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**Research Article**

# Comparison of Forage Quality, Productivity and β-carotene Content according to Maturity of Forage Rye (*Secale cereale* L.)

Guo Qiang Zhao[1], Sheng Nan Wei[1], Yan Fen Li[1], Eun Chan Jeong[1], Hak Jin Kim[2], and Jong Geun Kim[1,2,*]

[1]Graduate School of International Agricultural Technology, SNU, Pyeongchang, 25354, Korea

[2]Research Institute of Eco-friendly Livestock Science, GBST, SNU, Pyeongchang, 25354, Korea

## ABSTRACT

These experiments were to investigate the variations of rye on forage quality, productivity and β-carotene concentration affected by maturity in Pyeongchang region. Limited information are available about how forage quality and β-carotene content are affected by various factors. Samples were collected from rye harvested every 5 days, from April 25 to May 31 (April 25, April 30, May 4, May 9, May 15, May 21, May 25 and May 31). Dry matter (DM) content, plant height, DM yield and total digestible nutrient (TDN) yield increased continuously with the progressed maturity. However, crude protein (CP) content, *in vitro* dry matter digestibility (IVDMD) and relative feed value (RFV) decreased markedly with the delay of harvesting, while TDN content decreased from April 25 till May 15, then followed by a stable fluctuation. Conversely, acid detergent fiber (ADF) and neutral detergent fiber (NDF) value increased and then fluctuated slightly after blooming stage. For quality of plant parts, stem contained the lowest CP content and RFV value, and the highest ADF and NDF contents compared with other parts, while the grain showed the higher CP, IVDMD, RFV and lower fiber contents than others. With the plant matured, leaf proportion decreased while stem and grain proportion increased, and feed value of all the three parts decreased till blooming stage and followed by a stable phase. β-carotene concentration showed its highest on jointing stage, and then fell down sharply on the sequential stages. In conclusion, harvest around May 15 (blooming) is proper for forage rye if directly consumed by livestock as green chop in Pyeongchang under the consideration of both nutritive yield and forage quality.

(**Key words**: Rye, Productivity, Quality, β-carotene, Harvest time)

## Ⅰ. INTRODUCTION

Rye (*Secale cereale* L.) is recognized as an important forage crop in Korea and can be cultivated even in cold, droughty areas and barren soil. Recently, the cultivation area of rye has decreased due to the popularity of Italian ryegrass, but farmers still prefer it in the mid-northern and mountainous regions where the winter is severe. Rye is a hardy grain, it is more tolerant of frost and drought than wheat (Allen, 2013). So, even it is less palatable than other forages, it has advantages due to the high tolerance in bad condition and earlier maturity than most other cereal crops. And rye can be used alone or mixed with other forage crops like clover and ryegrass (David et al., 2016).

In livestock industry, forages provide the majority of necessary nutrients in ruminant diets and also play great role in the acquisition of digestion physiology of rumen. Forage quality is a critical factor which affect animal productivity (Mattews et al., 2019). Forage harvested from different stage of maturity also differs in quality. Generally, forage quality decreases while the yield of dry matter increases as the plant matures, so the proper stage of maturity for harvesting should be considered adequately. In grasses and legumes, leaves are almost the component which has the highest quality. Stems of immature grasses are similar with leaves in forage quality, however, quality decrease faster than leaves with maturity. Furthermore, leaves generally contain higher crude protein (CP) and lower fiber than stem (Rotz and Muck, 1994).

Harvest of plants from different maturation stages show great difference on quality, quantity and regrowth performance for forage. The proper harvesting stage should be decided under the considerations of species, season, location, climate conditions and other factors which are known to have big effects. It is known that forage yield increase while the forage quality decreases with the maturity of plant. A good example was described by White

*Corresponding author: Jong Geun Kim, Graduate School of International Agricultural Technology, Seoul National University, Pyeongchang 25354, Korea, Tel: +82-33-339-5728, Fax: +82-33-339-5727, E-mail: forage@snu.ac.kr

and Wolf (1996) that, with plants mature, dry matter yield and fiber content of forage plants increase, whereas nonstructural carbohydrates and protein content increase and then followed by a decrease.

