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Short Communication

Reed Sweet Grass *Glyceria maxima*: Role in Shoreline Protection

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Abstract

Our article presents the results of studies on the mechanical properties of Reed Sweet Grass *Glyceria maxima*. The samples were collected from Urszulewskie Lake near Sierpc, Poland. The experiment was conducted using an Instron 5966 universal tensile strength testing machine. Tensile force and tensile strength were determined and compared for individual parts of reed sweet grass, i.e., below-ground stems (rhizomes), the bases of stems, and above-ground stems. Dependencies between the selected mechanical and morphological parameters were described. Statistical analysis was conducted using the Statistica program. The obtained tensile strength results were compared to data obtained by other authors on select tree, shrub and plants species. Lastly, the benefits of using plants characteristic of bulrush over artificial concrete reinforcements were presented.

Keywords: reed sweet grass, tensile forces, tensile strength, rhizomes, stems

Introduction

The reinforcement and protection of shorelines using helophytes plays an important role in ecological engineering. Reed Sweet Grass *Glyceria maxima* is an important representative of these types of plants. It grows in shallow areas of lakes, old river basins, and artificial water ecosystems, such as ponds and melioration ditches. This species prefers eutrophic waters and grows on organic as well as organic-mineral soils. In Poland, reed sweet grass forms one of the most common plant formations in the litoral zone of water bodies, along with other accompanying species, i.e., *Rorippa amphibia*, *Rumex hydrolapathum*, *Sium latifolium*, *Galium palustre*, *Alisma plantago-aquatica*, *Carex gracilis*, *Iris pseudoacorus*, *Lemna minor*, *Lemna triscula*, or *Spirodela polyrrhiza* [1, 2].

The analyzed plant species possesses qualities that are important to the reinforcement of shorelines, such as: the ability to and ease of propagating vegetatively using modified stems (rhizomes) as well as a resistance to stretching. These properties could also be used for leachate re-circulation [3] on landfills and biological stabilization as a slope erosion control system [4, 5]. In general, the denser the plant community, the more stable and resistant it is to changeable environmental conditions [6]. This article compares and describes the possibilities of using reed sweet grass to reinforce the shorelines of water bodies.

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Experimental Procedures

Samples of reed sweet grass *Glyceria maxima* were collected in July 2012 from Urszulewskie Lake near Sierpc, Poland, from a fully mature community of *Glyceria maxima* with developed systems of above-ground and below-ground stems (rhizomes). Whole plant samples were collected by hand. Care was taken to avoid damaging the individual parts of the plants in any way. Specimens observed to have mechanical damage, deformations, or signs of disease were rejected on spot. More than 60 samples were selected and transported to the Water Center of Warsaw University of Life Sciences. In order to secure them from water loss, the plants were transported in thick plastic bags. Tensile strength experiments were conducted on the same day in the majority of cases. When this was not possible, the bagged plant samples were placed in basins at the Water Center and stored for no longer than three days.

Mechanical tests consisted of determining the tensile strength of: above-ground stems, bases of stems, and rhizomes of reed sweet grass *Glyceria maxima*. The tests were conducted using an Instron 5066 universal tensile strength testing machine (Fig. 1), with a measurement range of up to 10 kN performed with a guaranteed accuracy of ±0.5% [7]. The analysis was recorded using the Bluehill 2 Program [8]. The fixed displacement rate during the study was 2-6 mm/min. The types of machine clamps used depended on the type of samples. Fig. 1 presents clamps used for above-ground stems and rhizomes, respectively. For purposes of static tensile strength tests conducted on the base of the stem, the bottom clamp was modified (Fig. 1b).

The results were subjected to statistical calculations using the STATISTICA 10 and Microsoft Excel computer programs. Relationships between the mechanical parameters and the area of the cross-section were described using regression equations and the regression coefficient R^2. In order to precisely determine the significance of differences between average values, the ANOVA analysis of variance LSD test was applied at a significance level of 0.05, with differences significant for $p<0.050$.

Results and Discussion

Tensile forces for reed sweet grass were found to be the highest for the above-ground stem (93.5 N), next the base of the stem (90.8 N), and lastly the rhizome (49.6 N).

