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Evaluating the Nutrient Contents and Nutritive Value of Taif's Rose (*Rosa damascena* Mill var. *trigintipetala*) Waste to Be Used as Animal Forage or Soil Organic Fertilizers

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Abstract: This study aimed to evaluate the nutrient content and nutritive value of pruning waste of the Taif Damask rose for its potential use as an organic fertilizer or animal forage in the Taif region, Saudi Arabia. For this purpose, the pruning waste of Taif's rose and soil samples supporting the plant growth at different ages were collected from four farms (F1: 4, F2: 10, F3: 12, and F4: 20 years old). The total aboveground biomass (AGB) of the plants, stems, and leaves were measured in addition to the stem height and crown diameter. The results showed that the maximum stem height and crown diameter (184.20 and 243.5 cm) were recorded in the oldest farm (F4). Moreover, the stem, leaves, and aboveground biomass (AGB) of the waste were maximal (3.91, 1.30 and 5.21 t ha^{-1}) at F4. F1 had the highest N content (154.30 mg kg^{-1}) in the plant leaves, while F2 had the highest stem N and P (172.33 and P 9.40 mg kg^{-1}). Moreover, F3 had the highest concentrations of leaf P (7.17 mg kg^{-1}), leaf and stem K (112.47 and 277.30 mg kg^{-1}), stem Ca^{2+} (251.93 mg kg^{-1}), and leaf and stem Mg^{2+} (122.27 and 123.57 mg kg^{-1}). The stems had higher percentages of total proteins, fibers, ash, and NFE (total carbohydrates) than the leaves in F1 and F2, while the opposite was observed in F3 and F4. The leaves of F2 rose plants had the highest percentage of neutral detergent fibers (NDF), and their stems had the highest percentages of total proteins (10.71%). The leaves of F3 plants had the highest percentage of acid detergent lignin (ADL) and the lowest crude fibers (7.63 and 13.27%), while the stems had the highest NFE (72.71%). The plant–soil relationship expressed by the CCA biplot showed that all the measured plant parameters were at higher positions on the Mg axis, except for the plant height and crown diameter, which were at low positions on the N and NO_3 axes, respectively. In contrast, Cl^-, NO_3^-, HCO_3^-, and SO_4^{2-} had high positive correlations with axis 1 and negative values with axis 2, while EC, the total P, and Ca^{2+} had high positive correlations with, and pH had high negative values in relation to, axis 2. Due to its considerable high inorganic and organic nutrient contents, Taif's rose could be used in the manufacturing of organic fertilizer. Additionally, the analysis of the nutritive value of the pruning waste supports its use as animal forage. We strongly recommend that further studies be conducted on the application of plant waste as a soil amendment and animal forage in the field.

Keywords: damask rose; soil amendments; forage quality; inorganic elements; organic nutrients

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1. Introduction

Agricultural waste is improperly disposed of, which not only pollutes the environment but also wastes a large amount of precious biomass resources. To control pollution, an effective transformation of the process of agricultural waste recycling and utilization is regarded as a critical step in environmental conservation [1]. Recently, an enormous quantity of agricultural waste has been created annually all over the world. This waste has increased at a rate of 5–10% each year, on average. Air pollution, soil degradation, and other issues would from its haphazard abandonment and inappropriate use. Burning agricultural waste produces many hazardous gases, smoke, and dust, which significantly damage the air quality [2–4].

Agricultural waste recycling can take several forms, including the gasification of crops, the use of crop stalks as feed, fertilizers, or new building materials, and the production of manure from livestock dung [5,6]. Fruit, vegetable, and crop wastes are valuable sources of natural compounds and chemicals that are dependent on their fundamental properties and composition [7]. For instance, Torkashvand et al. [8] reported that peanut shell compost could be mixed with low-porosity substrates and applied as an appropriate growth medium to ornamental plants, as an alternative to peat. Great amounts of apple orchard waste (e.g., pruning branches, fruit thinning, and trunks) are produced, which might be considered as a promising alternative energy source for fuel and material manufacturing [9]. According to Sharma et al. [10], the agricultural recycling of organic waste is an eco-friendly and long-term waste management strategy. They also stated that organic waste is a rich source of beneficial plant macro- and micro-nutrients and organic matter. Organic waste additions boost plant production by improving the soil's physicochemical and biological qualities.

In Saudi Arabia, Taif's rose *(Rosa damascena* Mill. var. *trigintipetala*) is a conventional and interesting agricultural plant utilized for essential oil production [11–13]. Taif's rose cultivation is a long-standing tradition in the Taif region, and it has helped to transform this city in Saudi Arabia into a popular tourist destination. Saudi Arabia's rose oil output currently accounts for less than 5% of the total global production [14]. Essential oil and rose water are produced from Taif's rose [15] and are applied in medicine, the food sector, and perfumery. Water distillation is used to process roses in this part of the world. Many studies have been conducted on Taif's rose populations, including the chemical analysis of its oil and antimicrobial and antioxidant activities [14]; the phytochemical and pharmacological potential of its pruning wastes [11]; the effects of pruning systems and P-fertilizers on its growth and productivity [16]; and the effects of salinity on its oil and flower production [17–20]. Dragoev et al. [21] studied the chemical composition and quantity of the polyphenol content in dry rose petals, dry-pressed distilled rose petals, and wastewater, as well as the possibility for the re-utilization of dry-pressed distilled rose petals as feed material in animal production.

