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Abstract. Primary ramification morphogenesis has a significant influence on the yield of rapeseed. In order to quantify the relationship between rapeseed architecture indices and the organ biomass, a rapeseed primary ramification structural model based on biomass were presented. Intended to explain effects of cultivars and environmental conditions on rapeseed PR morphogenesis. The outdoor experiment with cultivars: Ningyou 18 (V1, conventional), Ningyou 16 (V2, conventional) and Ningza 19 (V3, hybrid), and designed treatment of cultivar-fertilizer, cultivar-fertilizer-density, and cultivar tests in 2011-2012 and 2012-2013. The experimental result showing that the leaf blade length of PR, leaf blade width of PR, leaf blade bowstring length of PR, PR length, and PR diameter from 2011 to 2012 were goodness, and their d_a values and *RMSE* values were -1.900 cm, 5.033 cm (n=125); -0.055 cm, 3.233 cm (n=117); 0.274 cm, 2.810 cm (n=87);-0.720 cm, 3.272 cm (n=90); 0.374cm, 0.778 cm (n=514); 0.137cm, 1.193cm (n=514); 0.806cm, 8.990cm (n=145); and -0.025cm, 0.102cm (n=153), respectively. The correlations between observation and simulation in the morphological indices were significant at P<0.001, but the d_{ap} values were < 5% for the second leaves length and the third leaves length, leaf blade bowstring length, PR length, and PR diameter, which indicated that the model's accuracy was high. The models established in this paper had definite mechanism and interpretation, and the impact factors of N, the ratio of the leaf length to leaf dry weight of primary ramification(*PRRLW*), and the partitioning coefficient of leaf blade dry weight of primary ramification(*PRCPLB*) were presented, enabled to develop a link between the plant biomass and its morphogenesis. Thus, the rapeseed growth model and the rapeseed morphological model can be combined through organ biomass, which set a reference for the establishment of FSPMs of rapeseed.

Keywords: biomass, FSPMs, rapeseed, primary ramification

1 Introduction

Rapeseed is a very good oil crop with high economic and nutritional values. In the ten years from 2004 to 2014, the production and consumption of rapeseed have increased significantly, and the growth rates of the plant area and total production of rapeseed were35% and 54%, respectively[1]. Plant morphological structure simulation and visualization is one of important content of agro-informatics in nowadays, and its latest trend is to establish Functional-structural Plant Models (FSPMs). Some crop morphological structure models had been developed based on GDD [2-7], which described the main stems, branches, leaves, leaf sheaths, and internodes of the morphological model of the crops, and realized the quantitative simulation of the crop morphogenesis process. With the maturity of the research conditions, crop morphological structure and physiological ecological process will become the new focus. In order to analyze the

relationships between the morphological parameters of the organs of crops and biomass, some related studies had been reported [8-11]. Rapeseed morphology directly influences its biomass production. In recent years, studies of the rapeseed morphological structure model had also been proposed[12-14]. A rapeseed leaf geometric parameters model based on biomass presented quantified the relationship between biomass and rapeseed leaf geometric parameters, a leaf curve model based on biomass for rapeseed was established, which described the relationships between the leaf curve and the corresponding leaf biomass for rapeseed on main stem, and a morphological structure model of leaf blade space based on biomass at pre-overwintering stage in rapeseed plant presented revealed the relationships between biomass and rapeseed architecture indices. These studies laid a good foundation for FSPMs of rapeseed. By combining LEAFC3-N with the FSPMs, rapeseed functional structural plant model was established, which could respond to the environmental conditions [15-16].

However, the rapeseed primary ramification morphological structural model based on biomass has not been reported. Vegetative organs of rapeseed including leaf, stem, ramification, and root[17]. Leaf is the crucial organs of photosynthesis, ramification leaves play gradually an important role in the rapeseed mid and late growth stage, and the ramification becomes a vital source. Therefore, how to accurate quantitative description of the rapeseed morphological variation is vitally important and difficult.

The objectives of this paper were to link primary ramification architectural parameters of rapeseed plant with biomass, by analyzing field experimental data from 2011-2012, and 2012-2013, to develop finally the rapeseed primary ramification morphological structural model, and to lay a foundation for rapeseed morphological structure model and visualization.

2 Experiments and Methods

2.1 Experimental Samples

Three varieties Ningyou 18 (V1) (conventional), Ningyou 16 (V2) (conventional), and Ningyou 19(V3) (hybrid)were used in experiments, and they all belong to *brassica napus*. Canopy morphology structure of the three cultivars had following traits:V1 with the overwintering half-vertical cultivars, and medium height, had higher rankof branch,compacter in plant type; V2 with the overwintering half-vertical cultivars,medium height, andcompact plant type; V3 with the overwintering half-vertical cultivars,had broader and thicker leaves, the leaves light green, and edge of leaves with saw teeth.

2.2 Experimental Methods

Experimental conditions: Field experiment was conducted at the experimental site (32.03° N, 118.87° E) of JAAS, China during the 2011 to 2013rapeseed growing period. The soil type is the yellow-brown soil, and its basic nutrient status: organic carbon, 13.8 gkg^{-1};available Nitrogen, 58.95 $mgkg^{-1}$; available Phosphorus, 29.25 $mgkg^{-1}$; available Potassium, 109.05 $mgkg^{-1}$; and pH 7.84. Three experiments were designed to implement.

Experiment on Cultivar and fertilizer: By split-plot design, fertilization levels ((N 180 $kghm^{-2}$, P_2O_5 120 $kghm^{-2}$, K_2O 180 $kghm^{-2}$ borax 15 $kghm^{-2}$ and CK) was assigned to the whole-plot, and cultivars (V1,V2,V3) to the sub-plot. Six treatments were repeated three times, and the 18 subplots were arranged randomly. The area of each plot was 7.0 m×5.7 m = 39.9 m^2, the density design is 30 cm of row spacing and 17-20 cm of distance between plants, respectively. The13 rows were planted in each subplot, and a blank line were stayed in the inter-plot. The sowing date and the transplanting date wasOctober 15 and November 4respectively, for both 2011 and 2012.The total amount of N-fertilizer application was 3.26kg in the fertilization area, and the basal: seedling: winter ratio was 5:3:2 respectively. Basalrate of $N+P_2O_5+K_2O$-compound fertilizer was at 16.3kg (mass fraction≥25%), rate of calcium superphosphate was at 7.3 kg

(mass fraction 12%), and rate of agricultural potassium sulphate was at 6.4 kg (mass fraction33%). the manure for seedling and winter dressing were all urea and its application amount was 1.41 kg, 2.12 kg, respectively (mass fraction of total N ≥46.2%). Other management activities followed local production practice.

