Nitrogen and Sulfur Fertilization in Kale and Swede for Grazing

Osvaldo Teuber 1, Dulan Samarappuli 2 and Marisol Berti 2,*

1 Institute for Agricultural Research, Coyhaique 5950000, Chile; oteuber@inia.cl
2 Department of Plant Sciences, North Dakota State University, Fargo, ND 58104, USA; Dulan.Samarappuli@ndsu.edu
* Correspondence: Marisol.Berti@ndsu.edu; Tel.: +1-701-231-6110

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Abstract: Species in the Brassicaceae family, hence forth brassicas, such as forage kale [Brassica oleracea L. convar acephala (DC)], swede (B. napus L. var. napobrassica), turnip [Brassica rapa L. var. rapa (L.) Thell], and hybrids (B. rapa L. × B. pekinensis L. or B. rapa L. × B. oleracea L.), have become an important source of forage for grazing worldwide. One of the limitations of forage brassicas is the relatively higher water content and low forage yield in rain-fed environments. The objective of this study was to determine swede and kale forage yield and nutritive value response to various nitrogen (N) and sulfur (S) fertilization rates. The study was conducted at two experimental field sites in North Dakota in 2012 and 2014. Kale cv. Maris Kestrel and swede cv. Major Plus and five N rates (0, 50, 100, 150, and 200 kg N ha$^{-1}$) and two rates of S (0 and 40 kg S ha$^{-1}$) were evaluated. Swede total forage yield was greater than kale across all nitrogen and sulfur rates. Compared with no N fertilization, N fertilization increased total leaf and root/stems yield and nitrogen accumulation in leaves, roots, and stems. Sulfur did not affect forage yield. Forage nutritive value was greater in swede than kale due to a higher proportion of edible root compared with kale’s higher proportion of fibrous stems. Nitrogen and sulfur interacted with some forage nutritive components. This study results suggest that growers will benefit from greater forage yield in kale and swede if they fertilize with N up to 200 kg N ha$^{-1}$. Forage yield and nutritive value of swede and kale in the northern Great Plains are novel results, since these crops are not grown for forage and represent an interesting and valuable new alternative for beef cattle growers.

Keywords: forage brassica; forage nutritive value; grazing

1. Introduction

Forage brassica species have different nutrient requirements, depending on soil fertility, intended use, and the expected yield response [1,2]. The amount of fertilizer to maximize forage yield depends on the difference between crop nutrient demand, and nutrient supply from the soil [2]. Nutrient supply needs to be closely matched to crop demand. Sub-optimal nutrient supply will result in lower yield, while excess nutrient application can lead to leaching and run-off of nutrients, and potentially create nitrate toxicity to animals [3].

Nitrogen (N) is required in large amounts in plant tissue, as a component of plant proteins, amino acids, nucleotides, nucleic acids, and chlorophyll [4]. Nitrogen fertilizer is the most important input in forage brassicas production due to brassicas high N requirement [5]. However, forage yield response to N depends on available soil N, water, and other factors influencing plant growth [3,5–7]. De Ruiter et al. [2] indicated the strongest response to N in forage rape (Brassica napus L.) was observed with available N soil content of greater than 150 kg ha$^{-1}$. Other authors reported forage yield increased with N rates of up to 300 kg ha$^{-1}$ [3,8].
Nitrogen application influences forage nutritive value in forage brassicas increasing crude protein (CP) content [8]. In turnip, N can also affect metabolizable energy (ME), neutral detergent fiber (NDF), and starch content [8].

Sulfur (S) is the fourth major nutrient in crop production, ranked immediately behind N, phosphorus (P), and K in importance to crop productivity [9,10]. Nitrogen and S requirements of crops are closely related because both nutrients are required for S-containing amino acids (cysteine and methionine), protein synthesis, and various other cellular components, including thiol and secondary S-containing compounds, which have a significant role on protection of plants against stress and pests [4,10,11].

Sulfur metabolism in plants is closely related to N nutrition [12] and N metabolism is strongly affected by the S status of the plant [13,14]. A deficiency in S supply has been shown to depress the uptake of nitrate and the activity of nitrate reductase in maize (Zea mays L.) and spinach (Spinacia oleracea L.) [15,16], resulting in transient or steady-state nitrate accumulation in other crops [17–19].

Sulfur deficiency can lead to slower growth and fewer leaves. Young leaves can become chlorotic and have reduced photosynthetic activity. Ahmad and Abdin [20] (2000) demonstrated that high S fertilization increases ribulose-1,5-bisphosphatecarboxylase/oxygenase (rubisco), chlorophyll, and protein contents in fully expanded upper leaves of Brassica juncea L. and B. campestris L., which implies a better photosynthetic activity in comparison with plants grown without S.

Some crops require as much S as other major nutrients, especially brassica species [4,10,21,22]. However, S fertilization has erratic results. Forage brassicas respond strongly to N fertilizer but seldom to S [1,23]. In general, N:S ratios from 4:1 to 8:1 are ideal for brassicas. A N:S ratio of 7:1 in the soil is required for optimum growth of forage rape [13,22]. Fazili et al. [24] reported that S deficiency limits the N use efficiency; therefore, S addition becomes necessary to achieve maximum N use efficiency from applied fertilizer. Wilson et al. [1] reported that kale’s S extraction was 100 kg S ha\(^{-1}\) while application of 45 kg S ha\(^{-1}\) recorded significantly higher forage yield than 30 kg S ha\(^{-1}\) in forage rape [10].

Brassica forage species can be used as supplemental forage due to their tolerance to low temperature, increasing forage availability in the fall and winter when most traditional forage grasses and legumes are not available or have low nutritive value. The possibility to extend the grazing season for livestock operations, can reduce the operational cost to farmers and improve the profitability of the operation.

Nitrogen and sulfur fertilization studies in forage brassicas in the northern Great Plains of the USA have not been conducted before. Determining optimum N and S fertilizer rates is critical to improve forage yield, nutritive value, and reduce production costs, when producing brassica forages. Therefore, the objective of this study was to determine swede and kale forage yield and nutritive value response to various N (0 to 200 kg N ha\(^{-1}\)) and S (0 and 40 kg S ha\(^{-1}\)) fertilization rates in different environments in the northern Great Plains region of the United States of America.

