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Optimum Transplanting Date for Rape Forage and Grain Yields in the Ridge Culture Place Planting System on the Yangtze River Delta

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Abstract: The ridge culture place planting system (RCPPS) is a promising technique for planting rapeseed that can promote the growth of rapeseed by late rice stubble, which has been widely adopted in the Yangtze River delta. To determine the optimum planting date for rape (*Brassica napus* L.) forage and grain yield in an intensive rice–rape rotation system, a field experiment was conducted with five transplantation dates (from 20 October to 30 November at 10 day intervals) in RCPPS. The forage/grain yield, nutrition, and growth parameters were analyzed. At podding, rape biomass yield was highest, and no significant differences were found among treatments. It was around 12.0% crude protein, 11.4% ether extract, 38.8% neutral detergent fiber, and 34.9% acid detergent fiber. In the treatments of 20 and 30 November, crude protein content increased and acid detergent fiber content decreased significantly. Compared with 20 October, the grain yield of rape transplanted in November decreased significantly by 17.2% to 22.5%. The grain yield was significantly correlated with the number of secondary branches, pods, and seeds. At the final flowering stage, rape transplanted in November had noticeably reduced leaf growth, rhizome width, and yield than 20 and 30 October. Overall, for multiple uses of rapeseed in the Yangtze River delta belt with RCPPS, it is optimal to plant in mid to late November for forage use with higher nutritional value, being coordinated with the previous rice crop, whereas late October is the appropriate planting time to obtain a higher grain yield.

Keywords: ridge culture place planting system; optimum transplant date; rape forage yield; rape grain yield; rape growth characteristics; rape forage nutrition

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1. Introduction

The summer rice–winter rapeseed (*Brassica napus* L.) rotation is the traditional cultivation system in the Yangtze River delta, in which the rice crop cycle is from June to October and afterwards, the winter rape typically grows from November to May. It is likely that oilseed rapeseed would increase rice production and improve soil fertility when used as a previous crop in a rotation system [1]. However, considering the late harvest of the preceding crop and low planting profit, traditional rapeseed is often classified as an uncertain crop compared with the local main crop of rice [2]. Therefore, because of the delayed planting date of rapeseed, low air temperature and high precipitation always occur, which inhibit the vegetative growth of rapeseed seedlings and lead to the poor development of pod formation and grain filling in the late period [3,4]. The planting costs of rapeseed have also increased substantially because the price of agricultural production material and labor resources has increased rapidly in the Yangtze River delta. In addition, large quantities of low-cost, high-quality imported oilseeds have negatively affected the development of domestic rapeseed production, in which rapeseed is grown conventionally for grain [5,6].

The hybrid varieties of low erucic acid and glusosiolate ('double-low') rape are high-yielding forage crops characterized by their high regrowth capacity [7] and nutritive value [8]. Thus, forage rape can be a substantial part of the feed rotation in pasture, particularly in autumn–winter when pasture growth is limited, and it therefore increases the economic benefits of rapeseed production. Forage rape has been promoted in a large area in northern China, including in Heilongjiang, Shanxi, and Gansu provinces [9]. In the northern region, forage rape typically grows from August to October, which is beneficial for improving the productivity in the complementary forage rotation of wheat–forage rape or bean–forage rape. In addition to enriching the species of forage in these agricultural areas, forage rape improves resource use efficiency, including that of temperature, water, and light, compared with fallow fields [10,11]. Forage rape is also beneficial because it reduces soil erosion and soil pathogens and improves soil characteristics [7,12].

In 2017, the National Agricultural Technology Extension Service Center issued 'Winter Rapeseed Production Technical Guidance Opinions 2017–2018', which first clarified the multiple uses of rape for oil, forage, flowers, honey, and fertilizer [13]. To improve rapeseed production, innovative uses of rape need to be developed, consistent with local conditions. In the loess hilly region, the combined uses of rapeseed for forage, sightseeing, and grain have promoted the development of multifunctional agriculture, which brings great economic and ecological benefits [9]. In the cold region of Northeast China, the first innovation in growing forage rapeseed was to plant two crops a year [14]. However, few studies have examined the cultivation of forage rape in the Yangtze River delta.