Experiment on Cultivar, fertilizer, and density: By split-plot design, fertilization levels (N, P_2O_5, K_2Oeach of 180 kghm^{-2}, 90kghm^{-2} kghm^{-2} and CK) was assigned to the whole-plot and cultivars (V1, V3) and density levels (D_1 (6×104 planthm^{-2}),D_2(1.2×105 planthm^{-2}) and D_3 (1.8×105 planthm^{-2}))to the sub-plot. Eighteen treatments were repeated three times, and the 54 plots were arranged randomly. The area of each plot was 3.99 m×3.5 m = 13.97 m^2, the density design is 42 cm of row spacing and the distance between plants was calculated by density. The 9 rows were planted in each subplot, and a blank line was stayed in the inter-plot. The sowing date and the transplanting date was October 8 and November 9 respectively, for both 2011 and 2012.

The basal: seedling: winter ratio of fertilizer application was 5:3:2 respectively. Folia application of borax was at a rate of 15 kghm^{-2} after bolting of rapeseed. Other management activities followed local production practice.

Experiment on Cultivar experiment: The experiments were a randomized complete block design, with three cultivars (V1, V2, V3), under the same fertilization level,N90(N, P_2O_5, K_2O each of 90 kghm^{-2})and density level,D_2 (1.2×105 planthm^{-2}),3 replications, and the 9 subplots. The area of each plot was7.98 m×3.5 m = 27.93 m^2, the density design is 42 cm of row spacing. Other treatments with the Cultivar, fertilizer and density experiment.

Measurements: we selected 3 plants with similar growth status in each treatment, and determined the blade length, blade width, and blade bowstring length at various leaf ranks on primary ramification more than 2.5 cm, and the length and the diameter of the primary ramification. Then, leaves were separated from the ramification, and into the paper bags, then put in oven, the temperature of green removing in 105℃ for 30 minutes, in 80℃until reaching a stable weight.

Blade Leaf blade length: measuring the length of the blade straight state from the leaf tip to the leaf base; Leaf blade width: measuring the maximum length of the leaf width value (in the middle of the blade),average value was gained by multiple measurements. Leaf blade bowstring length: as the elongation of the blade, due to gravity and other effects, the leaf is deformed, and bends into an arc downwardly. So the leaf blade bowstring length is from the leaf base to the leaf tip of the linear distance of space, average value was gained by multiple measurements.

Primary ramification (PR) Length of PR: the length of the straight state which is the distance from the basal of the PR to the top of the PR; Diameter of PR: measuring the base, middle and top of PR several times using the vernier caliper and average value was gained by multiple measurements.

Data Analysis: We used the MS EXCEL 2007 and SPSS version 19 to analyzed the experiment data. Part of the data of different cultivars and fertilizer levels were for the modeling and parameter determination in 2011-2012. The remaining independent data were for model testing and inspection.

Model validation: We used the root mean squared errors(*RMSE*), the correlation (*r*), the average absolute difference (d_a), the ratio of d_a to the average observation (d_{ap}), and 1:1 chart of measured values and simulated values properties to validate the models developed in this paper (Cao et al. 2012). The smaller *RMSE*, d_a, and d_{ap} values, the better consistency of simulated and observed values, and the deviation will be small, the simulation results of the model proved to be accurate and reliable. So the d_a, and d_{ap} are defined as:

$$d_i = X_{Oi} - X_{Si}$$

$$d_a = \frac{1}{n}\sum_{i=1}^{n} d_i$$

$$\bar{X}_O = \frac{1}{n}\sum_{i=1}^{n} X_{Oi}$$

$$d_{ap} = d_a / \bar{X}_O \times 100\%$$

With *i*=sample number, X_{oi}=observed values, X_{si}=simulated values, *n*=total number of measurements.

3 Results and Discussion

3.1 Model Description

Leaf is an important organ of photosynthesis, and the blades of PR are the main organ of photosynthesis in the mid and late period of rapeseed growth stages, which directly determines the photosynthetic capacity and the final yield. The morphology of the rapeseed leaves have characteristics with complexity, variability, and difficult to obtain, so it is an important part of the rapeseed plant model. According to the status of the petiole, the leaf for *brassica napus* can be divided into long-petiole, short-petiole, and sessile leaf on the main stem, and the leaves of PR are similar to the sessile leaf[18].

3.2 Leaf Blade Length Model

The production of the effective PR usually occurs in the axillary buds above the tenth leaf in the upper on the main stem. According to observation in 2011 to 2012 experiment, the leaf blade length with the leaf dry weight was close to proportional increasing trend (Fig. 1). Hereby, the models can be expressed as follows:

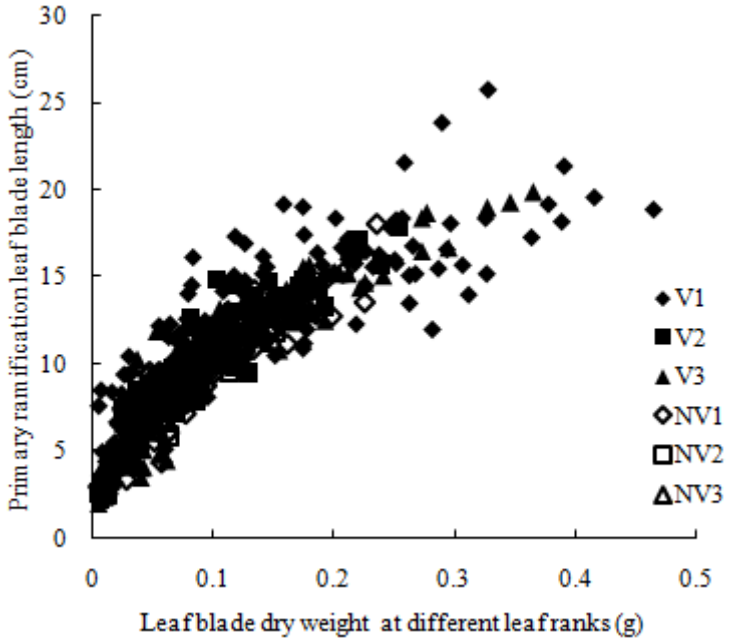
$PRLL_{jk}(i) = DWPRLB_{jk}(i) \times PRRLW_{jk}(i)$ (1)

$DWPRLB_{jk}(i) = PRCPLB_{jk}(i) \times DW_{SP}(i)$ (2)

$DW_{SP}(i) = MDW_{SP}(i) \pm SDW_{SP}(i)$ (3)

$MDW_{SP}(i) = DW_{CP}(i)/DES$ (4)

where, $PRLLjk(i)$is the kth leaf blade length of the jth primary ramification(cm), $DWPRLB_{jk}(i)$is the kth leaf dry weight of the jth primary ramification(cm), $PRRLW_{jk}(i)$ is the ratio of the kth leaf length of the primary ramification to leaf biomass (cm g^{-1}), $PRCPLB_{jk}(i)$ is the ratio of the kth leaf biomass of the primary ramification to the biomass of upper plant part (g g^{-1}), $MDW_{SP}(i)$ is the mean dry weight of per plant (g $plant^{-1}$), $DW_{SP}(i)$ is the dry weight of per plant (g$plant^{-1}$), $DW_{CP}(i)$ is the biomass in canopy per unit area (g m^{-2}), $SDW_{SP}(i)$ is the standard error of dry weight of per plant (g $plant^{-1}$) (determined by experiment), and DES is the plant number unit area (plant m^{-2}).



