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Full Length Article

Nitrogen Recovery and Transport Efficiency of Winter Rapeseed and Residual Nitrogen Effect on Subsequent Sesame using ^{15}N Labelling Technique

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Abstract

In China, the application rate of nitrogen in rapeseed is high, but the uptake and utilization efficiency is low, which may cause irreversible environmental pollution. Use of efficient nitrogen rate and to improve nitrogen recovery, transport and residues management is important for crop productivity and sustaining the environment. Therefore, a pot was conducted using two winter rapeseed cultivars of Huayouza No.9 (HZ9) and Huashuang No.5 (HS5) under two N levels (0.15-N_1 and 0.30-N_2 g N.kg^{-1} soil). The ^{15}N-uera was applied before sowing (basal) and at stems elongation stage (topdressing). The results indicated that ^{15}N recovery efficiency (^{15}NRE) of HS5 under N_1 increased by 5.89 percentage points compared to N_2, and the most obvious difference was observed in grain. However, no significant difference was observed in HZ9 between the two N levels. The ^{15}N transport efficiency (^{15}NTE) of the N_1 treatment (37.62~37.70%) was much higher than that of the N_2 treatment, with the difference mainly observed in stem (4.33~5.03%). The ^{15}NTE of basal was significantly higher than that of topdressing, with the difference mainly found in leaves (14.02~19.52%). The ^{15}NRE under topdressing treatment (56.85~61.60%) increased 8.18 and 8.58 percentage points relative to that under basal treatment, with the main difference observed in grain and pericarp. Additionally, about 1.62% nitrogen from rapeseed season in two N levels was absorbed by the subsequent sesame crop, with its yield increased by 26.00~89.19% compared to the control. The average ^{15}NRE of sesame from basal and topdressing was 1.91% and 1.34%, with a yield increase of 16.22% and 59.50% over the control, respectively. The integrated data indicated that higher N recovery and transport efficiency can be achieved by adequacy reducing application rate and increasing the proportion of topdressing, and the residual soil nitrogen of rapeseed can be recovered to some extent by planting sesame.

Keywords: ^{15}N Recovery efficiency; ^{15}N Transport efficiency; Cropping patterns; Residual N effect; Sesame; Winter rapeseed

Introduction

The Yangtze River Basin, one of the major winter rapeseed production regions in China, accounts for one-fifth of the rapeseed yield and cultivation area in the world (Li *et al.,* 2015). However, the nitrogen recovery efficiency of rapeseed was about 34.6% in Yangtze River Basin of China, which easy led to environmental pollution (Zou *et al.,* 2011). Most previous studies have demonstrated that nitrogen fertilizer could promote rapeseed growth, which may ultimately improve nitrogen absorption, accumulation and nitrogen requirement of rapeseed grain, but nitrogen fertilizer agronomic efficiency, partial factor productivity and recovery efficiency significantly decreased with increasing nitrogen supply(Gan *et al.,* 2008; Schulte-auf'm-Erley *et al.,* 2011; Johnson *et al.,* 2013).

Winter rapeseed showed relatively high nitrogen absorption ability, but there was still a certain amount of soil residual nitrogen after harvest (Dresbøll *et al.,* 2016). To date, the percentage of residual nitrogen recovery efficiency has not been fully explored. It has been reported that the recovery efficiency of residual soil nitrogen was affected by nitrogen fertilizer rate (Sepaskhah and Tafteh, 2012), fertilizing method (Xu *et al.,* 2015) and residue incorporation (Ichir *et al.,* 2003). The rapeseed and sesame cropping pattern was one of the important cropping models in the middle reaches area of Yangtze River, China. Hence, sesame is considered as a suitable crop for measuring N recovery efficiency of soil residual nitrogen of rapeseed.

Currently, ^{15}N isotope labeling method is used as an effective way for studying nitrogen fertilizer use efficiency and nitrogen transport efficiency (Gironde *et al.,* 2015a, b). Nitrogen uptake and utilization process also involves the conversion of nitrogen source-sink in the plant body. The