In the rice–rape rotation system in the Yangtze River delta, the planting date of rapes is restricted by various factors such as stubble configuration, weather, and soil conditions. The timing of transplanting inevitably affects the growth characteristics of rapes. Delayed sowing date with insufficient accumulated temperature would directly inhibit seed germination and early seedling growth, thus affecting the accumulation and transport of photosynthetic products, leading to low biomass and grain yield [15,16]. The ridge culture place planting system (RCPPS) is a promising technique for planting rapeseed that has been widely adopted in the Yangtze River delta [17]. With the RCPPS, the stress of waterlogging damage can be avoided, especially in the seedling stages. Furthermore, early seed sowing and seedling raising can facilitate the growth of rapeseed, particularly alleviating the inhibition of rape growth by rice stubble [17,18]. Sun et al. (2015) [17] found the grain yield with the RCPPS is significantly higher than that with traditional transplanting or a direct-seeding system in the Yangtze River delta.

However, information on the effects of transplanting dates on the growths and nutritional value characteristics, as well as the optimum transplanting dates of brassicas for forage and grains with the RCPPS is lacking, which has inhibited adoption by producers. Therefore, in a field experiment with the RCPPS, we compared the effects of different transplanting dates on the characteristics of rape that are important for forage and grain use. The objectives were the following: (1) to quantify and compare the effects of five transplanting dates on yield and nutritional value of forage grass as well as grain yield of rapeseed in the RCPPS, and (2) to identify the appropriate transplanting dates for rape intended for use as forage or grains. The results of this study will provide the basis for the efficient cultivation of rapeseed for multiple uses in the middle and lower reaches of the Yangtze River.

2. Materials and Methods

2.1. Site Description

A field experiment was conducted near Suzhou (31°27′ N, 120°25′ E; 2 m a.s.l.) in Jiangsu Province, China. In September 2016, soil samples were collected at the 0 to 20 cm depth with a soil auger (3.5 cm diameter) from five individual locations in each plot and then mixed together as one replicate. Soil organic carbon (SOC) and total nitrogen (TN) content were determined by using the Walkley–Black and Kjeldahl digestion methods, respectively [19,20]. Soil water-soluble phosphorus (P) was determined by the Olsen method [21]. Soil available potassium (K) was extracted with 1 M NH_4OAC (pH = 7) and analyzed by a flame photometer (M410, Sherwood, UK). Soil pH was measured in a 1:2.5 soil/water solution using a combined electrode pH meter (HI 98121, Hanna Instruments, Kehl am Rhein, Germany). The soil pH was 6.2, and the nutrient concentrations were the following: SOC, 31.6 $g \cdot kg^{-1}$; TN, 1.80 $g \cdot kg^{-1}$; available P, 35.0 $mg \cdot kg^{-1}$; and available K, 137.3 $mg \cdot kg^{-1}$.

The climate data during the growth period were collected at a meteorological station. Average monthly rainfall and daily temperature are summarized in Table 1. A north subtropical monsoon climate characterizes the Yangtze River delta, with an annual mean air temperature of 16.0 ± 1.9 °C. During the experimental years, the annual average precipitation was approximately 1074 mm, mainly distributed in the beginning of the growing season from October to November. The cumulative annual temperatures reached approximately 3987 °C. The total sunshine hours were 1101.3 h. The relative humidity was 71.9%. The 'double-low' hybrid rapeseed in the experiment was Ningza No. 1818, which was from the Jiangsu Academy of Agricultural Sciences.

Table 1. Meteorological conditions during the rapeseed growing season.

