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Effect of Fertilization on the Energy Profit of Tall Wheatgrass and Reed Canary Grass

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Abstract: Cultivation of energy crops is a part of modern agriculture. In particular, maize (*Zea mays* L.) is widely grown in central Europe. However, in terms of erosion risk and high demands on fertilization and protection against diseases and pests, its growing is not environmentally friendly. Therefore, possibilities of utilization of other more environmentally friendly energy crops have been examined at present. The aim of the study was to evaluate the effects of various fertilization (mineral, digestate, control) on the yields of tall wheatgrass (TWG) (*Elymus elongatus* subsp. ponticus) and reed canary grass (RCG) (*Phalaris arundinacea* L.) cultivated in a long-term field experiment on the experimental site in Czech Republic. The energy profit from cultivation of these crops and its protective anti-erosion effect were evaluated. The average yields ranged from 4.6 (RCG, mineral fertilization) to 7.4 t/ha (TWG, digestate fertilization). The more profitable species was tall wheatgrass, the biomass of which also had the higher heating value. The energy profit ranged from 80 GJ/ha (RCG, control variant and mineral fertilization) to 133 GJ/ha (TWG, digestate and mineral fertilization). It has been found that the tested plants excel in anti-erosion effect and could therefore be a suitable alternative to maize, especially in less-favored areas.

Keywords: biomass valorization; digestate; energy profit; mineral fertilizers; reed canary grass; tall wheatgrass; yield

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1. Introduction

The energy demand keeps on growing on a worldwide basis. For example, the European Union is increasingly dependent on imported energy sources. Their consumption has been accelerated especially by the increasing industrialization [1]. At present, a fundamental role in energy industry is played by fossil fuels which, however, contribute significantly to the production of greenhouse gas emissions [2].

Due to the aforementioned negatives associated with the use of fossil fuels and due to their limited reserves, the importance of renewable energy sources, which may help to mitigate the climate changes, has been growing [3]. Particularly important among these is biomass. One of the trends connected with diversification of agriculture is the growing of energy crops. Energy crops may be used, e.g., for heat generation through direct burning. It is a very simple and widespread technology of the conversion of biomass into thermal energy that may be further used [4].

Due to the high yield potential and good ensilability, one of the most prevalent energy crops is maize (*Zea mays* L.) [5,6]. However, its weakness is the high fertilizer and pesticide demand. The growth of this crop is also associated with a high risk of water erosion [7]

which results in a reduction in soil quality and a decline in the productivity of natural and agricultural ecosystems, as well as a loss of soil organic carbon [8].

In energy industry, maize is usually used as a substrate for biogas stations (BGS) in which biogas is produced by anaerobic fermentation. A secondary product of BGS, produced in a considerable quantity, is a mixture of a partially degraded organic mass, microorganisms and inorganic substances—digestate [9]. This residual product must be handled afterwards. However, the opinions on its agricultural use differ. A number of authors, e.g., [10,11] refer to its positives in the field of crop nutrition. Tambone et al. [12] considers the current knowledge of the properties of digestate and its use in agriculture insufficient. Other authors also refer to the negatives associated with the use of this material as a fertilizer. They point out mainly to the absence of labile fractions of soil organic matter [13] and pathway for the accumulation of other elements, including heavy metals into the crop products [14]. However, some authors deprecate this criticism, e.g., [15].

Compared to annual crops, perennial energy crops, which rank among second-generation biofuels [16], are valued better in environmental terms [17]. They usually provide a number of ecosystem services, such as the support of biodiversity [18] or water retention in the landscape. They also excel at soil protection from erosion [19,20], which is very important in the context of growing risks of severe storms and related occurrence of erosion [21]. Plants from grasslands protect the surface of the soil from the kinetic energy of raindrops and thus contribute to protecting the soil [22]. It was also found that permanent grasslands have a positive effect on the formation of soil aggregates [23], which play a significant role in soil fertility [24]. Suitable energy grasses are, e.g., reed canary grass (RCG) (*Phalaris arundinacea* L.) [25] and tall wheatgrass (TWG) (*Elymus elongatus* subsp. ponticus cv. Szarvasi-1) [26]. The yield and energy use of RCG are addressed in the publications of Rancane et al. [27] or Jensen et al. [28], Galatowitsch et al. [29] consider RCG to be a profitable grass. Furthermore, Oleszek [30] examined among other things its chemical composition. The cultivar Szarvasi-1 is regarded as an energy grass with very good prospects. Its origin and characteristics were described in detail by Csete et al. [26]. The yield characteristics of this crop are examined in the publications of Nazli et al. [31] and Dickeduisberg et al. [32].

López-Bellido et al. [16] point out that the growing and use of biomass does not automatically mean its sustainability. Therefore it is necessary to correctly assess the effect of energy use of biomass from various perspectives (food vs. fuel production, social aspects, provision of ecosystem services, etc.). Newly introduced crops have been far from being as thoroughly researched as maize that has been grown for thousands of years. So the current research should focus on their characteristics and growing [7].