2. Materials and Methods

2.1. Experimental Sites

Field experiments were conducted in 2012 and 2014 at Prosper (46°58′ N –97°3′ W, elevation 284 m) and in 2014 the Albert Ekre Grassland Preserve near Walcott (46°33′ N, –97°07′ W, elevation 296 m). The soil type at Prosper is a Kindred-Bearden silty clay loam (Kindred: Fine-silty, mixed, superactive, frigid Typic Endoaquoll; Bearden: fine-silty, mixed, superactive, frigid Aeric Calciaquoll; Perella: fine-silty, mixed, superactive, frigid Typic Endoaquoll). The soil type at Albert Ekre Grassland Preserve is a Mantador-Delamere-Wyndmere fine sandy-loam (Mantador: Coarse-loamy, mixed, superactive, frigid Aquic Pachic Hapludoll; Delamere: coarse-loamy, mixed, superactive, frigid Typic Endoaquoll; Wyndmere: coarse-loamy, mixed, superactive, frigid Aeric Calciaquoll) [25].
2.2. Experimental Design and Management

The experimental design was a randomized complete block with three replicates, and a split-plot arrangement. Kale cv. Maris Kestrel and swede cv. Major Plus were assigned to the main plot. The sub-plots were a factorial arrangement of five N rates (0, 50, 100, 150, and 200 kg N ha\(^{-1}\)) and two rates of S (0 and 40 kg S ha\(^{-1}\)). Nitrogen and S fertilizer treatments were applied as combinations of the two fertilizers. The fertilization was done using only N as urea and S as gypsum, in five incremental rates of N (0, 50, 100, 150 and 200 kg ha\(^{-1}\)) and two rates of S (0 and 40 kg ha\(^{-1}\)). Each plot received one of the ten fertilization treatments (5N \(\times\) 2S = 10), in other words, for each N rate there was one experimental unit with S (40 kg ha\(^{-1}\)) and one without S. The experiment with the same exact treatments and evaluation was repeated at three environments (Prosper in 2012 and 2014, and Walcott in 2014). The experiment originally had five environments but two of them were lost due to weather conditions.

Traditional tillage was utilized to prepare the soil, based on one or two passes of a chisel plow in the fall to incorporate crop residues. In spring, one or two passes of a harrow and one pass of a roller were used to prepare the seedbed. The previous crops in Prosper and Walcott was maize and mixed grass for hay, respectively. All the forage brassica plots were seeded with a plot-cone planter (Wintersteiger, Plotseed XL, Salt Lake City, UT, USA), using a sowing rate of 4.9 kg ha\(^{-1}\) and 1.8 kg ha\(^{-1}\) of pure live seed for kale and swede, respectively. Before planting, sowing rates were corrected by seed germination. The sowing depth was approximately 8–15 mm. Each plot was 1.2-m wide and 6.1-m long (7.4 m\(^2\)), with eight rows spaced 15-cm apart. Sowing and harvest dates of all experiments are indicated in Table 1.

### Table 1. Sowing and harvest dates and number of days from sowing to harvest for experiments at Prosper and Walcott, ND, USA, in 2012 and 2014.

| Location | 2012        | 2014        |
|----------|-------------|-------------|
|          | Sowing | Harvest | No. Days | Sowing | Harvest | No. Days |
| Prosper  | 2 May   | 25 Oct   | 176      | 23 May  | 15 Oct   | 145      |
| Walcott  |         |          |          | 16 May  | 22 Aug   | 98       |

During the first month after planting, grass weeds were controlled by applying Select Max™ (Valent U.S.A. Corporation, Walnut Creek CA, USA) (clethodim:(E)-2-(1-(((3-chloro-2-propenyl)oxy)imino)propyl)5-(2-(ethylthio)propyl)-3-hydroxy-2-cyclohexen-1-one) using 1.17 L active ingredient (a.i.) ha\(^{-1}\). Broadleaf weeds were controlled by hand-weeding, one or two times during the season, depending on the weed pressure and regrowth. All weed control was conducted when brassica crops were at rosette stage between stage 2 and stage 3 [25,26]. The crucifer flea beetle (Phyllotreta cruciferae Goeze), was present from emergence to adult plants in both studies. Asana XL (Valent U.S.A. Corporation, Walnut Creek CA, USA) (esfenvalerate: (S)-cyano (3-phenoxyphenyl)methyl (S)-4-chloro-alpha-(1-methylethyl)) was applied at the beginning of the season in 2012. Due to the inefficacy of this insecticide, thereafter flea beetle control was with Sniper (bifenthrin: (2 methyl(1,1′-biphenyl)-3-yl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethyl-cyclopropanecarboxylate) with 0.037 kg a.i. ha\(^{-1}\). Flea beetle control required two applications per season in 2014, and three applications in 2012. Helix Xtra (Syngenta Crop Protection, LLC, Greensboro, NC, USA) (difenoconazole: 1-(2-(2-chloro-4-(4-chlorophenoxy)phenyl)-4-methyl-1,3-dioxolan-2-ylmethyl)-1H-1,2,4-triazole) was used as a seed treatment to prevent flea beetle damage during emergence using 1.5 L 100 kg seed\(^{-1}\).

The fertilizer treatments were broadcasted in one single application approximately at growth stage 2–3 of brassicas (rosette stage), according with Harper and Berkenkamp [26] and Theunissen and Sins [27]. The fertilizers used in this experiment were: urea (CH\(_4\)N\(_2\)O), and gypsum (CaSO\(_4\) ×
(H\textsubscript{2}O)). The crops were harvested in October in Prosper, before the killing frost for forage brassicas, or in August at Walcott.

2.3. Evaluations

Soil samples were taken from 0- to 15-cm and 15- to 60-cm depths soon after planting. Three separate soil cores were taken from each plot, for each soil depth, using a closed tube, hand-held soil probe, and mixed together to make composite samples representing each of the two soil depths. Soil samples from 0- to 15-cm were tested for pH, organic matter (OM), sulfate (SO\textsubscript{4}), phosphorus (P), and potassium (K) by the NDSU Soil Testing Laboratory (Fargo, ND, USA) [28]. Soil P [29], and K were measured with the ammonium acetate method [30] with a Buck Scientific Model 210 VGP Atomic Absorption Spectrophotometer (Buck Scientific, East Norwalk, CT, USA). The nitrate (NO\textsubscript{3}-N) analysis was performed on the soil samples taken at 0–15 cm and 15–60 cm depth, using the method of transnitration of salicylic acid [31] (Table 2). The fertilization for this experiment was only with N and S. The plots were not fertilized with P and K, because soil test for both nutrients at the three sites were well-above the levels crop yield response is expected for most annual crops in North Dakota (i.e., >16 mg P kg\textsuperscript{-1} and >250 mg K kg\textsuperscript{-1}) (Table 2) [28].

