMTR < 0.22 \\ 1.0 - 6.4(ATMTR - 0.22)^2 & 0.22 < ATMTR < 0.35 \\ 1.47 - 1.66ATMTR & ATMTR > 0.35 \end{cases} \tag{13}$$

$$FRDF = MAX\left(F, 0.15 + 0.85\left(1.0 - e^{(-0.1/SINB(t))}\right)\right) \tag{14}$$

The instantaneous sky photosynthetically active radiation on the top of the colored cotton canopy can be divided into two parts, including the diffuse photosynthetically active radiation intensity DF_1 (J·m^{-2}·s^{-1}) and the direct photosynthetic effective radiation intensity DR_1 (J·m-2·s-1), both of which can be calculated by (15) and (16).

$$DF_1(t) = FRDF * PAR_1(t) \tag{15}$$

$$DR_1(t) = (1 - FRDF) * PAR_1(t) \tag{16}$$

3.1.3. Simulation of light distribution in the colored cotton canopy

The extinction coefficient can be used to describe the shielding and weakening effects of canopy leaves on radiation light [24]. For light coming directly from the zenith, the leaf projection area with an area of S will become $S * \cos\alpha$ (α is the leaf inclination angle). Therefore, it is necessary to use the extinction coefficients of direct light and scattering light to reflect the reduction effects of canopy leaves on solar direct radiation and solar diffuse radiation under spatial orientations of different leaves and various solar radiation incident directions. Due to the complexity of colored cotton canopy structures, the following process were performed:

① The colored cotton canopy was hierarchically divided by the leaf area index LAI from the top to the bottom. The canopy from the seeding stage to the squaring stage of colored cotton was thin, so there was only one layer with a small leaf inclination assumed to be within 0-15°. The canopy after the squaring stage was divided into 5 layers using the Gaussian 5-point distance according to the LAI of canopy. The corresponding depth $L(i)$ of the canopy leaf area of the Gaussian layer is shown in (17). The distance coefficient $DIS(i)$ and the weight $WT(i)$ are shown in Table 1. The leaf inclination angle α of each layer was divided into 6 intervals by 15 to study the reduction on the direct light.

$$L(i) = DIS(i) * LAI \quad (i = 1, 2, 3, 4, 5) \tag{17}$$

Table 1. Weight Values and Distance Coefficients of Gaussian 5-Point Integral Method

i	1	2	3	4	5
$WT(i)$	0.11846	0.23931	0.28444	0.23931	0.11846
$DIS(i)$	0.04691	0.23077	0.50000	0.76924	0.95309

② The solar direct radiation and the solar diffuse radiation received on the horizontal plane between adjacent leaf layers were calculated with depth according to the light distribution index decline model [25]. After the canopy was vertically divided into 5 layers, the thickness of each layer was relatively thin, so the difference between horizontal light intensities on the same layer can be ignored. In other words, it was assumed that horizontal light intensities on the same layer were the same.

③ Direct light exists in the form of light spots, making the radiation distribution on the leaf surface uneven. It was assumed that the direct radiations on a horizontal plane within a certain unit time at the same level were the same.

④ The diffuse radiation caused by reflections of leaves on the solar radiation was usually one order of magnitude smaller than the direct radiation at the same height and the diffuse radiation from the sky, which was ignored for simplicity.

According to Ross's theory of optical radiation transmission, for a given leaf layer, the direct light extinction coefficient K_{DR} was a function of the leaf inclination angle α, the leaf azimuth angle β, the sun elevation angle H, and the sun azimuth angle A, as shown in (18) and (19).

$$K_{DR}(\alpha, \beta, H, A) = \frac{1}{\sin(H)} \int_0^{2\pi} \int_0^{\pi/2} |\cos\theta(\alpha, \beta, H, A)| * \rho(\alpha, \beta)\, d\alpha d\beta \tag{18}$$

$$\theta(\alpha, \beta, H, A) = \cos^{-1}(\sin H * \cos\alpha + \cos H * \sin\alpha * \cos(A - \beta)) \tag{19}$$

$\theta(\alpha, \beta, H, A)$ refers to the angle between the direct light and the leaf surface vector, $\rho(\alpha, \beta)$ refers to the probability density of the leaf distribution in the leaf layer.