$\beta$-carotene, the most active biological form among the carotenoids, plays a great role in the forage nutrition as a precursor of vitamin A, a critical fat-soluble vitamin (Alice and Andrea, 2016). It has great benefit to human and livestock health. As many studies claimed, $\beta$-carotene and vitamin A are necessary for reproduction capacity and immune function for dairy cows (Chew et al., 1984; Kume and Toharmat, 2001). But for beef cattle, some other studies showed that levels of $\beta$-carotene and vitamin A have influences on beef quality as it has effects on fat stores and fat hardness (Siebert et al., 2006). So the $\beta$-carotene level should be considered carefully according to the target, dairy cow or beef cattle.

The purpose of this experiment to investigate the variations of rye in forage quality and $\beta$-carotene concentration affected by harvest dates. Specifically to say, is how harvest date of progressed maturity stages and different parts of plants affect forage quality and $\beta$-carotene concentrations in forage rye (*Secale cereale* L.).

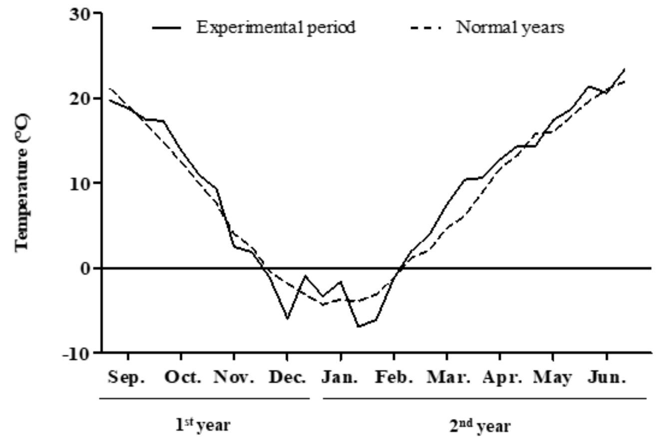


Fig. 1. Average temperature comparison between experiment period and normal years.

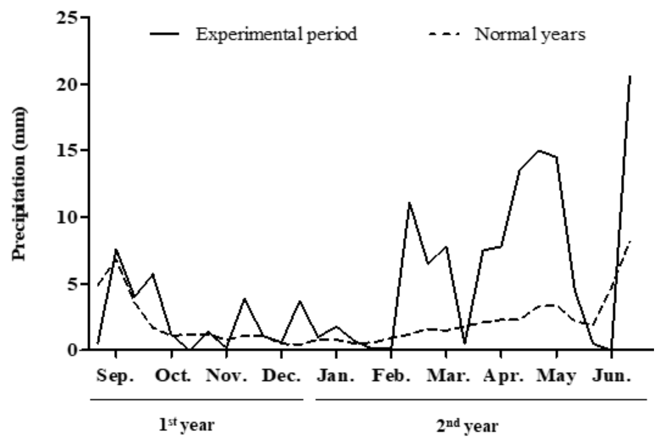


Fig. 2. Precipitation comparison between experiment period and normal years.

## Ⅱ. MATERIALS AND METHODS

### 1. General information

The experiment was carried out in experimental field of Seoul National University, Pyeongchang Campus (located at 37°32′46.1″N, 128°26′17.9″E, where, average altitude is about 600-700 m above sea level, more information are registered as annual mean temperature 11.5 ℃, average annual precipitation 113.4 mm, average annual wind speed 1.1 m/s, average annual humidity 68.0 %, Sin-ri, Pyeongchang, Republic of Korea) from September 30 to May 31. More detail meteorological information involved during the experimental period are shown in Fig. 1 and 2.

### 2. Preparation of rye

Rye in the experiment was seeded on September 30 and harvested every 5 days from jointing stage (April 25) to ripening stage (May 31), totally 8 times, with mower conditioner leaving a stubble height of about 5cm above soil level. Before harvesting, plant height was recorded by a meter stick. Besides, forage yield was investigated from 1 $m^2$(1m×1m) quadrat with 3 replications which were selected randomly and then converted to kg/ha. Around 500 g fresh samples were separated into stem, leaf (leaf sheath and blade) and grain part every 5 days and the ratio of each part were calculated on DM base.