Month	Average Temperature (°C)	Cumulative Temperatures (°C)	Total Rainfall (mm)	Total Sunshine Hours (h)	Relative Air Humidity (%)
October	20.2	615.5	282.9	42.6	82.9
November	13.1	385.2	131.8	87.0	79.6
December	8.9	276.2	55.6	120.5	74.3
January	7.0	199.2	67.3	104.5	74.2
February	7.9	196.7	28.9	130.7	65.4
March	12.8	332.4	74.1	129.2	66.6
April	20.8	538.9	90.4	169.6	63.2
May	26.3	703.0	83.0	186.9	65.0
Average	16.0	3987.0	1074.0	1101.3	71.9

2.2. Experimental Design and Field Management

The field experiment was conducted from 2016 to 2017 and was composed of five transplanting dates as experimental treatments that were arranged in a randomized block design with three replications. The five transplanting dates were 20 October, 30 October, 10 November, 20 November, and 30 November, with a 10 day interval, according to the harvest dates of previous rice variety. The size of each plot was 15 m^2 (3 m × 5 m).

The rapeseed was sown in the field in late September and then nursed for approximately 45 days. The seedlings of all transplant date treatments were planted in the RCPPS (Appendix A, Figure A1). The RCPPS in the plots consisted of 80 cm wide ridges of soil with 30 cm wide and 20 cm deep furrows on each side of a ridge. Each plot contained three ridges, and in each ridge, two rows of rapeseed were transplanted. One rape seedling at the age of 4.1 to 4.5 leaves was selected to transplant per hill at constant spacing (15.0 cm × 60.0 cm and 15.0 cm × 40.0 cm) with the transplanting density of 12,000 $seedlings \cdot ha^{-1}$. Nitrogen fertilizer of chemical urea was applied at 270 kg N ha^{-1} during the entire growth season at the ratio of 4:3:3 at transplanting, seedling, and bolting stages. All treatments were supplied with P (105 kg P_2O_5 ha^{-1}) and K (225 kg K_2O ha^{-1}) as a single application. The other agricultural management practices were consistent with those of local production.

2.3. Field Sampling and Laboratory Analysis

Observations of leaf age and growth stages were recorded at 5 day and 7 day intervals, respectively. Biomass yield was measured at the stages of budding, initial flowering, final flowering, and podding. On each sampling date, six hills were harvested. The plants were cut from the bottom, and the fresh weights were recorded. Then, the growth characteristics, namely, the number of effective leaves, rhizome thickness, and plant height, were measured in the lab. Subsamples of approximately 800 g plant were air-dried and then oven-dried at 70 °C until constant weight to determine the dry weight (DM) and water content.

At maturity, 8 m^2 of rapeseed was manually harvested (non-sampling area) from each plot to determine the grain yield. The grains were threshed, cleaned, and weighed after drying in the sun for one week. Subsamples of 500 g of grains were oven-dried at 70 °C until constant weight to determine the DM and water content. To prevent the loss of the pods, before the final harvest, six hills of representative plants were selected randomly to determine the yield components of rapeseed: the number of branches per plant, the number of pods and seeds at each level of branch, and the 1000 seed weight. In addition, subsamples of pods were taken randomly to determine the length and width and the number of seeds.

All plant samples were ground in a micro hammer (FZ102, Taisite, Tianjin, China). To avoid cross-contamination, it was cleaned between millings. After wet digestion with H_2SO_4–H_2O_2 at 220 °C, samples were analyzed for crude protein (CP%) by the micro-Kjeldahl procedure [22]. The contents of neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined by the Van Soest method [23] The ether extract (EE) was measured by the residual method [24].

2.4. Statistical Analyses

Statistical analyses were conducted using the Statistical Analysis System 9.3 [25] (SAS Institute, Cary, NC, USA, 2009). A one-way analysis of variance (ANOVA) with Tukey's post-hoc test ($p < 0.05$) was used to assess the differences in biomass and grain yield, as well as the parameters of nutritional content, yield components and growth between transplanting date treatments. A Pearson correlation between grain yield and yield components was adapted using SAS. All figures were plotted with Origin 2018 software (OriginLab, Northampton, MA, USA).