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growth period from emergence to early flowering is generally considered as the accumulation period of plant N source, and the stem and leaves were two major sources for apparent N remobilization to the pods. Nitrogen uptake after entering the early flowering stage is adjusted by the sink size. Especially, remobilization of N from stems and leaves was more important for pod N accumulation than N uptake after florescence. In order to decrease the crop-inherent high N budget surplus of winter rapeseed requires, and it should increase the low N remobilization efficiency particularly of pericarp N to the grains (Wang *et al.,* 2011; Koeslin-Findeklee and Horst, 2016; Wang *et al.,* 2016). Meanwhile the nitrogen transport efficiency is determined by the N supply levels and the genotypes (Gironde *et al.,* 2015b). Cai *et al.* (1995) investigated the rapeseed nitrogen recovery efficiency by ^{15}N labelling technique and reported that rapeseed plant recovery efficiency of nitrogen as basal and topdressing at the flowering stage was 44.0% and 33.4% of the applied N, respectively. Meanwhile, many researchers maintained that the apparent N transport efficiency of rapeseed grain was about 41.0~65.0% from vegetative tissues, and the transport capacity was obviously higher under moderate nitrogen stress conditions than under normal or severe nitrogen stress conditions, with the apparent N transport efficiency of rapeseed grain being roughly 70–94% (Hocking *et al.,* 1997; Rossato *et al.,* 2001; Malagoli *et al.,* 2005; Gombert *et al.,* 2010; Franzaring *et al.,* 2012; Gironde *et al.,* 2015a). However, there have been few reports available on the use efficiency of nitrogen fertilizer as basal and topdressing in different organs of rapeseed and the residual N recovery efficiency by the subsequent crop. To gain novel insights into these questions, the effects of different N levels and application time on the use efficiency of nitrogen fertilizer as basal and topdressing were studied by using the ^{15}N labeling method in this paper.

The objectives of this study were to explore the use efficiency of nitrogen fertilizer as basal and topdressing under two levels and two growth stages in terms of nitrogen recovery efficiency, transport efficiency after the early flowering stage and residual soil nitrogen recovery efficiency by planting sesame. This research provides theoretical support for the recovery efficiency of N fertilizer in rapeseed and residual soil nitrogen.

Materials and Methods

Plant Materials and Growth Conditions

Two rapeseed cultivars and one sesame cultivar were used as planting materials in this study. Huayouza No. 9 (HZ9) and Huashuang No.5 (HS5), a hybrid and a conventional rapeseed cultivar, were provided by Huazhong Agricultural University. Ganzhi No. 5 (GZ5) was a conventional cultivar of black sesame which was provided by the Crop Institute of Jiangxi Academy of Agricultural Sciences, China. The pot experiment was carried out at the glasshouse of the College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, Hubei Province, China (114°22'E, 30°29'N). Soil properties were: pH 6.1, 19.8 g organic matter kg^{-1}, 10.9 g total N kg^{-1}, 16.2mg Olsen-P kg^{-1}, and 75.2 mg NH_4OAc-extractable $K \cdot kg^{-1}$.

Experimental Design

The pot experiment was conducted using two factors randomized block design. Nitrogen application time (T_1-basal-60% before sowing and T_2-topdressing-40% at stem elongation stage) was the first factor, and nitrogen application rate (N_1-0.15 and N_2-0.30, g $N \cdot kg^{-1}$ soil) was the second factor with one control (N_0) set for comparison. Low nitrogen (N_1) and high nitrogen (N_2) represented the amount of 120 and 240 kg $N \cdot ha^{-1}$. Treatments details for HZ9 and HS5 are shown in Table 1. Plants were grown in 15 L containers (bottom diameter: 0.225 m, top diameter: 0.330 m, height: 0.250 m) including 10 kg soil and 5 kg sand. Eight replications were conducted for each treatment in the growth season of rapeseed and five replications were conducted for each treatment in the growth season of sesame.

Rapeseed seeds were directly sown for each pot by hand on 4th November, 2013. Six rapeseed seeds were sown in each pot, and seedlings were thinned to two plants per pot by hand at the 4th leaves stage. Under a low nitrogen conditions, the stem elongation stage, early flowering stage, and maturity stage of HZ9 and HS5 began on February 27 and March 3, March 14 and March 19, May 5 and May 7, 2014, respectively; under a high nitrogen condition, early flowering stage and maturity stage of HZ9 and HS5 were delayed by one or two days relative to those at a low nitrogen level. Eight sesame seeds were directly sown in each pot by hand on May 18, 2014, with four sesame plants maintained in each pot at the 3rd couple leaves stage, and the pots were harvested on August 22, 2014.

Fertilizers used were urea for N (46.4%), single superphosphate for P_2O_5 (12.0%), potassium chloride for K_2O (60.0%) and borax for B (10.0%). The doses were 0.075 P_2O_5, 0.105 K_2O, and 0.025 g B ($g.kg^{-1}$soil), respectively. P_2O_5, K_2O and B were applied once as a basal dose before sowing. The ^{15}N abundance in urea (N 46.4%, Shanghai Chemical Industry Research Institute, Shanghai, China) was 10.16%. ^{15}N fertilizer was fully dissolved in 500 mL water and then was poured into the pots. During seedling stage and stem elongation stage, both the rapeseed and sesame plants were regularly provided with 500 mL water to prevent the plants from wilting, but with 1,000 mL water during flowering and maturity stages. Pests, diseases, birds, and weeds were controlled as per requirement to avoid yield losses.

