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ORIGINAL PAPER

Future prospects for peat as a component of plant substrates – the economic aspect

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ABSTRACT

Efficient peat management has to consider both properties of this material, protective functions and economic aspects. A key task in the appropriate management of this resource is thus to assess profitability of commercial use of peat to produce peat-based substrates for forestry while observing all the above-mentioned criteria. The aim of this study was to conduct an economic evaluation of the role of peat in the production of a plant substrate used in container nursery production of woody plant seedlings and to undertake an economic assessment for the future use of this material. The analysis covered peat substrate manufacturing costs in the nursery company Gospodarstwo Szkółkarskie in Nędza in the years 2013-2022 (Rudy Raciborskie Forest District). For this purpose, an analysis of the cost structure was performed by determining the relative share of individual cost categories in total costs (*STS*), estimating the mean rate of their changes (*STZ*) was using the logarithmic method (Adamowicz *et al.*, 2016) and predicting unit production costs for the plant substrate by statistic analisis using polynomial regression. The mean share for costs of peat consumption (K1.1.1) in the total manufacturing costs amounted to 49% (43%<*STS*<62%), while their mean share in costs of material consumption (K1) was 69% (63%<*STS*<81%). In costs of basic materials (K1.1) the highest share was recorded for costs of peat (74%<*STS*<89%). The research indicated that the most stable variable was the production volume (*STZ*=0.029%), with a simultaneous increase in total manufacturing costs of the plant substrate (*STZ*=6%). The highest positive vector of changes was the cost of peat consumption (*STZ*=10%). It was found that changes in peat consumption costs showed a statistically significant relationship over time (R=0.66, *p*=0.037). Moreover, the costs of peat consumption in relation to the production volume showed a power-law relationship. The costs of peat consumption is the most important cost in the entire production process of the plant substrate. A particularly high increase was recorded in the last two years. The trend analysis showed that this situation will be aggravating. On this basis it was concluded that it is justified to search for alternative solutions and to gradually eliminate peat from the production of plant substrates.

KEY WORDS

cost structure, forest economics, peat consumption costs, peat substrates production, prediction analysis

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Introduction

Peatlands constitute an important component of global biodiversity (Posa *et al.*, 2011; Lipka and Stabryła, 2012; Carroll *et al.*, 2015). They provide a multitude of environmental services on the national and global scale (Reed *et al.*, 2014), including regulating (Pęczuła, 1996; Holden *et al.*, 2004; Gao *et al.*, 2016) and provisioning services (Taytsch, 1955; Ilnicki, 2002; Joosten and Clarke, 2002), while they are also ecosystems mitigating negative effects of climate change (Wodziczko, 1947; Okruszko, 1983; Maltby, 2010; Adamowicz and Keca, 2019; Leifeld *et al.* 2019; Humpenöder *et al.*, 2020). In view of the limited resources of peat and at the same time the long-term peat formation processes it is necessary to protect these ecosystems and the sustainable management of this resource both in the ecological and economic contexts, is becoming increasingly vital. Already in the late 1990s a reduction of peat excavation was observed in view of the increasing activity of environmental organisations (Rumpel, 1998). Initiatives for protection actions addressing peatland ecosystems resulted primarily from their carbon storage capacities (Yu *et al.*, 2010; Joosten, 2010; FAO, 2012) and potential mitigation of climate change (Wodziczko, 1947; Leifeld *et al.*, 2019; Humpenöder *et al.*, 2020; Doelman *et al.*, 2023). Postulates for the protection of peatland ecosystems were also put forward by Pawlaczyk (2005), DEFRA (2010), Tobolski (2012), Kiryluk (2013), Andersen *et al.* (2016) and Horabik and Smolarska (2019). In recent years concerns for the natural environment in Europe have promoted comprehensive actions for the preservation of peatland ecosystems and reduction of carbon emissions (UNESCO, 1971; Convention on biodiversity, 1995; Paris Agreement, 2015).