### 3. Chemical analysis of rye

All fresh samples were collected around 300 g and then dried in 65 ℃ air-forced dry oven for 72 hours for determination of dry matter (DM) content. All the dried samples were subsequently milled by a Willey Mill with 1 mm screen (Thomas Scientific, Inc., New Jersey, USA) into plastic bottles with screw tops and preserved in 4℃ dark-dried storage room prior to analysis.

Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were measured by the method of Van Soest et al. (1991) using "ANKOM2000 Automated Fiber Analyzer" (Ankom Technologies, Inc., Fairport, NY, USA). And heat-stable amylase and sodium sulfite were used for NDF procedure.

Crude protein was determined via Dumas method as described by Jean-Baptiste Dumas, (1884) using "Automatic Elemental Analyzer Euro Vector EA3000"(EVISA Co., Ltd, Milan, Italy).

Total digestible nutrient (TDN) and relative feed value (RFV) were calculated by the known formula described by Holland et al. (1990). TDN was calculated from ADF value (TDN % = 88.9 - 0.79 × ADF %). And, RFV was estimated through digestible dry matter (DDM % = 88.9 - 0.779 × ADF %) and dry matter intake (DMI% = 120 / NDF%) as RFV = (DMI % × DDM %) / 1.29.

For *in vitro* dry matter digestibility (IVDMD) analysis, the two-stage technique (Tilley and Terry, 1963) was used. The samples were placed into the Ankom DaisyII Incubator digestion jars (Ankom Technologies, Inc., Fairport, NY, USA) with 266 ml of buffer solution B and 1330 ml of buffer solution A (1:5 ratios, v/v), the reagents contained in buffer A and B are shown in Table 1. Rumen fluid was collected from two healthy cannulated Holstein steers before morning feed.

For $\beta$-carotene analysis, 2 g of the ground samples were used. The pretreatment are as follows: put 10 ml of 6 % pyrogallol and sonicate in the samples, reacted for 10 minutes. After sonication, 7 ml of 60 % KOH was added in and mixed evenly by vortexing. Then the mixture was incubated at 80 ℃ water bath for 1 hour and followed by 10 ml of 2 % NaCl and 15 ml of haxane-acetate, the ratio of which was 85: 15. Sequentially, the mixture was centrifuged at 5000 rpm for 15 minutes. After centrifuging, added 1 ml of chloroform and the $\beta$-carotene concentration was detected by HPLC using Agilent 1260 series (Agilent Technologies, CA, USA). The instrumental conditions were shown below (Table 2).

## 4. Statistical analysis

Data were analyzed by the general linear model (GLM) procedure of SAS 2002 (version 9.1). The complete random design was used for effect of harvest dates on rye forage quality and the split plot design was used for effect of plant parts (main plot) and harvest dates (sub plot), Differences were considered to be significant when $P < 0.05$.

**Table 1. Reagent of buffer solution A and B**

| Buffer Solution A | g/liter |
|---|---|
| $KH_2PO_4$ | 10.0 |
| $MgSO_4 \cdot 7H_2O$ | 0.5 |
| NaCl | 0.5 |
| $CaCl_2 \cdot 2H_2O$ | 0.1 |
| Urea (reagent grade) | 0.5 |
| Buffer Solution B | g/liter |
| $Na_2CO_3$ | 15.0 |
| $Na_2S \cdot 9H_2O$ | 1.0 |

**Table 2. Instrumental conditions of HPLC for determination of $\beta$-carotene**

| | |
|---|---|
| Column | CAPCELL PAK C18 UG120 S5,<br>4.6 mm I. D. × 250 mm |
| Mobile phase | A: acetonitrile: methanol (85: 15) |
| | B: dichloromethanol |
| | A (70%), B (30%) |
| Flow rate | 1000 $\mu$L / min |
| Inj. vol. | 3.5 $\mu$L |
| Temperature | 35 ℃ |
| Pressure | 4.9 MPa |
| Detector | UV 254 nm |

# Ⅲ. RESULTS AND DISCUSSIONS

## 1. Effect of harvest dates on agronomic characteristics and yield composition

Agronomic characteristics and yield composition of different growth stage was shown in Table 3. Plant height also showed the similar trend. Factors which have effects on plant height of cereals are various and among them maturity is the most vital factor (De Ruiter et al., 2002). In the current study, plant height increased significantly during study period from 53 cm on April 25 (jointing stage) and 180 cm on May 31 (ripening stage), the similar result was also found by Ku et al. (2018).