The waste generated by rose pruning in Taif province amounts to about 2700 tons, which can cause environmental concerns [11]. This pruning waste can be recycled so as to be used for various purposes such, as industrial and medicinal applications, forage, or fertilizers [11,12]. To our knowledge, the chemical composition of the major macronutrients, as well as the potential nutritive value, of the Taif rose plants have not yet been investigated. Accordingly, the objective of this study is to investigate the inorganic and organic macronutrients, as well as the potential nutritive value, of Taif's rose pruning waste destined to be used as soil organic fertilizer or animal forage. Such a study can be applied in the context of the recycling of waste materials and prevention of environmental pollution resulting from burning this waste. Additionally, it may aid in decision-making regarding the safe use of soil amendments such as sewage sludge or treated wastewater for improving soil quality.

2. Materials and Methods

For this study, we chose four farms in Al-Shafa highland, Taif Province, Saudi Arabia, to investigate the main morphological and biomass characteristics of Taif's Rose in addition to its nutrient contents and the potential nutritive value of its pruning waste. The selected farms had the same soil and climatic conditions, as well as the same agricultural practices. The four sampled farms (F1: 4 years; F2: 10 years; F3: 12 years; F4: 20 years) comprised an area of one hectare each. Taif's rose produces flowers once a year, during March and

April, for a period of 40–45 days. Annual pruning, which is performed once per year at the end of December and the beginning of January, is considered one of the most important agricultural practices of Taif's rose aiming to maximize its flower production. To increase the flower yield significantly, irrigation should be prevented for two months before and after pruning. After that time, irrigation is allowed and is usually achieved by natural dripping according to the needs of the plant during the rest of the year. Organic fertilizers, at a rate of 7.5 t/ha, are added immediately after the annual pruning.

2.1. Morphological and Biomass Characteristics

The stem maximum height (cm) and crown diameter (cm) were measured on about 10 individual plants of Taif's rose in each studied farm. Then, these individuals were pruned to maintain their height at about 80–90 cm. The fresh biomass of the stems and leaves of pruning waste was determined. The average biomass of each pruning waste was expressed as kg ha^{-1}, which was then multiplied by the number of individuals per hectare in order to calculate the total aboveground biomass (AGB) as t ha^{-1}.

2.2. Plant Chemical Analyses

From each of the ten individual rose plants, a sample of the stems and leaves were taken and combined to form three composite samples from each farm (N = 24). The oven-dried leaves and stems of Taif rose vegetative waste were ground separately in a metal-free plastic mill, passed through 2 mm-sized mesh, and finally stored in labelled plastic containers. For the chemical analyses, 1 g of either the milled leaf or stem samples was digested using a sulphury and perchloric acid mixture [22]. The determination of N, P, K, Ca, Mg, and Na in the extracts was carried out using Agilent 4210 MP-AES (Microwave Plasma-Atomic Emission Spectrometer, Agilent Inc., Santa Clara, CA, USA) at the Ecology Laboratory of the Faculty of Science, Helwan University. The instrumental settings and operational procedures were adjusted according to the manufacturer's user manual. The final concentrations were expressed as mg kg^{-1} of biomass dry matter for each element.

The ash content was estimated by igniting the ground leaves and stems in a muffle furnace for 3 h at 550 °C. The total N was measured by the Kjeldahl method, according to Chapman and Pratt [22]. The crude protein (CP) was calculated by multiplying the total N% by 6.25. The total lipids or fats were obtained by ether extract (EE), and they were determined by extracting the leaf and stem materials with diethyl ether using a Soxhlet extractor, according to Allen [23]. The crude fiber (CF) was gravimetrically determined after the chemical digestion and solubilization of the other present materials, according to Allen [23]. The nitrogen-free extract (NFE, i.e., total carbohydrates) was calculated in the leaves and stem samples according to Le Houérou [24], as follows:

NFE (% DM) = 100 − (CP + CF + Fat + Ash). The digestible crude protein (DCP) was determined according to NRC [25], as follows: % digestible crude protein (%DCP) = 0.85 X − 2.5, where X = crude protein % on the DM basis.

The fiber fractions of the cell walls consist of neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL), which were determined according to Goering and Van Soest [26] and Van Soest et al. [27]. Additionally, the hemicellulose and cellulose were calculated by difference, as follows: hemicellulose = NDF − ADF; cellulose = ADF − ADL.

The gross energy (kcal kg^{-1} DM) was calculated according to Blaxter [28], where each gram of crude protein = 5.65 kcal, each gram of fat = 9.40 kcal, and each gram of crude fiber and carbohydrate = 4.15 kcal. The animal obtains its energy through feed and loses energy through heat, feces, urine, and gases [29]. The digestible energy (kcal kg^{-1} DM) was calculated according to NRC [25], as follows: digestible energy (DE) = gross energy × 0.76. The metabolizable energy (kcal kg^{-1} DM) was calculated according to NRC [30], as follows: metabolizable energy (ME) = digestible energy × 0.82. The net energy (kcal kg^{-1} DM) was calculated according to NRC [30], as follows: net energy

(NE) = metabolizable energy × 0.56. The caloric values were expressed in Mcal kg^{-1} DM. The total amount of digestible nutrients (%) was calculated according to NRC [30]:

$$\%\text{Total digestible nutrients (TND)} = \text{digestible energy}/44.3$$

2.3. Soil Characteristics

Five composite soil samples were collected from the profiles, including the topsoil at a depth of 0–50 cm from each studied farm (*N* = 24). In the laboratory, the soil samples were air-dried, sieved through a 2 mm sieve, and then packed in paper bags for further chemical analysis. Soil water extracts (1:5, w:v) were prepared and used for the pH, EC, Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-, total N, total P, Ca^{2+}, Mg^{2+}, Na^+, and K^+ analysis. The pH of the soil samples was measured using a glass electrode pH meter (model 9107 BN, ORION type). The electrical conductivity (EC) of the soil water extract was measured with a multi-range Cryson-HI8734 electrical conductivity meter (Crison Instruments, S.A., Barcelona, Spain). The total N was measured by the Kjeldahl method. Bicarbonates were determined by titration against 0.1 N HCl, using methyl orange as an indicator, while chlorides were determined using silver nitrate solution [25,31]. Soluble soil cations (total P, Ca^{2+}, Mg^{2+}, K^+, and Na^+) were determined using Agilent 4210 MP-AES, as mentioned above in the case of the plant analysis. The concentrations of soil elements were expressed as mg kg^{-1} of dry weight.