The location of peatlands is uneven around the world. Asia has the largest share in the peatlands area – 38.4% (1.6 million km^2), 31.6% of the world's peatland area is located in North America (1.3 million km^2) and 12.5% in Europe (528.3 thousand km^2), of which 185.8 thousand km^2 in Russia, 71.9 thousand km^2 in Finland and 60.8 thousand km^2 in Sweden (Xu *et al.*, 2018). It is reported that in Europe over a half of peatlands has been lost as a result of human activity (Spiers, 1999; FAO, 2012). In the late 1960s abandoned open pit workings in Poland accounted for 14.5% peatland area (Kaczan, 1968), while in the early 1970s over 82% peatland area was managed commercially (Jasnowski, 1972). At present the total peatland area in Poland exceeds 12.5 thousand km^2 (FAO, 2012), which accounts for 4% area of the country. As it was reported by Kotowski and Piórkowski (2003), 70% of peatland is utilised by agriculture, while peat is extracted only from 4% total peatland area. Peatland management methods applied to date have led to multifaceted adverse transformations, limiting ecological functions of these ecosystems (Pęczuła, 1996; Schmilewski, 2008). For this reason it is essential for commercial peat use to meet the principles of sustainable development. The limited availability of this resource, very long peat formation processes, restricted potential for its extraction along with the need to ensure provision of environmental services and protect peatlands are primary factors determining costs of plant substrate production. Efficient peat management has to consider both properties of this material, protective functions and economic aspects. A key task in the appropriate management of this resource is thus to assess profitability of commercial use of peat to produce peat-based substrates for forestry while observing all the above-mentioned criteria. It was assumed that this study will facilitate assessment of commercial utilisation of peat resources in the context of sustainable peatland management and provision of their ecosystem services.

Material and methods

The aim of this study was to conduct an economic evaluation of the role of peat in the production of a plant substrate used in container nursery production of woody plant seedlings and to undertake an economic assessment for the future use of this material.

The basic component for the production of substrates is raw sphagnum peat with a degree of decomposition of up to 15%. The Rudy Raciborskie Forest District produces three types of substrates: peat-perlite, peat-perlite with Azofoska all-purpose fertiliser added as a starter fertiliser in dusty form and peat-vermiculite-perlite. Peat substrates were purchased from Polish suppliers selected on the basis of a tender procedure. In order to realise this aim the structure of costs was analysed by determining the relative shares of individual cost categories in total costs (*STS*), estimating the mean rate of their changes (*STZ*) and predicting unit production costs for the plant substrate (CP). Analyses covered the last 10 years, *i.e.* 2013-2022, focusing on the costs generated by the application of peat as a component of a plant substrate. Source data were collected from the financial records of a nursery, Gospodarstwo Szkółkarskie in Nędza (Poland). This nursery farm specialises in the production of B&B (balled and burlapped) tree seedlings (in the container system).

Analyses were conducted using source data to determine the total manufacturing cost (TMC) for the production of this plant substrate. Detailed data were collected from the Information System of the State Forests (Polish: System Informatyczny Lasów Państwowych SILP). The analyses included the volume of production in accordance with the attachment to the cost spreadsheet constituting an attachment to the balance for December 31 of each year.

Analysis of peat substrate production costs was conducted in terms of the division into the following categories and cost items: consumption of materials, including peat (K1); machine maintenance (K2); electricity (K3); labour (K4); external services (K5) and indirect costs (K6). In view of the fact that the specific subject of this study was connected with the cost of peat application in the production of a plant substrate, the category of costs K1 was investigated in detail by introducing the following subcategories: basic materials including peat (K1.1), packaging (K1.2), and additional materials (K1.3). In view of the fact that the cost of peat consumption to produce a plant substrate is classified to category K1.1, additional details were included by introducing level of detail 3. Category K1.1 was divided into the costs of: peat (K1.1.1), perlite (K1.1.2), vermiculite (K1.1.3), Azofoska all-purpose fertiliser (K1.1.4) and dolomite (K1.1.5).

The classical *STS* analysis was conducted for all the above-mentioned categories. The levels of individual costs classified to a given category or subcategory (C_k) were referred to total manufacturing costs or to total costs of the superior category (C_{total}) in the annual system.

$$STS = \frac{C_k}{C_{total}} \cdot 100\% \tag{1}$$

The mean rate of changes in costs (*STZ*) was assessed using the logarithmic method (Adamowicz *et al.*, 2016). Indexes of cost variation dynamics (W_{dzk}) (2) were applied, subjected to the decimal logarithm calculation (3) and after the logarithm number ($\bar{A}$) was identified (4), the mean rate of changes in production costs of peat substrates (*STZ*) was determined (5).

$$W_{dzk} = \frac{wd_t}{Wd_{t-1}} \tag{2}$$

where:

Wd_t – value of analysed variables in individual years,

Wd_{t-1} – value of a given variable in the previous year.

$$\log \frac{wd_t}{Wd_{t-1}} \tag{3}$$

$$\overline{A} = 10^{\left(\frac{1}{n-1} \cdot \sum_{t-2}^{n} \log \frac{wd_t}{Wd_{t-1}}\right)} \quad (4)$$

where:

$\overline{A}$ – logarithm number,

n – number of observations.

$$STZ = (\overline{A} - 1) \cdot 100\% \quad (5)$$

where:

STZ – mean rate of change.

