

## Article

# Fractional Harvest of Fodder Galega for Improved Herbage Nutritive Value

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**Abstract:** Fodder galega (*Galega orientalis* Lam.) is a long-lived perennial legume grown for forage and green manure in northern and central Europe. It is distinguished by a high proportion of leaves in the aboveground mass, tall hollow stems, and rhizomes. A method to harvest galega allowing the separation of leaves, upper stem fragments, and inflorescences from the thick, woody parts of the stem is therefore justified. This would significantly expand the possibilities of using galega herbage, including as feed for monogastric animals. A modified flail chopper (MFC), a machine originally used for harvesting green forage, was used for the fractionated harvest of galega. The aim of this study was to evaluate the yield potential of various plant fractions of the first and second cut of fodder galega at three development stages and their nutritive value when harvested with an MFC. With this harvest system, 68–78% of the potential dry matter yield of galega was harvested, where leaves accounted for 73% of the dry matter on average, while the proportion of leaves in the yield of galega harvested with a mower (M) ranged from 50% to 60%. In the biomass of the first cut of galega, harvested with the MFC, protein concentration was 215 g kg<sup>-1</sup>, 11.5% greater than in the biomass of the whole aboveground mass harvested with a mower. In the second cut, this difference, in favor of the MFC, was greater by 14%. The concentration of neutral detergent fiber (NDF) was 7.5% lower and acid detergent fiber 11% lower in galega forage harvested with the MFC compared to with a mower. Furthermore, galega harvested with MFC had 13% greater NDF digestibility and 6% greater in vitro true digestibility. The stubble remaining after MFC harvest accounted for 33% of the total height and 27% of the plant dry mass, and its qualitative composition indicates that it could be used in rations of livestock with low nutritional requirements or for non-forage purposes. Galega harvest with the MFC resulted in greater protein concentrations and overall improved nutritive value of the forage even at advanced development stages.

**Keywords:** *Galega orientalis* Lam.; forage legume; leaf harvest; flail chopper; leaf protein



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## 1. Introduction

Intensive livestock production requires year-round access to high-quality feed, including high-protein feed. However, in the European Union countries, and especially in central and northern Europe, a shortage of feed protein has been noted for many years. This gap is filled by the importation of soybean meal, because locally grown legume seed-crops have low and unstable yields [1], which is primarily due to unfavorable climate, including short growing season and increasingly frequent periods of drought. The full potential of perennial legumes, many of which are drought tolerant, is still untapped and their protein yields are often twice as high as that of annual crops. Currently, perennial legumes are mainly used for feeding ruminants but could also be used to feed monogastric livestock and as a feedstock for bioenergy production. To achieve this, however, the introduction of new technologies for harvest and crop management will be required [1].

Of the perennial legumes adapted to central and northern Europe, alfalfa (*Medicago sativa* L.) is the species with the greatest potential [2]. However, it is a challenge to grow

alfalfa in some regions because of less than ideal climatic and edaphic conditions and susceptibility to diseases. This has encouraged the search for alternative perennial legumes with similar biological and functional values, but with greater durability and yield stability. Such a plant could be fodder galega (*Galega orientalis* Lam.), distinguished by its persistence, especially with 2–3 cut management, and tolerance of drought and frigid winter temperatures [3,4]. This legume was first investigated as a forage crop in Estonia and Finland [5,6], and its usefulness was confirmed in many other regions of Europe, as well as in North America [7–11]. Annual dry matter yields of galega often exceed  $10 \text{ t ha}^{-1}$  and the forage, similar to alfalfa, is a rich source of protein and digestible fiber [10,12,13]. Fodder galega, fresh, ensiled, or dried, can therefore be successfully used in ruminant livestock rations [14]. A major factor limiting the forage use of this species is a rapid decline in nutritive value with advancing plant maturity. The decline in nutritive value is particularly intense in the first spring growth due to the increasing proportion of stems relative to leaves, and lignification of stem fibers [15,16]. However, the interest in use of biomass for heat production is growing [17], and mature galega stems could satisfy that role.

