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Response of Interspecific Geraniums to Waste Wood Fiber Substrates and Additional Fertilization

Agnieszka Zawadzińska [1,*], Piotr Salachna [1], Jacek S. Nowak [2] and Waldemar Kowalczyk [2]

[1] Department of Horticulture, West Pomeranian University of Technology, 3 Papieża Pawła VI Str., 71-459 Szczecin, Poland; piotr.salachna@zut.edu.pl

[2] The National Institute of Horticultural Research, 1/3 Konstytucji 3 Maja Str., 96-100 Skierniewice, Poland; jacek.nowak@inhort.pl (J.S.N.); waldemar.kowalczyk@inhort.pl (W.K.)

* Correspondence: agnieszka.zawadzinska@zut.edu.pl; Tel.: +48-91-4496-356

Abstract: Promotion of sustainable horticulture via wider use of peat substrate substitutes makes wood fiber an increasingly popular substrate component. Interspecific geraniums are plants of huge potential in the floriculture market, but there are not enough specific guidelines on their cultivation. This study investigated the effectiveness of enriching peat substrate with 10%, 20%, 30%, or 40% (by volume) waste wood fiber in the pot cultivation of interspecific geraniums cv. 'Calliope Dark Red'. It also examined plant response to additional fertilization with nitrogen in the form of $Ca(NO_3)_2$. Plants grown in the substrate with 10% and 20% of wood fiber did not differ in the leaf greening index, flower weight, and visual score from the plants grown in control (100% peat substrate). Wood fiber content of 40% negatively affected all growth parameters and leaf content of macro- and micronutrients. The plants growing in the peat substrate enriched with 20% of waste wood fiber and fertilized with nitrogen had the highest leaf greenness index, the greatest number of flowers, and the highest content of N, P, Ca, Na, Fe, Mn, Cu, and Zn. In summary, the study demonstrated that high quality ornamental plants can be successfully grown in peat substrate containing 20% of waste wood fiber and additionally fertilized with nitrogen.

Keywords: horticultural production; nutrient analysis; peat moss; *Pelargonium*; potting media

Citation: Zawadzińska, A.; Salachna, P.; Nowak, J.S.; Kowalczyk, W. Response of Interspecific Geraniums to Waste Wood Fiber Substrates and Additional Fertilization. *Agriculture* **2021**, *11*, 119. https://doi.org/10.3390/agriculture11020119

Academic Editors: Lourdes Rubio

Received: 7 January 2021
Accepted: 28 January 2021
Published: 2 February 2021

1. Introduction

Geraniums belong to the most important ornamental plants in the world, and are the leading commodity on the flower exchanges [1]. They are resistant to unfavorable environmental conditions and widely used in urban areas in flower beds, containers, and green areas [2,3]. Moreover, geraniums are natural accumulators of heavy metals and, as such, can be used for phytoremediation [4]. To maintain consumer interest and increase the sales of geraniums, breeding companies constantly seek new cultivars with distinctive decorative features, such as interspecific geraniums developed by crossing the two most important geranium species: *Pelargonium* × *hederaefolium*, syn. *P. peltatum* and *P.* × *hortorum*, syn. *P. zonale*. The new hybrids show some of the most desirable functional and morphological traits of *P.* × *hederaefolium* (resistance to high temperature, large, dark-green leaves, sizable inflorescences) combined with the advantages of *P.* × *hortorum* (abundant flowering, possibility of cultivation in hanging containers) [5]. A particularly attractive group of interspecific geraniums is Calliope developed by Syngenta/FloriPro Service company with cultivars characterized by vigorous growth, overhanging habit, and high disease resistance [6]. The guidelines for growing popular geranium species are well developed [7], but studies on potted plant production of interspecific geraniums are lacking.