Cost prediction (CP) in the case of peat substrates was analysed statistically using polynomial regression, making it possible to model relationships between two variables. The proposed model took the form of the following equation:

$$\hat{y} = b_0 + b_1 x + b_2 x^2 \quad (6)$$

Regression analysis was also conducted for costs of basic materials and the volume of production. Moreover, the hypothesis on goodness of fit for the proposed models was verified and the value of the coefficient of correlation R was determined. The significance level was assumed at $\alpha=0.05$. Statistical analyses were performed using the STATISTICA 13.3 software package (TIBCO, 2017).

Results

In the years 2013-2022 the analysed economic entity produced 133,158 m^3 plant substrate (the cost of 20.3 million PLN). The mean annual unit manufacturing costs of 1 m^3 plant substrate in the investigated period ranged from 128 PLN to 253 PLN. The highest *STS* in the plant substrate manufacturing costs was generated by K1. In the analysed period these costs on average accounted for 70% (66%<*STS*<77%) (Table 1). In turn, K4 ranked second in the structure of costs. The share of these costs in the total manufacturing costs of the plant substrate was 13% (11%<*STS*<15%). In the structure of costs the category classified as K6 on average accounted for 8% (6%<*STS*<10%), followed by K2 (mean *STS* 5%, 2%<*STS*<8%). The lowest share was recorded for K5 (0.1%<*STS*<0.7%).

The detailed *STS* analysis of category K1 was conducted according to the adopted methodology. It was found that K1.1 was dominant in this category of costs. Throughout the investigated period these costs showed the dominant (82%<*STS*<91%) and at the same time stable share in K1 (Table 1). Additionally, an upward trend was observed for the share of this cost category in K1 (from 2019 to 2022 *STS* increased by over 8 percentage points (Table 1).

Peat is the basic material used to produce plant substrates. The cost related with the utilisation of peat in the production of the plant substrate was classified, next to other costs, to category K1 as well as second-degree subcategory K1.1. The mean *STS* for costs of using peat in the total manufacturing costs amounted to 49% (43%<*STS*<62%), while their mean *STS* in K1 was 69% (63%<*STS*<81%). At the third level of specificity homogeneous data were obtained for the cost of peat consumption (K1.1.1) to produce the plant substrate. In K1.1 the highest *STS* was recorded for K1.1.1 (costs of peat). The mean *STS* of K1.1.1 in K1.1 amounted to 80% and in the individual years it fell within the range of 74%<*STS*<89%. In the years 2018-2022 *STS* exceeded 80% (81%<*STS*<89%) (Table 1). A particularly high increase of *STS* for K1.1.1 in K1.1 was found between 2020 and 2022. During that period the share of costs for the use of peat in

Table 1.
The structure of peat substrate manufacturing costs (*STS*, %) in the nursery company Gospodarstwo Szkółkarskie in Nędza in the years 2013-2022

