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Suitability of *Phragmites* for lightweight concrete

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Summary

In order to test the suitability of *Phragmites australis* as base material for lightweight concrete, reed straw was harvested from the protected mire area of the National Park Narew, NE Poland. In March 2004, plant material was collected along a transect extending from the margin of valley, across the floodplain up to the river. Studies on morphological properties like shoot length, shoot diameter, number of nodes, thickness of sclerenchyma rings and technical properties like bulk density, absorbing and binding of water were performed to elucidate the basics of the pressure stability (N mm^{-2}) of concrete probes.

Our results revealed that *Phragmites* growing far from the watercourse are characterised by low bulk density, better water characteristics and consequently higher pressure stability of concrete, reaching up to 0.5 N mm^{-2}. *Phragmites* growing close to the riverbank revealed significantly higher bulk density (over 100 kg m^{-3}), worse water features and as a consequence lower pressure stability of the concrete. The good parameters of obtained lightweight concrete blocs along with the rising industrial demand for cost effective, lightweight and robust insulating materials allow us to predict, that *Phragmites* has a great potential as feedstock for building materials.

Introduction

Poland like many others central and eastern European countries has recently undergone changes in its agricultural as well as political system, resulting in the neglect or abandonment of many former agricultural areas, e.g. semi-natural wet grasslands. In many cases cutting and grazing management of peatlands has almost completely ceased, due to limited accessibility of the area, low quality of hay and the use of intensively managed cultivated grasslands on the uplands for fodder production (BARTOSZUK et al., 2001). Unmanaged wetlands lose their nature conservation value, and is becoming dominated by a few robust plant species, mainly *Phragmites australis*, *Betula* or *Salix sp.* (DYRCZ, 1996; DEMBEK, 2002) at the expense of others. Maintenance of the biodiversity of these areas depends on the continuation of low-intensity agricultural management or/and implementation of other methods of peatland plants utilization (BEANSTED et al., 1999). There are many evidences that peatland biomass with commercial potential can be harvested for many purposes, which makes possible an economic exploitation combined with the conservation of natural mire functions (e.g. JOOSTEN and CLARKE, 2002). Winter harvested reed may be used e.g. as raw material for energy production (ALLIRAND and GOSSE, 1995), roofing material, form bodies as packaging material (THIEBODEAU and OSTRO, 1981), insulation material and construction sheets (CONSTANZA et al., 1997). It is of notice that winter harvest of reed probably can not stop its expansion, nonetheless, this management practice may play an important role in fire protection of valuable preservation areas (ROLLETSCHEK et al., 2000).

As a result of rising oil prices and therefore rising costs of artificial insolating material production, such as styrofoam, for years now research in Poland and Germany has been carried out on natural thermic protection. So far one of the major challenges is to find suitable plant material, as well as reasonable bonding agents, e.g. for the production of thermic protection (BOLTRYK et al., 1994). According to a recent patent it is possible to produce a solid building carcass on an ecological basis using biomass from selected plants (WO, 2004; PUDE et al., 2004). Since new, legal laws are considering thermic insulation in buildings and the trading of CO_2 emissions (MÜLLER-SÄMANN and HÖLSCHER, 2004), the use of renewable materials as construction material opens up an enormous scope of possibilities for farmers and industrial enterprises.

Different plants such as conifers, straw or *Miscanthus* × *giganteus*, provide an excellent resource basis for the production of plant-based lightweight concrete. The end product is made only from biomass mixed with special cement (PUDE et al., 2004). The former studies proved that the plant material of *Miscanthus* contains fibre compounds which are considerably stronger than e.g. straw (HESCH, 2000), and because of its chemical constituents like silicon, it represents a suitable basic material for building and construction (PUDE et al., 2004). In the literature there are many reports about using conifers or *Miscanthus* for production of lightweight concrete (BOLTRYK et al., 1994; HÖHN, 2002; PUDE et al., 2004); information about use of *Phragmites* biomass for that purpose is rather sparse in spite of the fact that the pressure stability of *Phragmites* is superior to that of *Miscanthus*, straw or conifers (PUDE, 2005).

The objective of this work was to test the suitability of *Phragmites australis* from the nature conservation area of Narew River Valley as base material for lightweight concrete. It was to be tested if there are differences in the quality (morphological properties) of *Phragmites* straw originated from the different locations which might influence the binding mechanism between cement and plant material. In addition, we intended to elucidate the mechanism of binding between *Phragmites* plant material and cement. The hypothesis was that the water binding capacity of biomass and lightweight concrete is the decisive factor for obtaining concrete with a very high pressure stability.