Table 1: Nitrogen fertilizer rate of different treatments in rapeseed and sesame cropping pattern (unit: g N.kg^{-1} soil)

Treatment	Basel of rapeseed (60%)	Topdressing of rapeseed (40%)	Sesame
N_0-0	0	0	0
N_1T_1-0.15	0.09#	0.06	0
N_1T_2-0.15	0.09	0.06#	0
N_2T_1-0.30	0.18#	0.12	0
N_2T_2-0.30	0.18	0.12#	0

indicated ^{15}N labeling fertilizer; N_0, N_1 and N_2 represented 0, 0.15 and 0.30 g N·kg^{-1} soil, respectively; T_1 and T_2 indicated basal labelling and topdressing labelling

Data Collection

At the early flowering stage and maturity stage of rapeseed as well as the maturity stage of sesame, three pots of basal and topdressing labelling treatments were harvested separately. The rapeseed samples were divided into roots, stems, and leaves, followed by drying at 105□ for half an hour, then at 80□ for four days to a constant weight (dry weight). The data of nitrogen content and ^{15}N abundance were determined at Crop Physiological Ecology and Tillage Key Laboratory in the Middle Reaches of Yangtze River of the Ministry of Agriculture, College of Plant Science and Technology, Huazhong Agricultural University, using Vario ISOTOPE Cube CN (Isoprime-100, Elementar Analysensysteme GmbH, Germany).

Related nitrogen use efficiency indexes were calculated according to the following equations:

(1) N_{dff}(N derived from fertilizer; %)＝(atom % ^{15}N plant organ–0.3663)×100/(atom % ^{15}N in fertilizer–0.3663);

(2) N_{uptake}(Fertilizer N uptake by whole plant from basal or topdressing; g.plant^{-1})＝total nitrogen content× ^{15}Ndff (basal or topdressing);

(3) NRE_{organ}[^{15}N Recovery Efficiency of plant organs (roots, stems, leaves, pericarps, grains);%]＝ N_{uptake}×100%/total ^{15}N supply(Choudhury and Khanif, 2001);

(4) NTA_{oragn}(Nitrogen Transport Amount; g)＝ nitrogen accumulation amounts of different organs at early flowering stage－nitrogen accumulated amounts of vegetative organs at maturity stage;

(5) NTE_{oragn}(Nitrogen Transport Efficiency; %)＝ NTA_{organ}×100%/total accumulation nitrogen of whole plant at early flowering stage (Ji *et al.* 2005).

The temperature data (from November 4, 2013 to August 30, 2014) in glasshouse were recorded once per hour with 0.1℃ precision by an automatic temperature recording instrument (DT618A, Hataike Science and Technology Corporation, Hangzhou, China). The recorded data were used to determine the average temperature per day, the maximum, minimum and mean temperature of one month.

Statistical Analyses

Two-way ANONA was used to analyze all datas with the statistical software package SAS 9.1. All figures were designed by Origin 8.0. Block and block interactions were considered as random effects, and the application rate and time of nitrogen were considered as fixed effects. Fisher's least significant difference (LSD) was used to test the difference between means of each treatment at 0.05 and 0.01 probability levels.

Results

Temperature during the Experimental Season

The mean, maximum and minimum temperature followed roughly the similar trend during the experimental season. The mean and minimum temperature decreased from seeding to the beginning of the stem elongation stage, followed by a gradual increase from March 2014 as the rapeseed reached the maturity stage, and it moderately decreased in August, 2014 (Fig. 1). However, the maximum temperature began to rise in January, 2014. The lowest and the highest temperature in the experimental season were 1.0°C (February, 2014) and 34.4°C (July, 2014), respectively. No extreme temperature was recorded during the growth season of rapeseed and sesame.

Yield and Yield Components of Rapeseed under Different Treatments

As the nitrogen application rate increased, the yield, pod number plant^{-1} of the rapeseed increased significantly (Table 2). Furthermore, the yield and pod number plant^{-1} of N_2 significantly increased by 28.16% and 16.51% in HZ9 compared to those of N_1 (Table 2). Nonetheless, no significant difference was observed in yield and pod number plant^{-1} of HS5 between N_1 and N_2 in this study, and no significant difference was observed in all traits between T_1 and T_2. Compared to HS5, the pod number plant^{-1} of HZ9 was 19.58% higher, but 1000-seed weight was 6.84% lower (Table 2).No significant interaction was noticed for N×T of all traits (Table 2). These results demonstrated that the application rate of nitrogen is the main factor affecting rapeseed yield and yield components.