| Location | NO\textsubscript{3}-N (0–15 cm) | NO\textsubscript{3}-N (15–60 cm) | NO\textsubscript{3}-N (0-60 cm) | S-SO\textsubscript{4} \textsuperscript{1} | P | K | OM | pH |
|----------|-------------------------------|-------------------------------|-------------------------------|-----------------|---|---|---|----|
|          | kg ha\textsuperscript{-1}     | kg ha\textsuperscript{-1}     | kg ha\textsuperscript{-1}     | mg kg\textsuperscript{-1} | g kg\textsuperscript{-1} | g kg\textsuperscript{-1} |     |    |
| Prosper  | 17 27 44                       | -                            | -                            | 29 305 39       | 39 | 7.2|
| 2012     |                               |                               |                               |                 |    |
| Walcott  | 57 145 202                     | 10                           | 24                           | 285 38          | 38 | 7.3|
| 2014     |                               |                               |                               |                 |    |

\textsuperscript{1} S-SO\textsubscript{4} pH, organic matter (OM), P—Olsen, K from 0–15 cm depth. Phosphorus (P), potassium (K), nitrate nitrogen (NO\textsubscript{3}-N).

Before harvest, average plant height was determined by taking three heights in each plot, from the soil surface to the longest vegetative part of the plant (held vertically). Harvest was conducted by hand using a 1 m\textsuperscript{2} square frame, to determine both above and below ground biomass. A sample from the total forage biomass (leaf and root/stem) per each plot was taken to analyze forage quality. The whole plant biomass harvested was divided into leaves and stems (kale) and into leaves and roots (swede). Enlarged roots were removed from the soil by pulling or using a shovel, to harvest the maximum of enlarged root tissue. Results are presented as dry matter (DM) leaf yield, and root/stem DM yield which is the sum of biomass of roots from swede and stems from kale. Additionally, senesced and dry material fallen off plants onto the soil surface under the canopy was collected, measured, and characterized as dead matter. Total forage biomass yield (leaf + root/stems) plus dead matter represented total biomass yield. Once separated, leaves of each sample were placed in burlap bags and then tagged. Swede roots were collected and washed on the same day, stored in a cold room (4 °C), and then chopped fresh using a food processor (Sunbeam, Le Chef model, Chicago, IL, USA), leaving pieces about 5-mm thick or less. Kale stems were cut longitudinally with a knife in four or more parts according to the thickness of the stem. Stems and chopped root pieces were placed in mesh plastic bags. All the samples (cut stems and chopped roots) were weighed to determine the wet weight and dried at 70 °C until constant weight. Samples were weighed to obtain the dry weight. Dried samples were ground in a mill (Wiley Mill standard Model No. 3, Philadelphia, PA, USA) to 1-mm mesh and then sent for forage quality analysis.
Chemical analysis for 50-leaf, -stem, and -root samples, respectively, were conducted at Animal Sciences Nutrition Laboratory at North Dakota State University. The results were used to build calibration equations to determine nutritional values for near infrared reflectance spectroscopy (NIRS) analysis. The total N content was measured with the Kjeldahl method [32], percentage of ash with Association of Official Agricultural Chemists (AOAC) Method 942.05, and crude protein (CP) with AOAC Method 2001.11. Quality analysis was conducted to determine acid detergent fiber (ADF) (ANKOM, 2011. A200 Method 5, ANKOM Technology, Macedon, NY, USA), neutral detergent fiber (NDF) (ANKOM, 2011. A200 Method 6) and in vitro dry matter digestibility (IVDMD) [33]. Total digestible nutrients (TDN) were then calculated from the above parameters according to Undersander [34]. Then, all samples were analyzed in a near-infrared reflectance instrument (Foss-Sweden Model 6500, Minneapolis, MN, USA), for the same forage quality components indicated previously, in Dr. Undersander’s laboratory, University of Wisconsin, Madison, following the methods described by Abrams et al. [35].

The N accumulation (N total) in each species/treatment plot was determined from the CP content, obtained from NIRS results. Nitrogen content was calculated with the equation: $N = \frac{CP}{6.25}$. Nitrogen accumulation was calculated arithmetically multiplying the above and below ground forage biomass yield in kg ha$^{-1}$ by the N content. Total N accumulation (kg N ha$^{-1}$) of forage produced was calculated using the N concentration (g kg$^{-1}$) in the tissue (leaf or root/stem), times the total biomass yield produced per ha.

2.4. Statistical Analysis

The statistical analysis was conducted using standard procedures for a randomized complete block design (RCBD) with factorial or split-plot arrangement. Each location/year combination was defined as an environment and was considered a random effect in the statistical analysis. Nitrogen and S fertilization rates and species were considered fixed effects. Analysis of variance and mean comparisons were conducted using the MIXED procedure in statistical analysis software (SAS, Cary, NC, USA) [36]. Error mean squares were compared for homogeneity among environments according to the folded $F$-test and, if homogeneous, then a combined analysis of variance was performed across environments. Only fixed effects and interactions among fixed effects are discussed. Significant interactions with environment are not discussed because represent a non-repeatable response. Treatment means separation was determined by $F$-protected least significant difference (LSD) comparisons at the $p \leq 0.05$ probability level. Regression analysis was conducted to determine the response to N and S fertilization. Leaf, root/stem, and dead matter yield values were converted to a relative scale from 1–100%, to account for the yield variation in different locations and years. Linear and quadratic regression models were constructed with both, relative and absolute values, and tested with the corresponding error. The regression models were all at the $p \leq 0.05$ level of significance.

