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ORIGINAL PAPER

Effects of Nitrogen Fertilization on Yield and Nitrogen Utilization of Film Side Planting Rapeseed (*Brassica napus* L.) Under Different Soil Fertility Conditions

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Abstract

Film side planting (FS) is a new water-saving and drought-resistant technology in dryland of southwest China, and nitrogen (N) is a main yield factor. However, the optimal N amount for FS rapeseed is unknown, especially in different soil fertility. Field experiments with N amounts (0, 60, 120, 180, 240, 300, and 360 kg ha^{-1}) for FS rapeseed arranged in four soil fertility levels (divided into < 0.5 t ha^{-1}, 0.5 ~ 1.0 t ha^{-1}, 1.0 ~ 1.5 t ha^{-1}, and > 1.5 t ha^{-1} based on the 5-year average rapeseed yield of not fertilizing, named respectively by F1, F2, F3, and F4) were conducted to analyze N utilization and yield. Besides, relationship between yield and N amounts was also discussed. The lower the soil fertility, the higher N amounts achieving high yield. Dry matter, N accumulation, N use efficiency, N agronomic efficiency, and effective pods were greatest for 360, 300, 240, and 180 kg ha^{-1} under F1, F2, F3, and F4 respectively. Eventually, 360, 300, 240, and 180 kg ha^{-1} obtained 27.31 ~ 242.32%, 35.26 ~ 129.44%, 15.92 ~ 142.00%, and 15.79 ~ 109.65% significantly greater yield than other N treatments under F1 and F2 (except 360 kg N ha^{-1}) and F3 and F4 (except 240 kg N ha^{-1}) respectively. Based on yield-N production function, the maximum rapeseed yields were obtained for F1 at > 360 kg ha^{-1} N, for F2 at > 360 kg ha^{-1} N, for F3 at 312 kg ha^{-1} N, and for F4 at 272 kg ha^{-1} N. Therefore, the optimal N amount for FS rapeseed under low soil fertility was 360 kg ha^{-1} or more and under high soil fertility was 272 ~ 312 kg ha^{-1}.

Keywords Rapeseed · Nitrogen fertilization · Film side planting · Yield · Nitrogen use efficiency

1 Introduction

Rapeseed (*Brassica napus* L.) is the largest oilseed crop in China (Yan et al. 2021; Huang et al. 2021). Sichuan is the main rapeseed cropping province and the double-low rapeseed dominant area of China, and its annual rapeseed yield ranks the top three and the first in the west in China (Xie 2017), which plays a pivotal role in ensuring the safety of food and oil in China. Nitrogen (N) fertilization has an important effect on increasing rapeseed yield (Ma and Herath 2016). As rapeseed yield increased, so did the amount of N applied, resulting in excessive and unbalanced fertilization, which lead to serious negative consequences such as low N efficiency (Li et al. 2020), water pollution (Panjaitan et al. 2020), and high greenhouse gas emissions (Chen et al. 2019). Therefore, reasonable fertilization needs to be adapted to local conditions.

Film mulching is an effective planting technology for agricultural promotion in arid regions of southwest China, which could increase temperature, capture rainwater, reduce evaporation, improve soil physical properties and enzyme activity, and improve fertilization use efficiency and crop yield (Luo et al. 2022; Zhang et al. 2021; Li et al. 2021; Gu et al. 2021). Film mulching has a history of nearly a hundred years, and its technology is constantly innovating and developing, and

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a film mulching technology system based on film side planting (FS) has gradually formed (Chen et al. 2018). Studies have shown that FS played an important role in yield increase, metabolite accumulation, and weed control (Gu et al. 2019; Niu et al. 2020; Mi et al. 2021). In addition, FS significantly reduced soil evaporation at early growth stages of crops, and the saved water could be used for crop transpiration during the middle and late growth stages, thus increasing crop yield and water use efficiency (Zhang et al. 2020; Wang et al. 2020a, b). However, the rapeseed optimal N amount under FS pattern is not yet clear, which is of great significance to further increase the rapeseed yield and enrich the FS basic theory.

Obviously, soil fertility has a great influence on crop yield and N use efficiency (NUE) (Wang et al. 2018; Kermah et al. 2018). Some agronomic practices had different potentials for increasing crop yield under different soil fertility, and increasing effective soil N content was more likely to promote crop yield and NUE in fields with low soil fertility (Zhou et al. 2019). By the boosted regression trees, manure, synthetic fertilizer, and soil properties (SOC storage, soil pH, and soil nutrients) accounted for 39%, 21%, and 40% of the variation of the relative yield, respectively (Cai et al. 2019). Main rapeseed production area in Sichuan is basin hilly area, which has large ground undulations, and in which the soil fertility level is also different. Previous researches have mainly focused on the effects of fertilization measures on crop yield under different soil fertility, or the effects of soil fertility on crop yield. However, limited studies have reported the relationship between N amount and yield under different soil fertility. Therefore, it is particularly important for the rational nitrogen application and the realization of high and stable production of rapeseed in Sichuan Province to study the nitrogen application effect of film side planting rapeseed under different soil fertility levels in this area and then to fertilize in a targeted manner. In this study, a 2-year field experiment was conducted to compare the yield-increasing effect and nitrogen absorption and utilization characteristics of film side planting rapeseed among treatments with different N application amounts under different fertility levels in Sichuan Province. Besides, the relationship between N application amounts and yield under different fertility levels was also analyzed. The main objectives of this study was to clarify the FS rapeseed optimal N amount under different soil fertility levels in Sichuan Province, which could provide a reference for rapeseed scientific nitrogen application in this area.

2 Materials and Methods

2.1 Description of the Experimental Site

The two-year winter rapeseed field experiment was conducted from October 2018 to May 2020 at Jianyang Experimental Station (30°40′ N, 104°55′ E; elevation 460 m), Sichuan Academy of Agriculture Sciences, Chengdu, China. This experimental station is located in the eastern part of Sichuan basin in China, which has a typical subtropical monsoon climate. The average annual air temperature was 17 ℃, and the average annual precipitation was 874 mm. According to the classification of the World Reference Base for Soil Resources the soil at the location of the field experiment can be classified as calcaric. The soil (0–20 and 20–40 cm) nutrient content and the 5-year average unfertilized rapeseed yield under different soil fertility conditions are shown in Table 1, which was determined by the conventional chemical analysis methods (Lu 2000).