The Percentage of N Derived from Fertilizer

The ^{15}N derived from fertilizer ($^{15}N_{dff}$) for different organs such as grain, stem, pericarp and root under high nitrogen was significantly increased by 3.82~7.56 percentage points compared to low nitrogen in HZ9 and HS5 (Table 3). The results indicated that genotype differences exhibited significant in N_{dff} for all organs at the flowering stage under the two nitrogen levels, and the difference of the low nitrogen-efficient variety was

Table 2: Yield and yield components of two rapeseed cultivars under different nitrogen application time points and rates

Treatment	Yield (g.plant^{-1})	Pod number per plant (pieces.plant^{-1})	Seed number per pod/pieces	1000-seed weight (g)
HZ9				
T_1	9.38a	171.33a	15.51a	3.40a
T_2	8.59a	156.02a	14.46a	3.68a
N_0	1.12c	25.25c	12.92a	3.60a
N_1	11.33b	215.13b	15.47a	3.44a
N_2	14.52a	250.65a	16.56a	3.59a
T	ns	ns	ns	ns
N	**	**	ns	ns
N×T	ns	ns	ns	ns
HS5				
T_1	8.51a	134.92a	15.96a	3.75a
T_2	8.92a	138.83a	15.73a	3.86a
N_0	1.36b	27.17b	15.99a	3.15b
N_1	12.14a	188.63a	16.14a	4.02a
N_2	12.65a	194.83a	15.41a	4.23a
T	ns	ns	ns	ns
N	**	**	ns	**
N×T	ns	ns	ns	ns

N, T and N×T represented nitrogen application rate and nitrogen application time, interaction of nitrogen application rate and nitrogen application time respectively; *, ** and ns indicated significant treatment effects at $P \leqslant 0.05$, $P \leqslant 0.01$ and not significant, respectively; HZ9 and HS5 represented Huayouza No. 9 and Huashuang No.5, respectively; N_0, N_1 and N_2 represented 0, 0.15 and 0.30 g N.kg^{-1} soil; T_1 and T_2 represented basal labelling and topdressing labelling; Means followed by the same small letter(s) within each column are not significant different at $P \leqslant 0.05$

Table 3: The percentage of nitrogen derived from ^{15}N fertilizer ($^{15}N_{dff}$ / %) for different organs at different stages

Treatment	Early Flowering Stage			Maturity Stage			
	Root	Stem	Leaf	Grain	Pericarp	Stem	Root
HZ9							
N_1	41.63	42.14	41.05	35.77	34.85	35.94	33.23
N_2	39.96	42.81	41.30	41.35	40.46	39.76	39.56
T_1	49.86	49.53	55.29	44.67	43.55	45.77	51.35
T_2	31.72	35.42	27.05	32.44	31.76	29.93	21.44
N	ns	ns	ns	**	**	**	**
T	**	**	**	**	**	**	**
N×T	ns	**	**	ns	**	**	ns
HS5							
N_1	39.44	40.65	40.56	34.77	34.22	34.03	33.44
N_2	43.67	44.25	42.62	42.33	41.13	40.52	39.30
T_1	52.07	46.47	52.04	44.20	42.48	43.71	51.22
T_2	31.04	38.42	31.14	32.89	32.86	30.84	21.52
N	**	**	**	**	**	**	**
T	**	**	**	**	**	**	**
N×T	*	**	**	ns	ns	ns	**

N, T and N×T represented nitrogen application rate and nitrogen application time, interaction of nitrogen application rate and nitrogen application time respectively; *, ** and ns indicated significant treatment effects at $P \leqslant 0.05$, $P \leqslant 0.01$ and not significant, respectively; HZ9 and HS5 represented Huayouza No. 9 and Huashuang No.5, respectively; N_1 and N_2 represented 0.15 and 0.30 g N.kg^{-1} soil; T_1 and T_2 represented basal labelling and topdressing labelling

more sensitive. After entering the maturity stage, significant differences were observed in N_{dff} for all organs in HZ9 and HS5.

At the two stages, the N_{dff} values of all organs were significantly higher under basal treatment than under topdressing treatment in HZ9 and HS5. At the maturity stage, the N_{dff} values of plant root and stem were reduced by 5.49~7.58 and 9.52~10.28 percentage points under topdressing nitrogen treatment compared to the early flowering stage. The $^{15}N_{dff}$ of root under topdressing was 21.44%, a decrease of 30% compared to that of basal treatment. The $^{15}N_{dff}$ values of grain, stem and pericarp were around 31.0%, which was a decrease of 9.62~15.84 percentage points relative to that under basal treatment (Table 3).