V1-Ningyou18 with fertilizer; V2-Ningyou16 with fertilizer; V3-Ningza 19 with fertilizer;NV1- Ningyou18 with no fertilizer;NV2-Ningyou16 with no fertilizer;NV3- Ningza19 with no fertilizer (the same as follows)

Fig.1 Variation of the primary ramification leaf length by the leaf dry weight for different treatments in 2011-2012

The data in the 2011 to 2012 and 2012 to 2013 experiment showed that the number of the ramification leaf has a definite relationship with ramification rank. Generally effective ramification was on the middle and upper part of the main stem, all can reach four leaves, and some ramifications was up to six or more but relatively less. Therefore, the first four leaves were studied in this study, and the other blades were not measured as it is difficult to determine the relationship with biomass.

The data in the 2011 to 2012 experiment showed that the values of $PRRLW_{jk}(i)$ with the leaf rank on primary ramification were close to quadratic function. The significant R=0.768 (n=74, $R_{(72,0.001)}$=0.375, P<0.001) and R^2=0.589 for the first leaf; R=0.584 (n=77, $R_{(75,0.001)}$=0.367,P<0.001) and R^2=0.341 for the second leaf; R=0.489 (n=32, $R_{(30,0.01)}$=0.452, P<0.01) and R^2=0.240 for the third leaf; R=0.557(n=36, $R_{(34,0.001)}$=0.525, P<0.001) and R^2=0.310 (Fig.2) for the fourth leaf (eq. (5) ,Table 1).

The F-values, t-values, c_1, d_1, e_1, c_2, d_2, e_2, c_4, and e_4 all were significant at $P<0.001$, apart from c_3, d_3, d_4, and e_3 (Table 1).

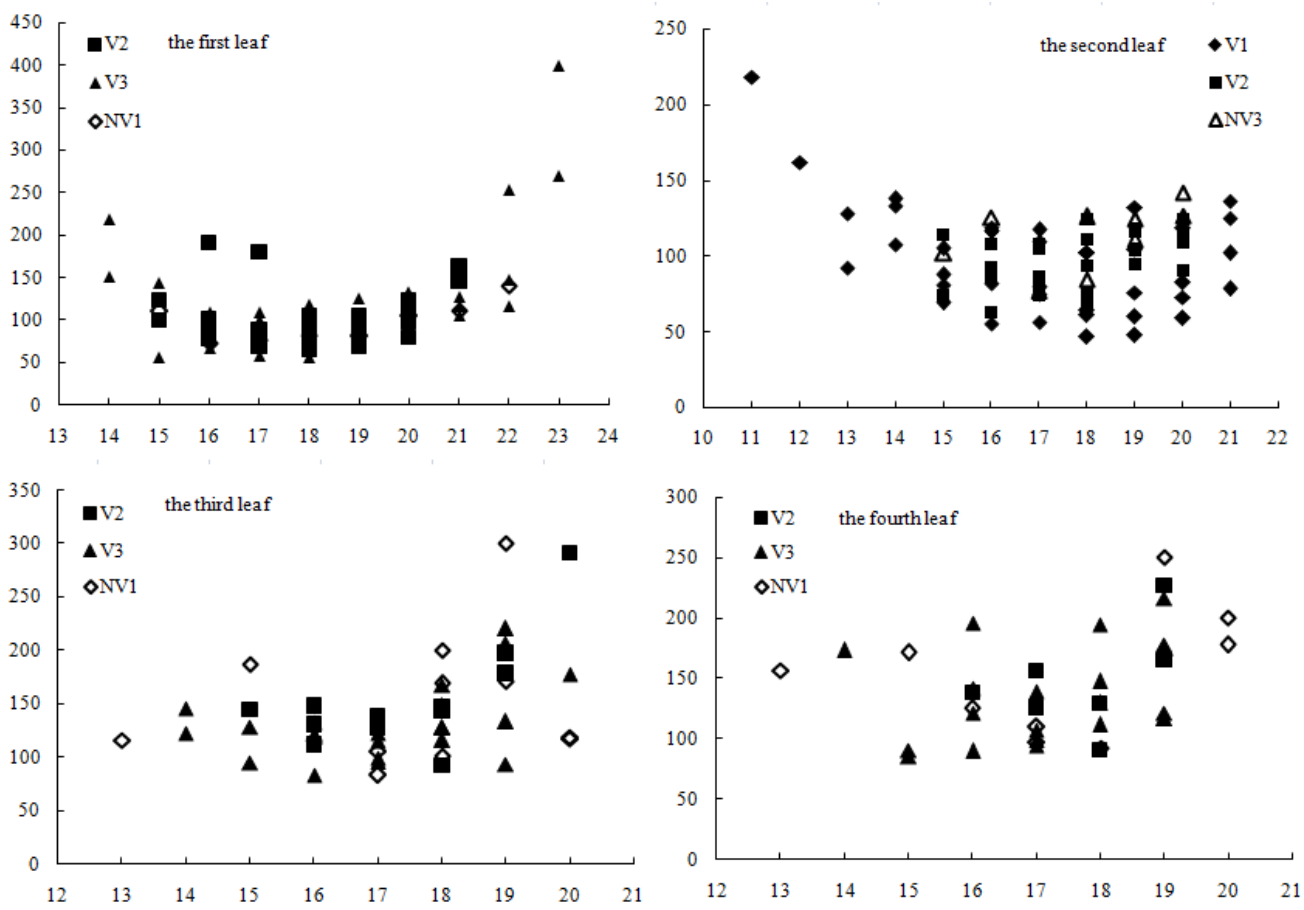


Fig.2 Variation of *PRRLW* values of different treatments of the first four leaf blade length by primary ramification rank in 2011-2012.

$$PRRLWjk(i)=\begin{cases} c_1PRR_{j1}(i)^2+d_1PRR_{j1}(i)+e_1 \text{ , the first leaf, } 14\le j\le 23 \\ c_2PRR_{j2}(i)^2+d_2PRR_{j2}(i)+e_2 \text{ , the second leaf, } 11\le j\le 21 \\ c_3PRR_{j3}(i)^2+d_3PRR_{j3}(i)+e_3 \text{ , the third leaf, } 13\le j\le 20 \\ c_4PRR_{j4}(i)^2+d_4PRR_{j4}(i)+e_4 \text{ , the fourth leaf, } 13\le j\le 20 \end{cases} \quad 1\le k\le 4 \quad (5)$$