When looking at Fig. 2, we can see that tensile forces increase along with the area of the cross-section. Tensile forces for the above-ground stem are greater than in the case of the base of the stem. However, upon exceeding a cross-sectional area of 95 mm^2, tensile forces for the above-ground stem are lower and have a tendency to even out a constant level, while exhibiting higher values for the base of the stem. The direction of tensile forces depending on the area of the cross-section of the above-ground stem is best described by the power function ($y = 18.99x^{0.426}$), and for the base of the stem – by the linear function ($y = 1.1483x+8.9919$). The curve for rhizomes, on the other hand, is between that of the base of the stem and above-ground stem. Along with an increase in the area of the cross-section, tensile forces take on nearly identical values (the line assumes an almost horizontal direction). Their course is best described by the logarithmic function ($y = 20.53\ln x – 10.303$). The value of the determination coefficient R^2 for all parts of reed sweet grass is approximately 0.50. This results from the morphological and anatomical differences in samples used for analysis.

Water content in the above-ground stem ranges from 73-92%, with values of 76%-95% in the rhizomes. A clear relationship between water content and tensile force for individual parts of reed sweet grass is not observed in the graph.

The significance of differences between tensile forces for individual parts of reed sweet grass has been presented in Table 1.

The average tensile strength of reed sweet grass is the highest in its rhizomes (2,725.7 kPa), next the above-ground stem (1,954.4 kPa), and, the base of the stem (1,369.9 kPa).

Table 1. Significance of differences between tensile forces for the individual parts of reed sweet grass.

Plant parts	p value		
	(1)	(2)	(3)
Above-ground stem (1)		1.0000	0.8687
Base of stem (2)	1.0000		0.8352
Rhizome (3)	0.8687	0.8352	

a)

b)

Fig. 1. Photographs illustrating clamps on an "Instron 5966" universal tensile strength testing machine used for measuring the tensile strength of the above-ground stem and rhizomes (a) and the base of the stem (b).

Fig. 4 shows that, for all parts of the reed sweet grass *Glyceria aquatic*, contrary to tensile force, tensile strength decreases along with an increase in the cross-section area of the sample. The curve for the above-ground stem for areas of the cross-section above 28.0 mm^2 runs above and almost parallel to the curve for the base of the stem. The relationship between tensile strength and the area of the cross section for the above-ground stem is best presented by the power function ($y = 3{,}420.6e^{0.0113x}$), and for the base of the stem by the logarithmic function ($y = -1{,}266.4\ \ln x + 6{,}698.7$). The rhizome curve, described by the power function ($y = 4{,}221e^{-0.0237x}$), lies the lowest of the curves. All the above-described curves drop gradually. The value of the determination coefficient R^2 is around 0.5 to 0.76 for all parts of the reed sweet grass. This is caused by the morphological and anatomical differences in the tested samples.

Similarly to tensile force, tensile strength does not depend on the amount of water contained in the individual plant parts (Fig. 5).

The significance of differences between tensile strengths of the individual reed sweet grass parts has been presented in Table 2.

Table 2. Significance of differences between average tensile strengths of individual reed sweet grass parts.

Plant parts	p value		
	(1)	(2)	(3)
Above-ground stem (1)		0.2462	0.0515
Base of the stem (2)	0.2462		0.0001
Rhizome (3)	0.0515	0.0001	

Fig. 6 presents charts with typical curves for static tensile tests conducted on the individual parts of reed sweet grass. In the chart presenting the base of the stem, tensile forces increase linearly along with displacement. Upon having achieved the maximum value, signifying that the sample had been destroyed, a rapid, vertical fall of tensile forces can be observed, during which time the displacement remains unchanged. Next, the line takes on a direction that is nearly parallel to the X axis and is characterized by numerous irregularities – this means that after the sample is