The search for and improvement of eco-friendly methods of plant cultivation have become the most important tasks for modern horticultural production [8,9]. One important factor in cultivation of potted plants is growing substrate. Peat moss is the major component of most potting substrates for ornamentals. Huge consumption of high peat for the production of greenhouse plants stimulates the search for raw materials from renewable sources that could effectively replace peat [10,11]. One of them is wood fiber, most commonly produced from fresh or waste pine wood [12,13]. Wood fiber can be used in plant production as an independent substrate or as an addition to other components, e.g., peat [10,14,15]. Usually the substrates enriched with wood fibers are used for pot cultivation of ornamental shrubs or bedding plants [16–18]. They are also useful in soilless cultivation of vegetables [19,20]. Wood fiber and other wood-based materials have a very wide C:N ratio [21], which may lead to immobilization of nutrients, mainly N, and limited uptake of N by plants [22]. The main reason for N immobilization is a biological sorption caused by microorganisms that decompose C and at the same time use the plant-available N [23]. This can lead to nutritional deficiencies in ornamental plants, and reduction of their aesthetic value [24]. The negative effect of N and other component sorption on the plant growth and flowering can be eliminated by appropriate fertilization [25]. The risk of sorption depends on many factors: the wood fiber content in the substrate, physiochemical properties of the fiber, its type, and origin [26–28]. Numerous studies on the use of wood fiber in horticulture focus on the fiber specially prepared (hammer mills, extruders, disc refiners) as a substrate component [16,17,19], while data on wood fiber being a waste generated in different industrial processes are less readily available.

No information is accessible regarding the effects of a substrate and fertilization on the growth and flowering of interspecific geraniums. Therefore, the objective of this study was to assess the usefulness of waste wood fiber in substrates used for cultivation of interspecific geraniums, and to verify if additional fertilization with nitrogen is necessary for obtaining high quality plants.

2. Materials and Methods

2.1. Plant Material

Rooted seedlings of interspecific geranium cv. ‘Calliope Dark Red’ in paper pots 30 mm in diameter were purchased from Vitroflora (Dobrcz, Poland). This cultivar is one of the best known among interspecific geraniums, and is distinguished by its red flowers, strong growth, and late flowering. From delivery until planting, the seedlings were stored in multi-pot pallets placed on tables in a lighted greenhouse at 22 °C during the day and 18 °C at night.

2.2. Experimental Location and Growth Conditions

The plants were grown for 11 weeks, from 26 April to 9 July 2018. For the first two weeks they were kept in a greenhouse, and then in a 25 m × 9 m × 4.7 m tunnel covered with a double layer of plastic and located at the West Pomeranian University of Technology in Szczecin (53° 25′ N, 14° 32′ E, 25 m above sea level, 7a USDA hardiness zone). Air temperature inside the tunnel was regulated by a two-sided roof vent that opened when the temperature exceeded 22 °C. The average monthly maximum/mean/minimum air temperatures in the plastic tunnel were, respectively: May 25.8 °C /17.1 °C /10.1 °C, June 28.9 °C /21.0 °C /15.0 °C, and July 31.8 °C /22.5 °C /15.6 °C. The average monthly maximum/mean/minimum relative humidity was, respectively: May 93.5%/74.7%/49.3%, June 92.6%/71.4%/44.0%, and July 92.4%/69.4%/41.1%. The plants were watered every three days with tap water pH 6.4 and electrical conductivity 0.64 mS cm^{-1}.

2.3. Substrate Components

The substrate was composed of acid sphagnum peat (Presto Durpes, Vilnius, Lithuania) and waste wood fiber produced by Steico company (Czarnków, Poland). The waste wood fiber was made from pine (*Pinus sylvestris*) chips that were first subjected to thermal treatment with steam at 145–155 °C and a pressure of 6–8 atmospheres, then dried, shredded, and combed into fibers 0.05 to 2.00 mm in diameter. The pine fiber is produced from wood chips and used in construction industry, e.g., for insulating buildings.

Wood fiber, sphagnum peat, and growing substrate samples were sent to the Soil Laboratory at the Research Institute of Horticulture in Skierniewice (Skierniewice, Poland) for the mineral analysis and physicochemical properties according to methods described by Kunka and Nowak [29] and Smolińska et al. [30]. Composition, physical, and chemical properties of the ingredients are presented in Tables 1–3.

Table 1. pH, electrical conductivity (EC), and nutrient concentrations of waste wood fiber and sphagnum peat. DW—dry weight.