With progressed maturity of rye, yield composition on fresh and dry matter (DM) showed some differences. Fresh yield increased until blooming stage and followed by a decrease, while DM yield showed the lowest value of 3,760 kg/ha and the highest

Table 3. Effect of harvest dates on agronomic characteristics and yield composition.

| Harvest date | Growth stage | Plant height (cm) | Yield composition (kg/ha) | | | |
|---|---|---|---|---|---|---|
| | | | FM | DM | CP | TDN |
| April 25 | Jointing | $53^{h}$ | $24,333^{d}$ | $3,760^{e}$ | $511^{c}$ | $2,707^{h}$ |
| April 30 | Early Boot | $75^{g}$ | $26,500^{cd}$ | $4,364^{e}$ | $508^{c}$ | $2,999^{g}$ |
| May 4 | Late Boot | $89^{f}$ | $34,333^{ab}$ | $5,651^{d}$ | $640^{a}$ | $3,762^{e}$ |
| May 9 | Heading | $111^{e}$ | $36,000^{a}$ | $5,970^{d}$ | $535^{ab}$ | $3,663^{f}$ |
| May 15 | Blooming | $141^{d}$ | $39,000^{a}$ | $7,408^{c}$ | $564^{b}$ | $4,210^{d}$ |
| May 21 | Milking | $155^{c}$ | $38,000^{a}$ | $9,157^{b}$ | $654^{a}$ | $5,218^{c}$ |
| May 25 | Dough | $164^{b}$ | $37,000^{a}$ | $9,880^{ab}$ | $625^{a}$ | $5,603^{b}$ |
| May 31 | Ripening | $180^{a}$ | $30,333^{bc}$ | $10,439^{a}$ | $389^{d}$ | $5,914^{a}$ |
| Mean | - | 121 | 33,187 | 7,079 | 533 | 4,260 |
| LSD(0.05) | - | 4.55 | 5109.60 | 1036.60 | 40.98 | 78.68 |

FM: fresh matter, DM: dry matter, CP: crude protein, TDN: total digestible nutrient.
Means within a column with different superscripts differ ($P < 0.05$).

of 10,439 kg/ha on jointing and ripening stage, respectively. Yield of forage rye increased quadratically in response to maturity as reported by Kantar et al. (2011). DM yield performance observed in this experiment was more acceptable than that of Hakan (2014), it was might due to the more favorable climatic parameters in the experimental site. However, Thelen and Leep (2002) reported that rye harvested on April 30 (early boot) got a yield of 1.7 tons/acre, which is close to the result 4,364 kg/ha (1.77 tons/acre) in this experiment. And similar yields were also found on rye harvested on late growth stages of this study and result reported by Tollenarr et al. (1992).

The crude protein yield at milking, late boot and dough stages showed higher than any other stages ($p < 0.05$). Total digestible nutrient (TDN) yield of DM in this study increased from 2,693 kg/ha on April 25 (jointing stage) to 5,825 kg/ha on May 31 (ripening stage), during which each advanced stages showed increases markedly than their earlier stages ($p < 0.05$). DM and TDN yield showed highly consistent trend with that of whole crop barley (Kim et al., 2010).

## 2. Effect of harvest dates on forage quality of rye

Effect of harvest dates on chemical composition and feed value of rye were shown in Table 4. DM content of rye increased by 121.68 % (155.00 g/kg on April 25 vs 343.60 g/kg on May 31) with the plant matured, which also showed the same trend with other forage plants such as wheat and corn (Yakup and Osman, 2016). Azim et al. (1989) reported that DM content would increase with the maturity processes of plant growth. Yield and forage quality are varied from harvest date of maturity. Forage production is considered to be a compromise between nutritive yield and forage quality. Previous studies have shown that forage yield increases while forage quality decreases with small grains mature from vegetative stage to reproductive stage (Cherney and Marten, 1982; Helsel and Thomas, 1987). The similar results of these previous studies were found in this experiment what rye harvested on early growth stages (late April or early May) could provide producers with high quality but low yield, since low quality and high yields could be obtained on late stages.