Categories and cost items	Years									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
STS (%, KC=100%)										
K1. Materials	70.98	74.27	69.79	71.68	67.30	67.01	72.23	66.48	66.53	76.96
K1.1. Basic materials	63.13	63.86	59.77	62.62	57.90	56.26	59.28	56.07	58.39	69.66
K1.1.1. Peat	47.03	47.95	47.25	46.73	42.61	46.19	48.66	45.44	51.23	62.14
K1.1.2. Perlite	11.19	9.54	8.00	11.11	10.41	7.00	7.38	7.00	4.39	5.19
K1.1.3. Vermiculite	3.50	4.92	2.82	2.85	3.29	1.20	2.00	2.35	2.09	1.49
K1.1.4. Azofoska all-purpose fertiliser	0.98	0.86	0.97	1.07	0.79	1.11	0.87	0.87	0.50	0.69
K1.1.5. Dolomite	0.44	0.60	0.72	0.85	0.79	0.77	0.38	0.40	0.17	0.15
K1.2. Packing	7.60	10.19	9.78	8.87	9.12	10.61	12.38	10.27	7.54	7.27
K1.3. Additional materials	0.25	0.21	0.24	0.19	0.29	0.14	0.57	0.13	0.60	0.02
K2. Machine maintenance	7.18	3.61	6.13	4.69	7.68	6.20	3.69	5.36	8.27	2.12
K3. Electricity	2.41	2.89	3.23	3.55	3.90	3.86	3.05	3.69	4.15	2.97
K4. Labour	11.92	11.83	12.46	12.91	13.34	14.44	14.37	15.44	10.96	12.14
K5. External services	0.17	0.70	0.25	0.12	0.15	0.19	0.21	0.24	0.14	0.22
K6. Indirect costs	7.34	6.70	8.14	7.04	7.63	8.31	6.46	8.78	9.95	5.59
STS (%, K 1=100%)										
K1.1. Basic materials	88.94	85.99	85.65	87.36	86.03	83.95	82.07	84.35	87.77	90.52
K1.1.1. Peat	66.26	64.57	67.71	65.19	63.31	68.93	67.36	68.36	77.01	80.75
K1.1.2. Perlite	15.76	12.84	11.47	15.50	15.46	10.44	10.22	10.54	6.60	6.75
K1.1.3. Vermiculite	4.92	6.63	4.04	3.98	4.89	1.79	2.76	3.53	3.14	1.93
K1.1.4. Azofoska all-purpose fertiliser	1.38	1.15	1.40	1.49	1.18	1.66	1.20	1.32	0.76	0.90
K1.1.5. Dolomite	0.62	0.80	1.03	1.19	1.18	1.14	0.53	0.61	0.26	0.19
K1.2. Packing	10.70	13.72	14.01	12.38	13.54	15.84	17.14	15.45	11.33	9.45
K1.3. Additional materials	0.36	0.29	0.34	0.26	0.43	0.21	0.79	0.20	0.90	0.03
STS (%, K 1.1=100%)										
K1.1.1. Peat	74.49	75.08	79.06	74.63	73.60	82.10	82.07	81.05	87.75	89.21
K1.1.2. Perlite	17.72	14.94	13.39	17.75	17.98	12.43	12.45	12.49	7.52	7.45
K1.1.3. Vermiculite	5.54	7.71	4.72	4.56	5.69	2.13	3.37	4.18	3.57	2.13
K1.1.4. Azofoska all-purpose fertiliser	1.55	1.34	1.63	1.71	1.37	1.98	1.46	1.56	0.86	0.99
K1.1.5. Dolomite	0.70	0.93	1.20	1.36	1.37	1.36	0.64	0.72	0.30	0.21

the costs of basic materials by 8 percentage points (p.p.). In turn, when comparing data for the entire period of analysis, the share of costs of peat consumption in K1.1 increased by 14 p.p. The share of the other costs, *i.e.* K1.1.2 – K1.1.5, in the individual years showed changes, while their decreasing share was observed in K1. For example, *STS* for K1.1.2 ranged from 7% to 18%, for K1.1.3 *STS* ranged from 2% to 8%. *STS* for K1.1.3 did not exceed 2%, whereas *STS* for K1.1.4 took values below 1%.

Based on the conducted analyses it was stated that the volume of production was the most stable category among the investigated variables. In the case of source data from the 10-year time series (Table 2). This shows that in the investigated period changes in the volume of production were relatively slow when compared to the changes in the analysed costs. Except for 2021 the mean annual level of production of the plant substrate ranged from 11 to 17 thousand m^3. We need to stress the fact that in 2021 a decrease was recorded in the volume of plant substrate production to the lowest level (7.5 thousand m^3). However, this decrease was not accompanied by a reduction of costs connected with the use of peat in the production process. In 2022 an increase was recorded (almost 2-fold in relation to the previous year). It is obvious that at an increase in production of peat substrates, and thus the increase in the use of peat, the total cost connected with its utilisation also increased. Nevertheless, the increase in costs was disproportionally higher in relation to the changes in production volume (*STZ* for the volume of production was 0.029%, *STZ* for cost of peat consumption was 9.56%).

Analysis of changes in unit costs confirmed the above observation. It was found that in recent years, irrespective of changes in the volume of production of the plant substrate, the cost of using peat per 1 m^3 of this substrate did not exceed 66 PLN (2018 – 64 PLN, 2019 – 66 PLN, 2020 – 64 PLN) a rapid growth in unit costs took place in 2021 to 104 PLN and next in 2022 up to 157 PLN. On this basis the effect of scale for the volume of production may be eliminated as a factor determining changes in the costs of peat use in the production of the plant substrate. The above observation may be confirmed by the fact that at a slight rate of production growth an increase was recorded for *STZ* for total costs. In the analysed period the rate of changes in these costs was 6% (Table 2). At the same time, all the cost categories, except for K2 (*STZ*=–7%), showed a positive vector of changes (3%<*STZ*<9%). The highest *STZ* was recorded for K5 and K3 (*STZ*=9%), followed by K1 (*STZ*=7%) and K4 (*STZ*=6%). The greatest growth dynamics was found for categories K5 and K3, whereas the highest *STS* was observed for K1. For this category high *STZ* amounting to 7% was also recorded. In view of the fact that *STS* for K1 was greatest, it needs to be stated that the costs of using materials, including peat, not only played a dominant role in the modification of total manufacturing costs of the plant substrate, but their importance was growing (particularly in relation to K2 (the negative vector), K4 and K6. Although a higher level of *STZ* was found for costs incurred for K3 and K5, it is known from earlier studies that their joint *STS* did not exceed 4.5% (Table 1).