The objective of the article is to acquaint the readers with the results of the long-term experiment monitoring the yield potential of the energy grasses RCG and TWG depending on the method of fertilization (mineral fertilizers, digestate). The energy profit was calculated for each variant, the area required to gain 1 TJ of energy was determined, and the erosion vulnerability of soils covered by the given grasses was expressed through the calculation based on the Universal Soil Loss Equation. The obtained results of the soil loss were compared with literature data of soil losses caused by the cultivation of maize, which is currently the main energy crop in the Czech Republic and poses specific risks of soil degradation, mainly due to a water erosion of the soil. The water erosion is currently a serious problem, because the rate of new soil formation is only about 1.4 t/ha per year [33].

2. Material and Methods

2.1. Field Experiments

Overall six years long small-plot experiments (1.25–8 m for each replication) with the grasses of C3 type, namely tall wheatgrass (Elymus elongatus subsp. ponticus cv. Szarvasi-1) and reed canary grass (Phalaris arundinacea L. cv. Chrastava) were established at the experimental site of the University of South Bohemia in České Budějovice. The weather conditions in the given location are shown in Table 1, and the characteristics of the plots are described in Table 2.

Table 1. Annual and seasonal climate including average temperature and precipitation of the years 2012–2017 at the experimental site of České Budějovice (modified from Czech Hydrometeorological Institute [34] and own data).

Year	Average Temperature (°C)		Precipitation (mm)	
	Year	Season	Year	Season
2012	9.3	15.3	798.1	567.7
Diff.	+1.1	+1.1	+215.3	+201.5
2013	9.1	15.3	685.4	469.5
Diff.	+0.9	+1.1	+102.6	+103.3
2014	10.2	15.1	595.9	428.7
Diff.	+2.0	+0.9	+13.1	+62.5
2015	10.5	16.9	487.7	233.8
Diff.	+2.3	+2.7	−95.1	−132.4
2016	10.5	15.7	680.9	447.7
Diff.	+2.3	+1.5	+98.1	+81.5
2017	9.7	16.4	630.3	438.8
Diff.	+1.5	+2.2	+47.5	+72.6
Long-term average (1961–1990)	8.2	14.2	582.8	366.2

Note: *Diff.*—difference from the long-term average; season includes April, May, June, July and August.

Table 2. Habitat characteristics and concentration of selected nutrients in soil recorded at the dates of sowing (analyzed according to Mehlich III).

GPS coordinates	48°97′44.13″ N, 14°44′88.37″ E
Altitude (m a.s.l.)	391.5–393.8
Soil texture class (WRB)	sandy loam
Soil type (WRB)	cambisols
Bulk density (g/cm^3)	1.27
C_{org} (%)	5.24
pH_{H2O}	6.1
pH_{KCl}	5.6
P (mg/kg)	46
K (mg/kg)	94
Mg (mg/kg)	80
CEC (mmol$_+$/kg)	72

Note: CEC—cation exchange capacity; C_{org}—organic carbon; WRB—World reference base for soil resources 2014 [35].

Before sowing, all plots were fertilized with mineral fertilizers dosed at 67 kg N/ha (ammonium nitrate with dolomite), 48 kg P/ha (triple superphosphate), and 30 kg K/ha (potassium chloride). A total of 24 fields (12 of RCG, 12 of TWG) were sown (row spacing 0.125 m) on 17/4/2013. The seeding rate was 35 kg/ha of seeds for TWG (germinability 89%) and 50 kg/ha of seeds for RCG (germinability 30%). Every field was 10 m^2 large. On 14/6/2013 the grass was cut to get rid of weeds. From 2014 to 2018 the fields were divided into three treatments (Mineral, Digestet, Control) by the intensity of fertilization (both species had three variants with four replications; i.e., 4 × 10 m^2 for each variant). The fertilizations were always carried out immediately after harvest (1 April 2014, 17 March 2015, 21 March 2016, 8 March 2017, and 13 March 2018). In the variant Mineral (M), the crops were fertilized at the doses 100 kg N/ha (60 kg N/ha ammonium sulphate, 40 kg N/ha ammonium nitrate with dolomite), 10 kg P/ha (triple superphosphate), and 30 kg K/ha (potassium chloride). The crops in the variant Digestate (D) were fertilized by the digestate from a biogas station (Žabovřesky, South Bohemia). The crops in the variant D were fertilized at the dose 27.8 t/ha in 2014. The content of nutrients in digestate is showed in Table 3. Because the composition of the digestate varied slightly over the coming years, the amount of digestate applied in the following years was adjusted according to the actual digestate composition in the range of 26.3 to 30.3 t/ha. The dose of digestate was selected to contain approximately the same quantity of total nitrogen as the variant Mineral. Among treatments a no fertilized Control (C) was set up.

Table 3. Nutrient and dry matter content of the used digestate (%).