Crude protein decreased with progressed maturity until dough development (Kantar et al., 2011). The CP level in this experiment decreased continuously, that was similar to previous studies which were well documented (McCormick et al., 2006; Harmoney and Thompson, 2010; Xie et al., 2012).

Acid detergent fiber and neutral detergent fiber content showed similar trend, which increased from April 25 until May 15 and then kept stable or fluctuated slightly, and the content after May 15 were significantly higher than the earlier stages ($p < 0.05$). The NDF of rye harvested from April 30 (early boot) was 499.83 g/kg of DM, which was in consistent with the 48.6% mentioned by Thelen and Leep (2002).

*In vitro* dry matter digestibility of rye herbage during experimental

**Table 4. Effect of harvest dates on chemical composition and feed value of forage rye.**

| Harvest date | DM | CP | ADF | NDF | IVDMD | TDN | RFV |
|---|---|---|---|---|---|---|---|
| | g/kg | | | | | % | |
| April 25 | 155.00[e] | 135.99[a] | 213.87[e] | 430.23[g] | 903.27[a] | 72.01[a] | 156[a] |
| April 30 | 164.63[e] | 116.46[b] | 255.50[d] | 499.83[f] | 871.17[b] | 68.72[b] | 128[b] |
| May 4 | 164.93[e] | 113.26[b] | 282.70[c] | 540.13[e] | 835.40[c] | 66.57[c] | 115[c] |
| May 9 | 165.67[e] | 89.60[c] | 348.63[b] | 599.93[d] | 825.13[c] | 61.36[d] | 96[d] |
| May 15 | 189.93[d] | 76.11[d] | 405.93[a] | 673.07[a] | 715.23[d] | 56.83[e] | 79[f] |
| May 21 | 240.07[c] | 71.45[d] | 404.07[a] | 664.57[ab] | 686.10[e] | 56.98[e] | 80[ef] |
| May 25 | 268.33[b] | 63.24[e] | 407.40[a] | 640.27[c] | 632.10[f] | 56.72[e] | 83[e] |
| May 31 | 343.60[a] | 37.26[f] | 408.17[a] | 646.50[bc] | 589.77[g] | 56.66[e] | 82[ef] |
| Mean | 211.52 | 87.70 | 340.78 | 586.82 | 757.27 | 61.98 | 103 |
| LSD (0.05) | 17.61 | 7.36 | 11.00 | 21.61 | 16.08 | 0.87 | 3.52 |

DM: dry matter, CP: crude protein, ADF: acid detergent fiber, NDF: neutral detergent fiber, IVDMD: *in vitro* dry matter digestibility, TDN: total digestible nutrient, RFV: relative feed value, Means within a column with different superscripts differ ($P$ < 0.05).

period went down continuously as the progressing plant maturity, which was in consistent with the observation mentioned by Kim et al. (2010) and Kantar et al. (2011). The forage harvested from early stages contained higher moisture and lower structural carbohydrates, like fiber, especially lignin, are not easy to be digested by rumen microbes.

The total digestible nutrients also showed similar slope with ADF and NDF content, which decreased from jointing to blooming stage and kept steady after blooming stage, as the component contained in fiber is tough to be degraded. And the TDN content contained on early stages were significantly higher than the late stages ($p$ < 0.05).

As for RFV index, rye quality was ranged into 6 grades as prime (>151), excellent (150∼125), good (124∼103), fair (102∼87), poor (86∼75) and reject (< 74) (Holland et al., 1990). The rye forage quality harvested with maturity in this study was defined as prime, excellent, good and fair, respectively, from April 25 (jointing stage) to May 9 (heading stage), however, RFV of rye harvested after heading all fell into the grade of poor, as the lowest level 79 appeared on May 15 (blooming stage) and the highest, 156, appeared on April 25 (jointing stage).