3. Results and Discussion

3.1. Forage Brassica N and S Effect on Leaf, Stem, and Root Yield

Kale and swede forage biomass yield (leaf and root/stem) increased linearly up to 200 kg N ha$^{-1}$, indicating that these species could actually have a response to greater N rates. The analysis of variance combined across three environments for Prosper in 2012 and 2014 and Walcott 2014, of leaf, root/stem, total biomass yield (leaf + root/stem), dead matter yield, total biomass yield, and total N concentration are presented in Table 3. The triple interaction of species by N by S was significant for root/stem yield and leaf + root/stem yield (Table 3). The double interactions N by S, S by species, and N by species were not significant for any parameter. The S main effect was not significant. Species main effect was significant for all parameters except leaf yield, total leaf N, and total root/stem N. The N main effect was significant for all parameters evaluated (Table 3).
Table 3. Analysis of variance and mean squares of absolute values for brassica leaf, root/stem, leaf + root/stem, dead matter and total biomass yield, and total nitrogen (N) for leaf, root/stem and total forage yield for N and sulfur (S) rates in Prosper 2012 and 2014 and Walcott, ND, USA in 2014.

| Source of Variation | df | Leaf Yield | Root/Stem Yield | Leaf and Root/Stem Yield | Dead Matter | Total Biomass Yield | Total Leaf N | Total Root/Stem N | Total Forage N |
|---------------------|----|------------|-----------------|--------------------------|-------------|---------------------|--------------|-------------------|---------------|
| Env                 | 2  | 19,577     | 199,414         | 281,525                  | 190,096***  | 922,590             | 79,425       | 34,552            | 196,746       |
| Rep(env)            | 6  | 2656       | 3302            | 10,839                   | 2091*       | 18,954              | 464          | 1925              | 4158          |
| Sp                  | 1  | 4068       | 851,286**       | 973,068**                | 30,190      | 1,346,052**         | 19,251       | 119,129           | 234,224*      |
| Env × Sp            | 2  | 26,761*    | 8532            | 5154                     | 1986        | 5649                | 3179         | 7908              | 7781          |
| Env × Sp × rep      | 6  | 3318***    | 1904            | 6393                     | 372         | 6171                | 2417***       | 734               | 5083**         |
| N                   | 4  | 15,018***  | 21,268*         | 70,275**                 | 4021**      | 107,042**           | 6887***       | 9635**            | 32,268***      |
| Env × N             | 8  | 632        | 3877            | 6544                     | 316         | 8843                | 132          | 879               | 1196          |
| S                   | 1  | 6645       | 4115            | 21,223                   | 633         | 29,195              | 18           | 755               | 540           |
| Env × S             | 2  | 6063***    | 14,617          | 36,627                   | 376         | 33,761              | 1357         | 3902              | 9168          |
| N × S               | 4  | 953        | 5299            | 8663                     | 224         | 7055                | 472          | 1046              | 1909          |
| Env × N × S         | 8  | 1223       | 3899            | 9205*                    | 393         | 10,674*             | 431          | 799*              | 1908*         |
| N × Sp              | 4  | 377        | 1321            | 1871                     | 1099        | 5287                | 273          | 591               | 1410          |
| Env × N × Sp        | 8  | 1692*      | 3227            | 7208                     | 405         | 8818*               | 484          | 998**             | 2427*         |
| S × Sp              | 1  | 10.1       | 1073            | 1096                     | 1006        | 4205                | 214          | 1164              | 2378          |
| Env × S × Sp        | 2  | 51         | 4958*           | 7829                     | 454         | 8367                | 97           | 2128**            | 1809          |
| N × S × Sp          | 4  | 1015       | 6310*           | 11,837*                  | 209         | 11,641*             | 302          | 1248**            | 2432*         |
| Env × N × S × Sp    | 8  | 647        | 1221            | 2180                     | 584         | 2392                | 217          | 142               | 413           |
| Error               | 108| 637        | 2571            | 4463                     | 374         | 5572                | 333          | 690               | 1470          |
| CV %                | 25 | 31        | 26              | 20                       | 21          | 30                  | 34           | 28                |               |

† Env = Environment, Rep = Replicate, Sp = Species and cultivars. †, ‡, § Significant at 0.05, 0.01, and 0.001 probability levels, respectively. § Mean squares values in columns 1–5 were divided by 1000, but not in columns 6–8. Total N accumulation = N accumulated by leaves + root/stem. Degrees of freedom (df), coefficient of variation (CV).

Leaf yield of kale and swede averaged across fertilization rates and environments ranged between 3.10 and 3.32 Mg ha⁻¹, respectively. Leaf yield across species, S rates and environments increased from 2.50 to 3.87 Mg ha⁻¹ with 0 to 200 kg N ha⁻¹ rates (Table 4). Root/stem yield was much higher than leaf yield with a stronger response to N than leaf yield (Table 4). Leaf area in swede ranged between 27–32% of the total plant biomass without considering dead mass. In kale, leaf area ranged between 46–54%. Even dead matter accumulated during the season responded to N rates. This was likely due to plants with higher N rates had more leaves dying due to shading from leaves above.

Table 4. Leaf, root/stem, leaf + root/stem, and dead matter yield, N accumulation in the root/stem and total nitrogen (N) accumulated in (leaf + root/stem) response to N rates averaged across sulfur (S) rates, species, and environments.

| N Rate (kg ha⁻¹) | Leaf Yield (Mg ha⁻¹) | Root/Stem | Leaf + Root/Stem N Accum (Mg ha⁻¹) | Dead Matter (Mg ha⁻¹) | Total N Accumulated (Mg ha⁻¹) |
|------------------|----------------------|-----------|-----------------------------------|-----------------------|-------------------------------|
| 0                | 2.50                 | 4.20      | 6.71                              | 2.85                  | 59                            |
| 50               | 2.54                 | 4.64      | 7.18                              | 2.76                  | 65                            |
| 100              | 3.16                 | 5.05      | 8.21                              | 3.12                  | 77                            |
| 150              | 3.74                 | 5.50      | 9.25                              | 3.41                  | 88                            |
| 200              | 3.87                 | 6.18      | 10.01                             | 3.52                  | 99                            |
| LSD (0.05)       | 0.43                 | 0.94      | 1.12                              | 0.27                  | 14                            |
| SE               | 0.35                 | 1.09      | 1.03                              | 1.03                  | 14.5                          |

Least significant differences (LSD); standard error (SE).

The triple interaction N by S by species was mainly due to magnitude difference between swede and kale yields, rather than a true interaction of treatments; however, this significant interaction seems to indicate that S fertilization might reduce the need of N fertilization in swede, but not in kale (Table 5). Swede had higher total root/stem yield and leaf + root/stem yield than kale for all N and S rates (Table 5). This is explained because in swede the biomass from the enlarged root is much greater than that of kale stems. Swedes root yield is about 2/3 of the total plant biomass while in kale stem and leaf yield are similar. Root/stem yield in swede was highest with the 200 kg N ha⁻¹ rate and no S application. When sulfur was applied, highest root/stem yield was obtained at 150 kg N ha⁻¹, however,
it was not significantly different than the 200 kg N ha\(^{-1}\) rate. In kale, N did not increase root/stem yield regardless of sulfur rate. For the leaf + root/stem yield, both species had the highest yield with the 200 kg N ha\(^{-1}\) rate. The addition of sulfur in swede produced the highest root/stem yield and leaf + root/stem yield with the 150 kg N ha\(^{-1}\) rate, which might indicate that in the presence of S less N fertilizer might be needed to achieve same total forage yield goal.