Year	2014	2015	2016	2017	2018
N_{min}	0.21	0.22	0.19	0.22	0.23
N_{org}	0.15	0.16	0.14	0.16	0.14
P	0.08	0.08	0.08	0.08	0.08
K	0.35	0.33	0.35	0.39	0.37
Ca	0.25	0.24	0.26	0.24	0.25
Mg	0.06	0.06	0.05	0.07	0.06
DM	7.50	7.80	7.50	7.40	7.70

Note: N_{min}—mineral nitrogen; N_{org}—organic nitrogen; DM—dry matter.

The crops were always harvested in early spring when their water content is the lowest (1 April 2014, 17 March 2015, 21 March 2016, 8 March 2017, and 13 March 2018). The crops were harvested with a finger bar cutter at the height of 6 cm. The phytomass from each field was weighed. After harvesting, the phytomass samples were dried to reach a constant weight. Subsequently, the dry matter yield per hectare was calculated.

2.2. Calculation of Higher Heating Value and Erosion Risk

Higher heating value

Dried samples of crops were homogenized and underwent an elementary analysis by means of the device Vario EL CUBE. The percentage content of oxygen was calculated (O = 100 − N − C − H − S − ash). Afterwards the higher heating value (*HHV*) (also known gross calorific value or gross energy) was calculated by using the formula that is recommended as the most precise one by Sheng and Azevedo [36]:

$$HHV = -1.3675 + 0.3137 \times C + 0.7009 \times H + 0.0318 \times O \quad (1)$$

HHV = higher heating value (MJ/kg)
C, *O*, *H* = weight of given elements in the dry sample (wt%)

Subsequently, the energy profit (*EP*) and the area required in each variant for gaining 1 TJ of energy were calculated:

$$EP = HHV \times \mathrm{Y} \quad (2)$$

EP = energy profit (GJ/ha)
Y = average yield of dry matter (t/ha)

Erosion risk

The long-term soil loss by water erosion was expressed through the Universal Soil Loss Equation (USLE) according to Wischmeier and Smith [37]:

$$Gha = R \times K \times L \times S \times C \times P \quad (3)$$

Gha = soil loss (t/ha/year)
R = the rainfall and runoff factor
K = the soil erodibility factor
L = the slope-length factor
S = the slope-steepness factor
C = the cover and management factor
P = the support practice factor

The values of factors used in USLE were selected on the basis of the methodology drawn up by Janeček et al. [38]. In accordance with this methodology, the C-factor was 0.05. The value of K-factor (0.47) was determined on the basis of the main soil unit. When calculating L-factor (1.4745), the actual slope length (77 m) was taken into account. The slope steepness is 8%, the slope length exponent is low for grasses, and thus S-factor was 0.9149. R-factor was 50.14, which is a value characteristic for this region. The P-factor amounted to 1—without anti-erosion measures. When multiplying Gha by the area that

would be required to gain 1 TJ of energy, we found out the quantity of soil that would be theoretically lost by water erosion when gaining this amount of energy.

2.3. Statistical Analysis

The data of dry matter yield, elementary analysis, and higher heating value from each year were statistically evaluated by an analysis of variance (ANOVA) and the results were subsequently compared by a post-hoc Tukey HSD test. The method of principal component analysis (PCA) and factor analysis (FA) [39] was used for multivariate statistical analysis of measured data. Statistical analyzes, including graphical outputs, were processed in STATISTICA (version 12, TIBCO Software Inc., Palo Alto, CA, USA).

3. Results and Discussion

3.1. Dry Matter Yield

The average yields in each year are summarized in Table 4. The table indicates a low phytomass yield in the year of establishment. In subsequent years the yield grew. Statistically provably higher yields were reached by TWG ($F(1, 118) = 30.361$, $p < 0.00001$). Dependency of the yield on the tested species is shown in Figure 1. Generally, no provable effect of fertilization on the yield of studied crops was found ($F(2, 117) = 0.67107$, $p = 0.51312$) (Figure 2). However, the lowest yields were reached in the variant Control, as expected. The yields of grasses in the variants Mineral and Digestate are very similar. This is also confirmed by the analysis of PCA and FA, see Figures 3 and 4 (cluster of variants TWG is close together). This result seems logical, because the addition of the main nutrient (nitrogen) has been balanced. The question is the uptake of phosphorus from digestate. Opinions on its accessibility to plants differ. Some researchers state, that the digestate has a higher content of phosphorus compounds in labile forms [40,41]. Nevertheless, other authors are of the opposite opinion [42,43]. No clear conclusions can be drawn from these results.

Table 4. Dry matter yield ± SD (t/ha) of tall wheatgrass and reed canary grass during the monitored period (2014 to 2018).