Parameter	Wood Fiber	Sphagnum Peat
pH	4.1	4.2
EC (mS cm^{-1})	0.28	0.18
N (% DW)	0.16	1.02
P (mg kg^{-1} DW)	57	181
K (mg kg^{-1} DW)	472	674
Mg (mg kg^{-1} DW)	346	472
Ca (mg kg^{-1} DW)	1574	3340
Fe (mg kg^{-1} DW)	46.5	1210
Mn (mg kg^{-1} DW)	123	34.4
Cu (mg kg^{-1} DW)	2.66	2.9
Zn (mg kg^{-1} DW)	17.1	20.1
B (mg kg^{-1} DW)	41	5.64
Cd (mg kg^{-1} DW)	< 0.10	0.11
Pb (mg kg^{-1} DW)	2.03	6.16
Cr (mg kg^{-1} DW)	6.62	0.76
Ni (mg kg^{-1} DW)	< 0.5	0.53
Hg (mg kg^{-1} DW)	Bdl [1]	< 0.50

[1] Bdl—below detection limit.

Table 2. Selected physicochemical properties of waste wood fiber and sphagnum peat.

Parameter	Wood Fiber	Sphagnum Peat
Moisture (%)	10.3	59.3
Organic matter (%)	99.8	98.7
Ash content (%)	0.15	1.3
Bulk density (g cm^{-3})	37.9	123
Shrinkage [1] (%)	0	27.4
Total pore space (%)	97.5	92.1
Water-filled pore spaces (%)	11.5	73
Air-filled pore space (%)	86	19.1

[1] After drying at 103 °C ± 2 °C.

Table 3. pH, electrical conductivity (EC; mS cm^{-1}), and nutrient concentrations (mg L^{-1}) in substrates containing wood fiber at 0% (control—100% sphagnum peat), 10%, 20%, 30%, and 40% before supplementation with multi-component fertilizer.

Substrate (Wood Fiber Content %)	pH	EC	N	P	K	Mg	Ca	S	Na	Cl
0	5.8	0.04	7	19	115	72	420	6	39	10
10	5.9	0.04	5	17	166	69	431	6	41	13
20	5.9	0.06	4	24	164	84	415	1	37	13
30	5.7	0.07	4	27	171	89	474	6	21	14
40	5.6	0.22	4	53	200	75	366	5	27	33

2.4. Experimental Design

The plants were placed individually in plastic pots 14 cm in diameter and 1 L volume filled with substrates prepared immediately before planting. The sphagnum peat deacidified until pH 5.7 with 2.5 g dm^{-3} chalk according to peat neutralization curve. The substrates containing wood fiber at 10%, 20%, 30%, and 40% were prepared in volume proportions with peat. This means that 1 L of the substrate enriched with 10%, 20%, 30%, and 40% of wood fiber contained on average 38 g, 72 g, 110 g, and 144 g of the fiber. The content of nutrients in the substrates is presented in Table 3. Both the control (100% peat) and experimental substrates were enriched with 2.0 g L^{-1} of a multicomponent fertilizer Azofoska containing 13.6% N, 6.4% P_2O_5, 19.1% K_2O, 4.5% MgO, 23.0% SO_3, 0.045% B, 0.18% Cu, 0.17% Fe, 0.27% Mn, 0.04% Mo, and 0.045% Zn. Additional fertilization with nitrogen was started in the fifth week of the cultivation. Each substrate variant was divided into two groups of fertilized and non-fertilized plants. A water-soluble two-component fertilizer in the form of 0.1% calcium nitrate $Ca(NO_3)_2$ (15.5% N, 18.8% Ca) was used at 100 mL of the solution per plant. The fertilization was applied seven times at four day intervals. The non-fertilized plants were watered with tap water. Each variant comprised 12 plants, 3 per every repetition.

2.5. Determination of Plant Growth Parameters

In the ninth week of the cultivation, we measured plant height from the substrate surface to the tip of the tallest leaf and leaf greenness index in Soil Plant Analysis Development SPAD (Chlorophyll Meter SPAD 502, Minolta, Osaka, Japan) that is correlated with chlorophyll content. To determine the decorative value of pelargonium, three researchers conducted a bonitation assessment (visual score) of 1–5, where the value of 1 denoted plant with the poor growth and unattractive habit, and 5 was the greatest ornamental value manifested in attractive habit, healthy foliage, and abundance and quality of flowering. On the last day of the experiment, the flowers were counted per plant, and the fresh weight of the flower and the above-ground parts were determined.