When investigating costs at the second level of specificity it was stated that the highest *STZ* was found for K1.1 (*STZ*=7%). In the analysed period an increase for K1.2 (*STZ*=6%) and a decrease in K1.3 costs (*STZ*=–18%) were also recorded (Table 2). Costs of the use of materials in the production of peat substrates showed changes, which were characterised by a varied rate and different vectors. A positive vector of changes was found for costs K1.1.1 (*STZ*=10%) and K1.1.4 (*STZ*=2%). In this case the highest positive *STZ* was recorded for K1.1.1 (cost of peat use). A negative direction of changes was found for costs of the other components used in the production of the plant substrate. The highest *STZ* with a negative vector of changes was found for K1.1.5 (*STZ*=–6%), followed by K1.1.3 (*STZ*=–3%) and K1.1.2 (*STZ*=–2%).

Table 2.
Mean rate of changes in unit manufacturing costs of peat substrates (*STZ*, %) in the nursery company Gospodarstwo Szkółkarskie in Nędza in the years 2013-2022

Costs and production volume	Years										*STZ* [%]
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	
K1. Materials	104.37	94.87	89.76	95.69	93.80	93.15	97.34	94.17	134.95	194.81	7.1803
K1.1. Basic materials	92.83	81.58	76.87	83.60	80.69	78.21	79.89	79.43	118.44	176.34	7.3897
K1.1.1. Peat	69.15	61.25	60.78	62.39	59.39	64.21	65.57	64.38	103.93	157.31	9.5627
K1.1.2. Perlite	16.45	12.18	10.30	14.84	14.51	9.72	9.95	9.92	8.91	13.14	–2.4654
K1.1.3. Vermiculite	5.14	6.29	3.63	3.81	4.59	1.67	2.69	3.32	4.23	3.76	–3.4141
K1.1.4. Azofoska all-purpose fertiliser	1.44	1.09	1.25	1.43	1.11	1.55	1.17	1.24	1.02	1.75	2.1900
K1.1.5. Dolomite	0.65	0.76	0.92	1.14	1.10	1.06	0.51	0.57	0.35	0.38	–5.7901
K1.2. Packing	11.17	13.02	12.58	11.85	12.70	14.75	16.68	14.55	15.29	18.41	5.7088
K1.3. Additional materials	0.37	0.27	0.30	0.25	0.40	0.19	0.77	0.19	1.22	0.06	–18.3010
K2. Machine maintenance	10.55	4.61	7.88	6.26	10.70	8.62	4.97	7.60	16.78	5.38	–7.2095
K3. Electricity	3.55	3.69	4.15	4.75	5.43	5.36	4.11	5.23	8.42	7.52	8.6979
K4. Labour	17.52	15.11	16.03	17.23	18.60	20.07	19.36	21.88	22.23	30.73	6.4423
K5. External services	0.25	0.89	0.32	0.16	0.20	0.26	0.28	0.34	0.29	0.56	9.3746
K6. Indirect costs	10.80	8.56	10.48	9.39	10.64	11.54	8.70	12.44	20.19	14.14	3.0393
Total production costs	147.04	127.74	128.61	133.49	139.38	139.01	134.76	141.66	202.85	253.14	6.2219
Production volume (m^3)	14 242	16 060	15 407	14 927	12 611	11 229	16 015	10 860	7 527	14 279	0.0290

In accordance with the adopted methodology the polynomial regression was determined, thanks to which it was attempted to model an increase in the costs of peat over time. It was stated that changes in this cost showed a statistically significant dependence in time (R=0.66, p=0.037). In view of the earlier results connected with the analysis of changes in the costs of peat in relation to the volume of production as well as a high *STZ* it was stated that the data show a power type dependence. Since the recorded increase in the costs of peat was greater than that of the total cost, this increment was faster than at the linear or exponential values. Thus it was stated that changes in the dependent value (costs of peat) are proportional to the power of changes in the independent value (the passage of time). It was established that the equation of this dependence takes the following form: $y=1.0558e^7-10473.18x+2.597x^2$. This equation was used to make predictions for the level of cost for 2023 and 2024. Based on the obtained results (2023 – 283 PLN, 2024 – 321 PLN) it was stated that K1.1.1 in the successive years will continue to grow (Fig. 1).