2.4. Multivariate Analysis

The relationships between the morphological and growth measurements of the Taif rose plants and the soil factors were analyzed by canonical correspondence analysis [32], using Canoco for Windows version 4.0 [33]. The soil variables in the CCA biplots were represented by arrows pointing in the direction of maximum variation, and their length was proportional to the rate of change [34]. Each arrow determined an axis upon which the morphological and growth variable points could be projected. Intra-set correlations determined from the CCA were used to evaluate the importance of the soil variables.

2.5. Statistical Analysis

A one-way analysis of variance (ANOVA I) test followed by Tukey's HSD test was used to assess the significant differences between the analyzed morphological and growth variables of Taif's rose at the studied farms. A two-way analysis of variance (ANOVA II) test was used to examine the significant differences in the nutrient contents between the studied farms and the interaction between the farm age and organ type on the nutrient concentrations and nutritive value of the Taif's rose populations grown in the studied four farms. When there were significant variations between the farms, a post hoc test (Tukey's test) was used. The statistical analysis was conducted using (SPSS software version 21.0 Armonk, NY, USA: IBM Corp) [35].

3. Results

3.1. Morphological and Growth Characteristics

The results of the current study showed that all the measured morphological and biomass parameters of Taif's rose were significantly different between the sampled farms, at $p \leq 0.001$ (Table 1). Additionally, Tukey's test showed significant intra-specific variations in the morphological and growth parameters. The maximum stem height (184.20 ± 3.10 cm) was recorded in the oldest farm (F4), while the minimum (110.50 ± 3.70 cm) was recorded in the youngest (F1). The crown diameter of the trees followed the same trend as the stem height, with the maximum (243.50 ± 3.10 cm) at F4 and the minimum (112.7 ± 3.9 cm) at F1. The highest stem and leaf waste biomasses were 3.52 ± 0.13 and 1.17 ± 0.04 kg $ind.^{-1}$, respectively, at F4, while the lowest were 0.89 ± 0.08 and 0.30 ± 0.03 kg $ind.^{-1}$ at F1. The maximum stem and leaf waste production levels were at F4 (3.91 ± 0.1 and 1.30 ± 0.05 t ha^{-1}, respectively). Likewise, the aboveground biomass (AGB) of the plants showed the same trend.

Table 1. Mean (±standard error, n = 10) morphological and biomass variables of the Taif rose populations grown in four farms in the mountainous area of Taif City in Saudi Arabia.

Variable	Farm No. (Age, Years)				F-Value
	1 (4 Years)	2 (10 Years)	3 (12 Years)	4 (20 Years)	
Height (cm)	110.50 ± 3.70 a	148.70 ± 3.70 b	155.30 ± 4.00 b	184.20 ± 3.10 c	69.8 ***
Diameter (cm)	112.70 ± 3.90 a	182.90 ± 2.60 b	204.50 ± 5.70 c	243.50 ± 3.10 d	186.4 ***
Stem biomass (kg ind.$^{-1}$)	0.89 ± 0.08 a	1.67 ± 0.07 b	2.49 ± 0.11 c	3.52 ± 0.13 d	128.5 ***
Leaf biomass (kg ind.$^{-1}$)	0.30 ± 0.03 a	0.56 ± 0.02 b	0.83 ± 0.04 c	1.17 ± 0.04 d	128.5 ***
AGB (kg ind.$^{-1}$)	1.19 ± 0.10 a	2.22 ± 0.09 b	3.32 ± 0.15 c	4.69 ± 0.17 d	128.5 ***
Stem biomass (t ha^{-1})	0.99 ± 0.08 a	1.85 ± 0.08 b	2.77 ± 0.12 c	3.91 ± 0.14 d	128.5 ***
Leaf biomass (t ha^{-1})	0.33 ± 0.03 a	0.62 ± 0.03 b	0.92 ± 0.04 c	1.30 ± 0.05 d	128.5 ***
AGB (t ha^{-1})	1.32 ± 0.11 a	2.47 ± 0.11 b	3.69 ± 0.16 c	5.21 ± 0.19 d	128.5 ***

F-values demonstrate the one-way analysis of variance (ANOVA), with degrees of freedom (df) = 3. Means in the same row followed by different letters are significantly different at $p < 0.05$, according to Tukey's HSD test. AGB: above-ground biomass; *** $p < 0.001$.