A significant interaction of nitrogen application rate and time with N_{dff} of stem and leaf were observed in HZ9 and HS5 at the early flowering stage, but not observed for the grain,pericarp and stem of HS5 at the maturity stage (Table 3).

^{15}N Recovery Efficiency

At the early flowering stage, ^{15}N recovery efficiency (^{15}NRE) of root, stem and leaves under low nitrogen treatment increased by 2.22 and 0.77, 9.66 and 6.95, 21.22 and 14.66 percentage points compared to those under high nitrogen treatment in HZ9 and HS5,

Table 4: ^{15}N recovery efficiency and variance analysis of different organs in different stages (^{15}NRE/%)

Treatment	Early Flowering Stage				Maturity Stage				
	Root	Stem	Leaf	Total	Grain	Pericarp	Stem	Root	Total
HZ9									
N_1	4.14	19.44	45.17	68.75	41.65	10.30	5.98	0.82	58.75
N_2	1.92	9.78	23.95	35.65	37.61	11.13	6.50	1.03	56.27
T_1	3.02	11.84	36.67	51.53	38.80	8.25	5.47	0.90	53.42
T_2	3.04	17.38	32.45	52.87	40.47	13.18	7.00	0.95	61.60
N	**	**	**	**	ns	ns	ns	*	ns
T	ns	**	*	ns	ns	*	ns	ns	**
N×T	ns	**	ns	*	ns	ns	ns	ns	ns
HS5									
N_1	3.42	18.54	42.29	64.26	42.09	9.00	3.65	0.77	55.51
N_2	2.65	11.59	27.63	41.87	30.50	10.83	6.96	1.33	49.62
T_1	3.25	13.35	36.86	53.45	33.19	8.57	5.31	1.20	48.27
T_2	2.82	16.79	33.07	52.68	39.40	11.26	5.30	0.90	56.85
N	*	**	**	**	**	**	**	**	**
T	ns	*	ns	ns	**	**	ns	**	**
N×T	ns	ns	ns	ns	ns	**	ns	ns	ns

N, T and N×T represented nitrogen application rate and nitrogen application time, interaction of nitrogen application rate and nitrogen application time respectively; *, ** and ns indicated significant treatment effects at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively; HZ9 and HS5 represented Huayouza No.9 and Huashuang No.5, respectively; N_1 and N_2 represented 0.15 and 0.30g $N.kg^{-1}$ soil; T_1 and T_2 represented basal labelling and topdressing labelling

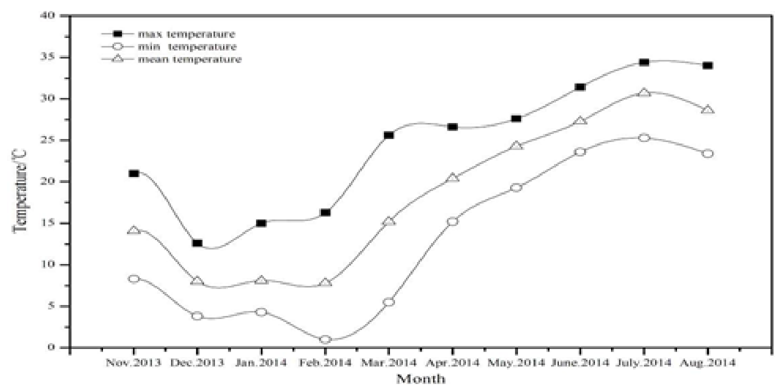

Fig. 1: The variation of monthly maximum (max), minimum (min) and mean temperature (mean) in glasshouse

respectively. ^{15}N recovery efficiency (^{15}NRE) of HS5 under low nitrogen was significantly increased by 5.89 percentage points compared to that of high nitrogen (49.62%) during the maturity stage, with the most obvious difference observed in grain (+11.59 percentage points). However, the ^{15}NRE values of the other organs under low nitrogen treatment were decreased by 0.56~3.31 percentage points compared to those under high nitrogen treatment (Table 4), but no significant difference was observed in HZ9 (56.27~58.75%) between the two N levels.