2.6. Determination of Nutrients

In the tenth week of cultivation the collected samples of the youngest fully expanded leaves from each treatment were placed for 48 h in a forced-air dryer at 70 °C. After grinding and wet mineralization in acids, the content of macronutrients (P, K, Ca, Mg, S, Na) and micronutrients (Fe, Mn, Cu, Zn, B) was determined in three repetitions using a sequential emission spectrometer with inductively coupled plasma (ICP Perkin-Elmer model Optima 2000 DV, Boston, Massachusetts, USA). Selected elements were determined at their characteristic wavelengths [31]. N content in plant samples was analyzed using the Kjeldahl method [32] (the Kjeldahl apparatus Vapodest, Königswinter, Germany). All nutrients were determined in three repetitions.

2.7. Statistical Analysis

Data were tested for normality by Shapiro–Wilk test and homogeneity of variances using Levene's test. No variables required transformation. The results were compiled using an analysis of variance (ANOVA) in a random block system for dual classification (media $\times$ fertilization). Tukey's test or t-test at the significance level $p \leq 0.05$ were used for detailed comparisons of significant factors and interactions using Statistica Professional 13.3 package (TIBCO Software, Palo Alto, CA, USA).

3. Results

3.1. Effects of Waste Wood Fiber Substrates and Additional Fertilization on Plant Growth

Plant height, leaf greenness index, and fresh weight of the above-ground part depended both on the type of substrate (Figure 1A–C) and additional fertilization (Figure 2A–C). The height of the plants grown in 100% peat substrate (control) was similar to that of plants grown in peat and 10% and 20% of waste wood fiber. When the wood fiber content was 30% or 40%, the plants were significantly ($p \leq 0.05$) lower than the control ones. Leaf greenness index in the plants cultivated in 100% peat reached 46 $\pm$ 1.01 SPAD and was similar to that in plants grown in peat enriched with 10% (46 $\pm$ 0.79 SPAD), 20% (46 $\pm$ 2.16 SPAD), and 30% (45 $\pm$ 0.86 SPAD) of wood fiber. However, when the ratio of wood fiber was 40%, the leaf greenness index decreased to 41 ± 1.56 SPAD. The highest fresh weight of the above-ground part was found in the control plants grown in peat-only substrate (141 ± 9.16 g). Supplementing the peat with 10%, 20%, 30%, or 40% of wood fiber reduced fresh weight of the above-ground part almost linearly by 3%, 11%, 24%, or 33%, respectively.