Table 1. The determination of model parameters and significance test

Eq.	*n*	Parameter Symbolic	Unstandardized Coefficients	*t*
$PRRLW_{j1}(i)= c_1PRR_{j2}(i)^2+d_1PRR_{j2}(i)+e_1$	74	c_1	6.364	8.554***
		d_1	-97.389	-7.69***
		e_1	451.118	8.752***
$PRRLW_{j2}(i)= c_2PRR_{j2}(i)^2+d_2PRR_{j2}(i)+e_1$	77	c_2	2.446	5.563***
		d_2	-36.179	-5.913***
		e_2	221.418	10. 806***
$PRRLW_{j3}(i)= c_3PRR_{j3}(i)^2+d_3PRR_{j3}(i)+e_3$	32	c_3	3.732	2.074*
		d_3	-40.823	-1.616
		e_3	230.506	2.684*
$PRRLW_{j4}(i)= c_4PRR_{j4}(i)^2+d_4PRR_{j4}(i)+e_4$	36	c_4	5.608	3.068***
		d_4	-46.053	-2.528*
		e_4	214.337	4.933***
$PRLW_{jk}(i)=c_5PRL_{jk}(i)+d_5$	262	c_5	0.528	36.285***
		d_5	-0.941	-5.356***
$PRBL_{jk}(i)=c_6PRL_{jk}(i)+d_6$	262	c_6	0.703	25.536***
		d_6	1.120	3.369***
$PRSL_{ji}=c_7PRSDW_{ji}^{d7}$	106	c_7	37.098	20.956***
		d_7	0.571	12.563***
$PRSD_{ji}=c_8PRSDW_{ji}+d_8$	96	c_8	0.082	5.619***
		d_8	0.508	30.897***

***, **, and * denotes P<0.001, P<0.01, and P<0.05, respectively.

The data in the 2011 to 2012 experiment showed that $PRCPLB_{jk}(i)$ and $PRRLB_{jk}(i)$ with primary ramification rank were linear function model and exponential function model, respectively.*R*19 was the inflexion under different treatment levels, and the fitting precision for $PRCPLB_{jk}(i)$ in various treatments were: fertilizer with cultivars significant R=0.603 (n=56, P<0.001, $R_{(54,0.001)}$=0.428), R^2=0.363 and R=0.568 (n=34, P<0.001, $R_{(32,0.001)}$=0.539), R^2=0.323; no fertilizer with cultivars significant R=0.567 (n=39, P<0.001, $R_{(37,0.001)}$=0.507), R^2=0.321 and R=0.599(n=32, P<0.001, $R_{(30,0.001)}$=0.554), R^2=0.359(Fig.3). The fitting precision for $PRRLB_{jk}(i)$ in various treatments were: fertilizer with cultivars significant R=0.592(P<0.001, n=159, $R_{(157,0.001)}$=0.264), R^2=0.351; no fertilizer with cultivars significant R=0.466(n=102, P<0.001, $R_{(100,0.001)}$=0.321), R^2=0.217(Fig.4, eq. (6),(7),(8), Table 2).

The *F*-values, *t*-values, all model parameters apart from B_5 were at P＜0.001 (Table 2).

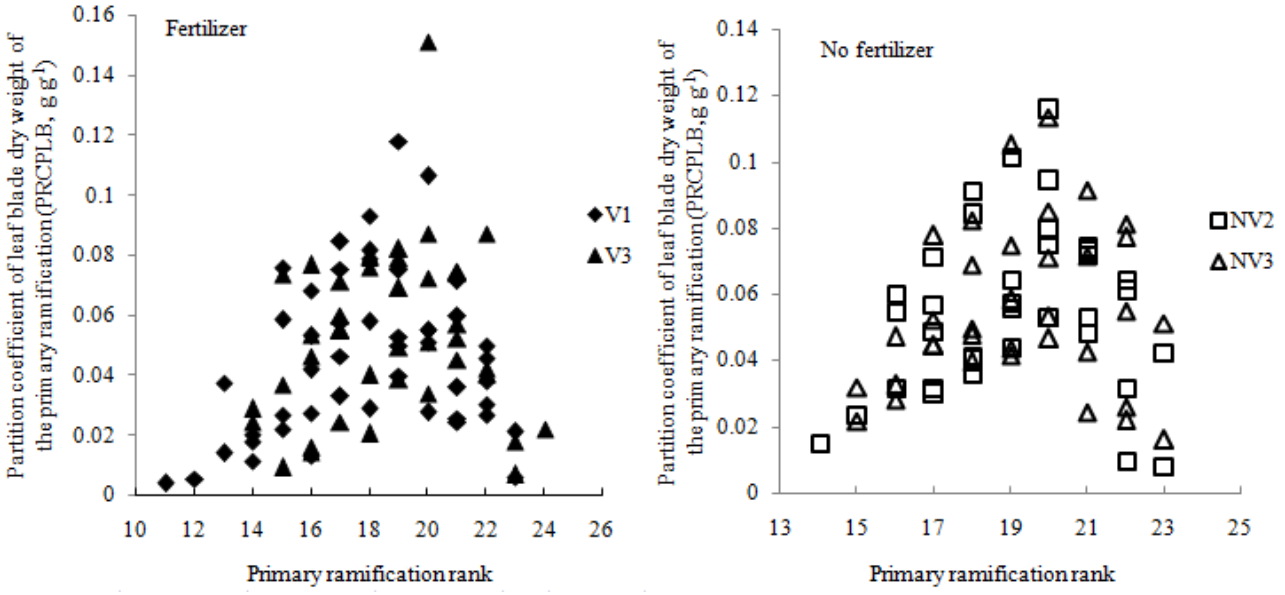


Fig.3 Variation of the $PRCPLB_{ji}$ values by primary ramification rank in 2011-2012

$$PRCPLB_{ji} = \begin{cases} A_3 PRR_{ji} + B_3, & 11 \le j \le 19 \\ A_4 PRR_{ji} + B_4, & 19 < j \le 24 \end{cases} \quad \text{Fertilizer} \quad (6)$$

$$NPRCPLB_{ji} = \begin{cases} A_5 PRR_{ji} + B_5, & 11 \le j \le 19 \\ A_6 PRR_{ji} + B_6, & 19 < j \le 23 \end{cases} \quad \text{No fertilizer} \quad (7)$$