Discussion

The total global peatland area is 4.23 million km^2, approx. 2.84% world land area (Xu *et al.*, 2018). At the same time, the global peat extraction in 2021 was approx. 27 million tons, of which in Poland it is 900 thousand tons, at the world reserves of 1.3 billion tons (U.S. Geological Survey, 2022). Most of the extracted peat worldwide is used to generate electricity (Mitsch and Gosselink, 2000). In Europe and North America peat is used primarily as a substrate for plant propagation (Caron and Rochefort, 2013; Barrett *et al.*, 2016). A conflict between protection and commercial use of peatlands is particularly evident in the countries with a high population density and pressure resulting from the competitive use of land by forestry or horticulture (Rawlins and Morris,

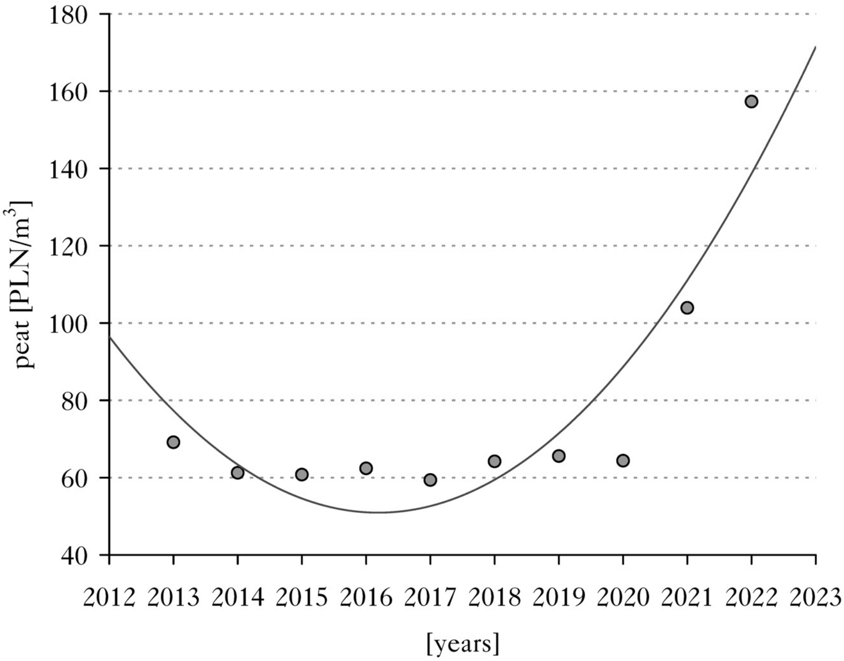

Fig. 1.
The trend for changes in the costs of peat used in the production of the plant substrate in the nursery company Gospodarstwo Szkółkarskie in Nędza in the years 2013-2022