### 3. Effect of harvest dates on β-carotene content

Effect of different harvest dates of maturity on β-carotene concentrations were shown in Fig. 3. The highest β-carotene concentration (27.14 mg/100g) was on April 25. After April

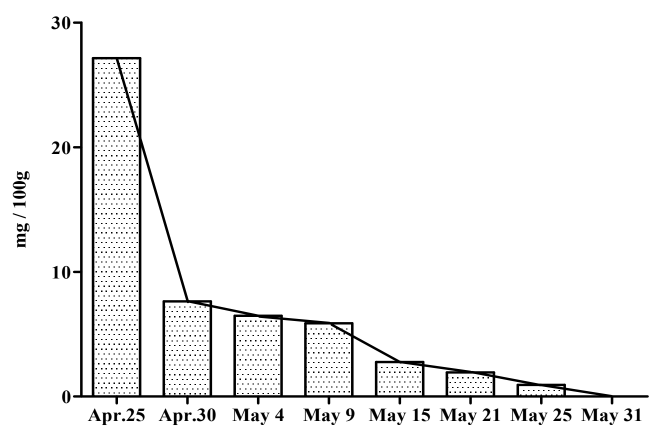


**Fig. 3. Effect of harvest date on β-carotene concentration of forage rye.**

25, β-carotene concentration decreased dramatically and reached its lowest point (0.93 mg/100g) on May 25. And there was no β-carotene detected on May 31 (ripening stage). The highest β-carotene concentration of forage plant was found on vegetative stage and lowest after flowering (Ballet et al., 2000). Besides, many researchers have found that β-carotene content in forages decrease with plant advancing maturity and that was due to the decreasing of leaf proportion in total plant (Olsson et al., 1955; Ballet et al., 2000).

### 4. Effect of harvest dates on leaf-stem-grain ratio

As the delay of harvest date, the ratio on dry matter of leaf, stem and grain showed some regular changes (Fig. 4). On jointing

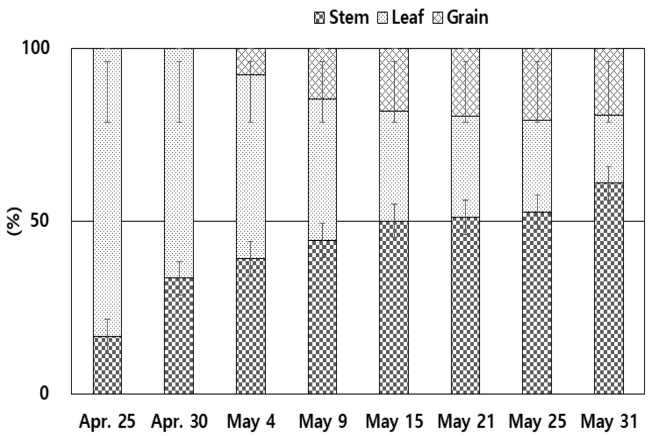


**Fig. 4. Effect of harvest dates on leaf-stem-grain ratio in forage rye.**

and early boot stage, there were only leaf and stem parts were separated from whole crop rye, within which, the stem part only took 16.19 % and 33.44 % of total, when leaf parts took 83.81 % and 66.56 %, respectively.

Grain parts started to develop from late boot stage, and leaf still was the dominant part among the total plant. After heading, leaf ratio decreased, while stem and grain ratio increased and gradually. As the plant elongated and developed, stem became the dominant part on dry matter of total plant. The highest stem ratio and lowest leaf ratio occurred on ripening stage. As plant matured, the leaf proportion decreased rapidly (Mowat et al., 1965), which was in consistent with the result in this study.