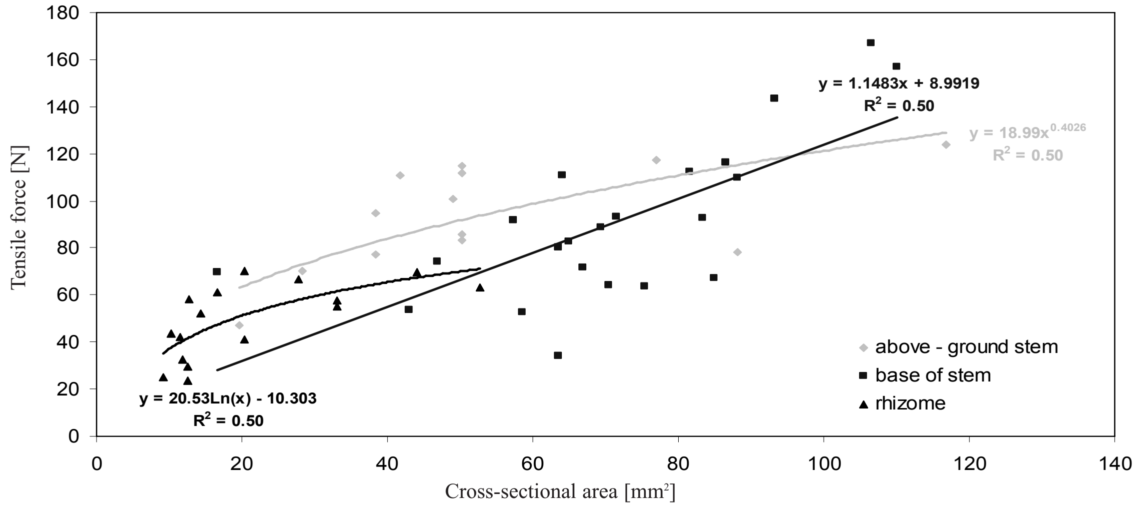

Fig. 2. Relationship between the tensile force and cross-sectional area of individual parts of reed sweet grass.

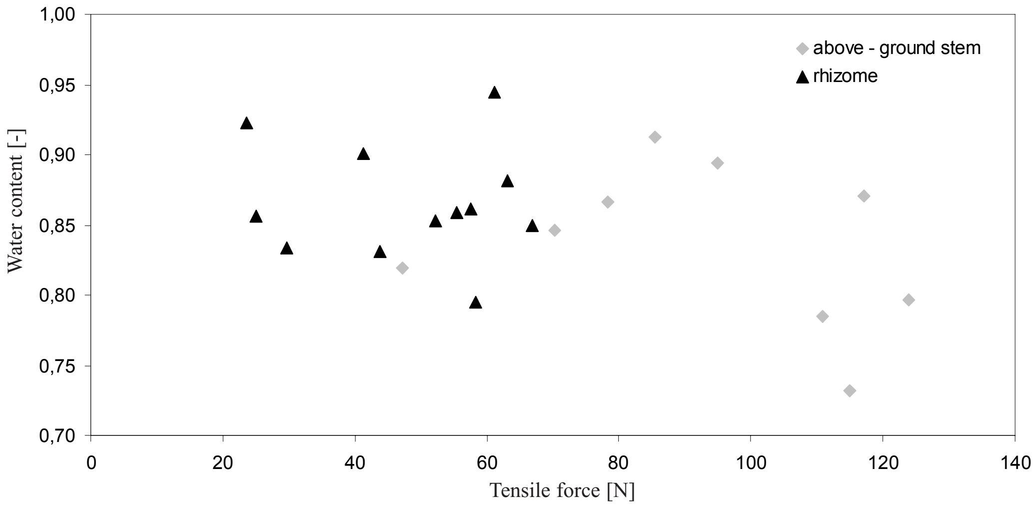

Fig. 3. Relationship between the water content and tensile force of individual parts of reed sweet grass