2.2 Experimental Design and Field Management

Seven N levels with three replicates were used under four soil fertility levels in this field experiment. The seven N levels were (1) N7, N application of 360 kg ha^{-1}; (2)

Table 1 Soil nutrients concentrations and the five-year average rapeseed yield of not fertilizing under different soil fertility conditions

Soil Layer (cm)	Soil fertility	Organic Matter (g kg^{-1})	Total N (%)	Total P (g kg^{-1})	Total K (g kg^{-1})	Alkali-hydrolysable N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Yield (t ha^{-1})
0–20	F1	8.08	0.06	0.77	30.80	157.28	7.30	61.67	< 0.5
	F2	11.70	0.06	0.79	31.13	172.52	10.27	65.67	0.5 ~ 1.0
	F3	14.18	0.08	0.87	31.67	204.84	24.67	80.33	1.0 ~ 1.5
	F4	16.33	0.10	0.99	33.17	246.99	25.03	98.67	> 1.5
20–40	F1	5.87	0.05	0.70	30.50	148.90	6.37	54.67	-
	F2	10.83	0.06	0.72	30.63	168.42	8.90	58.67	-
	F3	13.17	0.06	0.83	31.33	175.15	23.40	67.67	-
	F4	15.73	0.10	0.88	32.23	223.17	23.87	89.33	-

N6, N application of 300 kg ha^{-1}; (3) N5, N application of 240 kg ha^{-1}; (4) N4, N application of 180 kg ha^{-1}; (5) N3, N application of 120 kg ha^{-1}; (6) N2, N application of 60 kg ha^{-1}; and (7) N1, no N application. The plots were 4 m × 5 m in size and were arranged in a completely randomized design.

Rapeseed (Dexinyou-6, a locally adopted high-yielding rapeseed variety) seeds were directly sowed on October 5, 2018, and October 4, 2019, and harvested on May 2, 2019, and May 1, 2020. The wide row and narrow row spacing was respectively 50 cm and 30 cm, the distance between holes was 14 cm, and one seedling was preserved in each hole at the five-leaf stage of rapeseed. Before sowing in each season, all plots received 90 kg P_2O_5 ha^{-1} of calcium super-phosphate and 90 kg K_2O ha^{-1} of potassium sulfate additional with 70% of the corresponding N application amount of urea, and the remaining 30% of the corresponding N application amount of urea was applied at the bud stage of rapeseed. Figure 1 showed the experiment on the production of rapeseed under film side planting. The plastic mulch in this experiment was polyethylene (0.008-mm thick and 50-cm wide).

2.3 Measurements and Methods

2.3.1 Dry Matter Determination

During each growing season, five holes of rapeseed within each plot were randomly sampled to determine DM at the seedling (January 6), flowering (March 15), and maturing (April 24) stages. The plant materials (separated into roots, leaves, stems, and siliques) were dried at 105 ℃ for 30 min and then oven-dried at 75 ℃ until they were reached constant weight for determination of DM (total oven-dried weight of roots, leaves, stems, and siliques) (Gu et al. 2021).

2.3.2 N Content Determination

At maturity, after DM was weighed, the dry samples (roots, leaves, stems, and siliques) were ground and sieved through a 2.0-mm screen and then digested with a H_2SO_4–H_2O_2 mixture to determine plant nutrient content. The N contents were measured using the Kjeldahl method (Wang et al. 2020a, b).

2.3.3 Determination of Accumulation of N, Apparent Utilization, and Agronomic Efficiency

Total N uptake was calculated as the dry weight multiplied by the N content in each respective organ (Gu et al. 2021); N use efficiency and N agronomic efficiency are calculated according to the formulas of Wang et al. (2020a, b):

$$\text{N use efficiency (NUE, \%)} = (\text{N1} - \text{N0}) / \text{F} \times 100\% \tag{1}$$

$$\text{N agronomic efficiency } \left(\text{NAE, kg kg}^{-1}\right) = (\text{Y1} - \text{Y0}) / \text{F} \tag{2}$$

where *N1* and *N0* are the plant N content with N fertilization and plant N content without N fertilization, respectively; *Y1* and *Y0* represent the seed yield with N fertilization and seed yield without N fertilization, respectively; and *F* is nitrogen fertilization application amount in each respective treatment.

2.3.4 Economic Traits and Yield Determination

Ten holes of rapeseed within each plot were randomly sampled to determine effective siliques number (average of effective siliques for the 10 plants) and number of grains per horn (average of grains numbers for 10 main sequence siliques and 10 branch siliques per plant) before harvest. All rapeseed plants of each plot were hand harvested at maturity, and the yields and thousand-grain weights of all plots were determined after dried.

2.4 Statistical Analysis

SPSS 17.0 (SPSS Inc., Chicago, IL, USA) was used to conduct analysis of variance. Test of normalization (Kolmogorov–Smirnov) and homogeneity test of variances were done before ANOVA, and the comparisons of treatment means were based on S–N-K test at the $p < 0.05$ probability level. The relationship between N and yield was performed using correlation analysis. All data collected are presented as the mean ± standard error of three replicates for each treatment.

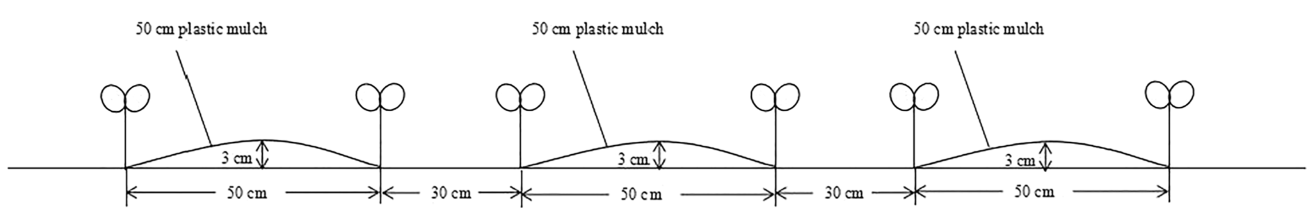

Fig. 1 Film side planting method of rapeseed

3 Results

3.1 Nutrient Concentrations Under Different Soil Fertility

The different soil fertility formed quite distinct nutrients concentrations. The variability explained by the first PCA components was 95.28% (0 ~ 20 cm) (Fig. 2A) and 91.48% (20 ~ 40 cm) (Fig. 2B). The two components were also analyzed and explained 3.44% (0 ~ 20 cm) (Fig. 2A) and 6.59% (20 ~ 40 cm) (Fig. 2B) of the variability. The big difference was found between F4 and F3, F4 and F2, F4 and F1, F3 and F2, and F3 and F1. The nutrients concentrations under the different soil fertility could be classified into three types. The first type was F4, which was caused the separation by TK (0 ~ 20 cm) and TN (20 ~ 40 cm). The second type was F3, which was characterized by AP (0 ~ 20 cm and 20 ~ 40 cm). The third type was F2 and F1, which had no strong correlation with the soil nutrients.