Species	Fertilization	Year					
		2014	2015	2016	2017	2018	Average
TWG	Control	$3.5 \pm 0.47^{a}_{a}$	$6.2 \pm 1.57^{ab}_{ab}$	$8.6 \pm 3.38^{abc}_{b}$	$8.3 \pm 1.90^{ab}_{b}$	$5.6 \pm 2.19^{a}_{ab}$	6.4 ± 2.62^{ab}
	Mineral	$3.5 \pm 0.36^{a}_{a}$	$8.3 \pm 0.67^{b}_{bc}$	$9.6 \pm 1.86^{bc}_{c}$	$8.9 \pm 1.30^{b}_{bc}$	$6.2 \pm 1.99^{a}_{ab}$	7.3 ± 2.57^{b}
	Digestate	$3.4 \pm 1.16^{a}_{a}$	$8.5 \pm 2.65^{b}_{b}$	$10.9 \pm 2.79^{c}_{b}$	$7.4 \pm 1.34^{ab}_{ab}$	$6.8 \pm 2.30^{a}_{ab}$	7.4 ± 3.09^{b}
RCG	Control	$3.0 \pm 0.45^{a}_{a}$	$4.2 \pm 0.78^{a}_{ab}$	$5.1 \pm 0.90^{a}_{ab}$	$6.3 \pm 1.06^{ab}_{b}$	$4.7 \pm 2.43^{a}_{ab}$	4.7 ± 1.55^{a}
	Mineral	$2.4 \pm 0.65^{a}_{a}$	$4.2 \pm 0.24^{a}_{b}$	$5.8 \pm 0.33^{ab}_{c}$	$5.7 \pm 0.55^{a}_{bc}$	$4.7 \pm 1.30^{a}_{bc}$	4.6 ± 1.38^{a}
	Digestate	$4.3 \pm 3.42^{a}_{a}$	$4.7 \pm 0.91^{a}_{a}$	$6.1 \pm 0.91^{ab}_{a}$	$6.0 \pm 0.39^{a}_{a}$	$3.9 \pm 0.57^{a}_{a}$	5.0 ± 1.71^{ab}

Note: TWG—tall wheat grass; RCG—reed canary grass; significant differences between variants within years are shown in upper case letters and between years within variants are shown in lower case letters (Tukey's honest significance test; $p = 0.05$).

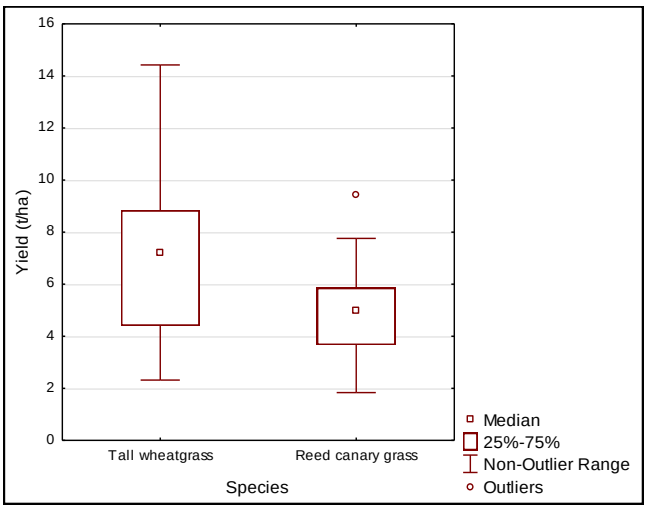

Figure 1. Average dry matter yield (t/ha) for the whole monitored period (2014 to 2018).