2010; Clarke and Rieley, 2019). For this purpose actions are required to reduce the use of peat to produce substrates for forest tree seedlings. Conducted studies indicate a very high share of costs of using peat. In the total production of the plant substrate the cost of peat use ranged from 43% to 62%, with a marked increase in the share of its costs observed in the last two investigated years of its production. A high, positive rate of changes in the share of this cost (*STZ*<9%) indicates the need to incur increasingly higher costs related with the use of peat to produce the plant substrate. In view of the above it needs to be stated that the increasing restrictions in the availability of traditional raw materials for the production of plant substrates result in increased costs of peat use. In the investigated period production costs of plant substrates in the analysed enterprise grew markedly. This resulted primarily from the increasing costs of peat use. The upward trend for the costs of peat use, being the basic component, at a practically constant volume of production, as well as the constant demand for forest tree seedlings indicate the need to search for peat substitutes in the production of plant substrates, appropriate in terms of their physical and chemical properties, while at the same time being economically profitable. The growing pressure exerted on producers, particularly in the horticultural sector, has led to the growing demand for alternative, renewable and reliable plant substrates (Ceglie, 2015; Gruda, 2019). Obtained results show a similar situation also in forestry. Coir (coconut fibre) is commonly used worldwide as an alternative for peat. In Poland the suitability of coir in the production of plant substrates was indicated *e.g.* by Treder (1999), Nawrocka-Grześkowiak (2004) and Nawrocka-Grześkowiak and Bielecka (2008). However, relatively few studies evaluated this substrate type in terms of its potential use in forest nurseries. Among others, a study by Mariotti *et al.* (2020) suggested that coir may be used as an alternative plant substrate for cultivation of seedlings of the genus *Quercus*. It seems advisable to consider the potential application of this raw material in Polish forest nurseries and determine profitability of production for plant substrates using this material. Availability of coir on the Polish market is limited. This raw material has to be imported from tropical countries. A problem may be associated with the fact that to date its suitability and potential use to cultivate native forest-forming species have not been tested. As indicated by Kratz *et al.* (2013), several renewable resources, agricultural and industrial waste or municipal waste are suitable for use as components in plant substrates for the production of forest seedlings, while plant substrates based on coir and carbonised rice hulls are more suitable than plant substrates produced based on biosolids. In turn, Alonso *et al.* (2018) recommended the use of plant substrates composed of biosolids to produce forest seedlings, indicating the positive effect of biosolids on the growth and quality of seedlings. The particular importance of plant substrate in the production of forest seedlings was indicated by Silva *et al.* (2020), while their study confirmed that seedlings produced in facilities using composted coffee grounds showed higher values of most analysed variables compared to seedlings produced in facilities with composted rice hulls and in the control. The potential use of harvest residue to produce plant substrates for forest tree seedlings was also shown by Monaco *et al.* (2020), who indicated the suitability of moinha coffee as a substrate for the production of eucalyptus (*Eucalyptus urograndis*) seedlings. In the production of the seedling material also sediments excavated from watercourses are recommended after being purified in the process of phytoremediation when used as plant substrates alternative to the traditional nursery substrate in the container production of evergreen oak (*Quercus ilex* L.) seedling material (Ugolini *et al.*, 2018). According to the results reported by Ugolini *et al.* (2018), reclamation of mining spoil may provide appropriate nursery substrates for forest tree species. It needs to be stated that the above study does not refer to financial aspects and – at least so far – do not indicate solutions to be applied on a commercial scale. For this reason it seems that the analyses presented in this paper constitute a valuable supplementation of the current state of knowledge on the subject.

It needs to be remembered that the potential use of peat to produce plat substrates, apart from the ecological aspects, is also determined by economic considerations. In view of the difficult economic situation caused by the Coronavirus pandemic along with its economic consequences, as well as the current military conflict in Ukraine, purchase of the basic raw material for the production of plant substrates is becoming increasingly difficult, which is manifested in the increased costs of peat and at the same time their share in the total production of peat-based substrates. The currently introduced legal changes related with the growing pressure in the EU focused on environmental protection in the near future may result in the complete ban on the extraction and import of peat to the EU. Great Britain was the first country, in which the complete ban on retail sale of peat was introduced in 2024. Since 2030 the ban will cover also the commercial market (Alexander *et al.*, 2008). Reaching a compromise between the commercial use and the preservation and protection of peatlands require an integrated concept for the functions of peatlands and an absolute understanding how disturbances and recreation of these habitats influence the climate and economy. On the one hand, postulates have been proposed for many decades concerning renaturation, regeneration of peatlands and wetlands as well as restoration of biodiversity and lost nature value to these areas (Schuch, 1993; Zollner, 1993; Siuda, 1995; Pfadenhauer, 1998a, b; Weid, 1999; Eigner, 2003, Frankl *et al.*, 2003). On the other hand, increasing problems with acquisition of peat and at the same time growing production costs of peat-based substrates indicate the need to search for alternative components to cultivate forest tree seedlings. Also the same challenges are faced by Polish forestry if the State Forests are planning to maintain and develop container nursery production.

Conclusions

Based on the conducted review of literature it was shown that due to environmental and climatic concerns the exploitation of peatlands for commercial purposes is being gradually restricted. In the production of forest plant substrates it is necessary to consider aspects connected with the protection and restitution of peatlands, while economic actions may not be limited to the importance and ecosystem functions of peatlands.

Based on the presented analysis of cost of peat consumption to produce a plant substrate:

- It was shown that at present unprocessed peat is the basic material for the production of plant substrates and this is the most important cost item in the entire production of soil substrates ($43\%<STS<62\%$).
- It was found that in the last decade the costs of peat consumption increased faster ($STZ=9.56\%$) than the production volume of peat substrates ($STZ=0.29\%$).
- A particularly high increase in the costs of peat consumption was recorded in the last two years. The trend analysis showed that this situation will be aggravating ($R=0.66$, $p=0.037$). The costs of peat consumption in relation to the production volume showed a power-law relationship. On this basis it was concluded that it is justified to search for alternative solutions and to gradually eliminate peat from the production of plant substrates.