3. Results

3.1. Effects of Transplant Date on Forage Yield and Nutrition of Rapeseed

The dry matter production of forage rape increased rapidly from the bud period to the final flowering stage but then increased gradually in the podding stage (Figure 1). At the final flowering stage, the transplantation on 20 October resulted in significantly higher biomass yield than that in the transplantations in November. However, no significant differences were found between transplanting periods in the other stages (Figure 1). Notably, compared with the transplanting dates of 20 and 30 October and 10 November, the 20 and 30 November transplanting treatments had significantly higher CP content and lower ADF content (Figure 2). There were no significant differences in EE and NDF contents among the treatments (Figure 2).

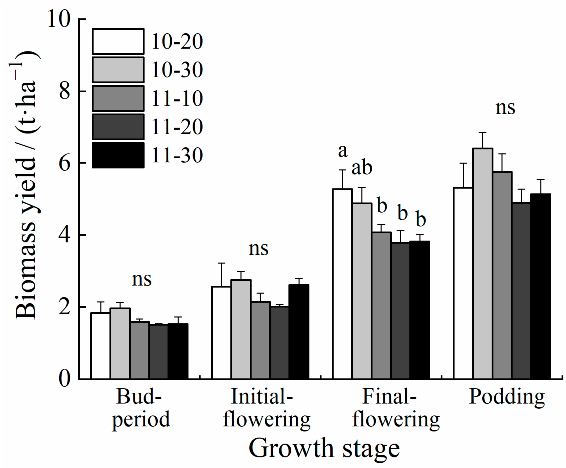

Figure 1. Biomass yield (t·ha^{-1}) of forage rapeseed at four growth stages (bud period, initial flower-

ing, final flowering, podding) as affected by transplanting date. The experimental treatments were five transplant dates (month-day): 10-20, 10-30, 11-10, 11-20, and 11-30. Different lowercase letters indicate significant differences among different transplanting dates in each growth stage at the 0.05 level. ns, no significant differences among different transplanting dates.

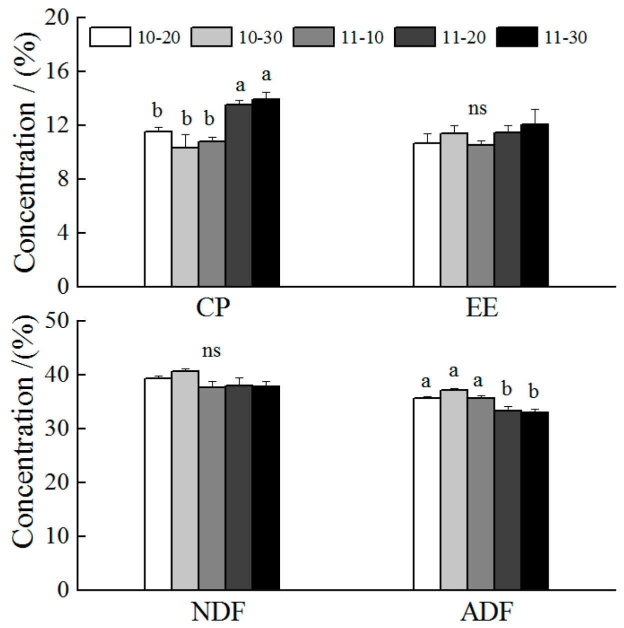

Figure 2. Nutritional content (%) of forage rapeseed at podding as affected by transplanting date. The experimental treatments were five transplant dates (month-day): 10-20, 10-30, 11-10, 11-20, and 11-30. The four measures of nutritional quality were crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), and acid detergent fiber (ADF). Different lowercase letters indicate significant differences among different transplanting dates at the 0.05 level. ns, no significant differences among different transplanting dates.