3.2. Soil Characteristics and Their Relationships with the Plant Variables

The chemical characteristics of the farms' soils showed that all the measured variables significantly differed between the four farms, with no influence of the farm age on the soil chemistry (Figure 1). The youngest farm (F1) had the highest values of soil pH (8.4), Cl^- (15.4 mg kg^{-1}), NO_3^- (4.4 mg kg^{-1}), SO_4^{2-} (1.0 mg kg^{-1}), and HCO_3^- (3.8 mg kg^{-1}), while F2 (10 years old) had the highest values of soil EC (0.9 mS cm^{-1}), total N (55.2 mg kg^{-1}), K^+ (104.5 mg kg^{-1}), Ca^{2+} (155.3 mg kg^{-1}), and Na^+ (170.5 mg kg^{-1}). On the other hand, the highest soil P content (8.9 mg kg^{-1}) was recorded in F3 (12 years old), while the highest soil Mg^{2+} (35.6 mg kg^{-1}) was recorded in the oldest farm (F4).

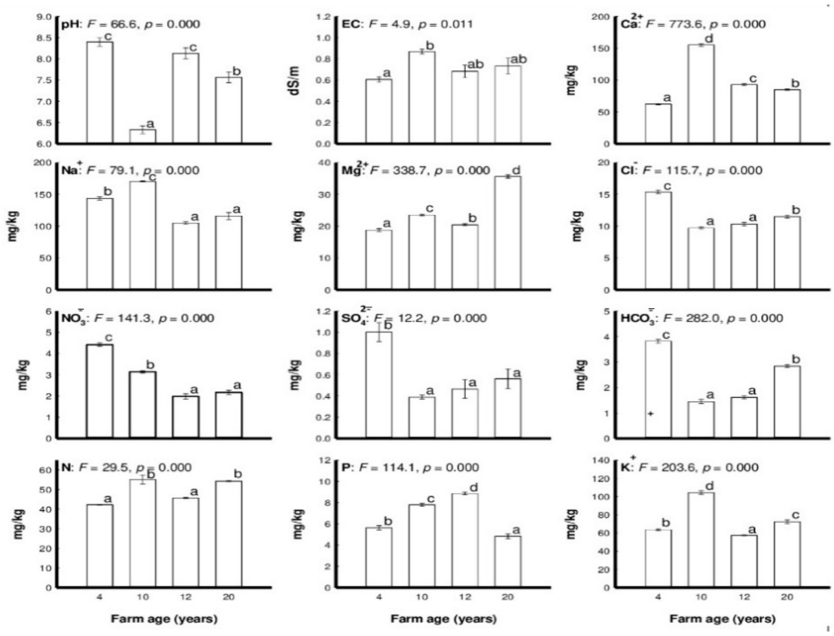

Figure 1. Mean soil characteristics of the four sampling farms in the mountainous area of Taif City in Saudi Arabia, supporting the growth of the Taif rose populations. The standard errors of the means (n = 6) are indicated by vertical bars. F-values demonstrate the one-way analysis of variance (ANOVA), with degrees of freedom (df) = 3. Means followed by different letters are significantly different at $p < 0.05$, according to Tukey's HSD test.

The plant–soil relationship was expressed using a CCA biplot, which showed that the plant height and crown diameter were at low positions on the N and NO_3 axes, respectively (Figure 2). In contrast, all the other measured plant parameters were at a higher position on the Mg axis. The interest correlations of the soil parameters (Table 2) showed that Cl^-,

NO_3^-, HCO_3^-, and SO_4^{2-} had high positive correlations with axis 1 and negative values with axis 2. In contrast, EC, total P, and Ca^{2+} had high positive correlations, while pH had high negative values, with axis 2. Moreover, Mg^{2+} was negatively correlated with axes 1 and 2.

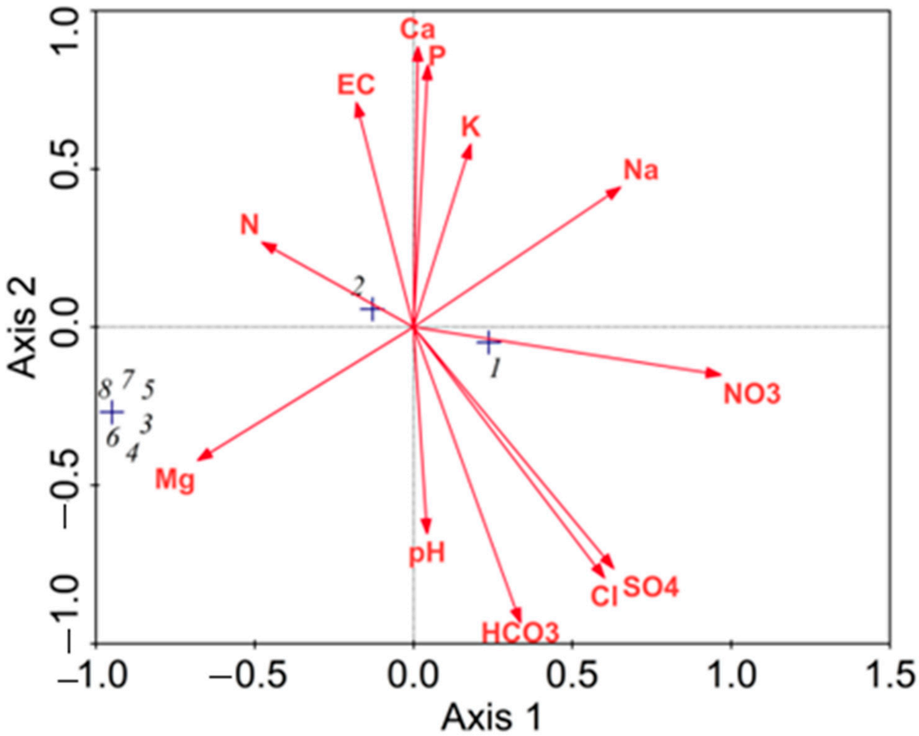

Figure 2. CCA biplot with the soil characteristics (→) and parameters (+) of Taif rose. 1: height (cm); 2: diameter (cm); 3: leaf biomass (kg ind.$^{-1}$); 4: stem biomass (kg ind.$^{-1}$); 5: above-ground biomass (kg ind.$^{-1}$); 6: leaf biomass (t ha^{-1}); 7: stem biomass (t ha^{-1}); 8: above-ground biomass (t ha^{-1}).