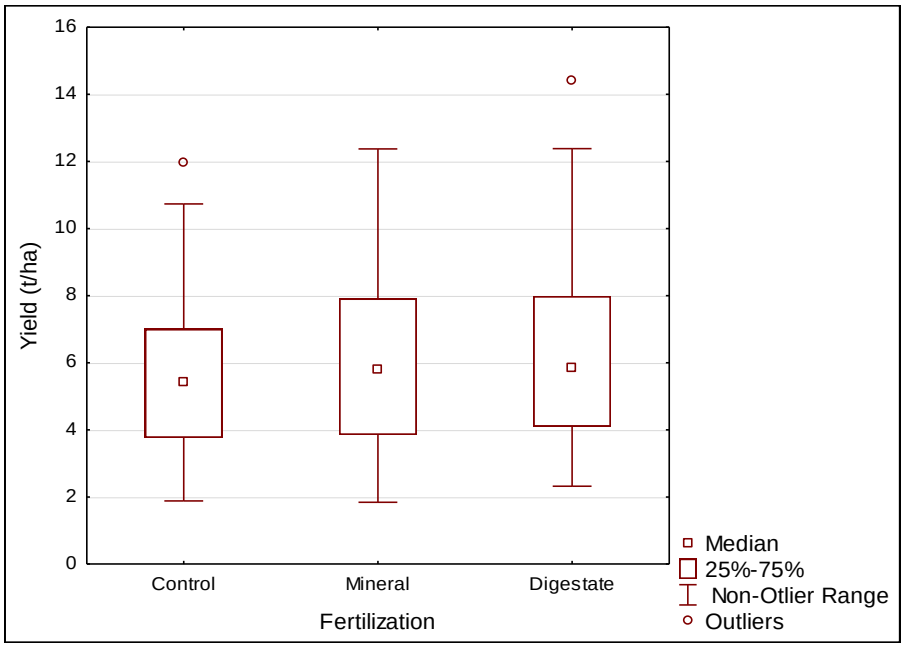

Figure 2. Effect of fertilization system on dry matter yield for the whole monitored period (2014 to 2018). In general, the yields can be regarded as rather low. However, except for 2015, the weather development was favorable for production. So the amount of yields might rather be influenced by a relatively low fertility of the given site. Danielewicz et al. [44] state the yields ranging from 6.6 to 10.4 t/ha of dry matter of TWG, depending on the intensity of fertilization. In our experiment, the yields we recorded are at the lower end of this range. Martyniak et al. [45] published higher yields, namely 10.0 to 12.6 t/ha. Nevertheless, Csete et al. [26] state an even higher yield potential. Where the soil is fertile, the harvested amount of dry matter of TWG may reach up to 25 t/ha. Schmidt et al. [6] write that RCG may reach a yield of dry matter exceeding 15 t/ha. Pocienė et al. [46] state approximately 11 t/ha of dry matter in the first and second year when using nitrogen fertilization dosed 120 kg/ha. In the variant without fertilization the yield was 7.7 and 4.7 t/ha, respectively. Muylle et al. [47] reached the average dry matter yield of 8.6 t/ha (cv. Palaton) and 9.0 t/ha (cv. Bamse) in the second year of growing, but afterwards RCG was withdrawn. Heinsoo et al. [48] inform about yield of RCG in an amount 6.8 t DM/ha in Estonian conditions. The production capacity of RCG was also examined by Prochnow et al. [49] and Wrobel et al. [50]. In our experiment, the highest yields were reached at the 3rd and 4th harvests. Given the weather development, the result of the harvest in spring 2016 is particularly surprising. Despite the very warm and dry weather in 2015, these energy crops produced the highest amount of phytomass in this year from all the reference years in many variants. The mechanisms that help TWG to overcome drought are referred to by Csete et al. [26]. Ust'ak et al. [25] refer about drought tolerance of RCG.