In immature fodder galega plants, leaves comprise 50–70% of the aboveground biomass [8,10]. Since leaves contain most of the protein, these organs are a potential source of raw material for obtaining high-quality dried feed or protein concentrates. By-products in the production of protein concentrate are pressed residues and so-called drainage. Pressed residues can be ensiled and used as forage, and the drainage unsuitable for animal feeding can be used as liquid agricultural fertilizer with a high concentration of potassium and non-protein nitrogen [8]. The stems of fodder galega can be used as natural fertilizer [18] or constitute a raw material for the production of thermal energy or biogas [19,20]. Additionally, Baležentienė [17] described the aesthetic value of the plant during flowering, and galega flowers are attractive to pollinators.

Apart from the authors' preliminary results [8,21], there are no studies on the nutritive value of fodder galega leaves. Galega leaves contain 27–30% crude protein and 19–20% crude fiber [8], which suggests the possibility of their use for feeding to monogastric livestock, e.g., pigs, as suggested for alfalfa by Hakl et al. [22], Liebhardt, et al. [23], and Péter et al. [24]. Moreover, the high proportion of leaves in the biomass of fodder galega and their yield suggest the usefulness of fractionating the aboveground biomass, preferably during harvest, into two or more components (leaves, thin upper fragments of stems with inflorescences, and stems).

The technical operations for fractionated harvesting are most broadly and best developed for alfalfa. They include both dry [25,26] and fresh plant material [27,28]. It is also possible to fractionate during the drying operation [29,30]. Of these different harvest methods, a relatively simple and inexpensive method for harvesting the leaves together with the upper, thin stem fragments and inflorescences using a modified flail chopper (MFC) was described by Andrzejewska et al. [27] and Ignaczak and Andrzejewska [31]. Bud-stage alfalfa harvested with an MFC produces feed that is suitable for swine. Moreover, this method makes it possible to delay alfalfa harvest until the end of its flowering period while maintaining adequate nutritive value for ruminant livestock. Galega plants have an upright growth habit and, compared to alfalfa, much larger leaves, but taller, thicker, hollow and rapidly lignified stems (the authors' observations). These characteristics suggest that harvesting galega with an MFC may be more effective than alfalfa and will provide a feed that is also useful for monogastric livestock.

The aim of the study was to assess the yield potential of various plant fractions of the first and second cut of fodder galega and their nutritive value, especially protein concentration, when harvested at different development stages using a modified flail chopper.

## 2. Materials and Methods

### 2.1. Experimental Site and Field Operations

The experiment was carried out in 2016 and 2017 at the Mochełek Research Station (53°12' N, 17°51' E), Poland, in a 20-year-old field of 'Risa' galega, with the first and second cuts at various development stages. Harvest times and galega development stages are presented in Table 1. The stand of galega was uniform and stem density was approximately 100 stems per m<sup>2</sup>, with no significant disease, insect, or weed pests observed in the field.

**Table 1.** Development stages and harvest times of fodder galega.

Year	Cut	Harvest Date	Number of Regrowth Days	Development Stage
2016	1	23 May	43 <sup>1</sup>	Early flower <sup>2</sup>
		2 June	53	Full flower <sup>3</sup>
		13 June	64	Late flower <sup>4</sup>
	2	4 July	32	Early flower
		8 July	36	Full flower
	2017	1	31 May	61 <sup>1</sup>
9 June			70	Full flower
19 June			80	Late flower
2		12 July	33	Early flower
		24 July	45	Full flower

<sup>1</sup> For the first spring cut, number of days of regrowth was counted from the day that average daily temperature reached 5 °C; <sup>2</sup> 10–20% stems with flowers; <sup>3</sup> 20–80% stems with flowers; <sup>4</sup> >80% stems with flowers.