The leaf azimuth angle of each layer of colored cotton canopy was basically uniformly distributed within [0,2 π]. As a result, the changes in the sun azimuth angle had no impact on the K_{DR} of each layer, and the extinction coefficient of direct light can be simplified from (18) to (21).

$$K_{DR}(\alpha, H) = \begin{cases} \cos\alpha & \alpha \le H \\ \cos\alpha[1 + 2(\tan\psi - \psi)/\pi] & \alpha > H \end{cases} \tag{20}$$

$$\psi = \cos^{-1}(\tan H \cot\alpha) \tag{21}$$

Due to the uneven distribution of leaf inclination angle in each layer of the colored cotton canopy [26], the extinction coefficient of direct light in each layer can be regarded as the weighted stacking of the extinction coefficient of each interval of the leaf inclination angle in the layer. Let the median value of the leaf inclination angle in the j-th interval of the i-th layer as α_{ij}, the ratio of the leaf area in this leaf inclination interval to the leaf area of the leaf layer as f_{ij}. The $K_{DR}(\alpha_{ij}, H)$ was approximately assumed to be the extinction coefficient of direct light in this leaf inclination interval, then the extinction coefficient $K_{DR}(i)$ of this layer can be calculated by (22). Different distributions of the leaf inclination angle on each leaf layer resulted in different direct light extinction coefficients of each leaf layer. According to the light distribution index decline model, the instantaneous photosynthetically effective radiation intensity DR_i(J·m^{-2}·s^{-1}) of direct sunlight from the i-th horizontal plane is shown in (23) (i=1, 2, 3, 4, 5, $K_{DR}(0) = 0, L(0) = 0$).

$$K_{DR}(i) = \sum_{j=1}^{6} f_{ij} * K_{DR}(\alpha_{ij}, H) \tag{22}$$

$$DR_i(t) = DR_1(t) * e^{-K_{DR}(i-1)*L(i-1)} \tag{23}$$

The sky diffuse radiation was isotropic, so the scattering light extinction coefficient was not affected by the position of the sun. In addition, cotton leaves were relatively flat, and most of the leaves had a small angle with the horizontal plane. After theoretical research and actual measurement, the scattering light extinction coefficient K_{DF} was close to 1.0 [8], [11]. Then the instantaneous photosynthetic effective radiation intensity DF_i (J·m^{-2}·s^{-1}) of the sun diffuse light of the i-th layer of the colored cotton canopy at the horizontal plane is shown in (24).

$$DF_i(t) = DF_1(t) * e^{-L(i-1)} \tag{24}$$

The distribution patterns of solar direct radiation and solar diffuse radiation at each layer of the canopy can be obtained from (23) and (24), thereby obtaining the instantaneous photosynthetically active radiation intensity $PAR_i(t)$ (J·m^{-2}·s^{-1}) of the i-th layer, as shown in (25).

$$PAR_i(t) = DR_i(t) + DF_i(t) \tag{25}$$

3.2. The Colored Cotton Canopy Biomass Production and Accumulation

3.2.1. A single leaf photosynthetic rate of the colored cotton canopy

It can be known from botanical studies that the photosynthesis of leaves had a Michaelis-Meten response to the light radiation intensity. In other words, when the light radiation intensity was weak, the photosynthetic rate would increase rapidly with the increasing light radiation intensity. But when the light radiation intensity reached a certain level, the photosynthetic rate would tend to be saturated and not increase with the increasing light radiation intensity [27], [28]. The relationship between the single leaf photosynthetic rate $V(PAR_i)$ (kgCO$_2$·hm^{-2}·h^{-1}) of colored cotton and the instantaneous photosynthetic effective radiation intensity PAR_i can be expressed by an S-type function, as shown in (26).

$$V(PAR_i) = V_{pmax1} * \left(1 - e^{-\kappa * PAR_i / V_{pmax1}}\right) \tag{26}$$

In (26), κ ($kgCO_2 \cdot hm^{-2} \cdot h^{-1} / J \cdot m^{-2} \cdot s^{-1}$) refers to the initial utilization efficiency of the leaf to PAR_i, indicating the photosynthetic capacity of the leaf under weak light, describing the characteristics of leaf biophysical processes. Studies showed that the κ value was relatively stable and mainly affected by the temperature, ranging from 0.54 to 0.36 at 10-40°C. Other environmental factors had small effects on κ value [29], [30], and it was 0.45 in this model. V_{pmax1}($kgCO_2 \cdot hm^{-2} \cdot h^{-1}$) refers to the actual maximum photosynthetic rate of a single leaf, reflecting the photosynthetic capacity of the leaf under a saturated light intensity. It had great changes and was mainly affected by factors such as the potential maximum photosynthetic rate V_{pmax} of the single leaf, the temperature factor TF, the physiological development time factor AF, the water factor WF, and the nitrogen factor NF, as shown in (27).

