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Effect of Nitrogen Rate on Growth, Yield, and Chemical Composition of Forage Rape Cultivars

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ABSTRACT

Four introduced forage rape (*Brassica napus*) cultivars, 'Akela', 'Ramon', 'Sparta', and 'Velox' and a leading rapeseed cultivar, 'Hallayuchae' were grown at nitrogen (N) rates of 0, 100, 250, 300, 350, and 400 kg/ha to (i) select forage rape cultivars adapted best to Cheju area, and (ii) determine the optimum N rate for the best cultivars. Days from seeding to flowering across the cultivars increased 190 to 195 days as N rate increased from 0 to 400 kg/ha. Average days to flowering of six cultivars ranged from 182 to 198 days. Plant height increased as N rate increased up to 300 kg/ha and then decreased with a further increase in N rate and ranged from 159 to 174 cm among the cultivars. The optimum N rate for the greatest dry matter yield of five cultivars ranged from 222 to 258 kg/ha. Sparta showed the greatest dry matter yield (35.79 Mg/ha), followed by Akela, Hallayuchae, Velox, and Ramon. As N rate increased, crude protein content linearly increased but crude fiber content declined curvilinearly. Akela and Sparta had higher protein content than the other cultivars did. The forage cultivars had lower crude fiber content than the oilseed cultivar Hallayuchae did. Our results demonstrated that Sparta was best adapted to Cheju area and the optimum N rate for Sparta was about 220 kg/ha.

Key words: forage rape, nitrogen rate, dry matter yield.

Forage rape introduced from Europe have the greater yield potential and higher quality in both northern and southern parts of South Korea. Kim et al. (1990) demonstrated that the dry matter yield of introduced forage rape was higher than that of oats, turnips, rye, and ryegrass in Suwon (northwestern part of South Korea) when crops were seeded in late summer and early fall, and harvested in late fall. The dry matter yield of forage rape harvested in late November ranged from 2.5 to 7.0 Mg/ha in Suwon. They also reported that *in vitro* dry matter disappearance of forage rape was higher than that of oats. According to Kim & Kim (1987), two introduced forage rape cultivars outyielded a leading Korean rapeseed cultivar and produced the dry matter of 2.84 to 7.11 Mg/ha at 70 days after sowing in Taekwanryong area depending on cultivars and sowing dates. Ahn et al. (1989) reported that the dry matter yields of 17 European forage rape cultivars ranged from 4.19 to 10.65 Mg/ha at flowering in Mooahn (southwestern part of South Korea).

Minimum amount of nitrogen N fertilizer required for maximum forage rape production benefits both producers and environments. The optimum N rate for forage rape production is highly dependent upon soil fertility, cultivar, and other cultural practices. Ahn et al. (1989) reported that the optimum N rate for Akela forage rape in Mooahn was 150 kg/ha at which crude protein content was highest and crude fiber content was lowest. It seems that forage rape cultivars adapted to Cheju area have not been selected and the optimum N rate for introduced forage rape has not been determined in Cheju area. The objectives of this study were to select the best forage rape cultivars adapted to Cheju area and to determine the optimum N rate for the best cultivars.

MATERIALS AND METHODS

A field study was conducted at the Research Farm of the College of Agriculture, Cheju National University (33° N latitude, 277m altitude) on volcanic ash soil. Mean soil test values were: pH = 5.7, organic matter = 8.6%, and available P_2O_5 = 51.1 ppm. Exchangeable K and Ca were 1.2 and 1.0 me/100g, respectively. Four forage rape cultivars (Akela, Ramon, Sparta, and Velox) and a rapeseed cultivar (Hallayuchae) were seeded on 1 October 1994 on 20-cm rows at a seeding rate of 10 kg/ha. Nitrogen rates as urea were 0, 100, 250, 300, 350, and 400 kg/ha. Half of nitrogen was applied at planting and on 10 February 1995, respectively. Phosphate (P_2O_5) and K_2O were applied at 250 and 150 kg/ha at planting.

Experimental units contained twelve rows with 3m long. The experimental design was a split-plot arrangement in a randomized complete block with three replications. The main-plots consisted of six nitrogen rates and the subplots five cultivars.