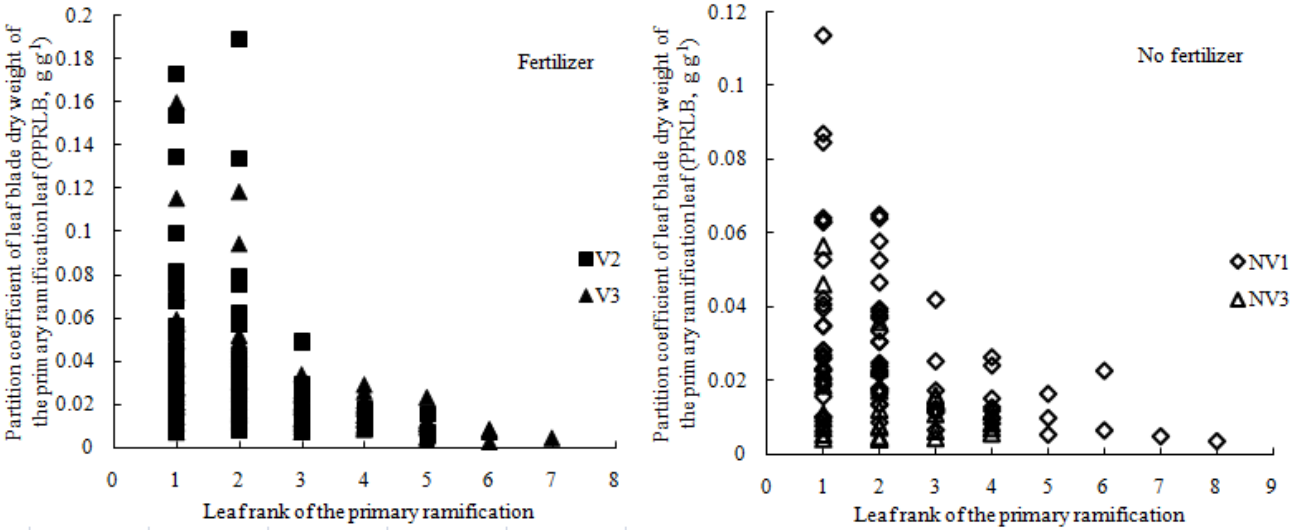


Fig.4 Variation of the *PPRLBjk(i)* values by leaf rank on primary ramification in 2011-2012

$$PPRLB_{jk}(i) = \begin{cases} A_7 \times e^{B_7 PRLR_{jk}(i)}, & 11 \le j \le 23 \quad \text{Fertilizer} \\ A_8 \times e^{B_8 PRLR_{jk}(i)}, & 11 \le j \le 23 \quad \text{No fertilizer} \end{cases} \quad (8)$$

Table 2. The determination of model parameters and significance test

Eq.	*n*	Parameter Symbolic	Unstandardized coefficients	*t*
$PRCPLBji=A_3PRRji+B_3$	56	A_3	0.008	5.549***
		B_3	-0.085	-3.513***
$PRCPLBji=A_4PRRji+B_4$	34	A_4	-0.015	-3.915***

		B_4	0.368	4.515***
$PRCPLBji=A_5PRRji+B_5$	39	A_5	0.009	4.187***
		B_5	-0.103	-2.778*
$PRCPLBji=A_6PRRji+B_6$	32	A_6	-0.016	-4.097***
		B_6	0.398	4.803***
$PRCLBjk(i)= A_7e^{B7PRLPjk(i)}$	159	A_7	0.053	-9.214***
		B_7	-0.341	9.645***
$PRCLBjk(i)= A_8e^{B8NPRLPjk(i)}$	102	A_8	0.033	-5.270***
		B_8	-0.258	7.554***

3.3Maximum Leaf Blade Width Model

The experiment on Cultivar and fertilizer in the 2011 to 2012 showed that the $PRLW_{jk(i)}$with the leaf length were described by a growth function (eq. (9)). R=0.914, n=262, P<0.001, $R_{(260,\ 0.001)}$=0.206, R^2 =0.835 (Fig. 5).

The F-values, t-values, c_5, d_5 all at P<0.001 (Table 1).

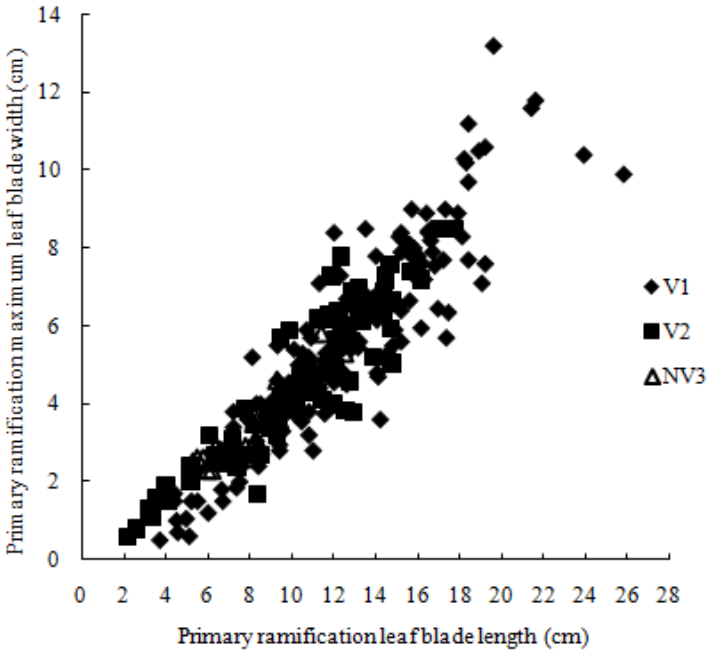


Fig.5 Variation of $PRLW_{jk(i)}$ values by leaf length in 2011-2012

$$PRLW_{jk}(i)=c_5PRL_{jk}(i)+d_5, \quad 11\leq j\leq 23 \quad (9)$$

3.4Leaf Blade Bowstring Length Model

Apparently, the maximum $PRBL_{jk}(i)$=PRLL$_{jk}(i)$. The experiment on Cultivar and fertilizer in the 2011 to 2012 showed that variation of leaf bowstring length with the leaf length could be represented by the linear function. R=0.846, P<0.001, n=262, $R_{(260,\ 0.001)}$=0.206, R^2=0.715 (Fig. 6).

The F-value ,t-values, c_6 , d_6 all were t at P<0.001 (Table 1).

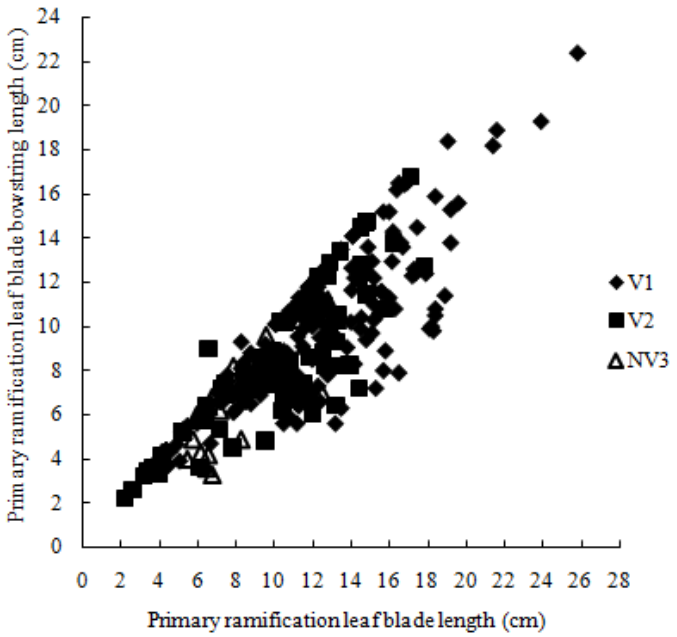


Fig.6 Variation of $PRBL_{jk}(i)$ values by primary ramification leaf blade length in 2011-2012

$$PRBL_{jk}(i)=c_6PRL_{jk}(i)+d_6, \qquad 11\leq j\leq 23 \qquad (10)$$

3.5 Stem Length Model of Primary Ramification

From the experimental data in the 2011 to 2012 we can see that the *j*th stem length of primary ramification (cm), $PRSL_{ji}$, changes with the dry weight could be described by a power function. R=0.776, n=106, P<0.001, $R_{(104,\ 0.001)}$=0.314, R^2=0.603 (Fig. 7).