Material and methods

Study area

The upper part of the valley of the Narew river is one of the last extensive undrained non-reclaimed valley wetlands in Central Europe. Narew is the biggest river in north east Poland with mean discharge (water level gauge Rzedziany, near study site) about 19-22 m^{3}s^{-1}, ranging from 120 m^{3}s^{-1} during peak discharge and 5 m^{3}s^{-1} during base flow (JEDRYKA and SMOLUCHOWSKA, 1996). The Narew valley developed within the Pleistocene sediments, mostly glacial till and glacio-fluvial sands. Its longitudial part between Suraz and Rzedziany, where an anastomosing river system is preserved in its almost pristine form (GRADZINSKI et al., 2003) is protected as a national park. In this section the width of the valley varies markedly, from 1-1,5 km in the narrow parts, up to 4 km in the wide ones. The valley is filled with organic deposits, mainly peat and mud, in some places lined with a thin layer of organic silts or clayey silts lying on deep alluvial sands. The studied river reach is neither regulated nor embanked and the valley is characterized by a fairly natural hydrological pattern. Annual flooding occurs in the period from the beginning of March until May, occasionally until June. During this period considerable parts of the valley are inundated (BANASZUK, 1996). In the Narew National Park, agricultural use, drainage and groundwater extraction are limited, so that the vegetation still consist of natural peat-forming plant communities -sedge *Caricetum elatae* and *C. gracilis* community (2600 ha; 38% of the area) and reedy rushes *Phragmitetum communis* (1700 ha; 25%). Small clusters of osier community (*Salicetum pentandro-cinereae*) and single arborescent willows occur locally. Alder carrs (*Ribo nigri-alnetum*) are found sporadically at the valley margins (DEMBEK et al., 2002).

The mean annual precipitation in the region is 587 mm (years 1956-2000), of which 60-70% falls in summer (April-September). Mean air temperature amounts 6.9°C. The growing season is relatively short, about 190-200 days.

Plant material

The plant material was collected from a 100 m wide mire belt located between the margin of the valley and river bed, along a transect starting at the valley margin, crossing the floodplain and ending at the river. The studied transect is quite flat rising gently from the river towards the valley edge. Soils and groundwater level amplitude along the transect line were studied before, in the years 1999-2000 (BANASZUK, unpublished). The above-ground biomass of *Phragmites australis* was harvested in March 2004 from four 10 m^2 sampling plots located 0, 20, 60 and 80 m away from the valley edge according to expected soil moisture and flood depth gradient (Tab. 1). At every plot standing biomass from four sub-plots ($1 m^2$) was cut at 3-5 cm above soil surface and subsequently combined to one representative sample.

Tab. 1: Name and origin of *Phragmites* variants

variant/distance from the edge of the valley (m)	soil classification (after WRB, 1998)	soil depth, cm	water depth, cm (mean value and range in brackets)
A / 0 m	Areni-Mollic Gleysols	40	-34 (-112;4)
B / 20 m	Eutri-Haplic Histosols	70	-20 (-67;32)
C / 60 m	Eutri-Haplic Histosols	95	-14 (-77;34)
D / 80 m	Eutri-Haplic Histosols	120	-10 (-66;40)

Morphological properties

After harvest of plant material the following characteristics were measured: shoot length above ground (cm), diameter of shoots (mm) at 20 cm stem height, number of nodes per stem, and length of internodes (mm). All measurements were done in eight replications. Furthermore, the thickness of the sclerenchyma ring from *Phragmites* stem at the height of 20 cm was measured using the light microscope Leica Wild-M8, Solms, Germany. The area of the sclerenchyma ring was calculated according to PUDE (2005).

The morphological features of the surface of untreated *Phragmites* shoots at 20 cm height were analysed at Siegen University with the environmental scanning electron microscope (SEM) „XL30 ESEM“, Fei Philips Co, Kassel, Germany. The micrographs were taken in a low vacuum modus.

Technical properties of plant material and concrete blocs

After drying to 18 % moisture plant material was chopped into pieces of 2 cm in lengths, and the bulk density (kg m^{-3}) was measured. In order to test the binding of water, 250 cm^3 of the chopped *Phragmites* straw was weighted and mixed with 0.4 l of water. After 3.5 hours the wet biomass was placed on a filter for three hours. After a total of 6.5 hours the weight of the plant material was measured and the water binding capacity (%) determined in order to evaluate the water absorption by the plant material, *Phragmites* stems of 20 cm length were split lengthwise and put upright into a beaker filled with a mixture of water and cement. The velocity of capillary water movement along the stem was determined with a stop watch, while height of capillary rise in the sclerenchyma was measured with a ruler.