**Table 5. Effect of plant parts and harvest dates on quality of forage rye**

| Plant part | Harvest Date | DM | CP | ADF | NDF | IVDMD | TDN | RFV |
|---|---|---|---|---|---|---|---|---|
| | | g/kg | | | | | % | |
| Leaf | April 25 | 206.73$^{d}$ | 125.74$^{a}$ | 215.60$^{g}$ | 457.13$^{f}$ | 905.70$^{a}$ | 71.87$^{a}$ | 147$^{a}$ |
| | April 30 | 217.20$^{cd}$ | 117.79$^{b}$ | 224.33$^{f}$ | 459.43$^{f}$ | 884.43$^{b}$ | 71.18$^{b}$ | 145$^{b}$ |
| | May 4 | 231.90$^{c}$ | 99.83$^{c}$ | 273.40$^{e}$ | 501.80$^{e}$ | 829.40$^{c}$ | 67.30$^{c}$ | 125$^{c}$ |
| | May 9 | 243.70$^{c}$ | 97.03$^{c}$ | 303.93$^{d}$ | 552.20$^{d}$ | 791.57$^{d}$ | 64.89$^{d}$ | 110$^{d}$ |
| | May 15 | 243.63$^{c}$ | 97.93$^{c}$ | 328.47$^{c}$ | 585.07$^{c}$ | 747.00$^{e}$ | 62.95$^{e}$ | 101$^{e}$ |
| | May 21 | 274.13$^{b}$ | 88.00$^{d}$ | 353.23$^{b}$ | 625.40$^{b}$ | 720.53$^{f}$ | 61.00$^{f}$ | 91$^{f}$ |
| | May 25 | 289.90$^{b}$ | 77.25$^{e}$ | 331.07$^{c}$ | 580.37$^{c}$ | 718.97$^{f}$ | 62.75$^{e}$ | 101$^{e}$ |
| | May 31 | 391.50$^{a}$ | 49.11$^{f}$ | 362.53$^{a}$ | 634.50$^{a}$ | 677.43$^{g}$ | 60.26$^{g}$ | 89$^{g}$ |
| | Mean | 262.34$^{B}$ | 94.08$^{B}$ | 299.07$^{B}$ | 549.49$^{B}$ | 784.38$^{A}$ | 65.27$^{B}$ | 114$^{B}$ |
| Stem | April 25 | 139.87$^{f}$ | 71.11$^{a}$ | 231.53$^{g}$ | 443.97$^{f}$ | 946.73$^{a}$ | 70.61$^{a}$ | 149$^{a}$ |
| | April 30 | 165.63$^{e}$ | 65.20$^{b}$ | 264.87$^{f}$ | 456.67$^{f}$ | 900.80$^{b}$ | 67.98$^{b}$ | 139$^{b}$ |
| | May 4 | 167.10$^{e}$ | 45.86$^{de}$ | 319.17$^{e}$ | 524.77$^{e}$ | 842.60$^{c}$ | 63.69$^{c}$ | 114$^{c}$ |
| | May 9 | 147.37$^{f}$ | 47.47$^{d}$ | 394.40$^{d}$ | 624.47$^{d}$ | 753.27$^{d}$ | 57.74$^{d}$ | 87$^{d}$ |
| | May 15 | 186.37$^{d}$ | 50.31$^{c}$ | 457.90$^{c}$ | 705.93$^{b}$ | 667.50$^{e}$ | 52.73$^{e}$ | 70$^{e}$ |
| | May 21 | 251.53$^{c}$ | 44.34$^{e}$ | 487.03$^{a}$ | 733.50$^{a}$ | 605.30$^{f}$ | 50.42$^{g}$ | 65$^{f}$ |
| | May 25 | 285.90$^{b}$ | 43.44$^{e}$ | 466.30$^{b}$ | 704.73$^{b}$ | 523.63$^{g}$ | 52.06$^{f}$ | 69$^{e}$ |
| | May 31 | 398.57$^{a}$ | 18.70$^{f}$ | 451.93$^{c}$ | 681.17$^{c}$ | 534.97$^{g}$ | 53.20$^{e}$ | 73$^{e}$ |
| | Mean | 217.79$^{C}$ | 48.30$^{C}$ | 384.14$^{A}$ | 609.40$^{A}$ | 721.85$^{B}$ | 58.55$^{C}$ | 96$^{C}$ |
| Grain | May 4 | 196.03$^{e}$ | 160.70$^{a}$ | 172.30$^{e}$ | 424.45$^{e}$ | 941.95$^{a}$ | 75.29$^{a}$ | 165$^{a}$ |
| | May 9 | 200.07$^{e}$ | 127.58$^{b}$ | 257.97$^{d}$ | 501.20$^{d}$ | 884.97$^{b}$ | 68.52$^{b}$ | 128$^{b}$ |
| | May 15 | 241.87$^{d}$ | 109.72$^{c}$ | 304.20$^{b}$ | 557.23$^{b}$ | 799.87$^{c}$ | 64.87$^{d}$ | 109$^{d}$ |
| | May 21 | 302.30$^{c}$ | 101.58$^{d}$ | 293.77$^{c}$ | 529.67$^{c}$ | 756.23$^{d}$ | 65.69$^{c}$ | 116$^{c}$ |
| | May 25 | 339.37$^{b}$ | 88.08$^{e}$ | 308.60$^{b}$ | 550.00$^{b}$ | 711.87$^{e}$ | 64.52$^{d}$ | 110$^{d}$ |
| | May 31 | 427.50$^{a}$ | 49.01$^{f}$ | 328.43$^{a}$ | 581.70$^{a}$ | 643.17$^{f}$ | 62.95$^{e}$ | 101$^{e}$ |
| | Mean | 284.52$^{A}$ | 106.11$^{A}$ | 277.54$^{C}$ | 524.04$^{C}$ | 789.68$^{A}$ | 66.97$^{A}$ | 121$^{A}$ |
| Mean | - | 252.19 | 80.72 | 324.13 | 564.33 | 763.09 | 63.29 | 109 |
| Probability | P | < .0001 | < .0001 | < .0001 | < .0001 | < .0001 | < .0001 | < .0001 |
| | D | < .0001 | < .0001 | < .0001 | < .0001 | < .0001 | < .0001 | < .0001 |
| | P × D | < .0001 | < .0001 | < .0001 | < .0001 | < .0001 | < .0001 | < .0001 |