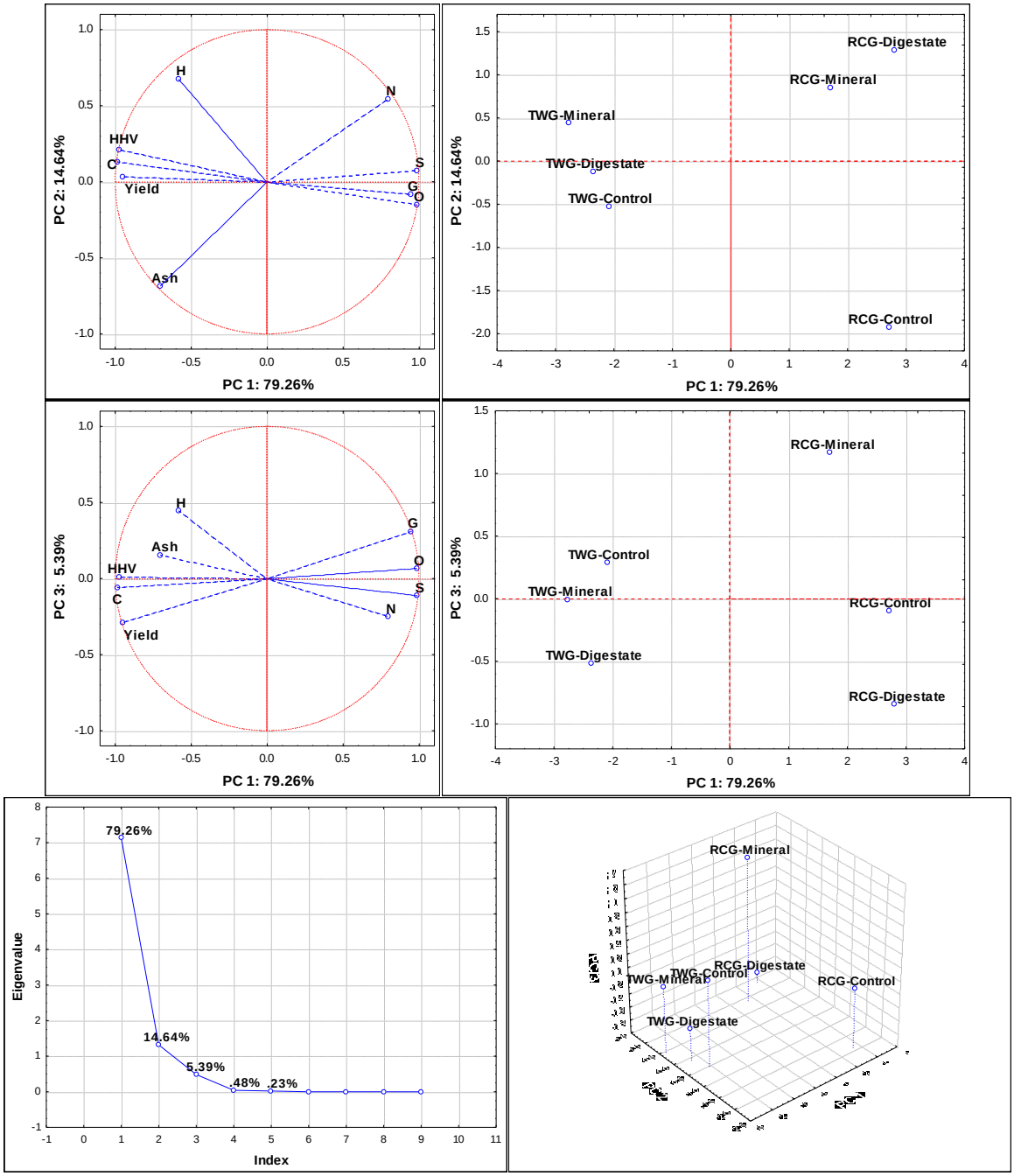

Figure 3. Principal components analysis of yield, chemical composition, HHV and erosion parameters. Note: N—nitrogen; C—carbon; H—hydrogen; S—sulfur; O—oxygen; HHV—higher heating value; G—soil loss.

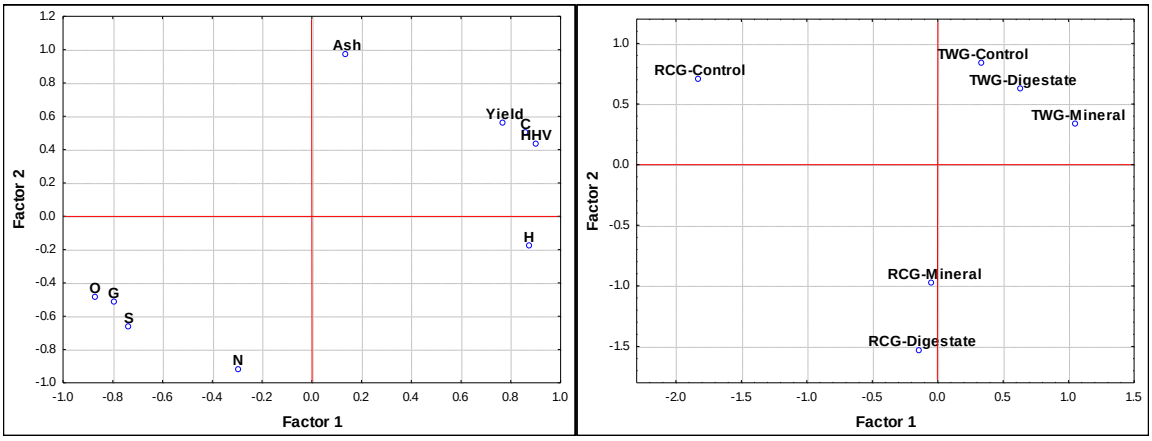

Figure 4. Factor analysis of yield, chemical composition, HHV and erosion parameters. Note: H—hydrogen, O—oxygen, S—sulfur, N—nitrogen, C—carbon, G—soil loss, HHV—higher heating value.

3.2. Higher Heating Value and Energy Profit

The characteristics and composition of biomass vary depending on the intensity of fertilization [41]. However, no large differences in the composition of biomass depending on fertilization were observed in our experiment. Table S1 shows the result of the elementary analysis of taken phytomass samples the calculated HHV values shows Table 5. In terms of energy, the C content of biomass is the most important. Our experiment showed values slightly lower than those published by other authors, e.g., [45,51], as well as the ash content [51,52]. Despite that, the calorific values more or less correspond to the data in literature. Yu et al. [53] state HHV of 17.92 MJ/ha for TWG. HHV values for RCG were published, e.g., by López-González et al. [54] and Greenhalf et al. [55] who stated 17.7 and 19.12 MJ/kg, respectively.

Table 5. Higher heating value (MJ/kg) of tall wheatgrass and reed canary grass during the monitored period (2014 to 2018).

Species	Variant	2014	2015	2016	2017	2018
TWG	Control	$17,991^{d}_{b}$	$17,975^{e}_{b}$	$17,684^{c}_{a}$	$17,934^{e}_{b}$	$18,030^{e}_{b}$
TWG	Mineral	$18,189^{e}_{d}$	$17,839^{d}_{a}$	$18,130^{e}_{c}$	$17,939^{e}_{b}$	$17,924^{d}_{b}$
TWG	Digestate	$17,987^{d}_{b}$	$17,943^{e}_{b}$	$18,055^{d}_{c}$	$17,820^{d}_{a}$	$17,968^{de}_{b}$
RCG	Control	$17,213^{a}_{b}$	$17,069^{a}_{a}$	$17,419^{b}_{e}$	$17,245^{a}_{c}$	$17,315^{a}_{d}$
RCG	Mineral	$17,590^{c}_{bc}$	$17,620^{c}_{c}$	$17,381^{a}_{a}$	$17,548^{c}_{b}$	$17,579^{c}_{bc}$
RCG	Digestate	$17,448^{b}_{b}$	$17,489^{b}_{c}$	$17,363^{a}_{a}$	$17,384^{b}_{a}$	$17,507^{b}_{c}$

Note: TWG—tall wheat grass; RCG—reed canary grass; significant differences between variants within years are shown in supper case letters and between years within variants are shown in lower case letters (Tukey's honest significance test; $p = 0.05$).