Flowering date was recorded to determine days from seeding to flowering. Plant height was measured at full flowering on ten representative plants. Forage was hand harvested from eight center rows with 2 m long (3.2 m^2) at a 3-cm cutting height at full flowering. Harvested material was weighed fresh. Subsample was collected for each plot and separated into leaves and stems + inflorescences, dried at 80℃ for 5 days in a forced oven, and then weighed to determine dry matter yield. Dried samples were ground through 1 mm-sieve for the analysis of chemical compositions. Total nitrogen was measured by the Kjeldhal procedure and reported as crude protein

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(N × 6.25). Crude fat, crude ash, crude fiber, and nitrogen free extract were determined by AOAC methods.

Analysis of variance (ANOVA) was used to test significant main effects and interactions. Single degree of freedom contrasts were tested for N rate effects and regression equations were developed on the basis of highest-order significant orthogonal contrast. The summary of ANOVA was not shown in this report to save space. Cultivar means and N rate means when there was no functional relationship between N rates and the traits were compared using Duncan's Multiple Range Test. The optimum N rate at which maximum dry matter and protein yields occurred was determined by differentiating the resulting quadratic equations with respect to N rate.

RESULTS AND DISCUSSION

Only main effects of N rate and cultivar on days to flowering and plant height are shown in Table 1 because seeding rate × cultivar interaction was not significant ($p < 0.05$). The N rate × cultivar interaction effects on the other traits are shown in Tables 2 to 6.

Days to flowering, plant height, and leaf weight ratio

Table 1. Main effects of nitrogen rate and cultivar on days from seeding to flowering and stem diameter of forage rape.

Treatment	Days to flowering	Plant height (cm)
Nitrogen rate (kg/ha)		
0	190	156
100	191	164
250	192	167
300	193	172
350	194	168
400	195	161
Coefficients of regression equations relating nitrogen rate		
Intercept	189.5	156.6
Linear	0.0126	0.57
Quadratic	NS	0.0002
Cubic	NS	-7×10^{-7}
R^2	0.98	0.89
Cultivar		
Akela†	198a‡	160c
Ramon	192b	169b
Sparta	198a	162c
Velox	192b	174a
Hallayuchae	182c	159c

† Akela, Ramon, Sparta, and Velox are forage cultivars ; Hallayuchae is an oilseed cultivar.

‡ Cultivar means followed by the same letter are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

Days to flowering and plant height was significantly affected by N rate and cultivar. Average days to flowering of five cultivars increased 190 to 195 days as N rate increased from 0 to 400 kg/ha (Table 1). The forage cultivars flowered 10 to 16 days later than the oilseed cultivar Hallayuchae which flowered 182 days after seeding.

Plant height was also affected by N rate and cultivar. Plant height response to N rate was cubic and across five cultivars, plant height increased as N rate increased up to 300 kg/ha, and then decreased with a further increase in N rate (Table 1). Velox (174 cm) was tallest, followed by Ramon, Sparta, Akela, and Hallayuchae (159 cm).

Leaf weight ratio which was determined by the percentage of leaf dry weight to above-ground dry weight was significantly affected by N rate, cultivar, and N rate x cultivar interaction. Leaf weight ratio increased as N rate increased up to a certain level of N and then decreased with a further increase in N rate (Table 2). Ramon (44.8%) had the highest leaf weight ratio, followed by Akela, Sparta, Hallayuchae, and Velox (34.2%).

Dry matter and crude protein yields

The effects of N rate, cultivar, and N rate × cultivar interaction on dry matter and crude protein yields were highly significant. The optimum N rates for the greatest dry matter yield of five cultivars ranged from 222 to 258 kg/ha (Table 3). These results are similar to those of Ahn et al. (1993) who reported that the dry matter yield of a leading Korean rapeseed cultivar was highest at a N rate of 20 kg/ha. Ahn & Kwon (1989) reported that the optimum N rate was 150 kg/ha for Akela which grown at planting space of 50×15 cm in Sunchon. Averaged across six N rates, Sparta showed the greatest dry matter yield (35.79 Mg/ha), followed by Akela (32.17 Mg), Hallayuchae (9.81 Mg/ha), Velox (9.43 Mg/ha), and Ramon (8.45 Mg/ha). Dry matter yield was significantly correlated with days to flowering ($r = 0.75$, $p < 0.001$, $n = 90$) (data not shown). These results agree with those of Kim & Han (1984).