At each harvest event, a 200-m<sup>2</sup> portion of the field was designated for sampling. Observations and measurements before each mechanical harvest were made in four representative sites of this area. The height of 10 plants was measured and averaged. A walk-behind sickle-bar mower was used to harvest galega from four 1-m<sup>2</sup> microplots leaving a 5-cm stubble, to represent the mowed (M) treatment. Fresh forage mass was recorded and an approximately 300-g sample was saved for leaf and stem separation. Yield fractions were dried at 60 °C and, after determination of dry matter concentration, were used for laboratory assessment of nutritive value. The remainder of the 200-m<sup>2</sup> area was harvested with a modified flail chopper (MFC). From the whole mass of the forage harvested in this way, four green samples of approximately 300 g each were taken at random and used for determination of dry matter concentration, leaf and stem proportions, and chemical analyses. Values for chemical analysis of separated leaves and stems were mathematically combined, based on proportions, to calculate values for the total harvested biomass. The height of residual stubble and its biomass were measured as described previously for the M treatment. The yield of green forage harvested using an MFC and its morphological composition were calculated using the results of the measurements of stem residues and fractionated plants from the M treatment. The plant material was dried at 60 °C for dry matter determination, and all yield and fractionation results are expressed on a dry matter basis. Each forage harvest with the MFC was preceded by a machine test to determine the optimal height setting and working speed.

### 2.2. Technical Characteristics of the Modified Flail Chopper

The galega was harvested using a modified Orkan 2 Flail Chopper (UNIA, Grudziadz, Poland). It is a trailed machine, aggregated with a 30–50 hp agricultural tractor, and driven by a power take-off shaft. The original machine is equipped with a flail-type cutting unit with 25 knives arranged on a drum in four rows. It is primarily used for harvesting green grass or legume forage crops, and it performs pneumatic transport of collected material to a trailer attached behind the machine. The working width of the machine is 1.25 m and the drum rotation speed is approximately 1400 rpm. The working speed, depending on the crop height and density, is 3–4 km h<sup>-1</sup>, with the ability to harvest 0.3–0.4 ha h<sup>-1</sup>. Other basic technical information about the Orkan 2 flail chopper is provided in the application

for a utility model registration [31] and in a paper describing its application to alfalfa [27]. The machine modification consisted of replacing the original knives and supports on the cutting drum of the Orkan 2 machine with 12 five-link pieces of chain arranged on the drum in two opposite rows. In the other two rows, knives were removed from the original supports, leaving 13 knife supports, inverted with the bend in the direction of rotation of the drum. Nominal inside chain link length was 24 mm, with 5-mm wire diameter. The installed chain sections had the same length as the original knives and fit within the drum cover precisely. This modification of the main working part of the machine allows stripping the leaves together with fragile stem tips without significant mechanical damage and pneumatic transport of the crop to the trailer.

### 2.3. Chemical Analysis of Plant Material

Dry subsamples were ground to pass through a 2.0-mm screen and then reground with a cyclone mill to pass through a 1-mm screen before nutritive value analysis. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed sequentially by the batch procedures outlined by the ANKOM Technology Corporation (Macedon, NY, USA) with an ANKOM 200 fiber analyzer and addition of heat-stable  $\alpha$ -amylase and sodium sulfite to the neutral detergent solution [32]. A modified Goering and Van Soest [33] procedure was used to determine 48 h *in vitro* true digestibility (IVTD) with buffered rumen fluid followed by a neutral detergent wash of post-digestive residues. The rumen fluid incubation was performed with ANKOM F57 filter bags and an ANKOM Daisy II incubator using the batch incubation procedure (ANKOM Technology, Macedon, New York, NY, USA). Neutral detergent fiber digestibility (NDFD) was calculated from NDF and IVTD values as  $((\text{NDF} - (1000 - \text{IVTD}))/\text{NDF}) \times 1000$ . Total N was determined by the Dumas combustion method with a LECO model FP-528 (LECO Corporation, St. Joseph, MI, USA), and crude protein (CP) was calculated as  $\text{N} \times 6.25$ .