The energy profit data are summarized in Table 6. As follows from the equation (EP = HHV × Y), the value of EP is highly dependent on the yield achieved. Differences in the composition among species are not likely to affect their combustion behavior from a practical point of view [56]. The low yield in the year of establishment is associated with the low EP from the first harvest. In the second year of vegetation (at the same time, the first year of full plantation use), a great increase in EP for TWG was evident. The average values of EP from all variants increased by 125% compared to the preceding year. For RCG, EP increased by 33%. However, in terms of EP, the best results were reached in harvests in 2016 and 2017. In the last reference year they decreased again. The average values of EP of RCG for the reference period are lower than those stated by Jasinskas et al. [57]. When fertilizing at the dose of 60 kg N/ha, he observed values ranging from 100 to 120 GJ/ha, depending on the year. Frydrych [58] stated 85.3 GJ/ha for the variant

fertilized at the dose of 50 kg N/ha and only 62.0 GJ/ha for the non-fertilized variant. Bernas et al. [59] stated the total value for three years. He determined the energy profit of 210 GJ/ha for RCG and 382 GJ/ha for TWG. Primary energy yields for various levels of fertilization of RCG present also Kołodziej et al. [51]. Bernas et al. [4] also stated an annual EP of maize in the amount of 210 GJ/ha for comparison.

Table 6. Energy profit (GJ/ha) of tall wheatgrass and reed canary grass during the monitored period (2014 to 2018).

Species	Fertilization	2014	2015	2016	2017	2018	Average
TWG	Control	62	112	154	149	101	116 ± 47
	Mineral	63	152	175	161	112	133 ± 46
	Digestate	60	154	197	133	123	133 ± 56
RCG	Control	52	73	87	108	81	80 ± 27
	Mineral	43	73	103	100	82	80 ± 24
	Digestate	75	82	107	105	67	87 ± 30

Note: TWG—tall wheat grass; RCG—reed canary grass.

3.3. Erosion Threats

Using the Universal Soil Loss Equation, it was calculated that a long-term soil loss through water erosion Gha is 1.59 t/ha/year on the given plot with all the crops examined. This value is lower than the average soil loss due to water erosion from arable soils in the Czech Republic, which was calculated by Panagos et al. [60] and which is 2.52 t/ha/year. As for the European Union, he states the value of 2.46 t/ha/year. Our experiment has proved that grass growths provide excellent protection from erosion [45]. Ciria et al. [61] even recommends TWG for anti-erosion use in areas facing erosion risk. This statement is confirmed by the analysis of PCA and FA see Figures 3 and 4 (cluster of TWG variants is close together—high anti-erosion effect compared to RCG variants—low anti-erosion effect). The level of erosion may also be compared with commonly grown crops. Wysocka-Czubaszek and Czubaszek [62] give examples of erosion losses for various crop rotations on a plot similarly sloped as the experimental site in České Budějovice. For example, for the sequence rye–oat–potatoes the loss is 3.93 t/ha/year, and for the sequence maize–triticale–potatoes the value increases to 6.60 t/ha/year. However, Podhrázská et al. [63] calculated the soil loss for a "typical plot of South Moravia" with the main crops: maize–common wheat–oilseed rape. She came to the erosion runoff value of 22.53 t/ha/year. However, an admissible loss on this plot was 4 t/ha/year. After determining EP, the size of the area that would be required to gain 1 TJ of energy could also be determined for all variants. If the value Gha is known, it is possible to calculate also the quantity of the soil (G) that would be lost due to the process of water erosion from such area. These data are summarized in Table 7.

Table 7. Average soil loss in the case of cultivating tall wheatgrass and reed canary grass (data from 2014 to 2018).

Species	Fertilization	Area (ha)	G (t/year/TJ)
TWG	Control	8.7	13.76
	Mineral	7.5	11.98
	Digestate	7.5	11.92
RCG	Control	12.4	19.76
	Mineral	12.5	19.81
	Digestate	11.4	18.19

Note: TWG—tall wheat grass; RCG—reed canary grass; G—soil loss.

Based on the ascertained data, the G value would vary approximately from 12 to 20 t/year/TJ for various variants. In a former study, maize was grown on the same plot for energy purposes. The study found out that the G value was 29.8 t/year/TJ [19].