The F-value, t-values, c_7, d_7 all were at P<0.001 (Table 1).

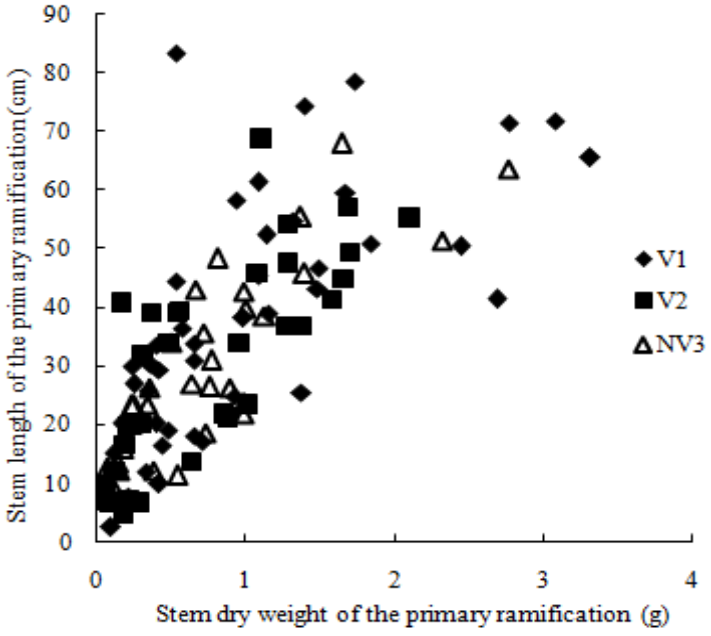


Fig.7 Variation of $PRSL_{ji}$ values of different treatments by the dry weight in 2011-2012

$$PRSL_{ji} = c_7 PRSDW_{ji}{}^{d_7}, 11 \le j \le 23 \quad (11)$$

3.6StemDiameterModel of Primary Ramification

The experimental data in the 2011 to 2012 showed that the *j*th stem diameter of primary ramification, $PRSD_{ji}$, changed with the dry weight could be described by a linear function with significant R=0.501, n=96, P<0.001, $R_{(94,\ 0.001)}$=0.331, R^2=0.251 (Fig. 8).

The F-value, t-values, c_8, d_8 all were at P<0.001 (Table 1).

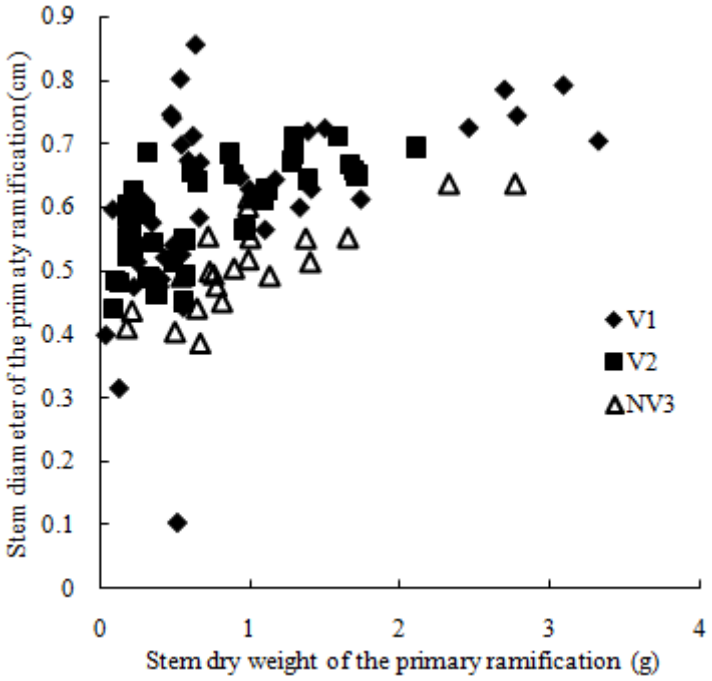


Fig.8 Variation of $PRSD_{ji}$values of different treatments by the dry weight in 2011-2012

$$PRSD_{ji} = c_8 PRSDW_{ji} + d_8, 11 \le j \le 23 \quad (12)$$

3.7Validation

we used the independent experimental data to validate the biomass-based rapeseed plant primary ramification morphological structure model proposed in this study. The *RMSE*, and the d_a in rapeseed primary ramification morphological parameters, leaf blade length, the maximum leaf blade width, the leaf blade bowstring length, stem length of PR, and stem diameter of PR were 5.033cm,-1.900cm (n=125);3.233cm, -0.055cm (n=117);2.810cm, 0.274cm (n=87);3.272cm, -0.720cm (n=90); 0.778cm, 0.374cm (n=514); 1.193cm, 0.137cm (n=514); 8.990cm, 0.806cm (n=145); and 0.102cm, -0.025cm (n=153), respectively. The r values in rapeseed primary ramification morphological properties all at P<0.001 or P<0.01, but the ratio of d_a to the average observation (d_{ap}) values were less than 5% for the second leaves length, the third leaves length, leaf blade bowstring length, the PR length, the PR diameter, *PRRLB* values for V2 and V3,which indicated these model's accuracy is high (Table 3).The 1:1 line in rapeseed primary ramification were represented in Fig. 9.

The r values in rapeseed *PRCPLB* all at P<0.001 or P<0.01, but the ratio of d_a to the average observation (d_{ap}) values