### 2.4. Statistical Analysis

Plant and stubble height as well as yield and stubble chemical composition data were analyzed using one-way analysis of variance, and yield and chemical composition of galega harvested with the MFC or mower were analyzed using two-way analysis of variance. The results are presented as a synthesis of the two-year study. The first factor of the experiment was harvest method: mower (M) or modified flail chopper (MFC); and the second factor was harvest time (cut and development stage of galega): first cut, early flower; first cut, full flower; first cut, late flower; second cut, early flower; and second cut, full flower. Significant differences between means were reported using the Tukey test (LSD;  $p < 0.05$ ). All analyses were carried out using the Statistica 12.1 software package (StatSoft Inc., Tulsa, OK, USA).

## 3. Results and Discussion

The levels of CP concentration, CP yield, NDF, and NDFD concentration in the harvested galega forage were significantly different in the two study years (Table 2). Harvest method and time significantly affected all monitored characteristics of the harvested crop. The harvest time  $\times$  method interactions were statistically significant for DM and protein yields and dry matter concentration in plants. A year  $\times$  harvest time interaction was observed for most of the characteristics (except of DM yield, CP concentration, and yield and IVTD). However, the magnitudes of the interactions were small and nonconsequential.

**Table 2.** Analysis of variance of the characteristics studied as a function of year, harvest time, and harvest method.

Characteristic	Year (Y)	Harvest Method (M)	Harvest Time (T)	Interaction		
				Y × M	Y × T	T × M
Dry matter yield (g m <sup>-2</sup> )	n.s.	**	**	n.s.	n.s.	*
Leaf proportion (g kg <sup>-1</sup> )	n.s.	**	**	n.s.	*	n.s.
Dry matter concentration (g kg <sup>-1</sup> )	n.s.	**	**	n.s.	**	*
Crude protein (g kg <sup>-1</sup> )	**	**	**	n.s.	n.s.	n.s.
Protein yield (g m <sup>-2</sup> )	**	**	**	n.s.	**	**
NDF (g kg <sup>-1</sup> )	**	**	**	**	n.s.	n.s.
ADF (g kg <sup>-1</sup> )	n.s.	**	**	**	n.s.	n.s.
NDFD (g kg <sup>-1</sup> NDF)	*	n.s.	**	n.s.	**	n.s.
IVTD (g kg <sup>-1</sup> )	n.s.	**	**	n.s.	n.s.	n.s.
Ash (g kg <sup>-1</sup> )	n.s.	**	**	n.s.	**	n.s.

n.s., non-significant; \* significant at the 0.05 level of probability; \*\* significant at the 0.01 level of probability.

The height of galega stems at first cut ranged from 90 to 120 cm, and at second cut from 52 to 65 cm, increasing significantly as the plants developed during each growth cycle. The height increase between successive harvests was about 14 cm (Table 3). On average, approximately 73% of the dry matter biomass was harvested with the MFC compared to with the mower. This yield at all harvest dates was significantly lower compared to the yield obtained with the mower. Regardless of the harvest method, the greatest yields were obtained in the first cut, especially when the plants were in full bloom and at the end of flowering. The yield of the second cut was on average 44% of the first cut yield. Other authors report a similar distribution of yield in the cuts [4,9,13,15]. In practice, as in this experiment, two harvests of galega are typically taken in a season. The total yield of the first and second cut, averaged over development stages, was 820 g m<sup>-1</sup>, which can be extrapolated to 8.2 t ha<sup>-1</sup>. This yield was obtained from a 20-year-old stand, and therefore confirms claims about the exceptional persistence of fodder galega [3,10]. This extreme persistence makes galega ideally suited to the requirements of sustainable agriculture, as outlined by Harasimowicz-Hermann and Ignaczak [34] and Ignaczak and Szczepanek [35,36].

**Table 3.** Plant height, dry matter yield, leaf proportion, and dry matter concentration of galega at two cuts and three maturities, depending on harvest method (mean over two years).