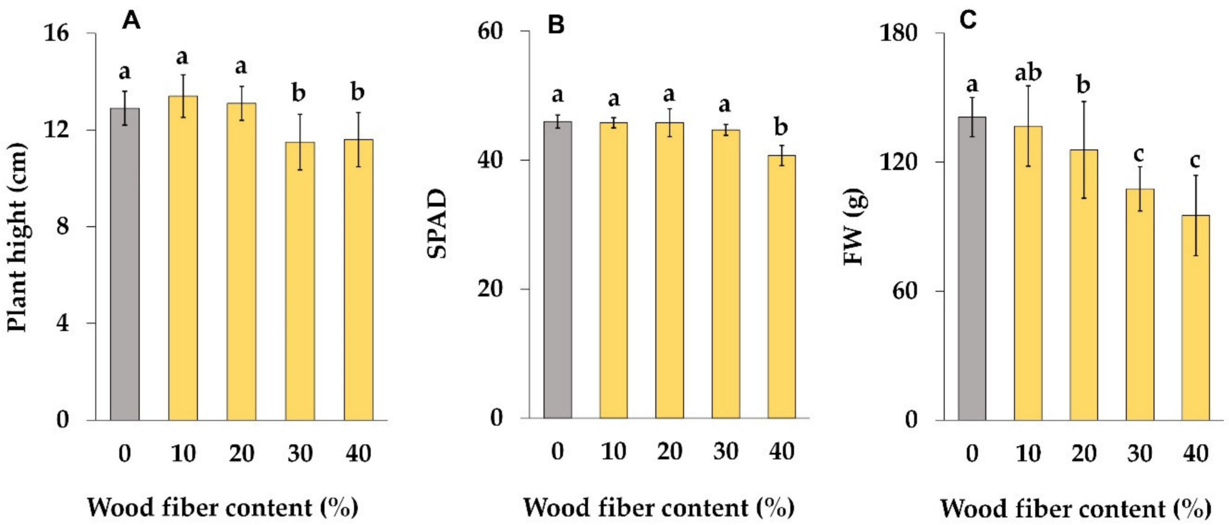

Figure 1. Main effect of waste wood fiber substrates and additional fertilization with nitrogen on (**A**) plant height, (**B**) leaf greenness index (SPAD), and (**C**) fresh weight of the above-ground part (FW) of interspecific geraniums. Data are mean ± SD. Different letters above the error bars indicate significant differences for $p \leq 0.05$.

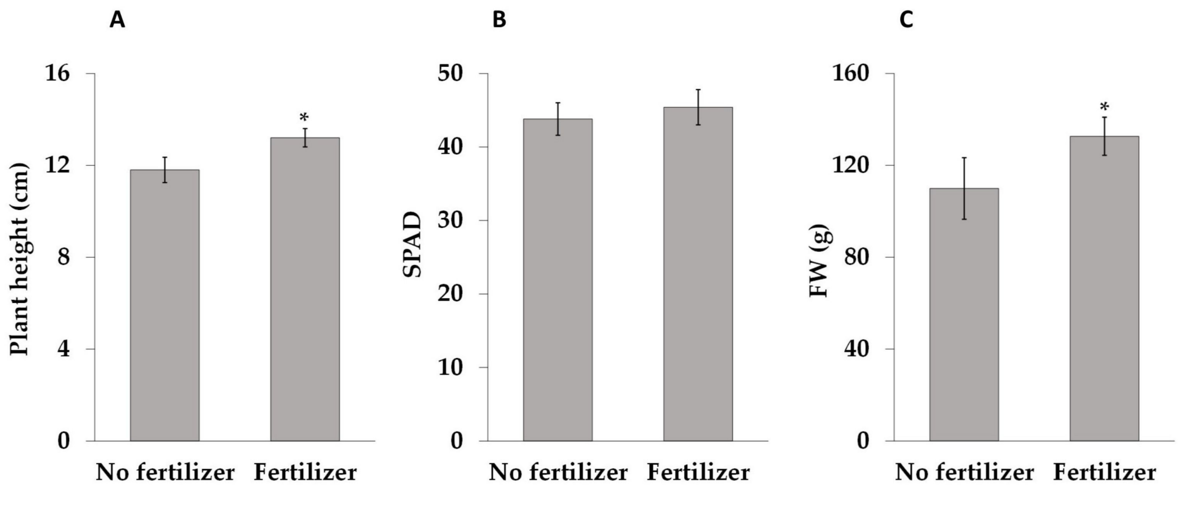

Figure 2. Main effect of additional fertilization with nitrogen on (**A**) plant height, (**B**) leaf greenness index (SPAD), and (**C**) fresh weight of the above-ground part of interspecific geraniums. Data are mean ± SD. * above the error bars indicate significant differences for $p \leq 0.05$.

Irrespective of the substrate composition, the plants additionally fertilized with nitrogen were by 12% higher, and by 21% greater fresh weight of the above-ground part than their non-fertilized counterparts. Additional fertilization with nitrogen did not significantly affect the leaf greenness index (Figure 2A–C).

A significant interaction was found between the type of substrate and additional fertilization for the leaf greenness index (p = 0.037) and fresh weight of the above-ground part (p = 0.009), but not for plant height (p = 0.181). The highest leaf greenness index (48 ± 0.43 SPAD) was noted in plants cultivated in peat enriched with 20% of wood fiber and additionally fertilized (Figure 3A–C).