The optimum N rates for the greatest crude protein yield ranged from 264 to 324 kg/ha depending on cultivars (Table 3). Averaged across six N rates, Sparta (2210 kg/ha) showed the greatest crude protein yield, followed by Akela (2180 kg/ha), Velox (500 kg/ha), Hallayuchae (490 kg/ha), and Ramon (460 kg/ha). Crude protein yield depended more greatly on dry matter yield ($r = 0.93$, $p < 0.001$, $n = 90$) than on crude protein content in leaves ($r = 0.59$, $p < 0.001$, $n = 90$) and stems ($r = 0.68$, $p < 0.001$, $n = 90$) (data not shown).

The optimum N rates for the greatest crude protein yields were 14 to 19% higher than for greatest dry matter yields depending on the cultivars because crude protein content increased with increasing N rate. The optimum N rates should be determined on the basis of the greatest dry matter yield rather than the basis of the greatest protein yield because it has been reported that N use efficiency generally reduce and NO_3 content of herbage in-

Table 2. Leaf weight ratio (%) of five rape cultivars as affected by nitrogen rate.

Nitrogen rate (kg /ha)	Akela†	Ramon	Sparta	Velox	Hallayuchae	Mean
0	36.2	42.1	33.1	29.8	35.1	35.3
100	40.5	44.8	35.5	28.1	36.0	37.0
250	43.0	46.5	44.6	38.3	38.7	42.2
300	40.8	45.6	43.0	38.8	39.2	41.5
350	39.9	44.7	36.8	40.0	37.2	39.7
400	37.8	44.9	36.7	30.1	36.5	37.2
Mean	39.7^{b}‡	44.8^{a}	38.3^{bc}	34.2^{d}	37.1^{c}	38.8
Coefficients of regression equations relating nitrogen rate						
Intercept	36.15	42.18	32.74	29.9	35.05	35.22
Linear $\times 10^{-3}$§	59.40	31.99	18.71	−109.20	0.21	2.14
Quadratic $\times 10^{-3}$§	−0.1	−0.07	0.3	1.1	0.1	0.2
Cubic $\times 10^{-7}$§	NS	NS	−8.0	−20.0	−3.0	−6.0
R^2	0.97	0.92	0.81	0.96	0.92	0.98

† Akela, Ramon, Sparta, and Velox are forage cultivars ; Hallayuchae is an oilseed cultivar.
‡ Cultivar means followed by the same letter are not significantly different at 5% probability level according to Duncan's Multiple Range Test.
§ To obtain the actual coefficients, the reported values must be multiplied by the factor.

Table 3. Dry matter and crude protein yields of five rape cultivars as affected by nitrogen rate.

Nitrogen rate	Dry matter yield (Mg /ha)						Protein yield (kg /ha)					
(kg /ha)	Akela†	Ramon	Sparta	Velox	Halla	Mean	Akela	Ramon	Sparta	Velox	Halla	Mean
0	24.49	6.14	29.48	7.43	6.79	14.87	1193	256	1364	334	250	679
100	30.14	8.10	32.88	7.80	9.50	17.68	1968	376	1624	350	363	936
250	38.45	9.77	45.75	10.39	10.53	22.97	2648	548	3044	546	535	1465
300	37.16	9.25	37.80	10.82	12.92	21.59	2610	536	2585	606	712	1410
350	31.28	8.88	37.09	11.73	10.26	19.85	2279	520	2455	682	582	1304
400	31.50	8.58	31.72	8.41	8.82	17.81	2363	507	2170	460	466	1193
Mean	32.17^{b}‡	8.45^{d}	35.79^{a}	9.43^{cd}	9.81^{c}	19.13	2177^{a}	457^{b}	2207^{a}	496^{b}	485^{b}	1165
Coefficients of regression equations relating nitrogen rate												
Intercept	23.62	6.11	27.63	6.80	6.55	14.14	1179.81	244.57	1164.96	287.71	211.74	617.21
Linear	0.109	0.026	0.123	0.027	0.042	0.065	10.19	1.88	11.21	1.76	2.69	5.55
Quadratic $\times 10^{-4}$§	−2.27	−0.51	−2.76	−0.49	−0.88	−1.38	−186.17	−30.54	−212.20	−27.25	−47.71	−100.96
R^2	0.86	0.98	0.72	0.62	0.79	0.89	0.96	0.98	0.79	0.67	0.79	0.93
Opti. rate¶	239.7	258.4	222.2	273.9	238.1	236.4	273.7	308.5	264.2	323.6	281.6	275.1