Characteristic	Harvest Method <sup>1</sup>	1st Cut			2nd Cut		Mean
		Early Flower	Full Flower	Late Flower	Early Flower	Full Flower	
Plant height (cm)	M and MFC	90 c <sup>2</sup>	104 b	120 a	52 e	65 d	90
Dry matter yield (g m <sup>-2</sup> )	M	544 Ab	705 Aa	748 Aa	257 Ac	315 Ac	514 A <sup>3</sup>
	MFC	369 Bb	524 Ba	539 Ba	192 Bc	246 Bc	374 B
	Mean	457 b	615 a	644 a	224 c	280 c	444
Leaf proportion (g kg <sup>-1</sup> )	M	582	497	517	622	595	563 B
	MFC	751	641	699	809	755	731 A
	Mean	667 ab	569 b	608 ab	715 a	675 ab	647
Dry matter concentration (g kg <sup>-1</sup> )	M	171 Ad	205 Ac	280 Aa	228 Ab	243 Ab	225 A
	MFC	138 Bd	190 Ac	256 Ba	221 Ab	237 Ab	208 B
	Mean	155 e	197 d	268 a	224 c	240 b	217

<sup>1</sup> Sickle-bar mower (M), modified flail chopper (MFC); <sup>2</sup> values within rows followed by different lowercase letters are significantly different at the 95% confidence level; <sup>3</sup> pairs of values within columns and characteristic followed by different uppercase letters are significantly different at the 95% confidence level.

The proportion of leaves in galega harvested with the mower ranged from 497 to 622 g kg<sup>-1</sup>, and when harvested with the MFC ranged from 641 to 809 g kg<sup>-1</sup>, approximately a 30% increase in both cuts (Table 3). Regardless of the harvest method, the highest proportion of leaves was found in the first cut when plants were at the early flower stage, and in the second cut. The leafiness of fodder galega is an important characteristic [5,8], and an inspiration to construct a device (MFC) to harvest leaves separately from stems [31]. Under the same natural and technical conditions as the current experiment, leaf proportion of alfalfa harvested with a mower ranged from 350 to 500 g kg<sup>-1</sup> and harvested with the MFC increased to 490 to 710 g kg<sup>-1</sup>, about a 40% increase [27].

The dry matter concentration of galega forage typically increased with maturity, to a greater extent in the first than in the second cut (Table 3). On average, dry matter concentration was lower in the forage harvested with the MFC because of a greater proportion of more hydrated leaves.

In the first year of the study, the mean CP concentration in galega forage was 213, and in the second year 178 g kg<sup>-1</sup>, but in both years the experimental treatments of harvest method and harvest time had similar effects on CP (data not shown). On average, for the two years of the study, CP concentration decreased significantly with increasing maturity in the first cut (Table 4) but in second cut CP concentration was similar in early flower and full flower galega. Crude protein concentration was always higher in forage harvested with the MFC than with the mower, by an average difference of 23 g kg<sup>-1</sup> or 13%. The mean CP yield of galega harvested with the MFC was, however, 19% lower than the CP yield harvested with the mower, with the differences tending to decrease as the harvest time was delayed. The percent loss of CP yield of galega harvested with the MFC was less than the reduction in the dry matter yield.

In the first year of the study, the mean NDF concentration in galega forage was 462 g kg<sup>-1</sup>, and, in the second year, it was 496 g kg<sup>-1</sup>, but in both years the direction of change in this characteristic was the same, as influenced by both experimental treatments (data not shown). The differences in NDF and CP between years can be explained by chronologically older plants, at similar maturity stages, in the second year of the study, especially in the first cut (Table 1). Similar relations between the number of regrowth days and the qualitative composition of galega fodder were reported by Møller and Hostrup [15], who suggested that, for this species, when determining the harvest time for fodder, one should be guided by the number of regrowth days and development stage of plants. Stem length of second cut galega was much shorter than first cut, which would be expected to be associated with lower fiber and greater CP concentrations. There is strong documentation with alfalfa that stem length is more closely related to NDF and ADF concentrations than maturity of the plant [37]. In North America, the first cut of alfalfa is typically based on stem length, approximately 70 cm, and subsequent harvests are made at 28–35-day intervals, depending on goals for nutritive value [38]. If interest in galega cultivation increases, development of precise harvest guidelines for it is warranted. On average, for both years of the study, the lowest NDF concentration was found in first-cut galega at the early flowering stage (Table 4). Neutral detergent fiber concentration was always lower in forage harvested with the MFC, on average by 37 g kg<sup>-1</sup> (7.5%).