3.2. Effects of Transplant Date on Grain Yield and Yield Components of Rapeseed

The rapeseed grain yield was significantly related to the transplanting date. The highest yield was 3922 kg·ha^{-1} in the transplanting treatment of 20 October, which was not significantly different from that in the transplanting treatment of 30 October. However, the yields in the transplanting treatments in November were significantly lower than that in the 20 October transplanting treatment by 17.2% to 22.5% (Figure 3).

Compared with the 20 October transplanting treatment, the number of primary branches decreased significantly by 31.2% in the 30 November transplanting treatment, while the number of secondary branches decreased significantly by 40.8% in the 10 November, 78.2% in the 20 November, and 57.1% in the 30 November transplanting treatments (Table 2). The numbers of primary and secondary branches were similar in the 20 and 30 October transplanting treatments (Table 2). With the extension in transplanting date, the numbers of pods in the main inflorescence and the primary branches firstly increased and then decreased (Table 2). However, compared with the earliest transplanting treatment of 20 October, in the other treatments, the number of pods on secondary branches decreased significantly by 26.9% (30 October), 69.7% (10 November), 82.4% (20 November), and 78.4% (30 November) (Table 2). There were no significant differences in the number of seeds in the main inflorescence among treatments. The number of seeds on the branches was lower in the 20 and 30 November transplanting treatments than in that of 20 October. The thousand-seed weight was not significantly different among transplanting date treatments (Table 2). Rapeseed grain yield was significantly positively correlated with the number of secondary branches, pod number of secondary branches, and seed number of secondary branches (Table 3).

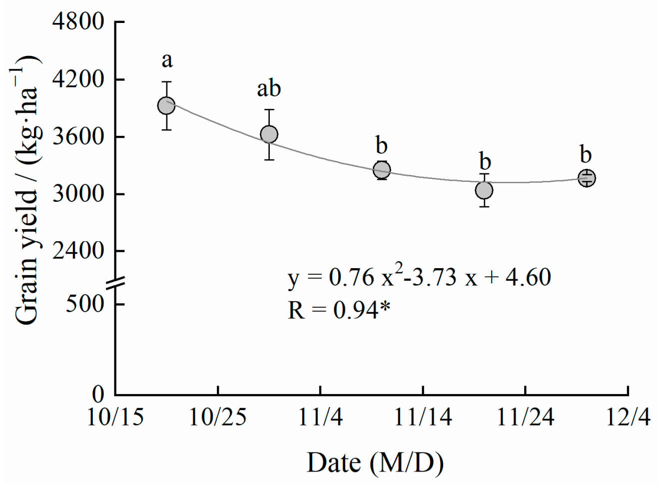

Figure 3. Grain yield (kg·ha^{-1}) of rapeseed at maturity as affected by transplanting date (month/day) and the *Pearson* coefficients. The experimental treatments were five transplant dates (month-day): 10-20, 10-30, 11-10, 11-20, and 11-30. Different lowercase letters indicate significant differences among different transplanting dates at the 0.05 level. * $p < 0.05$.

Table 2. Yield components of rapeseed at maturity as affected by transplanting date.

Transplanting Date (Month-Day)	Branch Number per Plant		Pod Number per Plant			Seed Number per Pod per Plant			1000 Seed Weight (g)
	Primary Branches	Secondary Branches	Main Inflorescence	Primary Branches	Secondary Branches	Main Inflorescence	Primary	Secondary	
10-20	7.7 a	14.7 a	73.7 b	306.0 ab	237.7 a	25.0 a	24.6 ab	22.9 a	3.9 a
10-30	8.3 a	13.0 a	79.0 ab	352.0 a	173.7 b	23.9 a	21.9 ab	24.2 a	4.1 a
11-10	9.0 a	8.7 b	92.0 a	367.7 a	72.0 c	24.6 a	25.5 a	25.1 a	4.1 a
11-20	7.3 ab	3.2 c	86.0 ab	254.2 bc	41.8 c	21.9 a	22.5 ab	17.2 b	3.9 a
11-30	5.3 b	6.3 b	70.7 b	211.3 c	51.3 c	21.6 a	20.6 b	19.6 ab	4.1 a

Values for transplanting dates with different lowercase letters representing significantly different at the same ensiling days at the 0.05 level.