3.2 Effect of Nitrogen Fertilization on Dry Matter Accumulation of Rapeseed Under Different Soil Fertility Conditions

N amounts had a significant ($p < 0.05$) influence on dry matter accumulation (DM) at seedling (SS), flowering (FS), and maturing (MS) stages, and that influence varied with soil fertility level (Fig. 3). Generally, the higher the soil fertility level, the higher the DM. Regardless of soil fertility level, the lowest DM at SS, FS, and MS were recorded in no N application (N1). These DM peaked in plots fertilized with 360, 300, 240, and 180 kg N ha^{-1} under F1, F2, F3, and F4, respectively. At maturing stages, the DM difference among N treatments reached maximum throughout the two seasons. DM in N7 under F1 was markedly greater than that in N1 ~ N5; DM in N6 under F2 differed significantly from that in N1 ~ N4; DM in N5 under F3 was remarkably higher than that in N1 ~ N3 and N7; DM in N4 under F4 was significantly higher than that in N1 ~ N3 and N7 ($p < 0.05$).

3.3 Effect of Nitrogen Fertilization on N Accumulation and Utilization of Rapeseed Under Different Soil Fertility Conditions

N content in plants was significantly ($p < 0.05$) affected by N amounts, and they varied with soil fertility level and seasons, whereby higher values were recorded in 2019–2020 than 2018–2019 (Table 2). The lowest N content was noted in no N application (N1) and a gradual increase in N content was observed with increasing N rates to peaks in N7. That is, rapeseed plants in N7 absorbed more N than that in N1 ~ N6 across the two seasons.

N amounts had a significant ($p < 0.05$) influence on N accumulation (NA), N use efficiency (NUE), and N agronomic efficiency (NAE), where the differences varied with soil fertility level (Table 2 and Table 3). Gradual increases in NA, NUE, and NAE were observed with increasing soil fertility level. Regardless of soil fertility level, the lowest NA was recorded in no N application (N1), and the lowest NUE and NAE were recorded in N2. These NA, NUE, and NAE peaked in plots fertilized with 360, 300, 240, and 180 kg N ha^{-1} under F1, F2, F3, and F4, respectively. Across the two seasons, the NA in N7 was 16.98 ~ 131.98% markedly higher than that in N1 ~ N6 under F1, in N6 was 20.51 ~ 107.26% markedly higher than that in N1 ~ N5 under F2, in N5 was 17.24 ~ 142.37% markedly higher than that in N1 ~ N4 and N7 under F3, and in N4 was 12.40 ~ 139.87% markedly higher than that in in N1 ~ N3 and N7 under F4 ($p < 0.05$). In addition, the NUE and NAE in N7 were 16.61 ~ 79.55% and 16.22 ~ 68.08% greater than that in

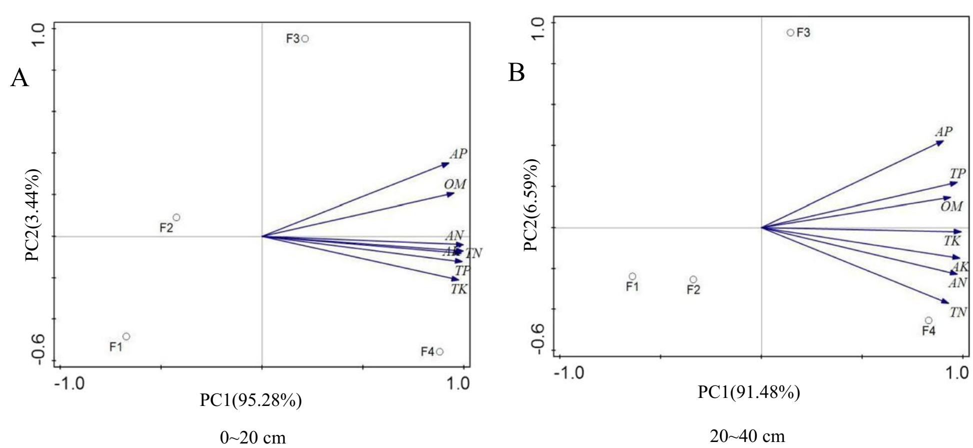

Fig. 2 PCA scores and corresponding loading values for nutrients concentrations under different soil fertility. F, soil fertility; OM, organic matter; TN, total N; TP, total P; TK, total K; AN, available N; AP, available P; AK, available K