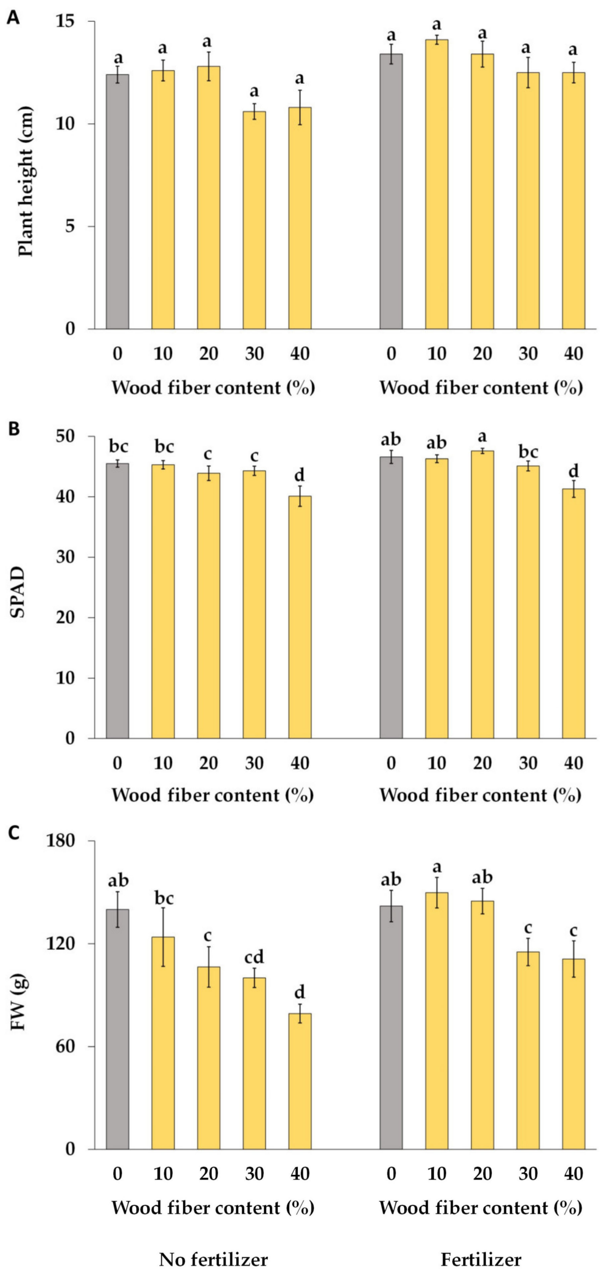

Figure 3. Interactive effects of waste wood fiber substrates and additional fertilization with nitrogen on (**A**) plant height, (**B**) leaf greenness index (SPAD), and (**C**) fresh weight of the above-ground part (FW) of interspecific geraniums. Data are mean ± SD. Different letters above the error bars indicate significant differences for $p \leq 0.05$.

The highest fresh weight of the above-ground part (150 ± 8.92 g) was observed in plants growing in peat enriched with 10% of wood fiber in the variant with additional fertilization (Figure 3C). The non-fertilized plants grown in peat supplemented with 40% of wood fiber had the lowest leaf greenness index (40 ± 1.68 SPAD) and the smallest fresh weight of the above-ground part (79 ± 5.47 g).

3.2. Effects of Waste Wood Fiber Substrates and Additional Fertilization on Plant Flowering

Both experimental factors, i.e., substrate type and fertilization significantly ($p \leq 0.05$) affected the number of flowers, fresh weight of flower, and visual score (Figures 4A–C and 5A–C).