In order to obtain concrete probes, 1000 cm^3 of chopped *Phragmites* of each treatment group was mixed with 250 g cement, 50 g lime and 250 ml water (World Patent Nr. WO 2004/037742-A1; WO, 2004) and transferred into 250 ml forms. All concrete samples were prepared as four replications for each *Phragmites* variant. Twenty-four days after preparing the probes the permanent binding of water in the lightweight concrete (in %) was measured. In earlier experiments it has been shown, that there is no more loss of water thereafter (PUDE, 2005). Two months later, the pressure stability (N mm^{-2}) of the lightweight concrete was measured up to a stress of 10% using the Instron apparatus (Instron model 1011 Instron Corporation, Massachusetts).

Experimental data were analysed statistically using SAS and Statgraphics software. There were always four replications, and a probability value of 5% was assumed. Limits of LSD 5% are given in the graphics; in the tables significant differences are documented by different letters.

Results

Morphological properties

Despite of the fact that plant samples were collected from the relative small homogenous area covering the transition zone between valley edge and river bank (ca. 500 m^2), the morphological properties of *Phragmites* shoots from four analysed sampling plots differed in a wide range (Tab. 2). Some features, as thickness and area of sclerenchyma, changed along the transect roughly according to the expected moisture gradient reaching their highest values at wetter places located close to the river bed. This pattern, however, was not clearly apparent in the case of such properties as shoot length and diameter. The highest values in shoot length was obtained in *Phragmites* from contrasting plots A and C, where they amounted 182.0 and 171.8 cm, respectively (Tab. 2). Shoots length of *Phragmites* from remaining two plots B and D were significant lower – 144 and 126 cm respectively. The spatial changes in shoot diameter behaved in a similar way.

We found no significant differences between the thickness of the sclerenchyma and the area of the outer ring of the 4 analysed *Phragmites* variants. Tendencially the thickest sclerenchyma ring with 0.9 mm and the biggest sclerenchyma area with 2.15 mm^2 were found for *Phragmites* growing 60 m away from the valley edge (Tab. 2; Fig. 1).

The morphology of *Phragmites* shoot surface was compared with the intensively researched *Miscanthus* material (PUDE, 2005). Micrographs of *Phragmites* shoot taken with the SEM revealed that its surface is much rougher than the shoot surface of *Miscanthus* (Fig. 2). It might be a reason for the good mechanical binding between plant material and cement.

Tab. 2: Morphological properties of *Phragmites* from different areas in Narew

	Shoot length (cm)	Shoot diameter (mm) in 20 cm high	Number of nodes per stem	Thickness of sclerenchyma ring (mm)	Area of sclerenchyma ring (mm²)
A	182.0 a	7.3 ab	10.3 a	0.63 a	1.07 a
B	144.3 b	6.8 bc	10.8 a	0.71 a	1.37 a
C	171.8 a	8.3 a	11.8 a	0.92 a	2.15 a
D	126.0 c	6.0 c	8.3 b	0.83 a	1.94 a

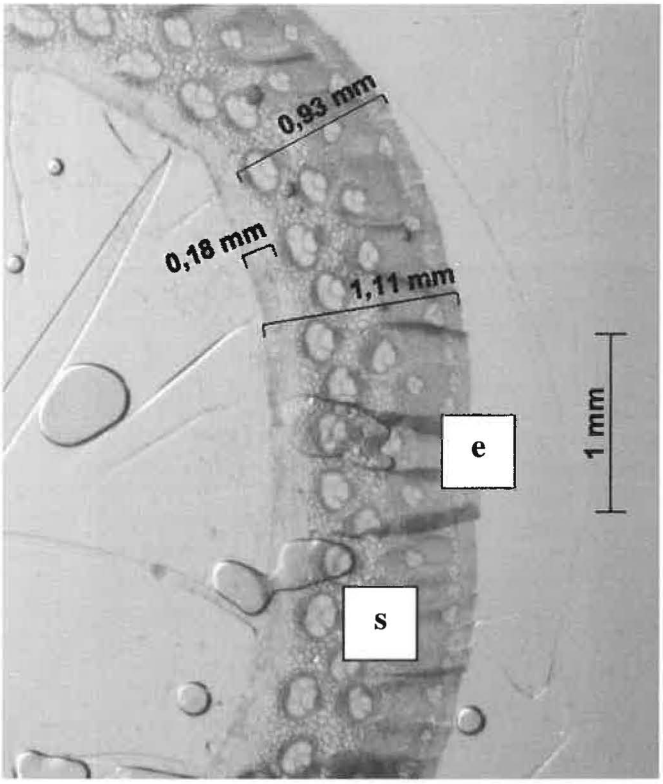

Fig. 1: Cross section of *Phragmites* shoot (e = epidermis, s = sclerenchyma)

Technical properties

The mean bulk density of reed changed along the transect in a regular way. The lowest values of 88-90 kg m^{-3} were found at the beginning of the transect, close to the valley edge. Approaching the river the bulk density of reed increased up to values slightly higher than 100 kg m^{-3}.