The strong response of both species to N was observed across S rates (Table 3). Most of the significant responses in root/stem yield and leaf + root/stem yield were between 0 kg N ha\(^{-1}\) and 200 kg N ha\(^{-1}\). Forage brassicas often respond strongly to N but seldom to S [1,6].

Leaf, stem and root yield of both crops were lower in Prosper in 2012 (data not shown). The most critical rainfall deficiency was in Prosper in 2012, with only 242 mm of rainfall during the growing season, compared with 445 mm of 25-year rainfall average (Figure 1). The rainfall in Walcott was slightly below the 25-year historical average, with 493 and 578 mm of rainfall during the growing season. In general, the rainfall between sowing and emergence time was adequate, with the lowest amount of rainfall (46.2 mm) in May, in Prosper in 2012 (Figure 1).

The minimum and maximum temperature recorded during 2012 and 2014 were relatively similar to the 25-year average (Figure 1). The highest minimum and maximum temperatures were observed in July and August, and the lowest minimum and maximum between December and February. The hottest summers were observed in 2012 in Prosper, with about 2.7 °C above average. The 2014 summer was similar to the average temperature in Prosper. In Walcott, the summer was the coolest, with 3 °C below average. These temperatures are adequate for plant growth of Brassica spp. [2].

The climatic parameters are highly important on forage brassica performance. Growing degree days (GDD, base temperature 0 °C) to maturity have a major effect on forage brassica biomass yield potential [2]. Forage brassicas, although cool-season crops, are highly tolerant to heat, but heat in general speeds up reproductive development. High dry matter production with temperatures of about 32 °C have been reported [37]. Forage brassicas accumulate about 1.1 Mg DM ha\(^{-1}\) per each 100 GDD, base temperature 0 °C and maximum temperature 32 °C, without soil water constraints nor fertility [2].

### Table 5. Swede and kale root/stem yield and leaf + root/stem yield with five nitrogen (N) rates and two sulfur (S) rates averaged across three environments at Prosper and Walcott, ND, USA, in 2012 and 2014.

| N Rate  | Root/Stem Yield | Leaf + Root/Stem Yield |
|---------|----------------|------------------------|
| kg N ha\(^{-1}\) | S Rate (kg S ha\(^{-1}\)) | Swede (Mg ha\(^{-1}\)) | Kale (Mg ha\(^{-1}\)) |
|---------|----------------|------------------------|
| 0       | 0 40 0 40       | 6.7 5.5 9.2 8.1        | 2.2 2.4 4.3 5.2        |
| 50      | 0 40 0 40       | 6.7 6.9 9.2 9.8        | 2.8 2.2 5.2 4.5        |
| 100     | 0 40 0 40       | 7.0 7.6 10.7 10.9      | 2.6 3.3 5.4 6.0        |
| 150     | 0 40 0 40       | 6.1 9.1 9.4 13.7      | 3.4 3.4 6.7 7.2       |
| 200     | 0 40 0 40       | 8.7 8.5 12.4 12.6      | 3.4 4.1 7.0 8.2       |
| LSD\(_1\) | 2.0          | 2.4                    | 1.25 1.55               |
| LSD\(_2\) | 2.3          | 3.3                    |                         |
| LSD\(_3\) | 1.7          | 2.7                    |                         |

Least significant differences (LSD\(_1\)) to compare between means of species for a same rate of N and S in different species. LSD\(_2\) to compare between means of S rates for same N rate and species. LSD\(_3\) to compare between means of N rates for same S rate and species. SE = Standard error for the interaction N × S × Species.
Water availability is the main environmental source of forage yield variation in brassica forages [2], and water deficits during the growing season reduce forage yield [38]. Swede needs 38 mm H₂O week⁻¹ during the season to maximize root yield [39]. Kale and rape have more vigorous root systems than swede and turnip and, therefore, they can utilize stored water more efficiently [2].

Regression analysis of yield response to N was conducted on relative values to account for magnitude differences among environments. Leaf and root/stem yield, leaf + root/stem) dead matter yield and total biomass yield (leaf + root/stem + dead matter biomass yield) showed linear response with increasing N rates (0, 50, 100, 150, and 200 kg N ha⁻¹) (Figure 2; Figure 3). These increments in forage yield with increased N rates are in accord with Chakwizira et al. [41], who reported a linear response in forage yield of brassicas to N rates up to 200 kg N ha⁻¹. Other authors also reported increments in yield with increasing N rates [42,43]; however, these authors found quadratic response instead of the linear response observed in the present study. In most of the cases, the difference in biomass yield between the highest N rate (200 kg N ha⁻¹) and the lowest (0 kg N ha⁻¹) was between 15% for dead matter yield and 23% for leaf yield.

Figure 1. Monthly average minimum and maximum air temperatures and monthly total rainfall in 2012, and 2014 compared with the 25-year (1990–2014) average in Prosper (A), and Walcott (B) [46].

Figure 2. Regression model for relative leaf (y₁), root/stem (y₂), and total forage yield (leaf + root/stem, y₃) averaged across swede and kale affected by different nitrogen (N) rates averaged across three environments in Prosper and Walcott, ND, USA in 2012 and 2014.
Figure 3. Regression model for relative dead matter (y1) and total biomass yield (leaf + root/stem + dead matter, y2) of swede and kale averaged, affected by different nitrogen (N) rates averaged across three environments in Prosper and Walcott, ND, USA in 2012 and 2014.

3.2. Response of N and S Fertilization on N Accumulation

As for total forage yield, a strong interaction of N by S by species was observed for total root/stem N and total forage N accumulation, which was likely due to a magnitude effect. Total N accumulation was greater in swede roots than in kale stems at all N and S rates (Table 6). This is likely related to the higher root yield in swedes compared with kale stems. Nitrogen accumulation increased as N rates increased. Nitrogen accumulation in root/stem and in total forage was significantly greater with S application only for the 150 kg ha\(^{-1}\) rate (Table 6). This might indicate that S interacted with N accumulation. Plants might accumulate more N in the presence of both nutrients, rather than just high N rates. In kale, the interaction of N by S was not significant for any N rate. Application of N fertilizer can lead to accumulation of nitrate (NO\(_3\)-N) in forage brassicas, particularly when N application rates exceed the requirement [7]. This may result in potentially toxic NO\(_3\)-N (antinutritional compounds) content in grazeable plant tissues, leading to animal health issues and/or environmental pollution [44].