^{15}NRE under topdressing (61.60% and 56.85%) increased by 8.18 and 8.58 percentage points as compared to that under basal in HZ9 and HS5, respectively, and the main difference was observed in grain and pericarp during the maturity stage. Under the basal conditions, plant leaves showed the highest ^{15}NRE among all plant organs at the early flowering stage. At the mature stage, ^{15}NRE of plant root and stem decreased by 2.05~2.12 and 6.37~8.04 percentage points compared to that at the early flowering stage. Under the topdressing condition, the ^{15}NRE values of plant root, stem and leaf at the early flowering stage were 2.82~3.04%, 16.79~17.38% and 32.45~33.07% in HZ9 and HS5, respectively. At the maturity stage, the ^{15}NRE of plant root and stem was 0.90~7.00%, whereas that of grain and pericarp was 39.40~40.47% and 11.26~13.18%, respectively (Table 4). There were significant interactions of nitrogen application rate and time with the 15NRE of plant stem and the total in HZ9 at the early flowering stage, but only that of the pericarp was noted at the maturity stage.

N Transport Efficiency

Under low nitrogen treatment, the ^{15}N transport efficiency (^{15}NTE) of plant stem was significantly higher than that under high nitrogen treatment in HZ9 and HS5, but the opposite trend was noticed in plant leaves; ^{15}NTE in plant root was higher than that under high nitrogen treatment, but a significant difference was only found in HZ9. Total ^{15}NTE significantly increased by 4.76 and 3.15 percentage points, and it was notably higher under low

Table 5: Effect of treatments of previous rapeseed on yield, total nitrogen, $^{15}N_{dff}$ of different organs and ^{15}NRE of sesame at mature stage

Treatment	Yield/g/plant	Total N/g/plant	N_{dff} /%				^{15}NRE
			Stem	Pericarp	Grain	Total	
HZ9							
N_1	0.32	0.02	10.97	12.84	14.39	13.33	1.43
N_2	0.70	0.04	16.94	18.33	19.60	19.05	1.81
T_1	0.58	0.03	18.10	20.00	22.59	21.39	2.02
T_2	0.43	0.02	9.81	11.17	11.40	10.99	1.22
N	**	**	**	**	**	**	*
T	**	**	**	**	**	**	**
N×T	ns	ns	ns	*	ns	ns	ns
HS5							
N_1	0.51	0.03	11.48	12.74	13.76	13.33	1.83
N_2	0.59	0.03	16.29	18.05	19.91	19.20	1.44
T_1	0.50	0.03	18.47	20.91	22.81	21.98	1.80
T_2	0.59	0.03	9.30	9.88	10.86	10.54	1.46
N	ns	ns	**	**	**	**	**
T	ns	ns	**	**	**	**	*
N×T	ns	ns	ns	**	ns	ns	*

N, T and N×T, represented nitrogen application rate and nitrogen application time, interaction of nitrogen application rate and nitrogen application time, respectively; *, ** and ns indicated significant treatment effects at P≤0.05, P≤0.01 and not significant, respectively;HZ9 and HS5 represented Huayouza No.9 and Huashuang No.5, respectively;N_1 and N_2 represented 0.15 and 0.30g N.kg-1 soil;T_1 and T_2 represented basal labelling and topdressing labelling

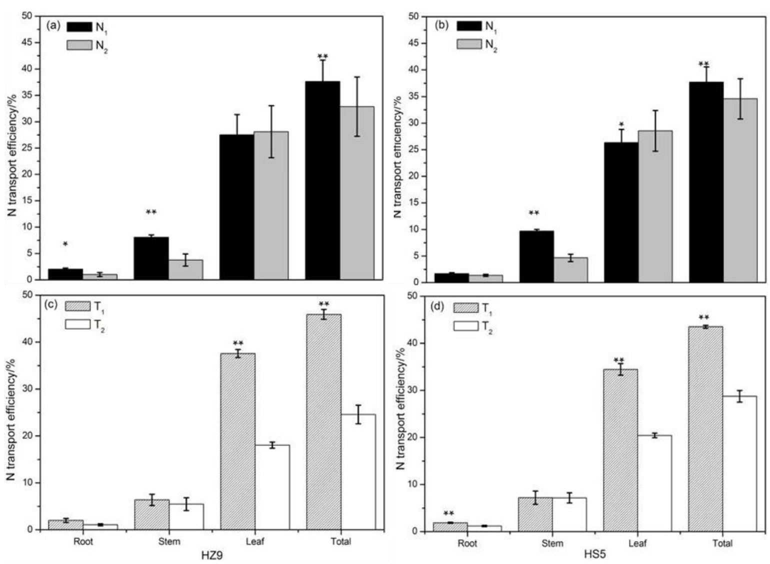

Fig. 2: ^{15}N transport efficiency from vegetative organs to pod after the early flowering stage of rapeseed

N and T represented nitrogen application rate and nitrogen application time, respectively; *, ** and ns indicated significant treatment effects at P≤0.05, P≤0.01 and not significant, respectively; HZ9 and HS5 represented Huayouza No.9 and Huashuang No.5, respectively; N_1 and N_2 represented 0.15 and 0.30g N.kg^{-1} soil; T_1 and T_2 represented basal labelling and topdressing labeling

nitrogen treatment than under high nitrogen treatment in HZ9 and HS5 (Fig. 2a and 2b).