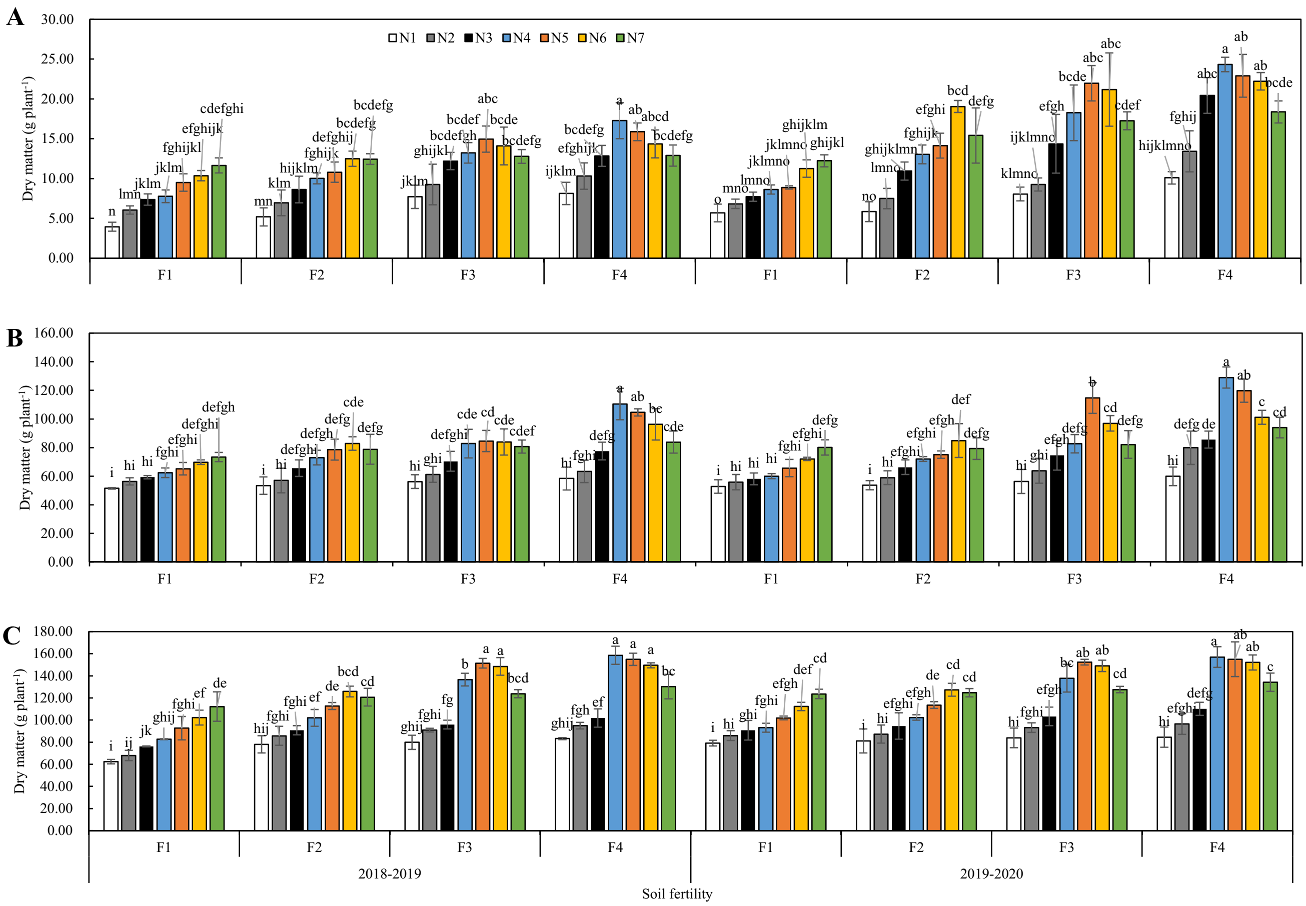

Fig. 3 The effect of nitrogen (N) fertilization on dry matter of film side planting rapeseed under different soil fertility conditions. **A** Seedling stage; **B** flowering stage; **C** maturing stage. Significant differences among treatments for a particular year based on S–N-K test ($p < 0.05$) were shown with different letters. F: soil fertility

other treatments under F1, in N6 were 21.12 ~ 46.24% and 25.00 ~ 103.45% greater than that in other treatments under F2, in N5 were 25.69 ~ 125.17% and 63.16 ~ 173.53% greater than that in other treatments (except N4) under F3, and in N4 were 34.66 ~ 200.00% and 34.41 ~ 257.14% greater than that in other treatments under F4.

3.4 Effect of Nitrogen Fertilization on Economic Traits and Yield of Rapeseed Under Different Soil Fertility Conditions

N amounts significantly ($p < 0.05$) improved rapeseed yield and effective pods, whereby the effect varied with soil fertility level (Table 4). Generally, there was an increase in the yield and effective pods with increasing soil fertility level. The highest yield and effective pods were registered in N7, N6, N5, and N4, respectively, under F1, F2, F3, and F4. Across the two seasons, the yield in N7, N6, N5, and N4 were 27.31 ~ 242.32%, 35.26 ~ 129.44%, 15.92 ~ 142.00%, and 15.79 ~ 109.65% significant higher than that in other N treatments, respectively, under F1, F2 (except N7), F3, and F4 (except N5) ($p < 0.05$). In terms of seeds per pod and 1000-grain weight, N amounts had no significant effect (Table 5).

3.5 Relationship Between N and Yield

The significant dependence of rapeseed yield on nitrogen application amount across the consecutive two seasons is presented in Fig. 4. This relationship was a second-degree polynomial function. It could be seen from the formulas presented in Fig. 4 that the yield of each nitrogen fertilization treatment under F1 and F2 showed an upward trend with the increase of nitrogen fertilization application amount, while under F3 and F4, the yield first increased and then decreased. When the nitrogen fertilization application amounts were 312 kg ha^{-1} and 272 kg ha^{-1}, the rapeseed yield reached the maximum under F3 and F4, respectively. These values could be considered as the approximate nitrogen fertilization requirements of rapeseed in the growing season.

Table 2 The effect of nitrogen (N) fertilization on N accumulation of film side planting rapeseed under different soil fertility conditions