$$V_{pmax1} = V_{pmax} * TF * AF * WF * NF \tag{27}$$

Related research showed that the value of V_{pmax} can be 50$kgCO_2 \cdot hm^{-2} \cdot h^{-1}$ [31]. It was found through tests that the growth of colored cotton tended to stagnate when the temperature was higher than 35°C or lower than 12°C. The optimum temperature for the development of colored cotton was 30°C. The effect of temperature on photosynthesis matched with the bell-shaped curve determined by these three temperatures, as sh10.17706/ijamp.2020.10.3.own in (28), where T indicates the daily mean temperature. The physiological age PT of colored cotton leaves had significant effects on photosynthesis. Before the flowering stage of colored cotton ($PT < 42$), the photosynthetic capacity of leaves was not affected by the physiological age. After the flowering stage ($PT \geq 42$), the photosynthetic capacity gradually decreased. The calculation formula of the impact factor AF to the physiological age is shown in (29), where β refers to the shape parameter of the curve. In this paper, it was taken the empirical value of 0.013. Because no water or fertilizer stress occurred in field management, the water factor WF and the nitrogen factor NF were set to 1.

$$TF = \begin{cases} e^{-(T-30)^2/(T-12)*(35-T)} & 12℃ < T < 35℃ \\ 0 & T \geq 35℃, T \leq 12℃ \end{cases} \tag{28}$$

$$AF = \begin{cases} e^{-\beta(PT-42)} & PT \geq 42 \\ 1 & PT < 42 \end{cases} \tag{29}$$

3.2.2. Production rate of the colored cotton canopy biomasses

Based on the single leaf photosynthetic rate, the instantaneous photosynthetic rates on 5 layers of the canopy were weighted for summation by the Gaussian 5-point integral method and then multiplied by the canopy leaf area index so as to obtain the overall instantaneous photosynthetic rate V, as shown in (30). Table 1 shows the weight $WT(i)$. The total daily photosynthesis amount P_{dg}($kg\ CO_2 \cdot hm^{-2} \cdot d^{-1}$) of colored cotton canopy can be obtained through integration V with one day time, as shown in (31).

$$V = \sum_{i=1}^{5} V(PAR_i) * WT(i) * LAI \tag{30}$$

$$P_{dg} = \int_{-\omega_0}^{\omega_0} V d\omega \tag{31}$$

$$\omega_0 = |\cos^{-1}(-\tan\phi * \tan\delta)| \tag{32}$$

In (31) and (32), ω_0 refers to the absolute value of the time angle at sunrise and sundown, ϕ refers to the geographic latitude, and δ refers to the solar declination. The photosynthetic rate of the colored cotton canopy at each integer time can be obtained according to (30), then, (31) was simplified to the discrete integer time form to calculate integral by accumulation, as shown in (33).

$$P_{dg} = 1 * \sum_{T=1}^{n-1} V(T) + DT_1 * V(0) + DT_2 * V(n) \tag{33}$$

In (33), T refers to each integer time from the first integer time after sunrise to the last integer time before sunset. DT_1 refers to the time interval from the sunrise time T_1 to the first integer time after sunrise, DT_2 refers to the time interval from the last integer time before sunset to the sunset time T_2.

$$DT_1 = \lceil T_1 \rceil - T_1 \tag{34}$$

$$DT_2 = T_2 - \lfloor T_2 \rfloor \tag{35}$$

Among (34) and (35), " ⌈ ⌉ " refers to round numbers upwards, and " ⌊ ⌋ " refers to round numbers downwards.

$$T_1 = 12 - \omega_0/15 \tag{36}$$

$$T_2 = 12 + \omega_0/15 \tag{37}$$

Experimental results showed that photosynthesis converted CO_2 into carbohydrates (CH_2O) with an efficiency of 0.682, and at last the total daily photosynthetic rate GP_{dg}($kgCH_2O \cdot hm^{-2} \cdot d^{-1}$) of the entire canopy was:

$$GP_{dg} = 0.682 * P_{dg} \tag{38}$$

During the growth and development of colored cotton, plants need to consume some carbohydrates to provide energy for the conversion from photosynthetic products to dry matters of cotton plant structures, which is called the growth respiration. Studies showed that cotton plants needed 1.502kg of glucose to produce 1kg of dry matters averagely. In addition to the growth respiration, colored cotton plants also need to consume some assimilations to maintain their biochemical and physiological states, which is called the maintenance respiration. The maintenance respiration intensity of colored cotton plants is directly proportional to biomasses, which is also affected by factors such as temperature and physiological age. The maintenance respiration rate R_{maint}($kgCH_2O \cdot hm^{-2} \cdot d^{-1}$) of the colored cotton is shown in (39).