Table 2. Inter-set correlations of the soil characteristics with CCA axes.

Soil Characteristic	Axis 1	Axis 2
pH	0.0424	–0.6525
EC (dS m^{-1})	–0.1797	0.7102
Cl^- (mg kg^{-1})	0.6106	–0.7924
NO_3^- (mg kg^{-1})	0.9681	–0.1516
SO_4^{2-} (mg kg^{-1})	0.6303	–0.7626
HCO_3^- (mg kg^{-1})	0.3367	–0.9351
Total N (mg kg^{-1})	–0.4778	0.2682
Total P (mg kg^{-1})	0.0451	0.8280
K^+ (mg kg^{-1})	0.1805	0.5779
Ca^{2+} (mg kg^{-1})	0.0140	0.8868
Mg^{2+} (mg kg^{-1})	–0.6800	–0.4213
Na^+ (mg kg^{-1})	0.6225	0.4416

EC: electrical conductivity.

3.3. Inorganic and Organic Nutrient Contents

The results of the statistical analysis (ANOVA II) showed that the concentrations of the analyzed inorganic macronutrients in the leaves and stems of Taif's rose significantly differed between the studied farms and the estimated organs, with a significant positive intercept between the farm age and plant organ (Table 3). F1 had the highest N content (154.30 ± 7.99 mg kg^{-1}) in the plant leaves but the second-highest concentrations of stem N, P, Ca^{2+}, and Mg^{2+} and leaf Mg^{2+}. Additionally, F2 had the highest concentrations of stem N (172.33 ± 3.70 mg kg^{-1}) and P (9.40 ± 0.29 mg kg^{-1}). Moreover, F3 had the highest concentrations of leaf P (7.17 ± 0.09 mg kg^{-1}), leaf and stem K (112.47 ± 3.90 and 277.30 ± 8.52 mg kg^{-1}, respectively), stem Ca^{2+} (251.93 ± 7.99 mg kg^{-1}), and leaf and stem Mg^{2+} (122.27 ± 2.31 and 123.57 ± 1.86 mg kg^{-1}, respectively), while F4 had the highest concentration of leaf Ca^{2+} (206.30 ± 7.99 mg kg^{-1}).

Table 3. Mean (±standard error, *n* = 6) inorganic nutrient contents of Taif Rose populations grown in four farms in the mountainous area of Taif City in Saudi Arabia.

Element	Organ	Farm No. (Age, Years)				F_{Farm}	F_{Organ}	$F_{Farm \times Organ}$
		1 (4 Years)	2 (10 Years)	3 (12 Years)	4 (20 Years)			
N (mg kg^{-1})	Leaf	154.30 ± 7.99	42.20 ± 1.48	92.00 ± 2.65	103.50 ± 4.15	84.6 ***	163.8 ***	94.4 ***
	Stem	161.30 ± 6.61	172.33 ± 3.70	85.07 ± 2.72	136.20 ± 2.62			
P (mg kg^{-1})	Leaf	6.10 ± 0.11	6.70 ± 0.24	7.17 ± 0.09	6.33 ± 0.09	68.4 ***	0.2 ns	65.7 ***
	Stem	6.33 ± 0.16	9.40 ± 0.29	5.47 ± 0.15	5.33 ± 0.09			
K (mg kg^{-1})	Leaf	94.70 ± 1.66	103.43 ± 4.25	112.47 ± 3.90	95.57 ± 3.14	139.0 ***	412.9 ***	92.5 ***
	Stem	91.87 ± 1.57	174.67 ± 4.71	277.30 ± 8.52	154.87 ± 8.01			
Ca (mg kg^{-1})	Leaf	152.30 ± 5.58	171.47 ± 1.64	165.63 ± 8.99	206.30 ± 7.99	44.6 ***	4.1 *	70.1 ***
	Stem	150.83 ± 0.72	125.03 ± 4.68	251.93 ± 7.99	134.03 ± 3.41			
Mg (mg kg^{-1})	Leaf	114.10 ± 1.94	20.57 ± 0.26	122.27 ± 2.31	84.77 ± 1.05	974.9 ***	78.2 ***	50.3 ***
	Stem	111.87 ± 1.88	56.17 ± 1.81	123.57 ± 1.86	92.87 ± 1.69			
Na (mg kg^{-1})	Leaf	170.70 ± 2.98	186.23 ± 3.76	173.03 ± 3.23	140.60 ± 3.29	77.7 ***	216.7 ***	307.3 ***
	Stem	142.53 ± 4.04	68.67 ± 1.28	128.00 ± 2.14	205.40 ± 2.54			

F-values demonstrate the two-way analysis of variance (ANOVA); * $p < 0.05$; *** $p < 0.001$; *ns*: not significant (i.e., $p > 0.05$).