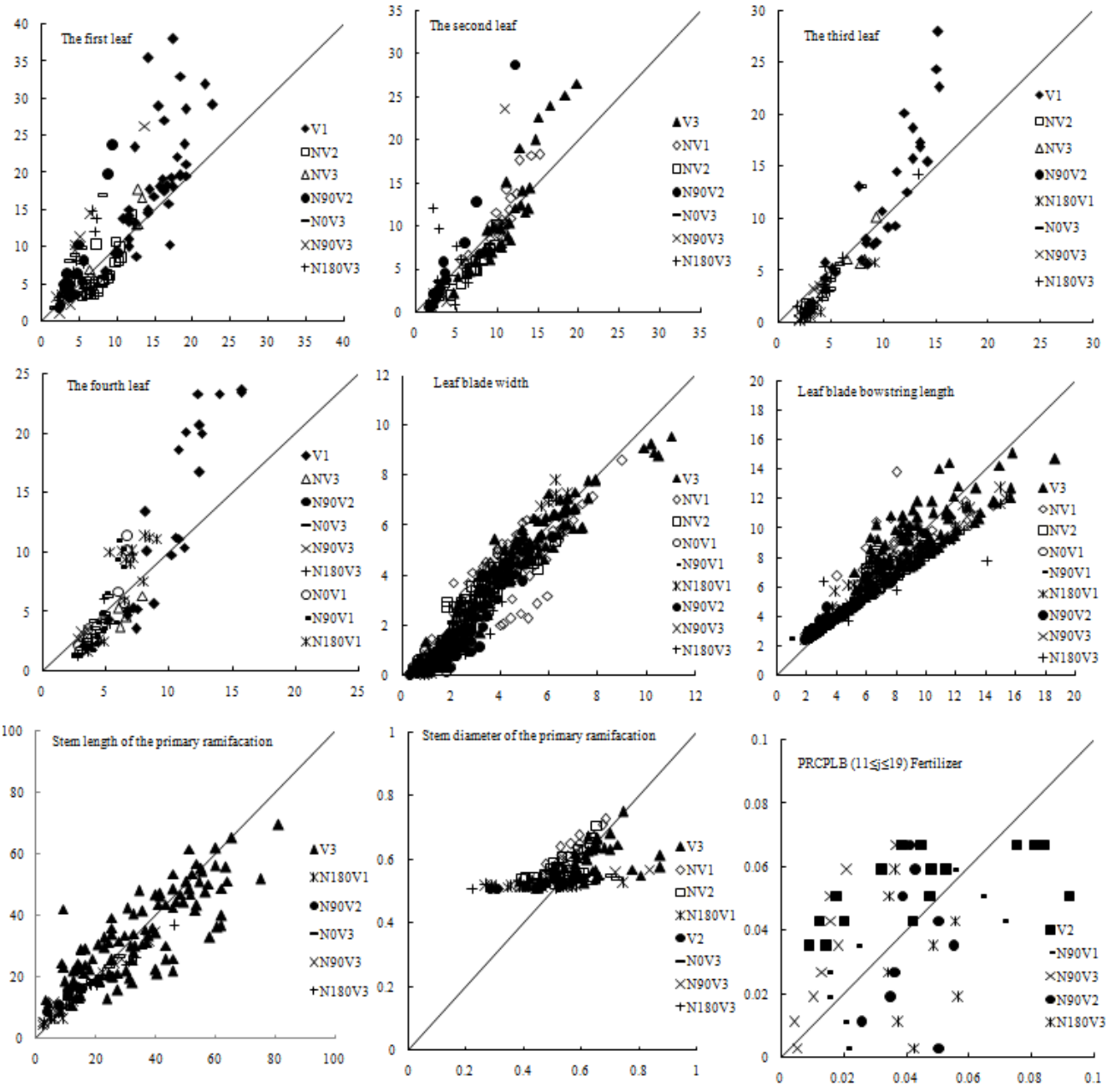
were between 5%-10% for *PRCPLB* with fertilizer (j>19) and *PRCPLB* no fertilizer (11≤j≤19), which indicated that these model's accuracy is good. The *dap* values of more than 10% which indicated that the model had a lower accuracy, but the d_a values and the *RMSE* of *PRCPLB* and *PRRLB* were small (Table 3). The 1:1 chart of measured values and simulated values in *PRCPLB* and *PRRLB* are represented in Fig. 9.

Notably, we had seen that the first leaf blade length and *PRRLB* value(no fertilizer)models had obvious errors from Table 3, and Fig. 9, which showed that the two models still needed to be improved and perfected in the further.

Table 3. Model validation results in 2012-2013

Model parameters		Statistic parameters of measured values and simulated values					
		r	d_a	d_{ap} *(%)*	*RMSE*	*n*	*Sig.*
LL_1(cm)		0.6520^{***}	-1.900cm	21.11	5.033cm	125	$r_{(123,0.001)}$=0.291
LL_2 (cm)		0.6846^{***}	-0.055cm	0.70	3.233cm	117	$r_{(115,0.001)}$=0.300
LL_3 (cm)		0.6169^{***}	0.274cm	4.54	2.810cm	87	$r_{(85,0.001)}$=0.347
LL_4 (cm)		0.5275^{***}	-0.720cm	11.56	3.272cm	90	$r_{(88,0.001)}$=0.341
LW of PR(cm)		0.9071^{***}	0.374cm	11.90	0.778cm	514	$r_{(512,0.001)}$=0.146
LBL of PR (cm)		0.8555^{***}	0.137cm	2.21	1.193cm	514	$r_{(512,0.001)}$=0.146
PRL(cm)		0.8325^{***}	0.806cm	2.73	8.990cm	145	$r_{(143,0.001)}$=0.273
PRD(cm)		0.4476^{***}	-0.025cm	4.64	0.102cm	153	$r_{(151,0.001)}$=0.264
V1-V3$PRCPLB_{ji}$(gg^{-1})	11≤j≤19	0.9091^{***}	-0.004 gg^{-1}	10.81	0.021g/g	50	$r_{(48,0.001)}$=0.451
	j>19	0.5079^{**}	-0.003gg^{-1}	5.41	0.021 g/g	26	$r_{(24,0.01)}$=0.496
NV2-NV3$PRCPLB_{ji}$(gg^{-1})	11≤j≤19	0.6364^{***}	0.003gg^{-1}	5.85	0.030 g/g	52	$r_{(50,0.001)}$=0.443
	j>19	0.6500^{***}	-0.013 gg^{-1}	29.55	0.028g/g	30	$r_{(28,0.001)}$=0.570
V2-V3 $PRRLB_{jk}(i)$(gg^{-1})		0.7440^{***}	-0.0001 gg^{-1}	0.458	0.008g/g	352	$r_{(350,0.001)}$=0.175
NV1-NV3 $PRRLB_{jk}(i)$(gg^{-1})		0.2385^{**}	0.004 gg^{-1}	17.39	0.012g/g	185	$r_{(183,0.01)}$=0.190

N0V1-V1 with no fertilizer, N90V1-V1 with normal fertilizer, N180V1-V1 with high fertilizer; N90V2-V2 with normal fertilizer; N0V3-V3 with nofertilizer, N90V3-V3 with normal fertilizer, N180V3-V3 with high fertilizer


The first leaf
V1
NV2
NV3
N90V2
N0V3
N90V3
N180V3
The second leaf
V3
NV1
NV2
N90V2
N0V3
N90V3
N180V3
The third leaf
V1
NV2
NV3
N90V2
N180V1
N0V3
N90V3
N180V3
The fourth leaf
V1
NV3
N90V2
N0V3
N90V3
N180V3
N0V1
N90V1
N180V1
Leaf blade width
V3
NV1
NV2
N0V1
N90V1
N180V1
N90V2
N90V3
N180V3
Leaf blade bowstring length
V3
NV1
NV2
N0V1
N90V1
N180V1
N90V2
N90V3
N180V3
Stem length of the primary ramifacation
V3
N180V1
N90V2
N0V3
N90V3
N180V3
Stem diameter of the primary ramifacation
V3
NV1
NV2
N180V1
V2
N0V3
N90V3
N180V3
PRCPLB (11≤j≤19) Fertilizer
V2
N90V1
N90V3
N90V2
N180V3