Season	Treatment	Nitrogen content (NC) (g kg^{-1})				Nitrogen accumulation (NA) (kg ha^{-1})			
		F1	F2	F3	F4	F1	F2	F3	F4
2018–2019	N1	7.7 ± 0.3^{e}	7.7 ± 0.9^{e}	8.0 ± 0.5^{de}	8.1 ± 0.4^{de}	86.0 ± 0.9^{l}	108.8 ± 7.2^{jkl}	114.7 ± 12.5^{ijkl}	121.9 ± 5.0^{hijkl}
	N2	7.9 ± 0.2^{de}	8.1 ± 0.5^{de}	8.1 ± 0.4^{de}	8.2 ± 0.4^{de}	96.5 ± 6.5^{kl}	124.7 ± 19.6^{ghijkl}	132.9 ± 5.1^{ghijk}	140.8 ± 10.4^{ghij}
	N3	8.2 ± 0.2^{de}	8.7 ± 0.4^{cde}	8.9 ± 0.4^{bcde}	8.9 ± 0.2^{abcde}	112.8 ± 3.0^{ijkl}	142.3 ± 0.9^{ghij}	153.0 ± 8.8^{fghi}	164.0 ± 11.4^{efgh}
	N4	8.7 ± 0.3^{cde}	8.9 ± 0.4^{bcde}	9.5 ± 0.4^{abcd}	10.3 ± 0.3^{abc}	129.1 ± 4.1^{ghijk}	163.0 ± 5.2^{efgh}	233.8 ± 15.3^{cd}	292.4 ± 8.3^{a}
	N5	8.7 ± 0.8^{cde}	9.1 ± 0.7^{abcde}	10.2 ± 0.1^{abc}	10.4 ± 0.9^{ab}	145.6 ± 30.0^{fghij}	185.1 ± 16.3^{ef}	278.0 ± 8.5^{ab}	290.8 ± 24.9^{a}
	N6	9.1 ± 0.4^{abcde}	10.0 ± 1.3^{abc}	10.4 ± 0.5^{abc}	10.5 ± 0.7^{ab}	167.2 ± 4.7^{efg}	225.5 ± 23.4^{cd}	277.1 ± 20.5^{ab}	282.8 ± 17.8^{ab}
	N7	9.9 ± 0.1^{abc}	10.3 ± 1.1^{abc}	10.5 ± 0.6^{ab}	10.6 ± 0.7^{a}	199.5 ± 22.3^{de}	224.2 ± 26.7^{cd}	232.9 ± 18.8^{cd}	249.0 ± 37.5^{bc}
2019–2020	N1	7.9 ± 0.6^{h}	8.0 ± 0.9^{gh}	8.7 ± 0.5^{fgh}	9.2 ± 0.3^{defgh}	112.1 ± 7.6^{h}	117.5 ± 24.9^{gh}	131.6 ± 16.2^{fgh}	139.4 ± 19.2^{efgh}
	N2	8.1 ± 0.8^{gh}	8.6 ± 0.7^{fgh}	8.9 ± 0.9^{efgh}	9.2 ± 0.1^{defgh}	125.2 ± 10.7^{gh}	134.5 ± 22.1^{fgh}	150.0 ± 20.0^{efgh}	159.4 ± 17.0^{defg}
	N3	8.6 ± 0.4^{fgh}	9.0 ± 0.4^{efgh}	9.2 ± 0.2^{defgh}	9.2 ± 0.4^{defgh}	139.8 ± 20.9^{efgh}	152.6 ± 13.6^{defgh}	170.5 ± 10.4^{def}	182.9 ± 14.6^{de}
	N4	9.4 ± 0.9^{cdefgh}	9.5 ± 0.5^{bcdefgh}	10.1 ± 0.2^{abcdef}	11.0 ± 0.2^{abc}	157.1 ± 11.2^{defg}	174.5 ± 11.4^{def}	251.7 ± 26.1^{bc}	310.0 ± 24.6^{a}
	N5	9.4 ± 0.1^{bcdefgh}	9.5 ± 0.4^{bcdefgh}	10.8 ± 0.9^{abcd}	11.0 ± 0.8^{ab}	173.3 ± 4.1^{def}	194.5 ± 12.8^{d}	295.1 ± 24.9^{a}	308.0 ± 9.7^{a}
	N6	9.6 ± 0.2^{bcdefg}	10.2 ± 0.1^{abcdef}	10.9 ± 0.8^{abc}	11.2 ± 0.4^{a}	194.4 ± 8.2^{d}	234.4 ± 8.8^{c}	293.0 ± 12.5^{a}	307.4 ± 14.4^{a}
	N7	10.2 ± 0.6^{abcdef}	10.4 ± 0.1^{abcde}	10.9 ± 0.6^{abc}	11.4 ± 0.8^{a}	227.4 ± 11.8^{c}	233.6 ± 7.9^{c}	251.0 ± 8.3^{bc}	275.8 ± 24.9^{ab}

	Summary of analyses of variance (p values) 2018–2019					Summary of analyses of variance (p values) 2019–2020				
Items	K-S	Levene	N	F	$N\times F$	K-S	Levene	N	F	$N\times F$
NC	>0.05	>0.05	<0.001	<0.001	0.743	>0.05	>0.05	<0.001	<0.001	0.958
NA	>0.05	>0.05	<0.001	<0.001	<0.001	>0.05	>0.05	<0.001	<0.001	<0.001

Significant differences among treatments for a particular year based on S–N-K test ($p<0.05$) were shown with different letters. F: soil fertility

Table 3 The effect of nitrogen (N) fertilization on N utilization of film side planting rapeseed under different soil fertility conditions

Season	Treatment	Nitrogen use efficiency (NUE) (%)				Nitrogen agronomic efficiency (NAE) (kg kg^{-1})			
		F1	F2	F3	F4	F1	F2	F3	F4
2018–2019	N2	17.6 ± 4.0^{f}	26.6 ± 7.5^{def}	30.2 ± 8.0^{def}	31.6 ± 2.0^{def}	2.6 ± 0.2^{f}	2.8 ± 0.2^{ef}	3.4 ± 0.4^{def}	3.5 ± 1.0^{def}
	N3	22.4 ± 1.8^{ef}	27.9 ± 5.4^{def}	31.9 ± 4.5^{def}	35.1 ± 5.3^{de}	3.2 ± 0.1^{def}	3.3 ± 0.1^{def}	3.7 ± 0.8^{def}	4.0 ± 0.1^{d}
	N4	24.0 ± 1.8^{def}	30.1 ± 1.2^{def}	66.1 ± 2.4^{b}	94.8 ± 2.0^{a}	3.4 ± 0.1^{def}	3.8 ± 0.3^{de}	9.1 ± 0.5^{b}	12.5 ± 1.1^{a}
	N5	24.8 ± 12.2^{def}	31.8 ± 3.8^{def}	68.0 ± 1.8^{b}	70.4 ± 8.3^{b}	3.5 ± 0.5^{def}	4.0 ± 0.1^{d}	9.3 ± 0.2^{b}	9.3 ± 0.3^{b}
	N6	27.1 ± 1.3^{def}	38.9 ± 5.9^{d}	54.1 ± 2.9^{c}	53.6 ± 4.5^{c}	3.7 ± 0.5^{def}	5.5 ± 0.2^{c}	5.7 ± 0.6^{c}	5.7 ± 0.1^{c}
	N7	31.6 ± 6.0^{def}	32.1 ± 6.3^{def}	32.8 ± 1.8^{def}	35.3 ± 9.2^{de}	4.37 ± 0.1^{d}	4.4 ± 0.2^{d}	4.4 ± 0.3^{d}	4.4 ± 0.2^{d}
2019–2020	N2	21.9 ± 2.0^{g}	28.4 ± 3.5^{defg}	30.5 ± 7.2^{defg}	33.4 ± 5.9^{defg}	2.8 ± 0.6^{d}	2.9 ± 1.1^{d}	3.6 ± 1.1^{d}	4.0 ± 0.6^{d}
	N3	23.1 ± 4.2^{fg}	29.3 ± 4.1^{defg}	32.4 ± 5.8^{defg}	36.3 ± 10.1^{def}	3.4 ± 1.0^{d}	3.6 ± 0.7^{d}	3.7 ± 0.4^{d}	4.4 ± 0.9^{cd}
	N4	25.0 ± 2.3^{efg}	31.7 ± 4.1^{defg}	66.7 ± 5.9^{b}	94.8 ± 6.0^{a}	3.4 ± 0.2^{d}	4.0 ± 0.5^{d}	9.1 ± 0.7^{b}	12.8 ± 0.2^{a}
	N5	25.5 ± 1.6^{defg}	32.1 ± 5.1^{defg}	68.1 ± 4.0^{b}	70.3 ± 4.0^{b}	3.6 ± 0.3^{d}	4.3 ± 0.9^{cd}	9.3 ± 0.7^{b}	9.3 ± 0.6^{b}
	N6	27.4 ± 0.5^{defg}	39.0 ± 5.4^{d}	53.8 ± 1.7^{c}	56.0 ± 4.1^{c}	3.7 ± 0.5^{d}	5.9 ± 0.4^{c}	5.7 ± 0.1^{c}	5.8 ± 0.2^{c}
	N7	32.0 ± 1.5^{defg}	32.2 ± 4.7^{defg}	33.2 ± 2.4^{defg}	37.9 ± 2.2^{de}	4.3 ± 0.3^{cd}	4.4 ± 0.3^{cd}	4.5 ± 0.1^{cd}	4.5 ± 0.2^{cd}