When growing TWG in the variant Digestate or Mineral, the gain of 1 TJ of energy would be associated with a soil loss that is lower by approximately 18 t than the soil loss associated with maize. Precise comparison of erosion losses in growing different crops in different locations is rather problematic due to various factors. There are even relatively high differences in the determination of the amount of eroded soil by using an individual models applied (without the need for field measurements) to the same territory within one study [64]. However, in the conditions of the Czech Republic, the erosion vulnerability of soils covered with maize was studied, e.g., by Kadlec et al. [65]. From 2008 to 2011, he monitored the soil loss in erosion events in the growths of maize grown in various modes. Depending on the technology and year, the soil losses ranged widely from 0.098 to 96.55 t/ha/year. So in terms of anti-erosion measures in sloping locations vulnerable to erosion, the growing of energy grasses is clearly more favorable than the growing of maize [66], which is very important because the highest quality layer of soil is carried away by water erosion [67]. In accordance with the Cosentino's [68] findings, it was confirmed that perennial cropping systems make possible to maintain low soil losses. Moreover, a grass cover provides a wide range of important ecosystem services [69,70].

3.4. Multicriteria Evaluation

This chapter provides an overview of the results obtained through principal component analysis. On the figure of component weights PC1, PC2, PC3 (Figure 3) the first two axes are significant, which together explain about 93% of the variability. The PC1 axis in the PC1 × PC2 graph characterizes the yield, G, HHV, and the content of elements C, O, S, which go directly along this axis and are correlated with it at a level exceeding 0.9 (high correlation) and N (r = 0.79). On the PC2 axis, there is a significant correlation with ash and H (r = −0.68 and 0.67). There is no significant correlation on the PC3 axis. In the scatter plot of scores, all fertilization variants and parameters (TWG, RCG) are clearly located along the PC1 axis. The TWG group (all fertilization variants) are very similar in all evaluated parameters (yield, N, C, H, O, S, ash, G, HHV). The RCG group (Mineral and Digestate fertilization variants) are also very similar in all evaluated parameters. The RCG-Control fertilization variant differs significantly from the RCG-Mineral and Digestate fertilization variants with its low N and ash content. The group of RCG fertilization variants differs significantly from the group of TWG fertilization variants in the parameters G and HHV.

Factor analysis (Figure 4) confirmed the PCA results and differentiated the group of fertilization variants as well as the group (TWG, RCG). Factor weights explain the correlations between factors and features (Table 8). They represent the most important information on which the interpretation of factors is based. Factor 1 describes the properties in terms of yield, soil erosion loss, and basic chemical composition. Factor 2 clearly describes the nitrogen and ash content. Communality represents the proportion of character variability expressed by the factors in question. It is similar to the value of R^2, which we obtain if the original characters are explained by regression by selected factors [39]. From the contribution of Factor 1 and Factor 2 to the Communality, it is evident how the Communality acquires high values, and thus the features of the values are very well taken into account by the proposed factor model.

Multivariate statistical methods (multicriteria evaluation using PCA and FA methods) significantly differentiated in the evaluated parameters (yield, N, C, H, O, S, ash, G, HHV) two groups: (i) TWG (high anti-erosion effect) and (ii) RCG (low anti-erosion effect); and in the RCG group individual fertilization variants (Control, Mineral and Digestate, low N and ash content).

Table 8. Factor weights and contributions of a given factor to the community for individual traits after rotation Varimax normalized parameters yield, chemical composition, HHV, and erosion.

Parameter	Factor Weights		Contributions of a Given Factor to Communality		
	Factor 1	Factor 2	Factor 1	Factor 2	Communality
Yield	0.769024	0.557612	0.591398	0.902329	1.000000
N	−0.296698	−0.918397	0.088030	0.931483	1.000000
C	0.859376	0.503139	0.738527	0.991676	1.000000
H	0.873744	−0.175124	0.763428	0.794097	1.000000
S	−0.735966	−0.662257	0.541647	0.980231	1.000000
Ash	0.134064	0.972888	0.017973	0.964484	1.000000
O	−0.871086	−0.483177	0.758791	0.992251	1.000000
HHV	0.899220	0.433944	0.808596	0.996903	1.000000
G	−0.796146	−0.513393	0.633848	0.897420	1.000000

Note: N—nitrogen; C—carbon; H—hydrogen; S—sulfur; O—oxygen; HHV—higher heating value; G—soil loss.

4. Conclusions

Yield, energy profit, and anti-erosion effect of two energy types of grass (tall wheat grass, reed canary grass) were evaluated with respect to different fertilization variants. Higher yields were reached by tall wheat grass, however, there was no significant effect of fertilization on the yield. Higher yields correspond with the higher energy profit of tall wheat grass which was also calculated based on the elementary analysis. Nonetheless, the yield and energy profit is still lower compared to maize. The main advantage of these two types of grass is their great anti-erosion effect. From this point of view, a 1 TJ of energy is produced with fewer soil losses compared to maize by both of the energy grasses. The importance of grasslands increase principally in marginal areas, where conventional crops are not able to achieve such yields as in fertile production areas. Besides, they require minimum of pesticides and provide a wide range of ecosystem services. For that reasons, their cultivation might be sustainable and more beneficial than the cultivation of maize for energy purposes.

Supplementary Materials: The following are available online at https://www.mdpi.com/2073-4395/11/3/445/s1, Table S1: Elementary analysis of tall wheatgrass and reed canary grass (%).

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