Authors' contributions

Conceptualization – K.A. and K.W.; methodology – K.A., A.A.-J. and M.M.-G.; validation – K.A., investigation – K.W. A.A.-J. and M.M.-G.; data curation – K.W.; writing-original draft preparation – K.W. and A.A.-J., supervision – K.A.; funding acquisition – K.A.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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STRESZCZENIE

Przyszłość torfu jako komponentu substratów glebowych – aspekt ekonomiczny

Ograniczona dostępność i możliwości pozyskania torfu, długotrwałe procesy torfotwórcze oraz realizacja funkcji ekosystemowych i potrzeba ochrony torfowisk są podstawowymi czynnikami determinującymi poziom kosztów produkcji substratów torfowych. Kluczowym zadaniem jest zatem ocena opłacalności gospodarczego wykorzystania torfu do produkcji substratów torfowych dla leśnictwa, z zachowaniem tych wszystkich kryteriów. W pracy przyjęto założenie, że przeprowadzone badania pozwolą na ocenę ekonomicznego wykorzystania surowca torfowego w kontekście zrównoważonego zarządzania torfowiskami i realizacji przez nie usług ekosystemowych.

Analizą objęto koszty poniesione na produkcję substratów glebowych w Gospodarstwie Szkółkarskim w Nędzy (Nadleśnictwo Rudy Raciborskie) w latach 2013-2022. Dla wszystkich wyszczególnionych kategorii i pozycji kosztów przeprowadzono klasyczną analizę struktury (*STS*), a następnie za pomocą metody logarytmicznej (Adamowicz i in. 2016) dokonano oceny średniego tempa zmian kosztów (*STZ*). Do analizy predykcji kosztów substratów torfowych zastosowano analizę statystyczną z wykorzystaniem regresji wielomianowej.

Największy udział w kosztach wytwarzania substratu glebowego miały koszty zużycia materiałów (K1) (66%<*STS*<77%) (tab. 1). Średni udział kosztów zużycia torfu (K.1.1.1) w całkowitych kosztach produkcji wynosił 49% (43%<*STS*<62%), z kolei ich średni udział w kosztach zużycia materiałów kształtował się na poziomie 69% (63%<*STS*<81%). Stwierdzono, że w kosztach zużycia materiałów podstawowych (K.1.1) najwyższy udział stanowiły koszty zużycia torfu (74%<*STS*<89%). W latach 2018-2022 przekroczyły one 80% (81%<*STS*<89%) (tab. 1).

Badania wykazały, że najbardziej stabilną zmienną była wielkość produkcji (*STZ*=0,029%), przy jednoczesnym wzroście kosztów całkowitych (*STZ*=6%) (tab. 2). Spośród kosztów zużycia materiałów (K1) do produkcji substratów torfowych najwyższym dodatnim wektorem zmian charakteryzowały się koszty zużycia torfu (K1.1.1) (*STZ*=10%). Stwierdzono, że zmiany kosztów zużycia torfu wykazywały istotną statystycznie zależność w czasie (R=0,66, p=0,037), ponadto koszty zużycia torfu względem rozmiaru produkcji wykazywały zależność potęgową. Na podstawie uzyskanych wyników badań stwierdzono, że koszty zużycia torfu w kolejnych latach będą wzrastać (ryc. 1).

Na podstawie przeglądu literatury wykazano, że ze względów środowiskowych i klimatycznych stopniowo rezygnuje się z eksploatacji torfowisk dla celów przemysłowych. W produkcji substratów glebowych dla leśnictwa konieczne jest uwzględnienie aspektów związanych z ochroną i restytucją torfowisk, a działania gospodarcze nie mogą ograniczać znaczenia i funkcji ekosystemowych torfowisk. Na podstawie zaprezentowanej analizy kosztów produkcji substratów glebowych udowodniono, że obecnie podstawowym materiałem do produkcji jest surowy torf. Jego koszt jest najistotniejszym kosztem w całej produkcji substratu glebowego. Stwierdzono, że w ostatnim dziesięcioleciu koszty zużycia torfu rosły, a szczególnie duży wzrost odnotowano w ostatnich 2 latach. Analiza trendu wykazała, że sytuacja ta będzie się pogłębiać. Na tej podstawie wyciągnięto wniosek, że zasadne jest poszukiwanie alternatywnych rozwiązań i stopniowe eliminowanie torfu z produkcji substratów glebowych, które są stosowane w leśnictwie.