† Akela, Ramon, Sparta, and Velox are forage cultivars ; Hallayuchae is an oilseed cultivar.
‡ Cultivar means followed by the same letter are not significantly different at 5% probability level according to Duncan's Multiple Range Test.
§ To obtain the actual coefficients, the reported values must be multiplied by the factor.
¶ The optimum N rate for the greatest dry matter yield or crude protein yield was calculated by differentiating the quadratic equation.

crease as N rate increase (Guillard & Allinson, 1988).

Chemical composition

Chemical composition in leaf and stem was significantly affected by N rate, cultivar, and N rate x cultivar interaction. Crude protein content in leaf and stem was linearly and curvilinearly increased with increasing N rate, and there were significant differences in slopes of equations among cultivars, resulting in N rate × cultivar interaction (Table 4). Crude protein content in leaf and stem was negatively correlated with crude fiber content in leaf ($r = -0.73$, $P < 0.001$, $n = 90$) and stem ($r = -0.75$, $P < 0.001$, $n = 90$) (data not shown). The forage cultivars had higher leaf crude protein content (7.6 to 9.7%) than the oilseed cultivar Hallayuchae (7.0%) did. Among the forage cultivars, Akela had the highest leaf protein content (9.7%), followed by Sparta, Velox, and Ramon (7.6%). Akela had the highest stem crude protein content (4.7%), followed by Sparta, Velox, Hallayuchae, and Ra-

Table 4. Crude protein contents (%) in the leaf and stem of five rape cultivars as affected by nitrogen rate.

Nitrogen rate	Leaf						Stem					
(kg/ha)	Akela†	Ramon	Sparta	Velox	Halla	Mean	Akela	Ramon	Sparta	Velox	Halla	Mean
0	7.3	6.3	7.7	6.5	5.6	6.7	3.5	2.7	3.1	3.6	2.7	3.1
100	9.4	6.9	8.0	6.5	5.7	7.3	4.6	2.8	3.3	3.7	2.8	3.4
250	9.8	7.9	9.6	7.5	7.5	8.5	4.7	3.6	4.3	3.9	3.5	4.0
300	10.3	8.0	9.7	8.3	7.7	8.8	4.8	4.0	4.7	3.9	4.1	4.3
350	10.5	8.1	9.8	8.7	8.1	9.0	5.2	4.1	4.8	3.9	4.3	4.4
400	10.7	8.3	10.0	8.8	7.4	9.0	5.5	4.0	5.1	4.0	4.2	4.6
Mean	9.7^{a}‡	7.6^{c}	9.1^{b}	7.7^{c}	7.0^{d}	8.2	4.7^{a}	3.5^{c}	4.2^{b}	3.9^{c}	3.6^{c}	4.0
Coefficients of regression equations relating nitrogen rate												
Intercept	7.9	6.4	7.7	6.2	5.5	6.8	3.5	2.7	3.1	3.6	2.7	3.1
Linear$\times 10^{-3}$§	7.6	5.1	6.4	6.6	6.3	6.3	17.3	3.7	0.9	1.4	−4.5	2.0
Quadratic$\times 10^{-6}$§	NS	NS	NS	NS	NS	NS	−80.0	52.0	37.0	−1.0	54.0	15.0
Cubic$\times 10^{-8}$§	NS	NS	NS	NS	NS	NS	10.0	−9.0	−6.0	−0.1	−8.0	−2.0
R^2	0.87	0.97	0.95	0.93	0.80	0.97	0.99	0.99	0.99	0.97	0.98	0.99

† Akela, Ramon, Sparta, and Velox are forage cultivars ; Hallayuchae is an oilseed cultivar.
‡ Cultivar means followed by the same letter are not significantly different at 5% probability level according to Duncan's Multiple Range Test.
§ To obtain the actual coefficients, the reported values must be multiplied by the factor.