P: plant part, D: harvest date. Within a column, different superscripts in capital letter mains main plot differ, in small letters means sub plot differ ($P < 0.05$).

### 5. Effect of plant parts and harvest dates on feed value of forage rye

Effect of plant parts and harvest dates on forage quality of rye were shown in Table 5. Plant part, harvest date and their interaction affected rye quality significantly ($p < 0.0001$). For all of the three parts, the dry matter content increased with the delay of harvest date and reached their highest content, 391.5 g/kg, 398.6 g/kg and 427.5 g/kg of FM, respectively, on May 31. Stem part lost its moisture at the fastest speed among the three. And the lowest DM content 139.9 g/kg occurred on stem part of April 25, when the highest (427.5 g/kg) was on grain part of May 31. MacDonald (1946) stated that nutritive composition of leaves and stems decrease as plant progressed maturity. As for CP content, grain contained the highest CP content compared with others while stem contained the lowest ($p < 0.0001$). On each stage, CP content contained in leaf part were 2-3 times as much as that contained in stem. Content in grain decreased during the measured period, for leaf and stem, the highest content was on April 25. Santis et al. (2004) proved that CP, IVDMD and other nutritive value decreased with the reduction of leaf stem ratio.

The ADF and NDF values showed similar tendency on three parts, as increased till May 15 (blooming stage), and after that, followed by a slight fluctuation. Stem contained the highest ADF and NDF contents while grain contained the lowest ($p < 0.0001$) compared with other parts. The lowest content of three parts appeared on the early growth stages. With rye matured, IVDMD of the three parts all decreased as a result of the increased fiber content, and grain and leaf were significantly ($p < 0.0001$) higher than stem, which showed as 721.85 g/kg. The TDN value showed similar trend with ADF and NDF, the highest value showed on early stages.

The RFV index of grain was the highest on May 4 and decreased until May 31 markedly ($p < 0.0001$), stem and leaf RFV were close on boot stage but stem decreased faster than leaf with prolonged harvesting date. For contents and trend of nutrient contained in leaf, stem and grain, consistent results were observed in several new developed cultivars of whole crop rice (WCR) in Korea as described by Zhao et al. (2018).

## Ⅳ. CONCLUSION

The DM content, plant height, DM yield and TDN yield increased continuously with the progressed maturity. However, CP content, IVDMD and RFV decreased markedly with the delay of harvesting, while TDN content decreased from April 25 till May 15, then followed by a stable fluctuation. Stem contained the lowest CP and RFV content, and the highest ADF and NDF content compared with other parts, while the grain showed the higher CP, IVDMD, RFV and lower fiber content than others. With the plant matured, leaf proportion decreased while stem and grain proportion increased, and feed value of all the three parts decreased till blooming stage and followed by a stable phase. β-carotene concentration showed its highest on jointing stage, and then fell down sharply on the sequential stages. In conclusion, harvest around May 15 (blooming) is proper for forage rye if directly consumed by livestock as green chop in Pyeongchang under the consideration of both nutritive yield and forage quality.

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