Water properties of biomass are thought to be a crucial factor controlling the characteristics and quality of the lightweight concrete, what has been demonstrated in earlier experiments with *Miscanthus* straw (PUDE et al., 2004). Since the chopped plant material sucked substantial amounts of water, also the cement mixture more easily intruded into the cellular structure of the biomass.

The highest absorption of water exhibited *Phragmites* biomass collected from the near-to-the river plots C and D (217.6 to 212.7%). The other variants had a distinctly lower capacity of water binding (Tab. 3).

Unlike immediate water binding the highest permanent binding of water was found in plants growing on drier sites placed close to the upland (43.4 to 46.8%). Plantmaterial from the middle of Narew River valley amounted only 28.6%.

It is not only important how much water and cement are sucked by the fibres; also the velocity of water transport is of significance. Binding between plant material and water-cement mixture takes place within the first 1-2 minutes (BOLTRYK et al., 1994; GÖRTZ et al., 2004). In our study we found that the highest uptake of water occurred during the first 30 seconds from the beginning of reaction. The significantly highest values of water suction were obtained for *Phragmites* from plot B after 0.5, 4 and 20 minutes (Fig. 3). As far as the maximum height of sucked water is concerned, also this variant was superior with 15.2 mm within 20 minutes (Tab. 3).

The most important factor for quality of lightweight concrete is its firmness. The best pressure stability of *Phragmites* probes was found for probes A and B with 0.45 and 0.50 N mm^{-2}, respectively, and the lowest one for probes from the middle of the valley (0.32 N mm^{-2}).

All reed plants (n=16) from plots analysed were classified, using cluster analysis (Ward's method) according to the following parameters: thickness of sclerenchyma ring, bulk density, height of absorbed water after 20 minutes, water binding capacity of dry matter, permanent water binding capacity and pressure stability. The results allowed a clear attribution of the plants to two distinct groups according to their technical parameters (Tab. 4, Fig. 4). The first cluster is formed almost entirely by plants from plots A and B. They are characterised by a low bulk density, better water characteristics and consequently higher pressure stability. Plants grouped into the second cluster (with one exception all of them were sampled from plots C and D) revealed significantly bad water characteristics. The pressure stability of the concrete probes was also distinctly lower.

Discussion

The comparison of morphological features of *Phragmites* biomass collected from a relatively small area showed a considerable variability. The plant material from four sampling plots located about 20 m away from each other differed in crucial parameters, such as a shoot length, stem diameter and internode length. Consequently, technical properties of biomass and manufactured concrete blocs differed depending on quality of plant material.

The question arises if the observed differences are caused by environmental factors. General site conditions, such as soil characteristics and water regime (apart from plot A) did not vary significantly within study area. The nutrient (N, K) supply is also very similar for all plots. Concentrations of nitrate and potassium in ground and pore water in peat deposits along the transect line was practically constant for the 100-metre-strip of the valley. Their content changed simultaneously throughout the year ranging from 1-2 to ten parts of mg l^{-1}. The pattern of groundwater phosphorus concentration differed from N and K. The higher P concentrations occurred at the beginning of transect, close to morainic upland. In this narrow strip the retention of sediment-bound P transported with erosion and surface runoff from the adjacent cropland may occur. In the middle strip of the mire PO_4^{3-} concentration dropped abruptly. It rose again in the part of the mire