Acid detergent fiber concentrations followed a similar pattern as NDF. Greatest ADF concentrations were found in first-cut forage harvested at the full and late flower stages, and significantly lower in plants harvested at other times. On average, the ADF concentration in forage harvested with the MFC was 38 g kg<sup>-1</sup> (11%) lower compared to forage harvested with the mower. The highest NDFD and the highest digestibility (IVTD) were found in forage of galega that was mowed at early flower in the first and second cuts. Harvesting with the MFC resulted in an average increase in NDFD of 69 g kg<sup>-1</sup> NDF (13%) and IVTD by 43 g kg<sup>-1</sup> (6%) and ash concentration by 6 g kg<sup>-1</sup> (7%) compared to their concentrations in plants harvested with the mower. The improvement in nutritive value associated with the MFC is associated with a greater proportion of leaves in the harvested forage. Greater ash concentration in MFC harvested forage is probably a

simple consequence of greater ash concentrations in leaves than in stems of many forage plants [39].

**Table 4.** Concentration and yield of CP, concentration of NDF, ADF, NDFD, IVTD, and ash in galega at two cuts and three maturities, dependent on harvest method (mean for two years).

Characteristic	Harvest Method <sup>1</sup>	1st Cut			2nd Cut		Mean
		Early Flower	Full Flower	Late Flower	Early Flower	Full Flower	
Crude protein concentration (g kg <sup>-1</sup> )	M	233	182	157	177	172	184 B <sup>3</sup>
	MFC	257	203	179	201	196	207 A
	Mean	245 a <sup>2</sup>	192 b	168 c	189 b	184 bc	196
Crude protein yield (g m <sup>-2</sup> )	M	128 Aa	128 Aa	118 Aa	46 Ab	54 Ab	95 A
	MFC	95 Ba	106 Ba	97 Ba	39 Bb	48 Bb	77 B
	Mean	111 a	117 a	108 a	42 b	51 b	86
NDF (g kg <sup>-1</sup> )	M	458	518	527	499	487	498 A
	MFC	416	474	486	470	456	461 B
	Mean	437 c	496 ab	507 a	485 ab	472 b	479
ADF (g kg <sup>-1</sup> )	M	327	382	378	340	338	353 A
	MFC	290	341	333	304	306	315 B
	Mean	309 b	362 a	356 a	322 b	322 b	334
NDFD (g kg <sup>-1</sup> NDF)	M	576	488	497	588	520	534 B
	MFC	662	562	559	652	579	603 A
	Mean	619 a	525 b	528 b	620 a	549 b	568
IVTD (g kg <sup>-1</sup> )	M	800	724	729	791	757	760 B
	MFC	874	772	773	828	793	803 A
	Mean	823 a	748 b	751 b	810 a	775 b	781
Ash (g kg <sup>-1</sup> )	M	75	60	64	77	79	71 B
	MFC	79	67	69	83	82	76 A
	Mean	77 a	63 b	66 b	80 a	80 a	73

<sup>1</sup> Sickle-bar mower (M), modified flail chopper (MFC); <sup>2</sup> values within rows followed by different lowercase letters are significantly different at the 95% confidence level; <sup>3</sup> pairs of values within columns and characteristic followed by different uppercase letters are significantly different at the 95% confidence level.