The statistical analysis (ANOVA II) of the organic nutrients in the leaves and stems of Taif's rose plants revealed significant variations in all the investigated nutrients between farms and organs and the intercept between farms and plant organs (Table 4). The leaves of F1 rose plants contributed the highest percentage of fats and total ash (0.79 and 14.07%, respectively), while their stems had the lowest ADL and percentage of fats (1.87 and 0.11%). Additionally, the leaves of the F2 rose plants had the highest percentage of NDF and the lowest total proteins (45.01 and 2.63%), while their stems had the highest percentages of total proteins and the lowest ash content (10.71 and 5.17%). Moreover, the leaves of the F3 plants had the highest percentage of ADL and the lowest of crude fibers (7.63 and 13.27%), while the stems had the highest NFE (i.e., total carbohydrates, 72.71%). The stems of the oldest rose plants in F4 had the highest ADF and crude fibers (32.60 and 45.90%) but the lowest NFE (38.37%), while the leaves had the lowest ADF and NDF (15.30 and 27.50%). It is noticeable that the stems had higher percentages of total proteins, fibers, ash, and NFE than the leaves in F1 and F2, while the opposite was observed in F3 and F4 (Table 4).

Table 4. Mean (± standard error, *n* = 6) organic nutrient contents of Taif Rose populations grown in four farms in the mountainous area of Taif City in Saudi Arabia.

Element	Organ	Farm Age (Years)				F_{Farm}	F_{Organ}	$F_{Farm \times Organ}$
		1 (4 Years)	2 (10 Years)	3 (12 Years)	4 (20 Years)			
ADF (%)	Leaf	18.20 ± 0.53	26.40 ± 1.24	31.60 ± 1.02	15.30 ± 0.83	40.1 ***	4.2 *	82.8 ***
	Stem	17.33 ± 0.40	25.13 ± 0.59	21.60 ± 0.61	32.60 ± 1.39			
ADL (%)	Leaf	2.67 ± 0.02	2.83 ± 0.09	7.63 ± 0.09	2.57 ± 0.06	690.9 ***	697.7 ***	391.1 ***
	Stem	1.87 ± 0.09	2.37 ± 0.09	3.03 ± 0.09	2.70 ± 0.04			
NDF (%)	Leaf	36.13 ± 1.04	45.10 ± 1.68	44.10 ± 0.79	27.50 ± 0.90	24.3 ***	5.8*	52.5 ***
	Stem	33.27 ± 0.38	36.10 ± 0.68	36.10 ± 1.04	40.57 ± 0.95			
Fat (%)	Leaf	0.79 ± 0.02	0.57 ± 0.01	0.24 ± 0.01	0.41 ± 0.01	198.5 ***	1627.5 ***	166.8 ***
	Stem	0.11 ± 0.01	0.23 ± 0.01	0.11 ± 0.01	0.11 ± 0.01			
Crude fiber (%)	Leaf	28.83 ± 1.52	28.27 ± 0.71	13.27 ± 0.71	17.07 ± 0.63	27.4 ***	161.3 ***	230.1 ***
	Stem	19.43 ± 1.08	17.43 ± 0.61	42.57 ± 1.02	45.90 ± 1.61			
Ash (%)	Leaf	14.07 ± 0.42	11.63 ± 0.82	8.03 ± 0.22	12.93 ± 0.58	4.7 **	147.8 ***	49.2 ***
	Stem	6.03 ± 0.28	5.17 ± 0.15	11.07 ± 0.79	7.10 ± 0.28			

Table 4. *Cont.*

Element	Organ	Farm Age (Years)				F_{Farm}	F_{Organ}	$F_{Farm \times Organ}$
		1 (4 Years)	2 (10 Years)	3 (12 Years)	4 (20 Years)			
Total Protein (%)	Leaf	9.65 ± 0.49	2.63 ± 0.09	5.75 ± 0.16	6.48 ± 0.25	87.6 ***	166.4 ***	95.8 ***
	Stem	10.08 ± 0.40	10.71 ± 0.24	5.31 ± 0.17	8.52 ± 0.17			
NFE (%)	Leaf	46.67 ± 0.61	56.91 ± 0.34	72.71 ± 0.66	63.11 ± 0.29	44.4 ***	117.6 ***	331.1 ***
	Stem	64.34 ± 0.97	66.47 ± 0.25	40.94 ± 1.97	38.37 ± 1.18			

ADF: acid detergent fibers, ADL: acid detergent lignin, NDF: neutral detergent fibers. *F*-values demonstrate the two-way analysis of variance (ANOVA); * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

3.4. Nutritive Value

The different calculated parameters of the nutritive values (except for the GE between farms) had significant variations between the studied farms and plant organs and the intercept between the farms and plant organs (Table 5). The range of DCP (%) in the leaves and stems of Taif's rose of this study ranged from 1.08–5.44% DM in F2 and F1 and from 1.42–6.43% DM in F3 and F2, respectively. The TDN (%) ranged from 55.97 to 60.85% in the leaves of F1 and F2 plants and from 54.77 to 58.56% in the stems of F2 and F3. Additionally, the ranges of DE and ME were 2.31–3.22 Mcal kg^{-1} in F1 and F3 and 1.89–2.64 Mcal kg^{-1} in the F2 and F3 plant leaves, respectively, while they were 2.07–3.15 Mcal kg^{-1} and 1.69–2.58 Mcal kg^{-1} in the F3 and F2 stems, respectively. Moreover, NE and GE varied significantly between the leaves (0.99–1.32 and 377.02–391.72 Mcal kg^{-1}, respectively) and stems (0.85–1.29 and 400.35–424.25 Mcal kg^{-1}, respectively) of the studied farms.

Table 5. Mean (± standard error, n = 6) nutritive values of Taif's Rose populations grown in four farms in the mountainous area of Taif City in Saudi Arabia.