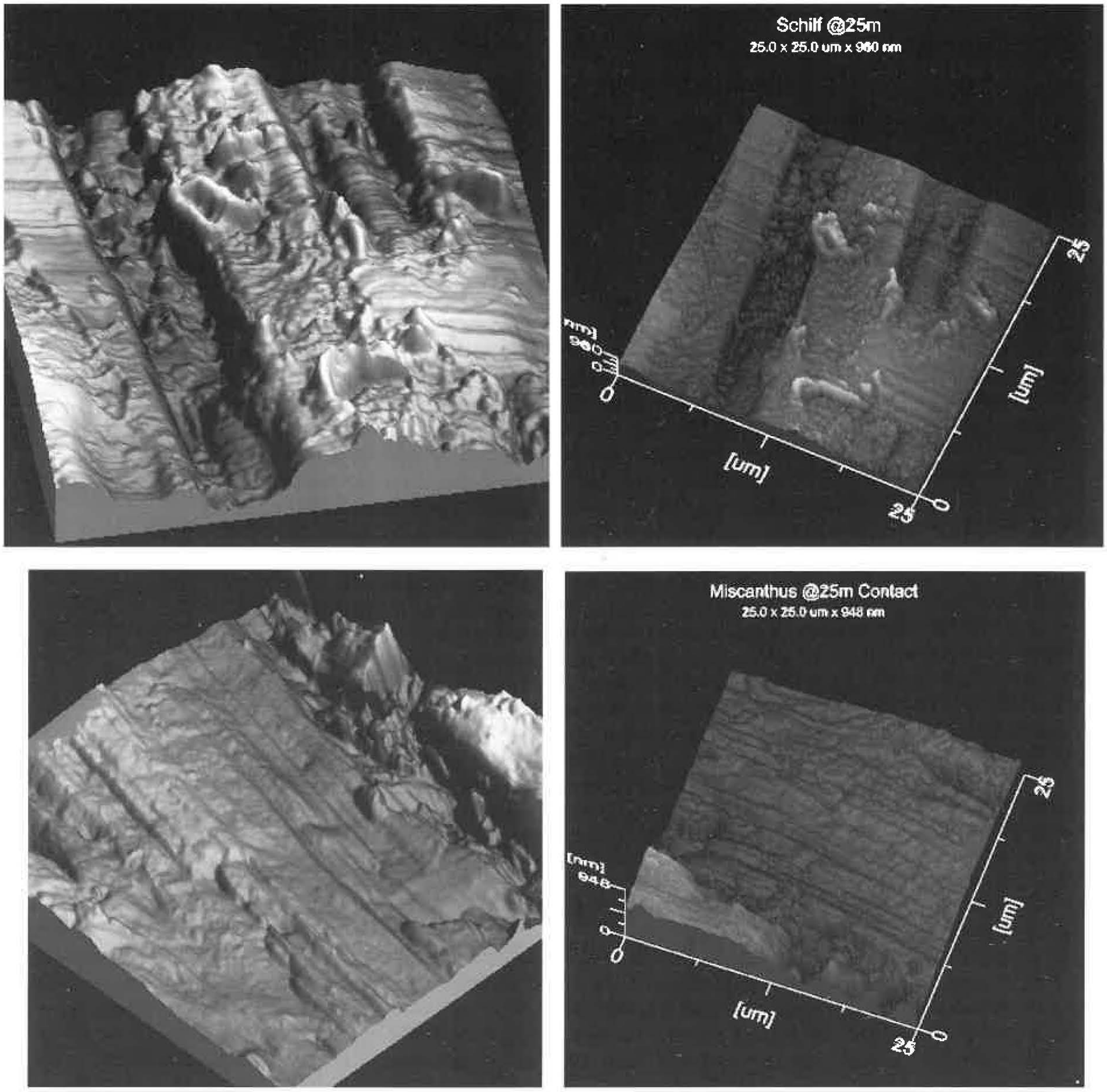

Fig. 2: Surface from shoot of *Phragmites* (above) and *Miscanthus* (below) (25 µm)

Tab. 3: Technical properties of *Phragmites* from different areas in Narew

	Bulk density ($kg\ m^{-3}$)	Water binding capacity of dry matter (%)	Height of absorbed water after 20 minutes (mm)	Permanent water binding capacity (%)	Pressure stability ($N\ mm^{-2}$)
A	90.1 ab	217.6 a	11.3 ab	46.8 a	0.45 ab
B	88.1 b	212.7 a	15.2 a	44.0 a	0.50 a
C	98.8 ab	197.0 b	10.0 b	43.4 a	0.41 ab
D	101.8 a	197.0 b	9.3 b	28.6 b	0.32 b

adjacent to the river (BANASZUK et al., in press). It is difficult, however, to judge to how extent P availability for plants could be responsible for the morphological variability detected within the analysed reed stand.

As alternative explanation one may assume that distinct growth forms as well as morphological and technical properties of *Phragmites* observed along the transect are determined by the genotype (KÜHL et al., 1999).

PUDE and TRESELER (2002) first described the suitability of grasses like *Miscanthus* as resource material for production of lightweight concrete. The advantages of *Miscanthus* compared to the common renewable materials like conifers are: (i) high thermal insolating qualities of parenchyma and (ii) the very high firmness of sclerenchyma (HESCH, 2000; HUTH, 2002).