Forage kale and rape (Brassica napus L.), generally have higher NO\(_3\)-N concentration than turnip and swede. This is because roots, the major yield component of swede, have lower NO\(_3\)-N content than stems, which make up the bulk of yield in kale and rape [7]. Additionally, Chakwizira et al. [41] reported that NO\(_3\)-N contents were higher in kale stems and petioles (which included the midrib of the leaf) than in leaves. In a survey conducted in Nebraska, they determined that 48% of fresh brassica samples were considered at risk for causing nitrate toxicity as they exceeded the 2100 mg NO\(_3\)/kg DM threshold [45].

On average, differences in total N between the highest and lowest N rate was higher in leaves (33%) than in roots and stems (20%). The trend observed in N as main effect could be explained because brassica forages respond to N fertilization up to 400 kg N ha\(^{-1}\) [23,44]. The available N for forage brassicas (swede and kale) in the present experiment could have limited the growth to reach the maximum potential yield, thus brassicas showed a linear response instead of typical quadratic response observed in experiments with different N rates [44]. Another important factor that could explain the observed response to N fertilization is the soil N content. Prosper 2012 and Walcott 2014 had 44 and 31 kg ha\(^{-1}\) of N-NO\(_3\) in the soil at 0–60 cm (Table 2). The soil N-NO\(_3\) plus the highest N rate used in the present experiment would have been less than 250 kg N ha\(^{-1}\) available for brassica growth, in these two environments (Table 2), which is less than the recommendations of Chakwizira et al. [45]. Conversely, Wilson and Manley [46] did not find a response to N in kale because the NO\(_3\)-N content...
of the soil was high. According to Fletcher et al. [47], kale can have null response to N in soils with high NO$_3$-N; conversely, in low N soils the response is usually significant. However, it is important to know that forage brassicas can take up water and nutrients from 0.9 to 1 m deep [6,7]. Thus, the N available for plant growth could have been greater than 250 kg N ha$^{-1}$. Additionally, Vos and van der Putten [48] reported that the response to N fertilizer in brassicas depends on the amount of residual and mineralized N in the soil, which is influenced by the cropping history.

Table 6. Swede and kale total root/stem nitrogen (N) accumulation and total N accumulated in forage (leaf + root/stem) with five N rates and two sulfur (S) rates averaged across three environments at Prosper and Walcott, ND, USA, in 2012 and 2014.

| N Rate (kg N ha$^{-1}$) | Total Root/Stem N (kg N ha$^{-1}$) | Total Forage N (kg N ha$^{-1}$) |
|-------------------------|-----------------------------------|---------------------------------|
|                         | S Rate (kg S ha$^{-1}$)           |                                 |
|                         | 0                                 | 40                              | 0                               | 40                              |
| Swede                   |                                   |                                 |                                 |
| 0                       | 86                                | 73                              | 144                             | 129                             |
| 50                      | 87                                | 91                              | 134                             | 151                             |
| 100                     | 104                               | 110                             | 180                             | 170                             |
| 150                     | 93                                | 136                             | 172                             | 228                             |
| 200                     | 127                               | 133                             | 215                             | 197                             |
| Kale                    |                                   |                                 |                                 |
| 0                       | 37                                | 42                              | 76                              | 84                              |
| 50                      | 50                                | 34                              | 94                              | 70                              |
| 100                     | 47                                | 50                              | 96                              | 90                              |
| 150                     | 62                                | 61                              | 120                             | 121                             |
| 200                     | 67                                | 73                              | 135                             | 125                             |
| LSD$_1$                 | 42                                | 50                              |                                 |
| LSD$_2$                 | 33                                | 49                              |                                 |
| LSD$_3$                 | 29                                | 42                              |                                 |
| SE                      | 18.2                              | 36.5                            |                                 |

Least significant differences (LSD$_1$) to compare between means of species for a same rate of N and S in different species. LSD$_2$ to compare between means of S rates for same N rate and species. LSD$_3$ to compare between means of N rates for same S rate and species. SE = Standard error for the interaction N × S × Species.

Nitrogen response is also related with the water availability. The response can be greater when irrigation is used or at least adequate rainfall occurs during the growing season [23,49]. Brassicas must have at least 500 mm of water to avoid yield reduction by water deficit [46]. Fletcher et al. [6] mentioned that drought conditions of 100 mm rainfall produce half of yield compared with full irrigation (328 mm). However, in the environments evaluated in the present experiment the rainfall was low (210, 267, and 251 mm of rainfall in Prosper 2012 and 2014 and Walcott 2014, respectively) (Figure 1). This agrees with de Ruiter et al. [2], who reported water availability is the main environmental source of forage yield variation in brassicas.

Forage yield was composed of 31% leaves and 58% dead matter at the lowest N rate, but with the highest N rate applied, the percentage of both leaves and dead matter increased (Figures 2 and 3), respectively. That probably occurred; because with limited N, the leaf area declined faster as leaves senesced mobilizing N to growing points and new leaves [46]. The relative total N was higher for leaves than for root/stem, and as N rates increased total N increased. The total N rate was greater in leaves which can be observed in Figure 4. These results are in accord with the information provided by Chakwizira et al. [41], and Wilson and Maley [46].
Forage nutritive value of leaves was not affected by N or S rates or species main effect but there was a significant interaction between species and S for crude protein (CP) and acid detergent lignin (ADL) (Table 7). Crude protein was greater in swede fertilized with 40 kg S ha\(^{-1}\) compared with kale at 40 kg S ha\(^{-1}\) (Table 8). Crude protein concentration in kale and swede leaves ranged from 95 to 138 g kg\(^{-1}\). Crude protein concentration in swede and kale in this study were above those needed by beef cattle. A gestating cow in the mid-1/3 of pregnancy and weighing 540 kg requires 10 kg of dry matter intake with 71 g kg\(^{-1}\) of crude protein [50] Several studies have reported that CP increases in leaves and stems with N fertilization but the response depends on N fertilization and weather conditions [43,51]. Higher CP can be explained by higher leaf:stem ratio which is promoted by N availability [51]. Conversely, other authors did not find effect of increasing N rates on leaf and root yield of turnip [5]. The lack of response of forage nutritive value to N in this study was likely due to high soil N or high mineralization rate of residues of the previous crop.