	Summary of analyses of variance (p values) 2018–2019					Summary of analyses of variance (p values) 2019–2020				
Items	K-S	Levene	N	F	$N \times F$	K-S	Levene	N	F	$N \times F$
NUE	> 0.05	> 0.05	< 0.001	< 0.001	< 0.001	> 0.05	> 0.05	< 0.001	< 0.001	< 0.001
NAE	> 0.05	> 0.05	< 0.001	< 0.001	< 0.001	> 0.05	> 0.05	< 0.001	< 0.001	< 0.001

Significant differences among treatments for a particular year based on S–N-K test ($p < 0.05$) were shown with different letters. F: soil fertility

Table 4 The effect of nitrogen (N) fertilization on effective pods and yield of film side planting rapeseed under different soil fertility conditions

Season	Treatment	Effective pods				Yield (kg ha^{-1})			
		F1	F2	F3	F4	F1	F2	F3	F4
2018–2019	N1	61.5 ± 17.2^{k}	115.9 ± 22.6^{fghi}	126.7 ± 11.7^{efgh}	129.2 ± 29.0^{defgh}	423.4 ± 33.7^{o}	998.4 ± 34.6^{m}	1220.8 ± 43.6^{klm}	1654.5 ± 74.7^{hi}
	N2	78.6 ± 8.2^{jk}	118.5 ± 13.0^{fghi}	137.3 ± 17.7^{cdefgh}	138.7 ± 9.1^{cdefgh}	578.4 ± 42.8^{o}	1166.1 ± 22.5^{lm}	1422.8 ± 62.6^{jk}	1863.5 ± 52.6^{gh}
	N3	92.7 ± 7.9^{ij}	127.1 ± 11.1^{efgh}	141.4 ± 10.7^{cdefgh}	143.3 ± 4.0^{bcdefgh}	810.4 ± 47.8^{n}	1397.2 ± 19.5^{jk}	1659.2 ± 110.9^{hi}	2138.4 ± 84.3^{f}
	N4	104.8 ± 5.9^{hij}	140.5 ± 5.5^{cdefgh}	153.0 ± 8.2^{bcdef}	203.4 ± 19.9^{a}	1028.8 ± 44.4^{m}	1685.1 ± 76.7^{hi}	2853.1 ± 124.1^{cd}	3906.9 ± 249.2^{a}
	N5	112.3 ± 10.8^{ghi}	148.3 ± 13.7^{bcdefg}	179.9 ± 18.1^{ab}	180.7 ± 11.8^{ab}	1253.2 ± 159.5^{kl}	1958.5 ± 20.9^{fg}	3443.2 ± 83.9^{b}	3884.3 ± 127.3^{a}
	N6	140.5 ± 12.9^{cdefgh}	167.1 ± 14.8^{bcd}	169.3 ± 12.7^{bc}	170.5 ± 16.8^{bc}	1526.3 ± 172.8^{ij}	2649.4 ± 92.8^{de}	2931.1 ± 204.1^{c}	3374.2 ± 89.5^{b}
	N7	150.1 ± 9.7^{bcdefg}	152.2 ± 11.0^{bcdef}	155.0 ± 13.9^{bcdef}	160.3 ± 4.1^{bcde}	1980.0 ± 51.8^{fg}	2567.9 ± 105.3^{e}	2802.2 ± 136.2^{cd}	3248.2 ± 70.5^{b}
2019–2020	N1	79.1 ± 4.8^{i}	145.7 ± 22.1^{fg}	153.1 ± 5.2^{efg}	158.4 ± 5.6^{defg}	526.9 ± 47.1^{p}	1053.6 ± 55.0^{o}	1497.0 ± 195.2^{jkl}	1750.4 ± 193.6^{hij}
	N2	80.3 ± 4.9^{i}	146.0 ± 4.1^{fg}	157.7 ± 11.5^{defg}	172.4 ± 19.9^{bcdef}	695.8 ± 78.5^{p}	1229.1 ± 101.9^{lmo}	1713.7 ± 28.8^{hij}	1988.8 ± 231.4^{fgh}
	N3	97.1 ± 6.6^{hi}	176.7 ± 7.0^{bcdef}	182.5 ± 19.1^{bcdef}	185.1 ± 7.9^{abcdef}	935.9 ± 163.2^{o}	1482.2 ± 118.3^{jkl}	1945.2 ± 147.0^{ghi}	2274.7 ± 146.6^{f}
	N4	107.1 ± 15.7^{hi}	186.7 ± 24.3^{abcdef}	201.9 ± 4.8^{abcd}	228.9 ± 25.8^{a}	1141.3 ± 46.5^{mo}	1776.0 ± 125.5^{ghij}	3143.6 ± 137.3^{d}	4060.8 ± 153.4^{a}
	N5	123.8 ± 20.9^{gh}	187.1 ± 19.1^{abcdef}	211.5 ± 21.2^{abc}	216.3 ± 3.4^{ab}	1380.0 ± 101.3^{klm}	2084.8 ± 240.8^{fg}	3723.4 ± 43.0^{b}	3986.3 ± 77.3^{a}
	N6	166.1 ± 5.7^{cdef}	197.0 ± 27.6^{abcde}	204.9 ± 29.5^{abc}	211.5 ± 10.9^{abc}	1643.9 ± 181.4^{ijk}	2820.0 ± 149.1^{e}	3212.0 ± 160.4^{cd}	3476.7 ± 140.6^{c}
	N7	195.3 ± 21.8^{abcde}	196.9 ± 6.1^{abcde}	199.6 ± 13.0^{abcd}	204.4 ± 13.6^{abc}	2092.8 ± 137.8^{fg}	2628.1 ± 167.9^{e}	3108.0 ± 176.1^{d}	3384.7 ± 118.8^{cd}

	Summary of analyses of variance (p values) 2018–2019					Summary of analyses of variance (p values) 2019–2020				
Items	K-S	Levene	N	F	$N \times F$	K-S	Levene	N	F	$N \times F$
Effective pods	> 0.05	> 0.05	< 0.001	< 0.001	< 0.001	> 0.05	> 0.05	< 0.001	< 0.001	< 0.001
Yield	> 0.05	> 0.05	< 0.001	< 0.001	< 0.001	> 0.05	> 0.05	< 0.001	< 0.001	< 0.001