Table 5. Crude fat, ash, and N free extract contents in the leaf and stem of five rape cultivars as affected by nitrogen rate.

Nitrogen rate	Leaf						Stem					
(kg/ha)	Akela†	Ramon	Sparta	Velox	Halla	Mean	Akela	Ramon	Sparta	Velox	Halla	Mean
Crude fat content (%)												
0	14.1a‡	12.2a	12.0b	8.0c	8.3b	10.9c	7.3c	7.4a	7.4b	5.8c	5.0c	6.6c
100	14.1a	12.2a	12.1ab	8.1c	8.4b	11.0c	8.4b	7.5a	7.5b	5.2c	6.0a	6.9b
250	14.1a	12.3a	12.0b	8.3c	8.4b	11.0c	9.2a	7.4a	7.4b	6.7b	5.7ab	7.3a
300	14.2a	12.3a	12.3ab	8.5bc	8.5ab	11.2b	8.4b	7.5a	7.6b	7.5a	5.5b	7.3a
350	14.3a	12.3a	12.5a	8.8ab	8.9a	11.4a	8.2b	6.8b	7.6b	6.0c	4.0e	6.5c
400	14.3a	12.3a	11.9b	9.3a	8.6ab	11.3ab	8.1b	7.9a	8.6a	5.7c	4.4d	6.9b
Mean	14.2^{a}§	12.2^{b}	12.1^{b}	8.5^{c}	8.5^{c}	11.1	8.3^{a}	7.4^{b}	7.7^{b}	6.1^{c}	5.1^{d}	6.9
Crude ash content (%)												
0	17.4ab	14.0b	16.4bc	16.6b	16.2a	16.1bc	14.6d	11.3d	11.8d	11.9a	12.4c	12.4d
100	17.9a	14.2b	16.2bcd	16.7b	16.3a	16.3ab	17.0a	12.0c	11.6d	11.6a	11.6d	12.8c
250	16.5d	15.1a	15.9cd	17.6a	15.8ab	16.2abc	16.4b	13.2a	13.7b	11.8a	11.1e	13.2b
300	16.9cd	15.5a	15.8d	16.3b	15.6b	16.0c	15.6c	13.3a	13.3c	11.9a	12.8b	13.4a
350	17.1bc	15.5a	17.2a	16.6b	15.4b	16.4a	15.4c	10.8e	13.9b	11.9a	11.8d	12.7c
400	17.1bc	14.2b	16.5b	16.6b	15.5b	16.0c	14.1e	12.7b	15.7a	11.2b	13.6a	13.4a
Mean	17.1^{a}	14.7^{e}	16.3^{c}	16.7^{b}	15.8^{d}	16.2	15.5^{a}	12.2^{c}	13.3^{b}	11.7^{d}	12.2^{c}	13.0
N free extract content (%)												
0	45.2a	46.3b	44.8c	51.8ab	47.2ab	47.1ab	27.6c	27.9c	32.0ab	32.5c	28.3b	29.7c
100	43.2b	45.9bc	48.3a	52.2a	47.5ab	47.4a	23.6e	27.3d	32.3a	34.1b	28.8b	29.2d
250	44.2ab	45.2bc	47.6a	50.2c	46.2b	46.7b	23.9e	26.8d	29.7d	32.5cd	29.3b	28.4e
300	43.7b	44.9c	47.5a	50.6bc	46.7ab	46.7b	26.0d	27.5cd	30.0d	32.2d	28.6b	28.8de
350	43.6b	45.1c	46.1bc	49.8c	46.2b	46.2c	29.9b	31.4a	31.2bc	34.3b	33.4a	32.0a
400	43.5b	48.2a	47.1ab	49.7c	47.8a	47.3a	31.1a	29.2b	30.6cd	36.4a	29.1b	31.3b
Mean	43.9^{d}	46.0^{c}	46.9^{b}	50.7^{a}	46.9^{b}	46.9	27.0^{e}	28.4^{d}	31.0^{b}	33.7^{a}	29.6^{c}	29.9

† Akela, Ramon, Sparta, and Velox are forage cultivars ; Hallayuchae is an oilseed cultivar.
‡ Within columns, means followed by the same letter are not significantly different at 5% probability level according to Duncan's Multiple Range Test.
§ Cultivar means followed by the same letter are not significantly different at 5% probability level according to Duncan's Multiple Range Test.