Forage brassicas are more succulent and higher in nutritive value than almost any other type of forage [37] and provide forage when the majority of warm- and cool-season grasses and legumes are unproductive [52–55]. However, the nutritional content of brassica crops is variable and depends on environment but also of the degree of maturity of the plant at harvest time [56]. Forage brassicas are highly productive, digestible forbs that contain relatively high levels of CP and digestible carbohydrates [37]. Crude protein concentration in leaves was higher in swede than in kale at 40 kg S ha\(^{-1}\) (\(p \leq 0.05\)) (Table 8). Crude protein values in forage brassicas ranges from 130 to 280 g kg\(^{-1}\) varying with species, harvest maturity, and environment [10,58,59]. Crude protein content in shoots and roots depends on the cultivars used [53]. Additionally, N fertilization and weather conditions influence CP content [60]. The null response to increasing N rates on CP in this study can be explained by soil water deficiency because 2012 was a very dry environment (Figure 1) or due to the high N content in the soils used in these experiments, mainly in Prosper 2014 (Table 2).
Table 7. Analysis of variance and mean squares of forage quality components of brassica leaves for nitrogen (N) and (S) rates and species in Prosper 2012 and 2014, and in Walcott, ND, USA in 2014.

| Source of Variation | df | Ash | CP § | NDF | ADF | ADL | IVDMD | NDFD | TDN |
|---------------------|----|-----|------|-----|-----|-----|-------|------|-----|
| Env †               | 2  | 60,970 | 109,225 | 75,505 | 17,385 | 2481 | 24,339 | 34,015 | 67,638 *** |
| Rep(Env)            | 6  | 1063 | 1889 | 327 | 53 | 86 | 158 | 82 | 856 * |
| Sp                  | 1  | 8989 | 41,466 | 1875 | 3389 | 769 | 16,859 | 7432 | 18,269 |
| Env × Sp            | 2  | 5440 | 73,904 *** | 26,503 * | 12,434 ** | 5254 *** | 3837 | 1681 | 5848 |
| Env × Sp × Rep      | 6  | 1377 *** | 1371 *** | 454 | 273 * | 99 *** | 214 * | 125 | 1408 *** |
| N                   | 4  | 1518 | 1914 | 780 | 467 | 97 | 194 | 55 | 1333 |
| Env × N             | 8  | 416 | 1056 | 551 | 397 | 65 | 348 | 195 * | 457 |
| S                   | 1  | 736 | 6504 | 1543 | 524 | 370 | 236 | 13 | 495 |
| Env × S             | 2  | 846 | 2370 | 809 | 117 | 89 | 368 | 222 | 1099 * |
| N × S               | 4  | 27 | 81 | 127 | 88 | 2 | 39 | 30 | 22 |
| Env × N × S         | 8  | 325 | 481 | 461 | 174 | 31 | 67 | 90 | 513 |
| N × S               | 4  | 286 | 231 | 1163 | 659 | 33 | 41 | 52 | 114 |
| Env × N × Sp        | 8  | 583 | 431 | 458 | 311 * | 35 | 259 | 236 * | 433 |
| S × Sp              | 1  | 358 | 2054 * | 148 | 0.005 | 97 * | 598 | 182 | 428 |
| Env × S × Sp        | 2  | 854 | 67 | 98 | 329 | 5 | 482 | 149 | 1088 |
| N × S × Sp          | 4  | 733 | 237 | 166 | 72 | 8 | 164 | 134 | 925 |
| Env × N × S × Sp    | 8  | 263 | 217 | 389 | 186 | 21 | 124 | 105 | 396 |
| Error               | 108 | 280 | 301 | 225 | 123 | 20 | 93 | 89 | 318 |
| CV, %               | 11  | 14 | 6 | 6 | 9 | 1 | 1 | 2 |

† Env=Environment, Rep=Replicate, Sp=Species. † *, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively. § Forage quality components: Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), in vitro dry matter digestibility (IVDMD), neutral detergent fiber digestibility (NDFD) and total digestible nutrients (TDN), coefficient of variation (CV), degrees of freedom (df).

Table 8. Crude protein and ADL for leaves and TDN for root/stems of swede and kale with five nitrogen (N) rates and two sulfur (S) rates across three environments at Prosper and Walcott, ND, USA, in 2012 and 2014.

| S rate (kg S ha⁻¹) | Species | CP Leaves | ADL Leaves | TDN Root/Stems |
|-------------------|---------|-----------|------------|----------------|
| 0                 |         |           |            |                |
| 40                | Swede   | 138       | 133        | 47             | 49             | 803 | 803 |
| 40                | Kale    | 114       | 95         | 50             | 54             | 706 | 716 |
|                  | LSD₀.₀₅ (SE) | 31 (32.4) | 6 (6.6)    | 14 (26.0)      |

Crude protein (CP), acid detergent lignin (ADL), total digestible nutrients (TDN), least significant differences (LSD), standard error for the interaction S × Species (SE).

Acid detergent lignin in leaves tended to be higher (p < 0.05) with 40 kg S ha⁻¹ rates than 0 without S fertilization, and also in kale compared with swede (Table 8). However, ADL was statistically higher in swede with no S applied compared with ADL in kale with 40 kg S ha⁻¹. These results agree with Jung et al. [43] and Kunelius at al. [61], who mentioned that kale usually has lower digestibility and higher fiber, due to their longer and fibrous stems.

Total digestible nutrients were higher (p < 0.05) in swede than kale, at both S rates averaged across all N rates (Table 8). Kale had a TDN of 700–710 g kg⁻¹ compared with 800 g kg⁻¹ TDN in swede. This can be explained by the higher concentration of water soluble carbohydrates in swede compared with kale. Additionally, kale usually has lower dry matter digestibility than other forage brassicas due to their longer and fibrous stems [42,61]. The N by S interaction was significant for NDF, ADF, ADL, NDFD, and TDN for root/stems averaged across species and environments (Table 9).