Due to the erect habit and relatively thick stems, especially in the rapidly growing first growth, it could be assumed that fodder galega is a species with lower forage nutritive value than other perennial legumes. An experiment with alfalfa, carried out under the same conditions [27], allows direct comparison of the nutritive value of galega and alfalfa harvested with a mower or MFC (Table 5). This comparison confirms the report by Teleuță et al. [10] of similar forage nutritive value of alfalfa and galega. The increase in CP concentration and decrease in NDF and ADF concentrations associated with MFC harvest were greater for alfalfa than galega forage. However, galega forage harvested with the MFC had greater improvements in NDFD and IVTD than alfalfa forage. Galega stems, unlike alfalfa stems, are hollow. Crushing stems before ensiling, as occurs with the MFC, not only accelerates wilting, but also facilitates removal of air, thus improving ensilability. When harvesting galega with the MFC, most of the stems remain in the field. The yield collected in this way can also be used, as in the case of alfalfa [40], for the preparation of silage, but with particular emphasis on the principles of ensiling high-moisture, high-protein raw material.

**Table 5.** Comparison of nutritive value parameters of alfalfa and galega forage depending on the harvest and harvest method (means over two years). Alfalfa data are adapted from Andrzejewska et al. [27].

Characteristic	Harvest Method	Alfalfa		Fodder Galega	
		1st Cut	2nd Cut	1st Cut	2nd Cut
CP, g kg <sup>-1</sup>	M	165	196	191	174
	MFC	192	222	213	198
	Difference (%)	+16.4	+16.3	+11.5	+13.8
NDF, g kg <sup>-1</sup>	M	494	478	501	493
	MFC	430	415	459	463
	Difference (%)	−13.0	−13.3	−8.4	−6.1
ADF, g kg <sup>-1</sup>	M	363	345	362	339
	MFC	312	272	321	305
	Difference (%)	−14.1	−21.2	−11.3	−10.1
NDFD, g kg <sup>-1</sup> NDF	M	522	556	520	554
	MFC	521	571	594	615
	Difference (%)	0	+2.7	+14.2	+11.1
IVTD, g kg <sup>-1</sup>	M	760	803	751	774
	MFC	766	829	806	810
	Difference (%)	+0.8	+3.2	+7.3	+4.6

Harvesting galega with the MFC resulted in, on average, 27% of the biomass remaining in the field as stubble, compared to harvest with a mower. The height of the stubble left was, on average, 33% of the total plant height (Table 6). Differentiation in the residual stubble left in the field after harvest with the MFC was related primarily to the setting of the working height, determined in test runs, which allowed collection all the leaves and leaving the stubble as tall as possible. In the first cut, residual stubble height increased with advancing maturity of plants and their dry matter concentration. In the second cut, when the plants were shorter, the MFC left significantly shorter stubble than in the first cut. Stubble dry matter concentration was greater in the second cut than at the same development stages of the first cut, which was related to higher air temperatures and lower soil moisture in the summer period. The CP concentration in the leafless stubble was on average 92 g kg<sup>-1</sup> lower than the concentration in the crop harvested with the MFC (207 g kg<sup>-1</sup>) (Tables 4 and 6). As in the harvested crop, the CP concentration in stubble decreased as galega maturity advanced. Neutral detergent fiber concentration was, on average, 139 g kg<sup>-1</sup> and ADF 129 g kg<sup>-1</sup> greater in stubble than in the harvested crop of galega. The plant development stage did not affect concentration of either fiber fraction in the stubble. The NDFD of stubble was, on average, 170 g kg<sup>-1</sup> NDF lower, and IVTD 244 g kg<sup>-1</sup> lower than in the harvested crop. The highest values of stubble NDFD and IVTD were found in the first cut at the early flowering stage. Ash concentration in the stubble was 11 g kg<sup>-1</sup> lower than that of galega forage harvested with the MFC. A similar phenomenon was noted in harvesting alfalfa [27] and is a result of greater ash concentrations, often double, in leaves than in stems of forage crops [39].