A first comparison of *Miscanthus* and *Phragmites* showed that the surface of *Phragmites* shoot is much rougher than that of *Miscanthus* (Fig. 2). This phenomenon could to some extent explain a good mechanical binding between plant material and cement. However, previous experiments carried out with *Miscanthus* showed that additionally some other morphological and technical parameters of the biomass are responsible for the binding mechanism (PUDE et al., 2004; PUDE, 2005); therefore the intention of this trial was to elucidate the binding between *Phragmites* and cement mixture and to test the influence of different harvest qualities of *Phragmites* on the binding process.

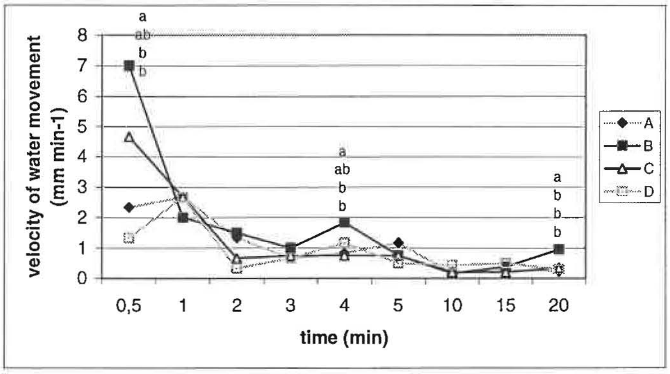

Fig. 3: Velocity of water movement in *Phragmites* shoots (mm min^{-1})

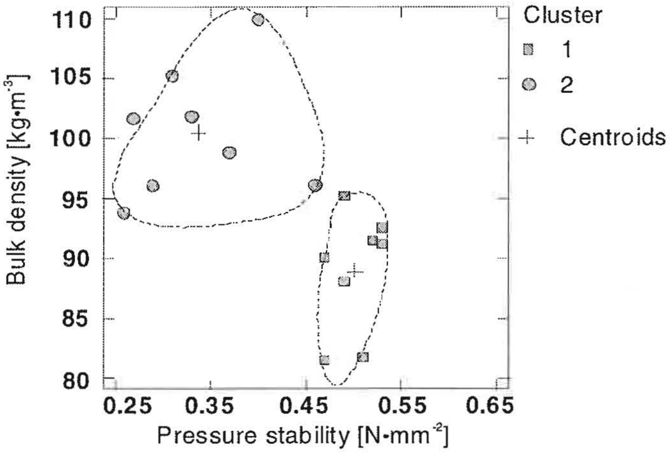

Fig. 4: Cluster scatterplot of analyzed reed samples. Cluster analysis (Ward's method; n=16) performed on the following variables: thickness of sclerenchyma ring, bulk density, height of absorbed water after 20 minutes, water binding capacity of dry matter, permanent water binding capacity and pressure stability.

For the production of lightweight concrete some technical properties are of importance, e.g. bulk density, because of the transport of the end products. With bulk density ranging from 88.1 to 101.8 kg m^{-3} the chopped reed was comparable to *Miscanthus* × *giganteus* (PUDE et al., 2004; PUDE, 2005). For high pressure stability of the building material it is necessary that biomass and cement form a tight and strong unit. Since cement is mixed with water, the absorption of this admixture by the *Phragmites* shred might be an important factor controlling the binding mechanism. The binding capacity of water by *Phragmites* amounted on average 206.1%. This value is very low compared to *Miscanthus* genotypes in which it can reach up to 368% (PUDE, 2005). A high water binding capacity correlates with high pressure stability of concrete blocs (PUDE, 2005). From this point of view *Phragmites* from plots A and B resulted in a stronger concrete.

Comparable to *Miscanthus* the absorption of water from *Phragmites* takes place in the sclerenchyma (PUDE, 2005). We found that thickness of sclerenchyma of reed harvested in the Narew valley is similar to *Miscanthus* genotypes, but its sclerenchyma area is slightly smaller. While the best genotypes of *Miscanthus* reached a sclerenchyma area of 3.6 mm² and the best *Phragmites* variants only 2.1 mm², this might be reason for differences in the water binding capacity.

In the process of producing lightweight concrete it is necessary that the plant material and the cement get in close contact very rapidly in order to start chemical reactions. These exothermic reactions can be measured as heat release (WO, 1994; GÖRTZ et al., 2004). Our results showed that all *Phragmites* variants absorbed most of the water-cement admixture within the first 60 seconds. PUDE (2005) has found that not only the rapid absorption of water, but also the capacity for long-term binding of water are important in the binding mechanism. It is of notice that three of four analysed *Phragmites* probes bound between 43.4 and 46.8% of water. These values are comparable to those obtained for *Miscanthus* (PUDE, 2005).