Element	Organ	Farm No. (Age, Years)				F_{Farm}	F_{Organ}	$F_{Farm \times Organ}$
		4	10	12	20			
DCP (%)	Leaf	5.44 ± 0.46	1.08 ± 0.08	1.82 ± 0.15	2.50 ± 0.23	81.8 ***	98.8 ***	48.7 ***
	Stem	5.85 ± 0.37	6.43 ± 0.22	1.42 ± 0.16	4.40 ± 0.16			
TDN (%)	Leaf	55.97 ± 0.34	60.85 ± 0.06	58.34 ± 0.11	57.95 ± 0.17	78.5 ***	222.5 ***	96.5 ***
	Stem	55.13 ± 0.30	54.77 ± 0.18	58.56 ± 0.13	56.25 ± 0.13			
DE (Mcal kg^{-1})	Leaf	2.31 ± 0.02	2.44 ± 0.02	3.22 ± 0.02	2.74 ± 0.02	35.1 ***	9.2 **	418.9 ***
	Stem	3.02 ± 0.06	3.15 ± 0.01	2.07 ± 0.05	2.18 ± 0.02			
ME (Mcal kg^{-1})	Leaf	1.89 ± 0.02	1.99 ± 0.02	2.64 ± 0.02	2.25 ± 0.01	35.1 ***	9.2 **	418.9 ***
	Stem	2.48 ± 0.05	2.58 ± 0.01	1.69 ± 0.04	1.79 ± 0.02			
NE (Mcal kg^{-1})	Leaf	0.95 ± 0.01	0.99 ± 0.01	1.32 ± 0.01	1.12 ± 0.01	35.1 ***	9.2 **	418.9 ***
	Stem	1.24 ± 0.02	1.29 ± 0.01	0.85 ± 0.02	0.90 ± 0.01			
GE (Mcal kg^{-1})	Leaf	388.83 ± 1.94	385.15 ± 3.66	391.72 ± 1.75	377.02 ± 2.29	2.0 ^{ns}	324.4 ***	28.9 ***
	Stem	411.09 ± 0.91	414.76 ± 0.71	400.35 ± 2.15	424.25 ± 2.09			

DCP: digestible crude protein, TDN: total digestible nutrients, DE: digestible energy, ME: metabolized energy, NE: net energy and GE: gross energy. *F*-values demonstrate the two-way analysis of variance (ANOVA); ** $p < 0.01$; *** $p < 0.001$; *ns*: not significant (i.e., $p > 0.05$).

4. Discussion

One of the global goals is to ensure the long-term sustainability of agricultural systems. Organic fertilizers can help to improve sustainability by lowering the usage of chemical fertilizers. Keeping this in mind, the addition of vegetative waste to the soil during rose cultivation aims to the return of nutrients removed by the plants, which can help to reduce the contamination of the environment and play a role in the operation of this industry as a component of a bioeconomy [36]. As shown by the current results, the plant height and crown diameter increased with the increase in the farm age. The effect of age on the biomass of the plant stems and leaves was higher. The AGB value of 1.32–5.21 t/ha, due to the yearly pruning of rose plants in Taif, should be exploited in soil fertilization or animal feeding. The application of organic fertilizers can reduce the cost of chemical fertilizers, as well as the energy consumption during their production [37]. Composting rose waste is, in theory, an excellent way of producing stable organic fertilizers. This compost is usually rich in numerous microbial communities, including bacteria, fungi, and actinomycetes, which decompose organic matter in the presence of oxygen, resulting in a sustainable humic substance with a high nutritive quality [38]. Recently, following an unregulated biodegradation process, several industries have begun to add rose waste to the soil as compost.

The application of organic amendments, such as sewage sludge is, required in order to maintain the high organic matter content of rose-growing soils, but these amendments must be sustainable [36]. Since the same fertilization practices were applied to the four farms, the old farms accumulated more mineral nutrients than the youngest ones over the same time and, thus, the N contents in the old soils were higher than those in the young soils. The macronutrient contents of rose pruning wastes are promising for their use as compost and for increasing soil quality. Our results revealed that the age of the farms had a significant effect on the nutrient content of Taif rose plants, but without an exponential increase with age. The nutrient content of the Taif rose was lower than that reported for herbal plant residues [39] and olive mill waste [40]. However, in general, composting agriculture residue and converting it into organic fertilizer can help to reduce the need for chemical fertilizers and nutrient requirements [41]. Despite the importance of organic fertilizers to soil quality, they may not be an absolute substitute for chemical fertilizers, since their nutrient release rate is too slow to meet the crop requirements within a short time [42].

Forage quality, expressed mainly by the levels of crude protein (CP), crude fiber (CF), digestibility, and other associated characteristics, are essential for animal productivity [43]. CP and CF are classically viewed as indicators of the nutritional value of food for grazing animals [44]. CP is used as energy and helps to build tissue. Its calculation is based on a laboratory nitrogen analysis, from which the total protein content in foodstuff can be calculated by multiplying the total nitrogen by 100/16 or 6.25. This works on the assumption that nitrogen is derived from protein containing 16% nitrogen [45]. However, a certain portion of the N in most feeds is non-protein nitrogen and, therefore, the value calculated by multiplying N $\times$ 6.25 is referred to as the crude rather than true protein. According to MAFF [46], the minimum protein level in animal diets ranges between 6 to 12% DM, and accordingly, most of the recorded values of the CP content in the leaves and stems of the Taif rose lie within this range. Additionally, Taif rose has higher CP than that reported for certain grasses, such as *Hyperrhenia hirta* and *Chloris pycnothrix* [47]. Taif rose lies within the required range of CP for gestating cows (7–9%), as reported by NRC [25]. The crude fiber (CF) in plants represents all the cell wall fractions that are resistant to the action of digestive enzymes and includes the insoluble residue of acid hydrolysis, as well as alkaline hydrolysis [48]. The CF content is considered as a major indicator of the chemical composition when determining the energy feeding value of the forage [49]. In this study, the crude fiber was higher in the leaves than in the stems of young plants (F1 and F2), while the opposite was true for old plants (F3 and F4). The range of the CF in Taif's rose (13.27–45.90% DM) was either within or slightly higher than that which has been reported for some known wild forage plants, such as *Phragmites australis* (29.9% DM), *Panicum repens* (27.3% DM), and *Cynodon dactylon* (20.5% DM) [50,51]. Moreover, the range of the CF content in the young leaves and old stems of Taif's rose was higher than the mean content of temperate legumes (25.3%) and grasses (20.0%) [52].