Significant differences among treatments for a particular year based on S–N-K test ($p < 0.05$) were shown with different letters. F: soil fertility

Table 5 The effect of nitrogen (N) fertilization on seeds per pod and 1000-grain weight of film side planting rapeseed under different soil fertility conditions

Season	Treatment	Seeds per pod				1000-grain weight (g)			
		F1	F2	F3	F4	F1	F2	F3	F4
2018–2019	N1	18.7 ± 1.3[a]	21.4 ± 1.5[a]	22.8 ± 2.4[a]	20.1 ± 2.2[a]	4.0 ± 0.4[a]	3.6 ± 0.4[a]	3.6 ± 0.5[a]	4.2 ± 0.5[a]
	N2	19.8 ± 1.4[a]	19.8 ± 2.2[a]	21.4 ± 1.3[a]	19.8 ± 2.3[a]	3.9 ± 0.3[a]	4.0 ± 0.3[a]	3.7 ± 0.2[a]	3.9 ± 0.5[a]
	N3	20.5 ± 1.5[a]	20.3 ± 2.5[a]	20.3 ± 0.7[a]	20.4 ± 1.8[a]	3.9 ± 0.3[a]	4.4 ± 0.6[a]	3.6 ± 0.4[a]	4.1 ± 0.2[a]
	N4	16.9 ± 0.8[a]	20.9 ± 2.9[a]	19.2 ± 2.0[a]	25.0 ± 2.0[a]	4.3 ± 0.3[a]	4.5 ± 0.1[a]	3.7 ± 0.2[a]	3.8 ± 0.4[a]
	N5	17.5 ± 2.6[a]	20.9 ± 4.2[a]	18.5 ± 2.3[a]	21.2 ± 1.0[a]	4.0 ± 0.3[a]	3.6 ± 0.4[a]	3.8 ± 0.3[a]	4.1 ± 0.2[a]
	N6	18.6 ± 2.3[a]	21.0 ± 1.8[a]	23.2 ± 2.1[a]	21.3 ± 2.2[a]	3.9 ± 0.6[a]	3.8 ± 0.2[a]	3.8 ± 0.4[a]	4.2 ± 0.4[a]
	N7	18.4 ± 1.1[a]	20.2 ± 2.6[a]	18.4 ± 1.8[a]	21.5 ± 1.3[a]	3.6 ± 0.5[a]	4.3 ± 0.3[a]	3.9 ± 0.4[a]	4.2 ± 0.5[a]
2019–2020	N1	22.7 ± 1.5[a]	22.9 ± 0.8[a]	26.0 ± 0.7[a]	23.4 ± 3.3[a]	4.9 ± 0.4[a]	4.9 ± 0.1[a]	4.6 ± 0.1[a]	4.6 ± 0.2[a]
	N2	20.0 ± 0.7[a]	23.8 ± 1.8[a]	19.6 ± 0.9[a]	23.9 ± 2.9[a]	5.2 ± 0.2[a]	4.8 ± 0.8[a]	5.1 ± 0.5[a]	4.8 ± 0.3[a]
	N3	23.2 ± 2.1[a]	24.0 ± 1.0[a]	21.8 ± 2.2[a]	21.6 ± 1.6[a]	5.1 ± 0.3[a]	4.6 ± 0.3[a]	4.9 ± 0.3[a]	4.7 ± 0.4[a]
	N4	25.2 ± 3.0[a]	21.7 ± 1.9[a]	20.8 ± 0.3[a]	21.0 ± 3.0[a]	5.0 ± 0.1[a]	4.8 ± 0.4[a]	4.9 ± 0.3[a]	4.8 ± 0.2[a]
	N5	23.3 ± 2.4[a]	23.8 ± 1.0[a]	22.8 ± 2.8[a]	20.0 ± 2.6[a]	5.2 ± 0.2[a]	4.8 ± 0.4[a]	5.4 ± 0.4[a]	5.1 ± 0.2[a]
	N6	24.9 ± 1.8[a]	24.0 ± 1.0[a]	24.6 ± 2.2[a]	22.4 ± 2.6[a]	5.5 ± 0.3[a]	4.6 ± 0.2[a]	5.7 ± 0.3[a]	4.7 ± 0.4[a]
	N7	25.1 ± 3.0[a]	21.8 ± 1.7[a]	23.8 ± 3.3[a]	22.0 ± 2.4[a]	4.6 ± 0.3[a]	5.1 ± 0.4[a]	5.6 ± 0.4[a]	4.7 ± 0.6[a]

Significant differences among treatments for a particular year based on S–N-K test ($p < 0.05$) were shown with different letters

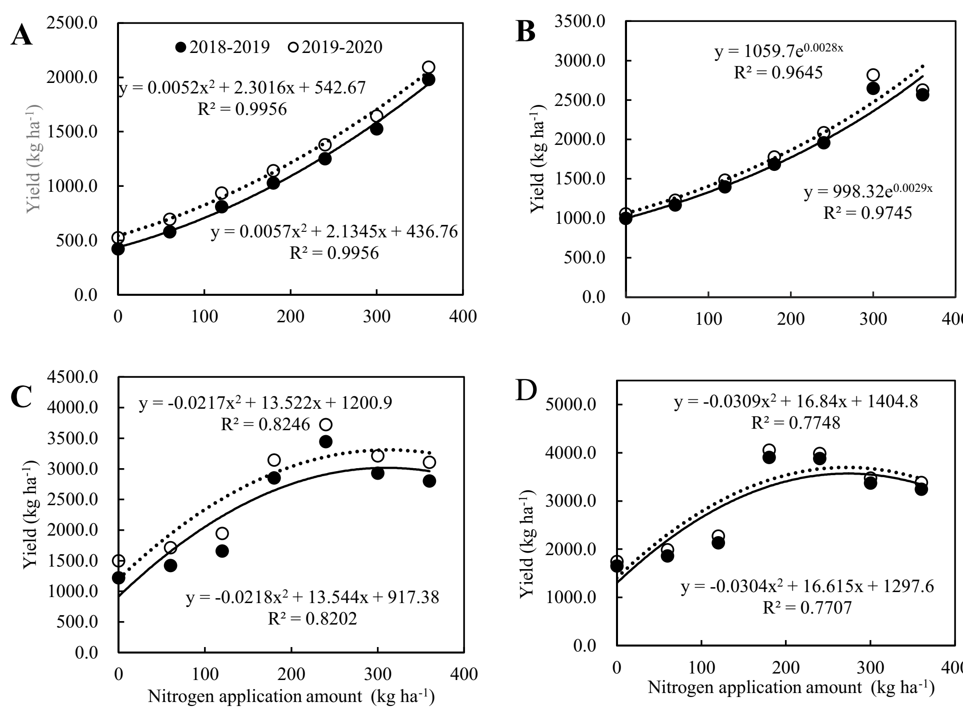

Fig. 4 The relationship between nitrogen application amount and yield under different soil fertility conditions. **A** Soil fertility 1; **B** soil fertility 2; **C** soil fertility 3; **D** soil fertility 4