The use of stubble may be similar to that proposed by Andrzejewska et al. [27] for alfalfa, i.e., it can be used as feed for classes of ruminants with low nutritional demand, such as dairy heifers or dry cows; provide mulch from fragments of stems cut and left in the field; or be used as a source of bioenergy. Leaving tall stubble has a negative effect on the yield of subsequent regrowth of alfalfa [41], so after harvesting galega with the MCF it may be necessary to mow it. Our own observations indicate that fodder galega can be mowed very short because it regrows primarily from underground portions of crowns and rhizomes. Furthermore, residual uncut stubble would make subsequent harvests with the MFC more difficult. It would therefore be desirable to retrofit the MFC with a second cutting mechanism to mow the stubble in the same operation as leaf harvest. Leaving tall stubble



of galega without mowing in the last harvest of the season would aid in retaining snow on the field, thus improving soil moisture in the subsequent season. Furthermore, this would reduce machinery costs, provide a mulch to reduce weed infestation, and enrich the soil with organic matter, contributing to EU sustainable agriculture goals. This is especially important on light soils with a pH > 5.6, where galega cultivation is recommended [6].

**Table 6.** Characteristics of residual stubble after galega was harvested with a modified flail chopper (mean for two years).

Characteristic	1st Cut			2nd Cut		Mean
	Early Flower	Full Flower	Late Flower	Early Flower	Full Flower	
Stubble height, cm	33 b <sup>1</sup>	35 b	41 a	26 c	28 c	33
Dry matter, g kg <sup>-1</sup>	141 d	182 c	293 a	223 b	254 b	219
Crude protein, g kg <sup>-1</sup>	128 a	122 a	108 b	110 ab	106 b	115
NDF, g kg <sup>-1</sup>	567	621	612	583	619	600
ADF, g kg <sup>-1</sup>	416	461	461	427	456	444
NDFD, g kg <sup>-1</sup> NDF	493 a	457 b	412 c	399 c	402 c	433
IVTD, g kg <sup>-1</sup>	712 a	663 b	640 b	650 b	628 b	659
Ash, g kg <sup>-1</sup>	67	70	58	68	65	65

<sup>1</sup> Means within rows followed by different letters are significantly different at the 95% confidence level.

Our results add to the body of literature suggesting that, in the temperate climate of central and northern Europe, galega is an underutilized forage crop with additional significant non-fodder value. It is an exceptionally durable species, high-yielding in light soils, with fodder quality parameters comparable to alfalfa. Furthermore, the amino acid composition of both alfalfa and galega protein is dominated by aspartic acid, but galega protein contains more arginine, lysine, and leucine [10,14], contributing to usefulness as a protein source for non-ruminant livestock. This study demonstrates that forage with good nutritive value is obtained by harvesting galega at the early flower stage, and, additionally, the nutritive value can be significantly improved by harvesting plants using an MFC. Green forage obtained in this way may be a suitable feed not only for ruminants, but also for sows [24,42] and possibly also for geese [43]. Moreover, it has been proposed that fodder galega be used as a bioenergy feedstock [13,44] or for soil bioremediation [45], which increases the versatility and economic value of the crop.

#### 4. Conclusions

Fodder galega, one of the few forage legumes adapted to northern regions of Europe to have rhizomes, is more persistent than other perennial legumes and could play an increased role as a protein crop and livestock feed in the future. Its outstanding persistence contributes to stable productivity and reduced incidences of reestablishment, an operation that typically involves tillage and exposing land to erosion. Protein concentration and nutritive value of harvested herbage are significantly improved by the fractionated harvest proposed here, which allows obtaining herbage with a dominant proportion of protein-rich leaves with low fiber and high digestibility. The proposed harvest method with the MFC enabled collection of most leaves and upper parts of plants, including inflorescences, with simultaneous pneumatic transport to a trailer attached behind the machine. With the MFC, about 70% of the potential mass of the crop was harvested, with nutritional value substantially greater than that of mower-harvested galega. The crop harvested in this way retained high forage nutritive value even in advanced development stages. The stubble after harvesting galega in the flower stage with an MFC had a mediocre nutritional value, and after mowing it should be used for livestock with low nutritional requirements or for non-fodder purposes. A 20-year-old stand of fodder galega remained productive and served as a valuable source of forage, and nutritive value was enhanced by harvest with an MFC. Further improvement of fodder galega harvest technology, with the use of an MFC, should aim at more precise separation of leaves from stems, so that they can be used more effectively as a feed protein source for non-ruminant livestock.

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