$$R_{maint} = MBC * BIOM * TIF * PAIF \tag{39}$$

In (39), MBC($kgCH_2O \cdot kg^{-1}DM \cdot d^{-1}$) refers to the maintenance respiration coefficient of colored cotton and DM refers to the dry matter. When the temperature was 28°C, MBC was about 0.026. $BIOM$ refers to the total biomasses, TIF refers to the temperature effect factor, $PAIF$ refers to the physiological age effect factor. The research of Pan [11] showed that TIF was shown in (40).

$$TIF = 2^{(T_{av}-28)/10} \tag{40}$$

In (40), T_{av} is the daily mean temperature. From plant physiology studies, it can be seen that the maintenance respiration intensity of plants would decrease with the increasing leaf age. In addition, the maintenance respiration intensity of different organs also varied at different physiological development stages. Among them, leaves and roots had stronger maintenance respiration intensity than other organs. Because the proportion of dry matter weight of leaves and roots to the total dry matter weight of the plant gradually decreased with the increasing physiological age of plants, the maintenance respiration intensity of plants would also decrease accordingly. Based on the comprehensive consideration of changes in leaf age of colored cotton plant, as well as changes in proportions of cotton roots, stems, leaves and bolls along with physiological development time, the physiological age impact factor can be expressed with a linear function of growth and development time T_* [26].

$$PAIF = 1 - 0.0056 * T_* \tag{41}$$

After subtracting the losses generated by maintenance respiration and growth respiration from the daily total photosynthetic assimilation amount of colored cotton plants, the daily dry matter production rate G_{net}(kgDM·hm^{-2}·d^{-1}) of colored cotton can be expressed as:

$$G_{net} = \left(GP_{dg} - R_{maint}\right)/1.502 \tag{42}$$

3.2.3. Simulation of dry matter accumulation

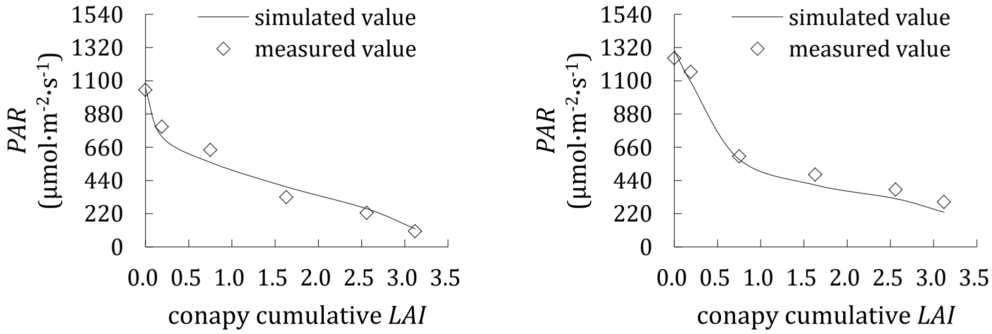
Through the daily dry matter production rate G_{net} of colored cotton, the plants dry matter cumulates $BIOM$(kgDM·hm^{-2}) can be obtained.

$$BIOM_i = BIOM_{i-1} + G_{net} \tag{43}$$

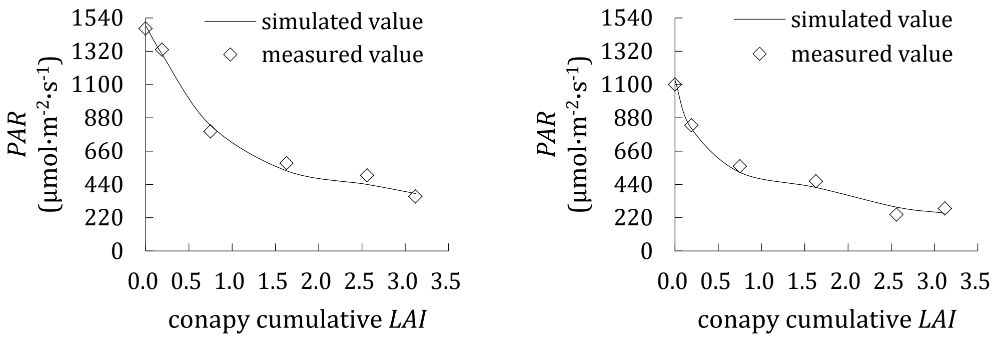
In (43), $BIOM_i$ and $BIOM_{i-1}$ refer to the biomass (kgDM·hm^{-2}) of the *i*-th and *i*-1-th day, respectively. When i=0, $BIOM$ is the seeding quantity.