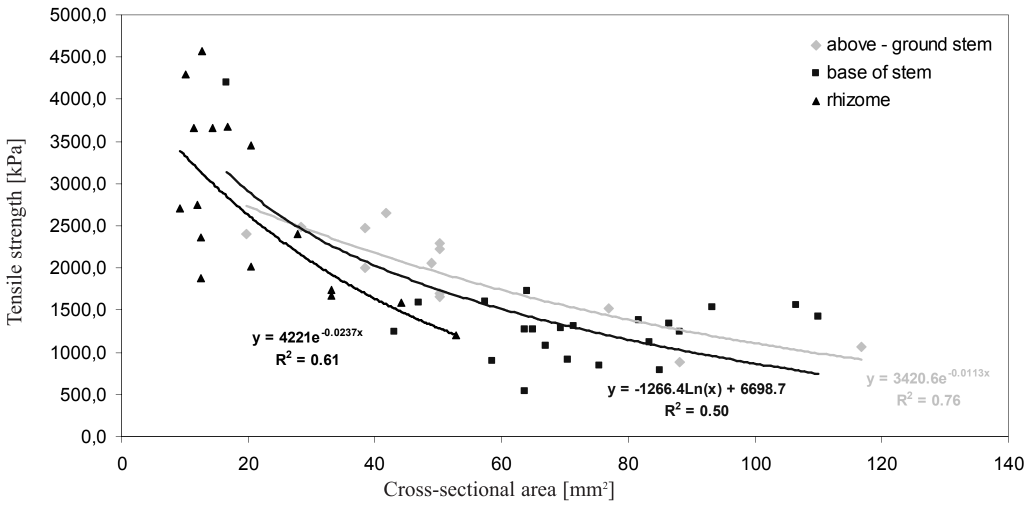

Fig. 4. Relationship between tensile strength and cross-sectional area of individual reed sweet grass parts.

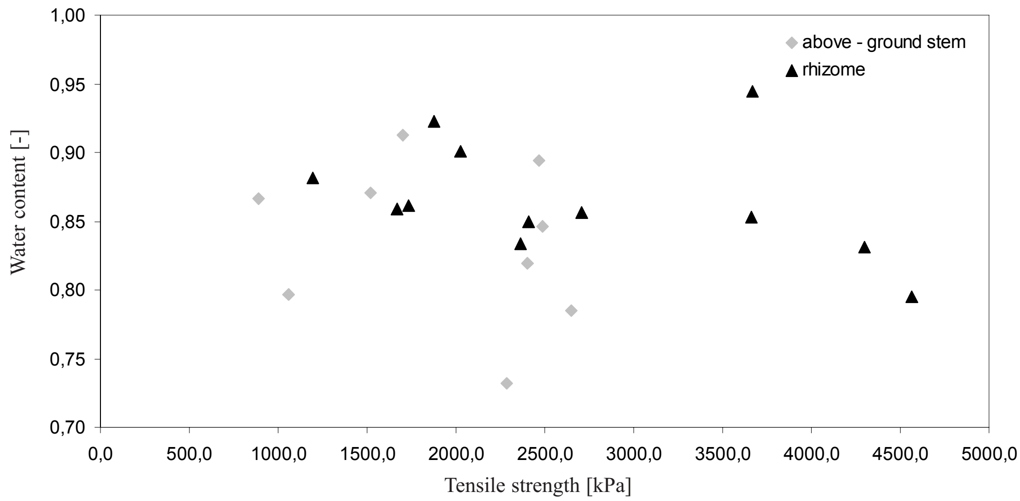

Fig. 5. Relationship between the water content and tensile strength of individual reed sweet grass parts.

broken at the point where the above-ground stem turns into the rhizome, numerous adventitious roots and dead remains of the plant create resistance. Upon destroying all elements, tensile force drops rapidly, without changes in displacement. In charts for the above-ground stem and rhizome, tensile forces increase proportionately to displacement (the line takes on a linear shape or various degrees of convexity). Upon having reached the maximum value, signifying that the sample had been destroyed, a sharp, vertical drop of tensile forces is noted, at which point displacement remains