The total ^{15}NTE of basal application was significantly increased by 21.33 and 14.77 percentage points compared to that of topdressing in HZ9 and HS5, respectively. For plant leaves, ^{15}NTE of basal nitrogen significantly increased by 19.52% and 14.02% compared to that of topdressing, respectively; meanwhile, a similar tendency was observed for total ^{15}NTE. However, for root, a significant difference of ^{15}NTE was only observed in HS5 (Fig. 2c and d). Hence, the total N transport efficiency of low nitrogen and basal were significantly higher than that of high nitrogen and topdressing, with the maximum difference of N application rate among all plant organs observed in stem (4.33~5.03%), and that of application time observed in leaves (9.52~14.02%).

Residual Effects of N Fertilizer by Subsequent Sesame

The sesame yield and total nitrogen content of plant underground under high nitrogen treatment were significantly increased by 118.75% and 100% in HZ9 compared to low nitrogen treatment, respectively. The sesame yield of nitrogen fertilizer treatment in rapeseed reason was increased by 26.00~89.19% than that of the control (N_0, 0.37 g/plant). Meanwhile, the N_{dff} values of all organs under high nitrogen treatment were 4.80~6.14 percentage points higher than those under low nitrogen treatment in HZ9 and HS5. However, there was a significant difference in the ^{15}NRE of sesame between the two N levels; with the ^{15}NRE of N_2 being higher than that of N_1 in HZ9, but it was the opposite in HS5, with a value of 1.44~1.83% (Table 5).

No significant differences were observed in the sesame yield and total nitrogen content of the plant above the ground in HZ9 between basal and topdressing. The sesame yield of basal and topdressing in rapeseed reason was increased by 16.22~59.50% relative to that of the control (N_0, 0.37g/plant). The N_{dff} value of each organ of sesame under the basal condition increased by 8.29~11.96 percentage points compared to that under the topdressing condition. The^{15}NRE value of basal (1.83~2.02%) was significantly increased by 0.34~0.80 percentage points compared to topdressing (1.22~1.46%) in HZ9 and HS5 (Table 5). Meanwhile, significant interactions were observed for N×T on N_{dff} of pericarp in HZ9 and HS5 and ^{15}NRE of whole plant in HS5 (Table 5).

Discussion

In the present study, the total nitrogen recovery efficiency of the two rapeseed varieties decreased with the increase of nitrogen level at the maturity stage, which was similar to several previous studies (Adriana *et al.,* 2002; Franzaring *et al.,* 2012). Meanwhile, the total ^{15}N recovery efficiency of topdressing was significantly higher than that of basal at the maturity stage, with the difference between them being 8.18 and 8.58 percentage points in HZ9 and HS5, respectively (Table 4). However, Cai *et al.* (1995) reported that the topdressing recovery efficiency (33.40%) was significantly lower than that of basal (44.00%) at the flowering stage, which may be due to the different sampling time. In this study, the sampling was performed at the maturity stage, while it was performed 35 days after topdressing in the research of Cai *et al.* (1995). The N recovery efficiency of topdressing was higher than that of basal under rapeseed normal growth conditions, probably because the stem-elongation stage is the key time for vegetative growth and reproductive growth of rapeseed, when the accumulation of nutrient could not meet the requirements of the rapid growth of rapeseed and most of the basal nitrogen fertilizer has been absorbed at the seedling stage, thus little nitrogen fertilizer can be absorbed by rapeseed. When supplied by topdressing, N fertilizer could be much better absorbed at the stem elongation stage. Therefore, reducing basal nitrogen and increasing topdressing nitrogen could promote the absorption of more fertilizer nitrogen by rapeseed plant, and also improved the nitrogen recovery efficiency and protect the environment from contamination. The ^{15}N recovery efficiency of grain was 33.19~40.47% under basal and topdressing labelling conditions (Table 4), which was lower than the 41.00~50.70% of the spring rapeseed reported by Franzaring *et al.* (2012), but it was higher than the value of 25.00% for the winter oilseed rape reported by Macdonald *et al.* (1997). The differences in the ^{15}N recovery efficiency of grain might be related to different soil conditions, climate characteristics or varieties (Macdonald *et al.,* 1997).