4. Model Verification and Analysis

The colored cotton sown on April 16, 2019 was used as samples to verify the model. The light distributions in the canopy at Beijing time 10:00, 12:00, 14:00 and 16:00 on July 30 are shown in Fig. 1. The RMSEs of simulated and measured photosynthetically active radiation (*PAR*) values at each time were 58.2, 64.1, 43.4 and 39.7μmol·m^{-2}·s^{-1}, respectively. The simulation results can accurately describe the light distribution in the canopy. The thin clouds in the sky at Beijing time 10:00, 12:00, 14:00, and 16:00 on July 30, may have a certain effect on the regularity of solar radiation, resulting in errors to some extent. In addition, inaccurate operation of instruments, disturbances to the colored cotton canopy and damages of individual leaves during the measurement may also exacerbate the differences between the measured values and the simulated results.



(a) Beijing Time 10:00 (b) Beijing Time 12:00



(c) Beijing Time 14:00 (d) Beijing Time 16:00

Fig. 1. Measured and simulated values of light distribution in colored cotton canopy at different moments.

For samples sown on April 16, 2019, the observed values and simulated results of dry matter accumulation above ground on the test field are shown in Fig. 2. The RMSE of the simulated and observed values was 412.6kgDM·hm^{-2}, reflecting the good simulation effect of the model. The actual situation showed that the observed value was generally lower than the simulated value, which may be because it was difficult to control the environmental stresses such as water and fertilizer under experimental conditions to reach the best, making the actual dry matter production rate lower than the simulated production capacity.

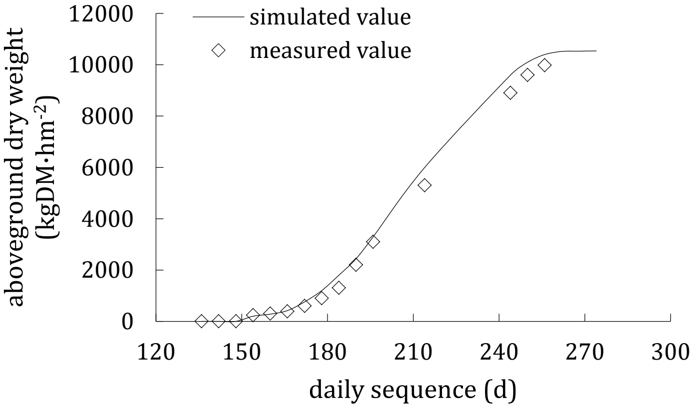


Fig. 2. Observed and simulated values of dry matter accumulation in colored cotton above ground.

5. Conclusion

Based on Ross's theory of optical radiation transmission, the Gaussian 5-point integral method was used to calculate the light distribution of the canopy and the overall instantaneous photosynthetic rate, with consideration of influences of diurnal variations of photosynthetically active radiation and changes in the solar elevation angle on the direct light extinction coefficient, compared with other cotton photosynthetic production models that evenly divided the daily total radiation and used the simple integration method of the leaf area index, or those used the Gaussian integration to three representative time points in one day, the method used in this paper made great improvement. In addition, effects of factors such as temperature and physiological age on photosynthesis and respiration were also studied, making the model have obvious physiological & ecological significance and universality, thereby realizing the combination of mechanism and practicality. The field test was conducted to inspect the canopy light distribution and the dry matter accumulation of colored cotton, and the simulated values agreed well with the measured values, indicating that the model can effectively simulate the canopy light distribution, photosynthetic production and dry matter accumulation of colored cotton. The model has strong applicability and predictability, laying a solid foundation for the quantitative simulations of colored cotton production.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Zhenqi Fan conducted the research and wrote the paper; Lixin Zhang analyzed the data; all authors had approved the final version.

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