The cluster analysis showed clearly that reed from sites laying far from the watercourse possess most favourable features for concrete production. Reed growing close to the river bank was characterized by the higher bulk density and worse water characteristics, resulting in lower pressure stability of the concrete. Reed from the river bank is better and, what is most important, it is continuously supplied with minerals due to its contact with the watercourse. It seems that over consumption of some minerals such as silicon or calcium contained in water column may lead to higher saturation of cellular structure with these elements compared to the reed from other parts of the mire. This phenomenon may result in increase of the bulk density of the biomass and, regardless, may aversively affect the water properties of the biomass. Analysis of correlations between bulk density and height of the capillary rise, water binding capacity and pressure stability of concrete revealed significant, moderately strong, negative relationship (r=-0.64, -0.71 and -0.62 respectively; at $\alpha<0.05$), suggesting that bulk density of the biomass may be considered as an integrated, easy to determine indicator, which can describe or summarize other technical parameters of reed. In practise it is also possible to determine the quality of *Phragmites* by testing the water absorption.

Our results in combination with the experiences with *Miscanthus* (PUDE

Tab. 4: Results of classification of reed plants performed with cluster analysis (Ward's method; n=16); mean values of technical parameter of reed in obtained clusters; s-differences statistically significant, n.s. – differences non-significant

	Thickness of sclerenchyma ring (mm)	Bulk density (kg m^{-3})	Height of absorbed water after 20 minutes (mm)	Water binding capacity of dry matter (%)	Permanent water binding capacity (%)	Pressure stability (*N* mm^{-2})
Cluster 1	0,71	88,99	13,20	214,53	43,90	0,50
Cluster 2	0,85	100,40	9,70	197,58	37,53	0,34
	s	s	n.s.	s	n.s.	s

et al., 2004) allow to predict that reed material have great potential for lightweight concrete production. Further studies should focus on the thermal insulation properties of *Phragmites* lightweight concrete.

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References

ALLIRAND, J-M., GOSSE, G., 1995: An above-ground biomass production model for common reed (*Phragmites communis* Trin.) stand. Biomass Bioenergy 9, 441-448.

BANASZUK, H., 1996. Paleogeografia, naturalne i antropogeniczne przeksztalcenia doliny Górnej Narwi. Wyd. Ekonomia i Srodowisko, Bialystok.

BARTOSZUK, H., DEMBEK, W., JEZIERSKI, T., KAMINSKI, J., KUPIS, J., LIRO, A., NAWROCKI, P., SIKOR, T., WASILEWSKI, Z., 2001: Spasanie podmoklych lak w dolinach Narwi i Biebrzy jako metoda ochrony ich walorów przyrodniczych. Biblioteczka wiadomosci IMUZ, 98, Falenty.

BENSTEAD, P., JOSE, P., JOYCE, C., WADE, M., 1999: European Wet Grassland, Guidelines for management and restoration. RSPB, Sandy.

BOLTRYK, M., DAWDO, C., SYCZEWSKI, M., SOBOLEWSKI, J., 1994: Wiórobeton w budownictwie – Wlasciwosci, projektowanie, produkcja, zastosowanie. Politechnika Bialystok, Rozprawy Naukowe 26, ISNN 0867-096X.

CONSTANZA, R., D'ARGE, R., DE GROOT, R., FARBER, S., GRASSO, M., HANNON, B., LIMBURG, K., NAEM, S., O'NEIL, R.V. PARUELO, J., RASKIN, R.G., SUTTON, P., VAN DEN BELT, M., 1997: The value of the world's ecosystem services and natural capital. Nature 387, 253-361.

DEMBEK, W., 2002: Dylematy zwiazane z ochrona terenów otwartych w dolinach rzecznych. In: Dembek, W. (ed.), Aktualne problemy ochrony mokradel. Walory przyrodnicze mokradel mokradel ich uzytkowanie. Wyd. MUZ, Falenty, 82-92.

DEMBEK, W., SZEWCZYK, M., OSWIECIMSKA, Z., 2002: Ochrona Ekosystemów ladowych. Plan Ochrony Narwianskiego Parku Narodowego, manuscript.

DYRCZ, A., 1996: Wplyw sukcesji krzewów na awifaune w Biebrzanskim Parku Narodowym. In: Potrzeby i mozliwosci kierowania rozwojem roslinnosci zaroslowo-lesnej na torfowiskach niskich. Mater. z kon. Osowiec 16-17, 10.1996. Osowiec, BPN, 34-37.

GÖRTZ, B.R., TRETTIN, T., KOWALD, PUDE, R., 2004: Nutzung nachwachsender Rohstoffe in Bindebaustoffen – Hydratationsverlauf, Mikrogefüge und Eigenschaften. Proc. GDCh-Tagung Bauchemie, Erlangen.