In this study, ^{15}N transport efficiency was obviously affected by nitrogen application rate and time. Specifically, the low nitrogen treatment showed significantly higher ^{15}N transport efficiency than high nitrogen treatment with a difference range of 3.15~4.76% and the total ^{15}N transport efficiency of the two varieties was 32.86~34.55% (Fig. 2a and b). The total ^{15}N transport efficiency of basal treatment was significantly higher than that of topdressing, with a difference range of 14.77~21.33%, and the total ^{15}N transport efficiency of the two varieties was 24.58~45.91% (Fig. 2c and d). These results demonstrated that the effect of nitrogen application time on N transport efficiency was greater than that of nitrogen application rate, and the transport of nitrogen from leaf was dominant regardless of application rate and time. However, previous researchers reported that the apparent nitrogen transport efficiency of the rapeseed grain was about 48.00~65.00% from vegetative tissues, which was higher than that in this study (Hocking *et al.,* 1997; Rossato *et al.,* 2001; Malagoli *et al.,* 2005; Gombert *et al.,* 2010). This difference may be attributed to the separate calculation of the ^{15}N transport efficiency of basal and topdressing, and there was no distinction between grain and pericarp. The application rate mainly affected the ^{15}N transport efficiency of stem, while the application time mainly affected that of leaf, and their change trend was similar to that of total ^{15}N transport efficiency. Thus, the transport efficiency of rapeseed stem can be used as a good indicator for the whole plant at different N levels, while that of rapeseed leaf can be used as a good indicator for the whole plant at different application time. However, the specific influence mechanism needs to be further studied. A proper reduction of basal nitrogen application rate and an increase of topdressing nitrogen could promote the absorption of more fertilizer nitrogen in rapeseed plant, and also improve nitrogen recovery efficiency and protect environment. In view of high N transport efficiency, a certain application rate of basal N should be maintained to improve the plant nitrogen transport efficiency. To maximize the rapeseed recovery efficiency and transport efficiency, it is necessary to establish proper total nitrogen and a desirable proportion between basal and topdressing to coordinate the crop source-sink for the high yield and high efficiency of rapeseed.

In this study, significant differences were found in the sesame yield and total nitrogen content between nitrogen application rates. Meanwhile, significant differences were also observed in the N recovery efficiency of soil residual nitrogen in sesame between nitrogen application time points. The ^{15}N recovery efficiency (^{15}NRE) values of basal and topdressing were 1.80~2.02% and 1.22~1.46%, respectively. The ^{15}NRE of N_1 and N_2 was 1.43% and 1.81% in HZ9, but 1.83% and 1.44% in HS5 (Table 5). The average ^{15}NRE of sesame (1.34~1.91%) was lower than that of the winter wheat without fertilization (6.3%) reported by (Macdonald *et al.* 2002). It suggested that the ^{15}NRE of sesame was affected by the previous rapeseed, even without fertilizer added during sesame growth, which was similar with the report by Xu *et al.* (2015) and Macdonald *et al.* (2002), but the value was low, and it could be attributed to the immobilization of large amounts of fertilizer N in organic matter (Ichir *et al.,* 2003). It could be meaningful to study whether N recovery efficiency of rapeseed residual soil nitrogen can be improved by adding a certain amount of nitrogen, phosphorus or potassium fertilizer or NPK complex fertilizer as basal or topdressing during sesame growth. Hence, the application of a suitable amount of fertilizer to rapeseed followed by the growth of sesame with less fertilizer requirement after rapeseed harvest not only can reduce the consumption of nitrogen fertilizer, but also can make full use of soil residual nitrogen and increase the economic income of farmers.

Conclusion

Appropriate application rate and time of N fertilizer is essential for improving crop productivity, economic management, N use efficiency and sustainability of the environment. N recovery efficiency of topdressing was significantly increased by about 8.0 percentage points compared with basal application, and the change range of N recovery efficiency of N application time was greater as compared to N application rate. Total ^{15}N transport efficiency was significantly higher when N was applied in the lower rate as a basal dose compared to application of N at higher rate as a topdressing, and significantly higher difference of N application rate among plant organs was observed in stem (4.33%~5.03%), whereas in case of N application time was observed in leaves (9.52%~ 14.02%). Meanwhile, the 1.34%~1.91% of rapeseed residual soil nitrogen was recovered by the succeeding sesame. Overall, higher N recovery and transport efficiency can be achieved by reducing nitrogen application rate and increasing the proportion of topdressing. Further studies need to focus on the improvement of the recovery efficiency of soil residual N through fertilizer application to sesame.

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