Fiber components, NDF and ADF, were lower when only S fertilizer was applied compared with no S or N fertilizer application. Oppositely, at the highest N rate, NDF and ADF were higher when S was applied than without application. In addition, fiber digestibility and TDN were significantly higher when S was applied in the absence of N fertilizer compared with no S application (Table 10). At higher N rates, plants grow faster and taller changing the proportion of root/stems and leaves. Fiber
digestibility is higher in leaves than in stems and roots. Without N fertilization, S fertilizer application (40 kg S ha\(^{-1}\)) reduced NDF, ADF, and ADL content increasing digestibility and TDN in comparison to no S application. Sulfur, similarly to N, has a role in protein synthesis, including many enzymes in cell wall components synthesis. Sulfur, likely substituted N functions in part when N was a limiting factor, allowing the plant to mobilize carbon resources away from fiber synthesis and secondary pathways leading to lignin formation. In addition sulfur mobility in the plant is limited, thus in the treatment with no N or S application, sulfur could not complement N functions [13,14].

**Table 9.** Analysis of variance and mean squares of forage quality components of brassica root/stem for nitrogen (N) and sulfur (S) fertility in Prosper 2012 and 2014, and in Walcott, ND, USA in 2014.

| Source of Variation | df | Ash | CP § | NDF | ADF | ADL | IVDMD | NDFD | TDN |
|---------------------|----|-----|------|-----|-----|-----|-------|------|-----|
| Env †               | 2  | 2013| 13,055| 467,585| 269,692| 15,525| 411,292| 275,838| 96,691|
| Rep(Env)            | 6  | 278 | 815   | 1029 | 632 | 53  | 1063  | 1034  | 736  |
| Sp                  | 1  | 18,666| 39,073| 733,317| 438,376| 30,135| 661,025| 714,087| 377,346|
| Env × Sp            | 2  | 3408| 5476  | 45,904 | 29,045 | 2257 | 50,573 | 42,278 | 24,718 |
| Env × Sp × Rep      | 6  | 239 | 651   | 1262 | 722  | 44  | 1134  | 1244  | 688  |
| N                   | 4  | 316 | 1045  | 1432 | 910  | 80  | 1936  | 1631  | 785  |
| Env × N             | 8  | 159 | 526   | 784  | 519  | 47  | 1215  | 838   | 454  |
| Sp                  | 1  | 765 | 3125  | 186  | 216  | 37  | 777   | 61    | 1307 |
| Env × S             | 2  | 584 | 2256  | 224  | 207  | 37  | 716   | 197   | 450  |
| N × S               | 4  | 56  | 208   | 2417 | 1463 | 102  | 2549  | 2421  | 629  |
| Env × N × S         | 8  | 68  | 246   | 234  | 132  | 16  | 284   | 226   | 149  |
| N × Sp              | 4  | 124 | 283   | 1496 | 844  | 50  | 1126  | 1171  | 386  |
| Env × N × Sp        | 8  | 25  | 131   | 1031 | 664  | 68  | 1576  | 1401  | 593  |
| S × Sp              | 1  | 948 | 3538  | 159  | 144  | 35  | 423   | 18    | 1271 |
| Env × S × Sp        | 2  | 322 | 1159  | 1960 | 1105 | 80  | 2085  | 2954  | 50   |
| N × S × Sp          | 4  | 29  | 94    | 436  | 259  | 29  | 543   | 407   | 227  |
| Env × N × S × Sp    | 8  | 57  | 166   | 183  | 100  | 7   | 148   | 112   | 132  |
| Error               | 108| 49  | 165   | 458  | 275  | 24  | 540   | 453   | 179  |
| CV, %               | 9   | 12  | 6     | 6    | 10   | 3   | 3     | 2     |      |

† Env = Environment, Rep = Replicate, Sp = Species and cultivars. § Forage quality components: Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), in vitro dry matter digestibility (IVDMD), neutral detergent fiber digestibility (NDFD) and total digestible nutrients (TDN), coefficient of variation (CV), degrees of freedom (df).

**Table 10.** Neutral detergent fiber, ADF, ADL, NDFD, and TDN for root/stems with five nitrogen (N) rates and two sulfur (S) rates averaged across two species and three environments at Prosper and Walcott, ND, USA, in 2012 and 2014.

| N Rate (kg ha\(^{-1}\)) | S Rate (kg S ha\(^{-1}\)) | NDF | ADF | ADL | NDFD | TDN |
|-------------------------|--------------------------|-----|-----|-----|------|-----|
| 0                       | 0                        | 353 | 334 | 272 | 257  | 48  |
| 50                      | 40                       | 354 | 345 | 272 | 263  | 47  |
| 100                     | 40                       | 352 | 358 | 271 | 275  | 48  |
| 150                     | 40                       | 364 | 353 | 281 | 271  | 51  |
| 200                     | 40                       | 334 | 356 | 257 | 274  | 45  |

LSD\(_{0.05}\) (SE) 12 (51.2) 9 (38.9) 3 (9.3) 11 (39.5) 11 (23.5)

Forage quality components: neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), neutral detergent fiber digestibility (NDFD), and total digestible nutrients (TDN). Least significant differences (LSD), standard error for the interaction N rate × S rate (SE).

**4. Conclusions**

Kale and swede forage biomass yield (leaf and root/stem) increased up to 200 kg N ha\(^{-1}\) in a linear response, indicating that these species could actually have a response to greater N rates. However, higher N rates will likely not be economical; even if forage yield is increased and might lead water contamination and environmental problems. Swede total forage yield was greater than that of kale across all N and S rates. Nitrogen fertilization increased total leaf, root/stems, and dead matter yield
and N accumulation in both leaves and roots. Thus, the recommendation for growers in the northern Great Plains is to fertilize with at least 200 kg ha\(^{-1}\) of N for maximum forage yield and a high valuable feed resource for early fall.

The interaction of N and S rates did not affect forage yield but had an effect on some of the root/stems quality constituents. Nitrogen fertilization main effect across species did not increase crude protein as expected. This likely because crude protein content in swede was significantly higher than that of kale. Forage nutritive value was greater in swede than kale due to higher proportion of edible root compared with kale higher proportion of fibrous stems. This study results suggest that growers will benefit from greater forage yield in kale and swede if they fertilized with N up to 200 kg N ha\(^{-1}\), but not with S. Forage yield and nutritive value of swede and kale in the northern Great plains are novel results, since these crops currently are not grown for forage and represent an interesting and valuable new alternative for beef cattle growers.

**Author Contributions:** O.T. conducted experiments, analyzed data, made tables and figures, wrote the first manuscript draft and edited it further. D.S. collaborated on the execution of experiments and editing and formatting of manuscript. M.B., obtained the funding, wrote project proposal, designed experiments, assisted with statistical analysis, and wrote the final manuscript. All authors have read and agreed to the published version of the manuscript.

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