Based on the plant age, the CP, ash, and CF contents were significantly affected, whereby they increased according to the N fertilization practices. Similar results were reported by Čop et al. [53] on the CF, Mohammed et al. [54] on the ash content, and Dindová, et al. [55] on the CP, CF, ash, and lipids. The lipid, or fat, percentage in Taif's rose in this study was very low compared to the dry leaves and shoots of *Vossia cuspidaa* [56,57] and corn stover (2.2%) [58]. The NFE was considerably high in Taif's rose leaves and stems (38.37–72.71%), similarly to other studied plants, such as *Echinochloa. stagnina* and *Eichhornia crassipes* ($\approx$54%), and higher than *C. demersum* (33.4%) [59]. This high carbohydrate content is effective in providing the rumen microbes with enough energy, which finally benefits lactating cows [60].

The nutritive value of forage is mainly the result of the chemical composition, including the CP content and fiber fractions such as NDF, ADF, and ADL [46]. Long-term fertilization showed consistent effects on the NDF, ADF, hemicellulose, cellulose, and ADL, as did the whole plant ash content [61]. After the ignition and/or oxidation of plant organic matter at a high temperature, the inorganic residue of the remaining chemical elements is called ash. The ash content in Taif's rose pruning waste was comparable with that of many plants, such as *V. cuspidata* (10.44%, [56]), *Panicum turgidum* (9.1%) [62], and *E. stagnina* (12.9%) [59]. In this study, the ADF was lower than that of wheat straw (46.5–50.8%, [63]), but the NDF was comparable to that reported for *Trifolium alexandrinum* [64] and *Leucaena lanceolata* (32.1%) [65]. Additionally, it was found that the ADF, NDF, and ADL increased, to some extent, with the farm age, receiving more long-term fertilization, in line with the study of Coblentz et al. [61] on oat plants. Furthermore, the percentages of CP, NDF, and ADF of Taif's rose were lower than 4.9%, 74.4%, and 44.4%, respectively, which were the values recorded in central Oklahoma [66], while values of 10.0%, 57.5 %, and 31.6 % were reported in western Washington [67] for forage intermediate wheatgrass. In the same context, Favre et al. [68] reported values of 11.4% CP, 59.7% NDF, and 33.7% ADF for Kernza intermediate wheatgrass in Wisconsin.

The DCP is an important component of proteins that is ingested and absorbed by the animal and not excreted in feces [69]. In this study, Taif's rose had a low DCP content (1.08–6.43%), which is comparable to that reported for *E. stagnina* (2.8%) and *E. crassipes* (3.7%) [60]. Additionally, it was lower than that reported for the shoots of *T. alexandrinum* (9 %) [70] and the leaves of *V. cuspidata* (13.82%, [56]). The total digestible nutrients (TDN) are defined as the energy content of the feeds available to animals after the digestion-induced losses [49]. The calculated TDN values of Taif's rose in this study (54.7–60.8%) were comparable to or higher than those of certain investigated plants, such as the leaves of *P. australis* (41.58%) [71], the shoots of *E. crassipes* and *L. stolonifera* (54.2% and 51.5%, respectively) [72], and the shoots of *C. demersum* (48.6%) [60]. This study revealed that Taif's rose has suitable contents of TDN for mature dry gestating beef cows, which require 55–60% [73].

The estimated values of the DE and ME of Taif's rose pruning waste were comparable to the values of 2.65, and 2.17 Mcal kg^{-1} DM, respectively, recorded for the hay of alfalfa (*Medicago sativa*), and 2.43 and 1.99 Mcal kg^{-1} DM for red clover (*Trifolium pratense*) [25]. The values of GE of Taif's rose pruning waste (377.02–424.25 Mcal kg^{-1} DM) were remarkably higher than those reported for *Cynodon dactylon* (389 Mcal kg^{-1} DM) and *Panicum repens* (398 Mcal kg^{-1} DM) [51] and the shoots of many grazable plants on the western Mediterranean coast of Egypt (399 Mcal kg^{-1} DM) [74].

5. Conclusions

The AGB value of 1.32–5.21 t/ha, due to the yearly pruning of rose plants in Taif, should be exploited in soil fertilization or animal feeding. The recycling of Taif rose pruning waste could be used in the manufacturing of organic fertilizer as a co-compost cover material. Taif rose pruning waste can also be considered as an interesting raw material due to its high content of digestible proteins and high energy compared with other sources of protein frequently used in animal feed. Moreover, the positive response, in terms of the growth performance of the rose plants, to the soil nutrient contents may allow us to consider the safe use of soil amendments, such as sewage sludge and treated wastewater, for improving production.

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