Table 3. Pearson coefficients of correlation between grain yield and yield components at maturity.

Yield Component	*r* Coefficient	Pr > F
Primary branch number	0.333	ns
Secondary branch number	0.795	***
Pod number of main inflorescence	−0.072	ns
Pod number of primary branches	0.448	ns
Pod number of secondary branches	0.834	***
Seed number of main inflorescence	0.272	ns
Seed number of primary branches	−0.031	ns
Seed number of secondary branches	0.670	**
1000 seed weight	0.186	ns

** $p < 0.01$; *** $p < 0.001$; ns, not significant.

3.3. Effects of Transplant Date on Growth Characteristics of Rapeseed

With the RCPPS, all treatments had comparable leaf age at the seedling stage. However, compared with the 20 and 30 October transplanting treatments, the transplanting treatments in November had significantly lower leaf age in the late growth period (Figure 4). From budding to flowering stages, late transplanting significantly inhibited the rhizome thickness, whereas at the podding stage, no significant differences were found among transplanting dates (Figure 5). The transplanting date had significant effects on plant height from flowering to podding stages (Figure 6). With the delay in transplanting date, the plant height tended to increase and then decrease. At the podding stage, the lowest plant height was in the 30 November transplant treatment (Figure 6).

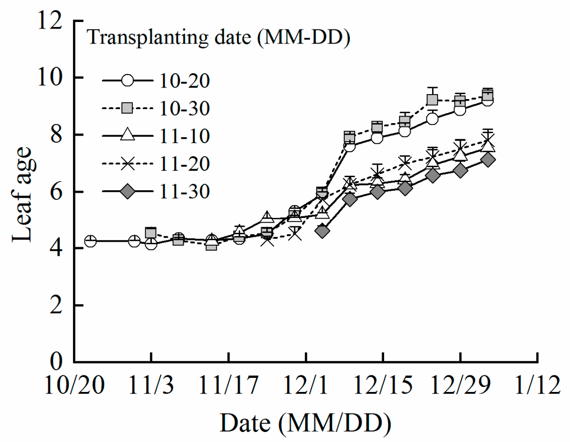

Figure 4. Dynamics of rapeseed leaf age as affected by transplanting date (month/day). The experimental treatments were five transplant dates (month-day): 10-20, 10-30, 11-10, 11-20, and 11-30.

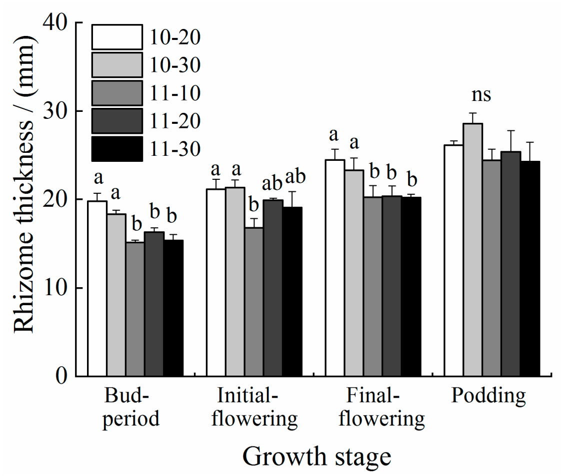

Figure 5. Rhizome thickness (mm) of forage rapeseed at four growth stages (bud period, initial flowering, final flowering, podding) as affected by transplanting date. The experimental treatments were five transplant dates (month-day): 10-20, 10-30, 11-10, 11-20, and 11-30. Different lowercase letters indicate significant differences among different transplanting dates in each growth stage at the 0.05 level. ns, no significant differences among different transplanting dates.