Table 6. Crude fiber contents (%) in the leaf and stem of five rape cultivars as affected by nitrogen rate.

Nitrogen rate	Leaf						Stem					
(kg /ha)	Akela†	Ramon	Sparta	Velox	Halla	Mean	Akela	Ramon	Sparta	Velox	Halla	Mean
0	16.0	21.2	19.1	17.1	22.8	19.2	47.0	50.8	45.8	46.2	51.7	48.3
100	15.5	20.9	15.5	16.6	22.1	18.1	46.5	50.5	45.4	45.4	50.8	47.7
250	15.5	19.5	14.9	16.6	22.0	17.7	45.9	49.0	44.9	45.3	50.4	47.1
300	14.9	19.4	14.6	16.3	21.6	17.4	45.3	47.7	44.4	44.5	49.0	46.4
350	14.5	19.1	14.4	16.2	21.5	17.1	41.3	46.9	42.5	43.9	46.6	44.3
400	14.3	17.1	14.6	15.6	20.8	16.5	41.2	46.2	40.1	42.7	48.8	43.8
Mean	15.1^{e}‡	19.5^{b}	15.5^{d}	16.4^{c}	21.8^{a}	17.2	44.5^{c}	48.5^{b}	43.9^{d}	44.7^{c}	49.5^{a}	46.3
Coefficients of regression equations relating nitrogen rate												
Intercept	15.97	21.27	19.06	17.10	22.79	19.20	46.89	50.86	45.81	46.18	51.52	48.10
Linear$\times 10^{-3}$§	−5.3	−8.9	−50.8	−8.9	−11.6	−16.8	−1.0	−2.1	−12.3	−13.1	6.5	4.6
Quadratic$\times 10^{-5}$§	2.2	4.1	18.8	4.9	5.8	7.1	2.0	−2.5	10.7	7.6	−9.7	−4.0
Cubic$\times 10^{-8}$§	−5.0	−10.0	−20.0	−9.0	−10.0	−10.0	−10.0	NS	−30.0	−20.0	10.0	NS
R^2	0.94	0.94	0.99	0.99	0.97	0.99	0.89	0.99	0.99	0.99	0.72	0.94

† Akela, Ramon, Sparta, and Velox are forage cultivars ; Hallayuchae is an oilseed cultivar.
‡ Cultivar means followed by the same letter are not significantly different at 5% probability level according to Duncan's Multiple Range Test.
§ To obtain the actual coefficients, the reported values must be multiplied by the factor.

mon (3.6%).

Leaf crude fat content within each cultivar varied slightly with N rates (Table 5). There were no consistent trends in stem fat content as N rate increased. Averaged across the N rates, Akela had the highest crude fat content in leaf (14.2%) and stem (8.3%), followed by Ramon and Sparta, Velox, and Hallayuchae (8.5 and 5.1%).

There were no consistent relationship between N rate and crude ash content in leaf and stem (Table 5). Averaged across the N rates, Akela had the highest leaf crude ash content (17.1%), followed by Velox, Sparta, Hallayuchae, and Ramon (14.7%). Akela had the highest stem crude ash content (15.5%), followed by Sparta, Ramon and Hallayuchae, and Velox (11.7%).

Crude fiber content in leaf and stem curvilinearly decreased with increasing N rate (Table 6). The forage cultivars across six N rates had lower crude fiber content in leaf (15.1 to 19.5%) and stem (43.9 to 48.5%) than the oilseed cultivar (21.8 and 49.5%) did.

There was no consistent trend in N free extract (NFE) content in leaf and stem among the N rates within a cultivar (Table 5). Across six N rates, Velox had the highest NFE content in leaf and stem (50.7 and 33.7%), followed by Hallayuchae and Sparta, Ramon, and Akela (43. 9 and 27.0%).

In conclusion, Sparta was best adapted to Cheju area in terms of dry matter and protein yields. The optimum N rate for the greatest dry matter yield for Sparta forage rape was about 220 kg/ha.

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