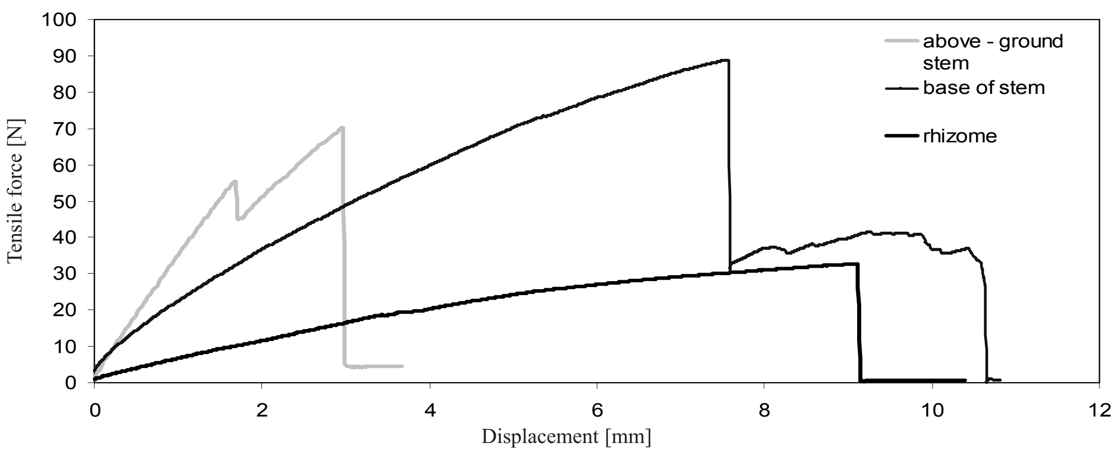

Fig. 6. Characteristics of subjecting individual parts of reed sweet grass *Glyceria maxima* to tensile forces.

Table 3. Comparison of select tree, shrub, and plant species.

Form	Species	Tensile strength [kPa]
Trees	European Beech *Fagus silvatica*	57,470[9]
Trees	Douglas-fir *Pseudotsuga menziesii*	25,790 [10]
Shrubs	Dog rose *Rosa canina*	22,950 [11]
Swamp plants	Broadleaf cattail *Typha latifolia*	758.5 [12, 13]

unchanged (the line takes on a vertical direction). Small ups and downs occasionally appear (local decreases of tensile forces); they signify that the walls of the sample had started to break before it was ultimately torn apart.

The results of the study indicate the rhizomes to be the strongest part of reed sweet grass with an average tensile strength of 2,725 kPa.

The obtained average values for the below-ground stem (rhizome) of reed sweet grass were compared to data collected from the analysis of roots of selected tree species, shrubs, and plants provided by various authors. These have been compiled in Table 3.

When compared to the rhizomes of reed sweet grass, the roots of trees and shrubs are characterized by a high tensile strength. This does not, however, mean that they are suitable for reinforcing the shorelines of water bodies. The roots of many species grow in a direction opposite to that of the shore or above groundwater level, or parallel to it. Exposed to constant flooding, the roots rot after a certain time [14] and, in consequence, become weaker and cease to help protect the shorelines of water bodies. Moreover, during the autumn period, the large quantities of leaves falling into the water can lead to excessive amounts of organic material and in effect accelerate the eutrophication of a given water body.

Reed sweet grass, on the other hand, is well-adapted to growing in conditions of constant flooding, eutrophia, environmental pollution, and human pressure. It can quickly regenerate after mechanical damage suffered as a result of changes in the water level or high winds. Its rhizomes form a dense network that extends up to 1.0 m into the ground [1, 15, 16].

Reed sweet grass communities possess other positive qualities that augment their function of soil reinforcement. Oxygen enters the bog environment through air channels of the above-ground and below-ground stems and creates oxygen microspheres that make nitrifying bacteria activity possible [17]. Thanks to this, reed sweet grass bulrush is able to effectively clean domestic sewage, which could potentially enter the water body [18, 19]. Its role is particularly important in the removal of nitrogen [19]. Moreover, these plants create an ecotonic zone between land and deeper parts of the water body inhabited by the largest variety of aquatic and land animal species, and those which are characteristic to bulrush beds, including endangered amphibians, reptiles, and birds [20] that require active protection (on the territory of Poland). This cannot be said of artificial concrete reinforcements.

Conclusion

The studies concluded the rhizomes to be the strongest part of reed sweet grass. Average tensile strength of reed rhizomes was found to be 2,725 kPa, followed by the above-ground stem and the base of the stem. Significant differences between average tensile strengths were noted only between the rhizome and the base of the stem. What is more, reed sweet grass was determined to be suitable for reinforcing the shorelines of water bodies – an environment that is unfavorable to most trees and shrubs.

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