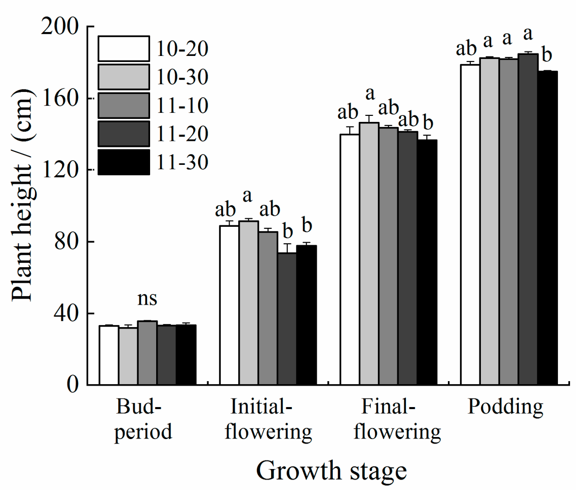

Figure 6. Plant height (cm) of forage rapeseed at four growth stages (bud period, initial flowering, final flowering, podding) as affected by transplanting date. The experimental treatments were five

transplant dates (month-day): 10-20, 10-30, 11-10, 11-20, and 11-30. Different lowercase letters indicate significant differences among different transplanting dates in each growth stage at the 0.05 level. ns, no significant differences among different transplanting dates.

4. Discussion

Dry matter yield is one of the important factors used to evaluate the productivity of forage [26,27]. In this study, the biomass yield of forage rape increased rapidly from budding to final flowering stage, followed by a gradual increase in the podding stage (Figure 1). Regardless of the transplanting date, the highest dry matter yield was in the podding stage, reaching 6.4 $t \cdot ha^{-1}$ in the 30 October transplant date treatment. This forage yield accumulation is consistent with that of the rape blanket seedlings transplanted technique, which has a maximum forage yield of approximately 6.3 $t \cdot ha^{-1}$ in the Yangtze River delta [28]. The growth rate was highest at the bud period and then decreased after flowering. However, the yield of forage rape in Gansu reaches 11 $t \cdot ha^{-1}$, which is approximately two times higher than the yield in the Yangtze River delta [12]. The difference in yield is likely primarily due to different experimental sites with specific soil characteristics and different varieties and planting methods. For example, the rapeseed in Northwest China is primarily directly sowed mechanically after the harvest of wheat, and the crops show vigorous growth, particularly in the early growth period. In addition, in the northern region, a waterlogging disaster during the growing season is unlikely. However, in this study, low temperatures and continuous rainfall occurred during the transplanting and the seedling growth period, with the cumulative precipitation reaching 414.7 mm in October and November (Table 1), which may also affect the soil nutrient availability, severely inhibiting the growth and yield formation of rapeseed before winter. The nutritional value of forage grass primarily depends on the crude protein content, whereas the digestibility of forage primarily depends on the ADF content [12]. Of the main nutrient measures of forage rape at the podding stage (Figure 2), the crude protein content was 11.6% to 14.0%, the NDF content was 37.7% to 40.7%, and the ADF content was 33.0% to 37.2%, which meet the classification standards for legumes in the United States [29].