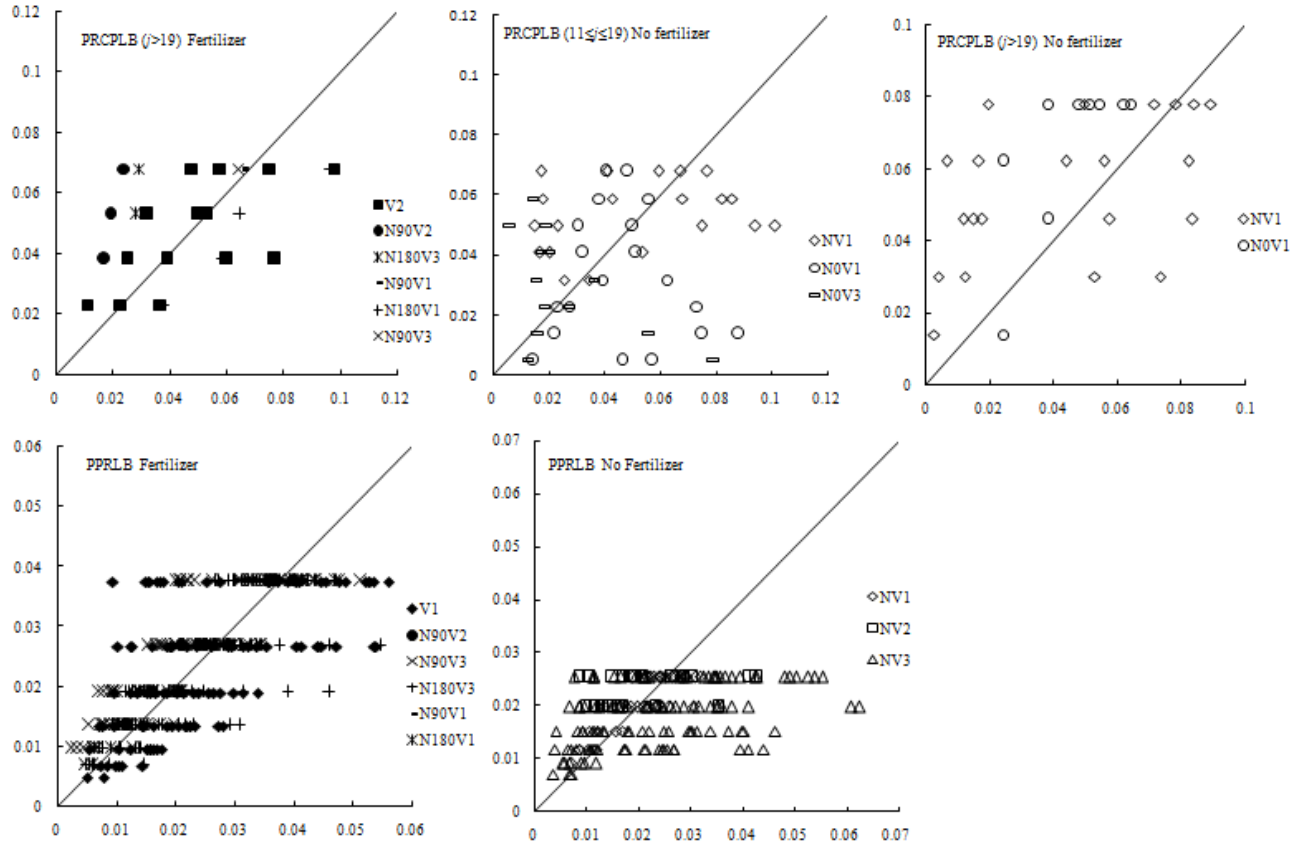


Fig.9Comparison of the observed with the simulated in 2011-2013

3.8Discussion

The study on FSPMs of rapeseed has important theoretical and application value for selection ideal plant type and regulation of plant type. One of the most important methods to establish the Function-Structural Model of rapeseed is to combine the rapeseed growth model with the morphological structure model by biomass. This paper establishes relationship between morphological parameters of rapeseed and organ biomass, realized the organic combination of rapeseed growth model and rapeseed morphological model. It lays the basis for the establishment of FSPMs of rapeseed.

Studies on crop morphological structural models, such as rice, wheat, cotton, corn have been many reported. Chang *et al*. [19] constructed the simulation model of leaf elongation process in rice, analyzed the variation of leaf blade geometric morphology indices of rice with the growth process and environment conditions, and provided facilitate to digital and visualization of rice. Zhang*et al*. [20] established a process-based model with the methods of system analysis and dynamic modeling techniques. Fournier *et al*. [21]by using L-systems proposed a detailed description of the relationship between leaf functions and chlorophyll content of leaf. The concept of the relative leaf area index (LAI) and the relative accumulated temperature were put forward, and fitted parameters of the model by using MATLAB, the dynamic simulation model of leaf area index of corn was established [22].By the computer model based on combining crop physiological and ecological process with visualization, a digital and visualization techniques of cotton growing system was presented [23].

Through there were some studies on rapeseed growth models and morphological models [24-25], there are many research on growth-development law and structural characteristics of rapeseed [26, 15]. However, the combination of rapeseed growth model and morphological model is lack of further study. Yue[6] conducted a rapeseed ramification morphological structure model based on GDD, but the combined with the growth model was not mentioned.

In this paper, the leaf length models can be linked with the rapeseed dry matter production models through biomass, and the models also can be linked with the rapeseed growth models by biomass. The maximum leaf blade width model and the leaf blade bowstring length model are represented by a linear function with leaf blade length well. Stem length model and stem diameter model of primary ramification are represented by a power function and a linear function, respectively. One of the most important factors is the angle between primary ramification and main stem, and we will complete it in the coming.

The research on morphological structure of rapeseed primary ramification hasa certain complexity, and influenced by the external environment and difficult to obtain morphological indices accurately, tends to appear some experimental error. We will improve measurement methods, such as digital camera, and 3D laser scanner etc., in order to get the whole morphology of plant leaves and ramifications, exploration of the way to enhance the model accuracy.

4Conclusions

In this paper, we developed a rapeseed PR structural model, which indented to explain the response mechanism of the PR morphogenesis to environmental conditions and varieties. Validation of the model with the independent experiment data indicated a good fitness between the simulated and observed in rapeseed.

The *PRRLW* was first put forward, and the relationships between rapeseed plant primary ramification morphological structure and the organ biomass to be established by *PRRLW.* It is a morphological structural parameter of rapeseed with a biological significance, and enhanced mechanism of this study.

Thus, the rapeseed plant primary ramification morphological structure model in this paper is feasible. We expect the proposed to be useful for other morphological indices of rapeseed in the further.

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