GRADZIŃSKI, R., BARYLA, J., DOKTOR, M., GMUR, D., GRADZINSKI, M., KEDZIOR, A., PASZKOWSKI, M., SOJA, R., ZIELINSKI, T., ZUREK, S., 2003: Vegetation-controlled modern anastomosing system of the Upper Narew River (NE Poland) and its sediments. Sedimentary Geology 157, 253-276.

HESCH, R., 2000: Bau- und Dämmplatten sowie Schüttdämmung aus *Miscanthus x giganteus*. In: Pude, R. (ed.), *Miscanthus* – Vom Anbau bis zur Verwertung. Beiträge zu Agrarwissenschaften Bd. 19, 63-67. Verlag Wehle, Bad Neuenahr.

HÖHN, H., 2002: Mineralisch gebundene Baustoffe – *Miscanthus*. In: Pude, R. (ed.), Anbau und Verwertung von *Miscanthus* in Europa. Beiträge zu Agrarwissenschaften Bd. 26, 30-32. Verlag Wehle, Bad Neuenahr.

HUTH, H.-V., 2002: Ermittlung bauphysikalischer und baustatischer Eigenschaften von *Miscanthus*- Leichtbeton. In: Pude, R. (ed.), Anbau und Verwertung von *Miscanthus* in Europa. Beiträge zu Agrarwissenschaften Bd. 26, 33-38. Verlag Wehle, Bad Neuenahr.

JEDRYKA, E., SMOLUCHOWSKA, A., 1996: Rozrzad wody na obszarze Narwianskiego Parku Krajobrazowego. Zesz. Prob. Post. Nauk Roln. 428, 167-182.

JOOSTEN, H., CLARKE, D., 2002: Wise use of mires and peatlands. Background and principles including a framework for decision-making. International Mire Conservation Group and International Peat Society.

KÜHL, H., KOPPITZ, H., ROLLETSCHEK, H., KOHL, J-G., 1999: Clone specific differences ia a *Phragmites australis* stand. I. Morphology, genetics and site description. Aquat. Bot. 64, 235-246.

MÜLLER-SÄMANN, K., HÖLSCHER, T., 2004: Klimaschutz und Anbau von Miscanthus und anderen Nachwachsenden Rohstoffen. In: „Anbau, Verwertung und Erfolgsaussichten von *Miscanthus* in Europa". Tagung vom 2.-3. März 2004 in Bonn. Kurzfassungen der Vorträge. Beiträge zu Agrarwissenschaften Bd. 28, 52-56. Verl. M. Wehle, Bad Neuenahr.

PUDE, R., TRESELER, C.-H., 2002: Neue Ansprüche an *Miscanthus*-Genotypen bei stofflicher Nutzung. In: Pude, R. (ed.), Anbau und Verwertung von *Miscanthus* in Europa". Beiträge zu Agrarwissenschaften Bd. 26, 13-17. Verlag Wehle, Bad Neuenahr.

PUDE, R., 2003: Neue sichere Anbaumethoden von *Miscanthus* in Europa. Berichte über Landwirtschaft Bd. 81, 405-415. Landwirtschaftsverlag Münster-Hiltrup.

PUDE, R., TRESELER, C.-H., NOGA, G., 2004: Morphological, Chemical and Technical Parameters of Miscanthus Genotypes. J. Applied Botany Food Quality 78, 58-63.

PUDE, R., 2005: Bedeutung morphologischer, chemischer und physikalischer Parameter sowie ihrer Interaktionen zur Beurteilung der Baustoffeignung unterschiedlicher *Miscanthus*-Herkünfte. Habilitationsschrift, Universität Bonn. Beiträge zu Agrarwissenschaft Bd. 30, Verl. M. Wehle, Bad Neuenahr.

ROLLETSCHEK, H., ROLLETSCHEK, A., HARTZENDORF, T., KOHL, J-G., 2000: Physiological consequences of mowing and burning of *Phragmites australis* stands for rhizome ventilation and amino acid metabolism. Wetlands Ecology and Management 8, 425-433.

THIEBODEAU, F.R., OSTRO, B.D., 1981: An economic analysis of wetland protection. J. Environmental Management 12, 19-30.

WO (world patent office), 1994: Method of producing composite mouldings, WO 94/29232 from 22.12.1994.

WO (world patent office), 2004: Method for the production of a plantbased construction material and construction material obtained by means of said method, WO 2004/037742 A1 from 06.05.2004.

WRB, WORLD REFERENCE BASE FOR SOIL RESOURCES, 1998: World Soil Resources Reports FAO, ISRIC, ISSS, Rome.

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