At the final flowering stage, the dry matter yield of forage rape was higher in the October transplant date treatments than in the November transplant date treatments, whereas there was no significant difference among transplant date treatments at the podding stage (Figure 1). Relatively few studies have examined the effect of transplanting date on the characteristics of forage rape with RCPPS. With the rape blanket seedling transplant technique, the biomass yield of forage rape transplanted before 20 October is significantly higher than that of rape transplanted in late October in the Yangtze River delta [28]. With the direct-seeding technique, forage rape should be sowed earlier, because the accumulation of dry matter yield is primarily limited by air temperature, particularly in northern China. The temperature always declines rapidly in August in Gansu Province, which significantly inhibits the dry matter formation of rape in the late growth period. From 30 July to 8 August, the biomass yield of rape was significantly decreased by 50% due to the delay of 5 days [10]. In addition, the yield and plant height of forage rape were both higher when sowed in mid-July than in early August in Heilongjiang Province [14]. Notably, with the delay in transplanting in the 20 and 30 November treatments, the crude protein content increased significantly, whereas the ADF content decreased significantly (Figure 2). By contrast, the increase in ADF would reduce the amount of digestible dry matter, influencing the digestibility of forage [29]. The duration of the growing season is decided by the sowing date, which therefore influences the accumulation of biomass yield and nutrients [30]. In Heilongjiang Province, the contents of crude protein, crude fat, carbohydrates, and trace elements in early sown forage rape were all higher than those in late-sown rape [12]. Overall, we conclude that transplanting in late November with RCPPS for forage use has distinct advantages in the rice–rape rotation, as it can maintain yield and improve nutritional value of forage rape, so as to alleviate the stubble contradiction between late harvested rice in the Yangtze River delta. All these findings can substantially improve the annual economic benefits for growing rice–rape crops, which will promote the application of the rice-rape rotation system.

Considering the conventional use of rapeseed for grains, the rapeseed transplanted on 20 and 30 October had comparable grain yields. However, compared with the 20 October transplant date, the rapeseed transplanted in November had significantly lower grain yields by 17.2% to 22.5% (Figure 3). Grain yield is determined by the number of pods per plant, the number of seeds per pod, and the weight of one thousand seeds. Moreover, the number of pods per plant is considered to be the most important factor in determining yield, which is also easily influenced by agricultural management [31]. Compared with traditional transplanting methods, the increase in yields in the RCPPS is primarily attributed to the number of pods [17]. With the RCPPS in this study, the grain yield was most affected by the number of secondary branches, as indicated by the significant positive correlations between yield and the number of secondary branches and the number of pods and seeds on secondary branches (Table 3). Compared with the earliest transplanting treatment, the number of pods on secondary branches in the November transplanting treatments decreased significantly by 69.7% to 82.4% (Table 2). The late transplanting dates significantly inhibited leaf growing stage and resulted in a reduced number of effective leaves and diameter of pre-winter root (Figures 4 and 5, respectively). Xiong et al. (2016) [15] found that substantial dry matter accumulation and the number of effective pods promote high grain yield under the appropriate planting date. In Jiangxi Province, with a simplified transplanting technique, the yield was optimum when sown on 20 September and then nursed for nearly 40 days. Changes in the quantitative processes of yield under different planting dates with RCPPS should be explained in terms root morphology and physiology in future.

5. Conclusions

In conclusion, in the rice–rape rotation system with the RCPPS in the Yangtze River delta, transplanting rape from 20 to 30 October led to higher grain yields by 19.6% on average, which were significantly correlated with numbers of secondary branches, pods, and seeds. Thus, relatively early maturing rice varieties should precede the rape crop. Alternatively, to alleviate the competition for resources between rape and rice crop seasons, forage rape can be transplanted in mid-November and harvested from the final flowering to podding stages to improve forage yield and nutritional value, particularly with improved crude protein content and reduced acid detergent fiber content. Thus, considering the security of oil and forage production, the right transplanting time of specific use could be adopted for farmers in RCPPS to improve the value of rapeseed meanwhile ensure the yield of previous rice crops, which is flexible and sustainable in multi-cropping rice rotation system in Yangtze River delta.

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Conflicts of Interest: We declare that we have no financial and personal relationships with other people or organizations that could inappropriately influence our work. There is no professional or other personal interest of any nature or kind in any product, service, or company that could be construed as influencing the position presented in, or the review of, the manuscript.

Appendix A

Figure A1. Ridge culture place planting system (RCPPS) for rapeseed (Suzhou Comprehensive Experimental Station of China Rape Research System).

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