4 Discussion

N is a key factor influencing rapeseed growth, N utilization and yield. Appropriate N amounts can not only achieve high yield and high efficiency of crops (Gu et al. 2017), but also avoid the risk of N leaching and environmental pollution (Wang et al. 2019a, b). The basic nutrient status of soil is the basis for rational fertilization. Previous study based on ordinary fertilizers had shown that improving soil fertility could reduce crop's dependence on N fertilization. Besides, the crop yield increased with the increase of soil fertility, and there were significant differences among the soil fertility levels (Huang et al. 2017). Obviously, different soil fertility levels require different N application amounts. This was also observed in the present study: Nitrogen fertilization application significantly increased ($p < 0.05$) dry matter, N accumulation, effective pods, and yield of rapeseed, compared to no N treatment. These dry matter, N accumulation, effective pods, and yield peaked in plots fertilized with 360, 300, 240, and 180 kg N ha^{-1} under soil fertility 1 (F1), soil fertility 2 (F2), soil fertility 3 (F3), and soil fertility 4 (F4), respectively (Table 2, Table 3, Table 4, and Fig. 3).

As the content of organic matter, alkali-hydrolysable, available P, and available K in 0 ~ 20 and 20 ~ 40 cm soil layers under F3 and F4 exceeded that under F1 and F2 (Table 1), significant ($p < 0.05$) and greater increase in dry matter and N content in plant were found under F3 and F4 than that under F1 and F2. Besides, F3 and F4 needed more than 60 kg ha^{-1} less N than F1 and F2 to achieve high dry matter and N content in plant, which might be related to the nutrient content in soil. Tian et al. (2020) found that the good nutrient status in the root zone was beneficial to root growth, and a well-developed root system allowed the crop to absorb more soil N. Compared to F1 and F2, F3 and F4 had greater organic matter and effective nutrient, thereby increasing the dry matter and N content in plant.

Improving the ability of N accumulation is the first step to increase N content in plant (Du et al. 2020). In this study, N accumulation peaked in plots fertilized with 360, 300, 240, and 180 kg N ha^{-1} under F1, F2, F3, and F4, respectively. This was also related to the response of rapeseed dry matter accumulation to nitrogen fertilizer under different soil fertility levels. The increase in dry matter promoted the storage capacity of soil N, providing sufficient space for rapeseed N accumulation (Girondé et al. 2015). Previous studies in maize (Geng et al. 2019), rice (Pal et al. 2017), and wheat (Ren et al. 2022) had similar results. Our study also showed that N use efficiency and N agronomic efficiency were highest in 360, 300, 240, and 180 kg N ha^{-1}, respectively, under F1, F2, F3, and F4, which was related to the response of rapeseed N accumulation to nitrogen fertilizer under different soil fertility levels.

In both years, the improved dry matter, N accumulation, N use efficiency, and N agronomic efficiency could explain the improved rapeseed yield observed in 360, 300, 240, and 180 kg N ha^{-1}, respectively, under F1, F2, F3, and F4. Increased dry matter, N accumulation, N use efficiency, and N agronomic efficiency are known to improve crop economic traits and yield, including rapeseed (Tian et al. 2020). On the basis of both years' results, 360, 300, 240, and 180 kg N ha^{-1}, respectively, under F1, F2, F3, and F4 achieved the highest yield than other N treatments. Our results were consistent with several other studies, where improving soil foundation fertility could reduce rapeseed's dependence on chemical fertilizers on the basis of ensuring high yield (Adeleke and Babalola 2020; Wang et al. 2018; Djaman et al. 2020; Han et al. 2018).

Many studies had shown that the correlation between crop yield and N application amount was extremely significant and crop yield increases with the increase of N application amount within a certain range (Oladeleab et al. 2019; Leghari et al. 2016). Under different soil fertility levels, the corresponding N application amount for highest crop yield was different (Mustafa et al. 2017). Study had shown that the wheat yield was still increasing without fertilization for 50 consecutive years under high soil fertility level, which declined year after year without fertilization continuously under low soil fertility level (Hejaman and Kunzova 2010; Kunzova and Hejaman 2009). In this study, the yield of each nitrogen fertilization treatment was fitted with the N application amount, and it was found that the N application amount corresponding to the highest rapeseed yield decreased with the increase of the soil fertility level. It also showed that fertilizing the soil and improving soil fertility could reduce the demand for nitrogen fertilization.

The high soil fertility explains, to a large extent, the good plant growth conditions observed in both years for the low demand of nitrogen fertilization to achieve high yield. High soil fertility had a significant positive effect on rapeseed yield, compared to low soil fertility. Therefore, we interpret this as showing that the impact of N fertilization on crop yield may change over time as the effect of N fertilization on soil fertility (Wang et al. 2019a, b).

5 Conclusions

A 2-year field study was carried out to determine the response of nitrogen amounts under different soil fertility levels on rapeseed, to find out the optimal nitrogen amount. The results from the current study had revealed the existence of significant variability in rapeseed performance (dry matter, nitrogen accumulation, nitrogen use efficiency, nitrogen agronomic efficiency, effective pods) based on differences in nitrogen amounts under different soil fertility levels. This therefore bears a significant penalty on rapeseed yield. Hence, it is inferred that application of 360, 300, 240, and 180 kg N ha^{-1} proved more effective and viable in improving rapeseed yield under soil fertility 1, soil fertility 2, soil fertility 3, and soil fertility 4, respectively, compared to other nitrogen treatments. In addition, the study revealed that the optimal nitrogen amount for film side planting rapeseed in arid regions of southwest China under the low soil fertility conditions were 360 kg ha^{-1} or more, and under the high soil fertility conditions were 272 ~ 312 kg ha^{-1}. Nevertheless, further research may focus on the long-term effects of these treatments on soil fertility and economic sustainability.

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Data Availability All data and materials are included in this published article.

Declarations

Conflict of Interest The authors declare no competing interests.

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