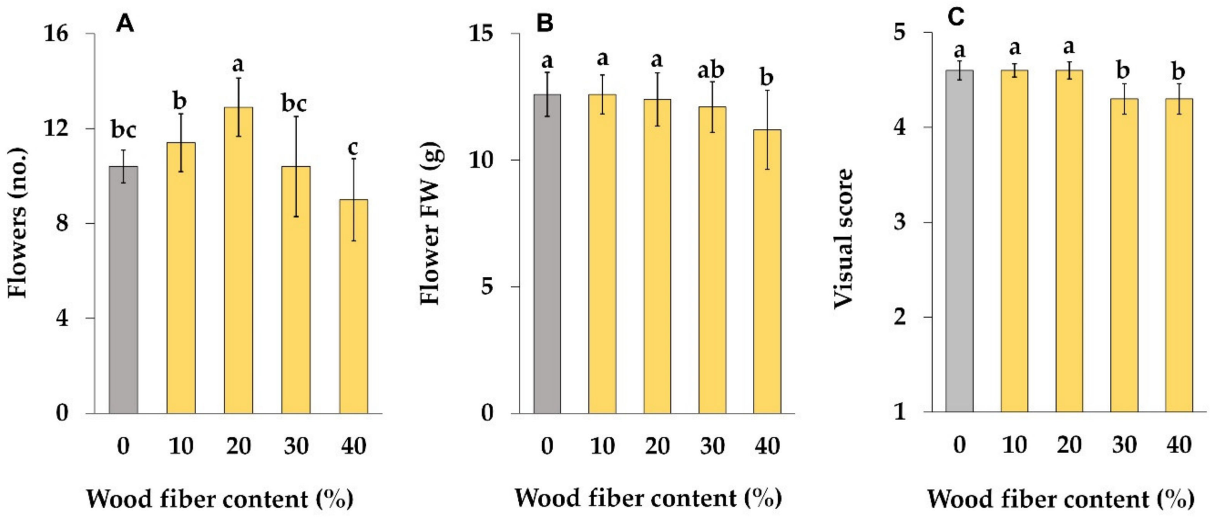

Figure 4. Main effect of waste wood fiber substrates on (**A**) number of flowers (**B**) fresh weight (FW) of flower, and (**C**) visual score of interspecific geraniums. Data are mean ± SD. Different letters above the error bars indicate significant differences for $p \leq 0.05$.

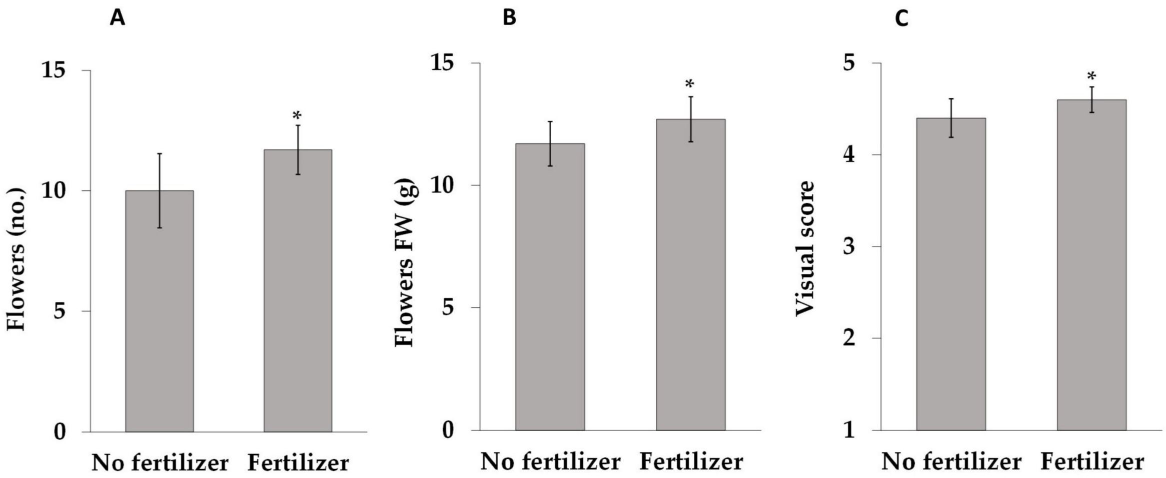

Figure 5. Main effect of additional fertilization with nitrogen on (**A**) number of flowers per plant, (**B**) fresh weight of flower, and (**C**) visual score of interspecific geraniums. Data are mean ± SD. * above the error bars indicate significant differences for $p \leq 0.05$.

The substrate most conducive to flowering was peat supplemented with 20% of wood fiber (13 ± 1.23 flowers per plant), while plants grown in peat enriched with 40% of wood fiber formed the lowest number of only 9 ± 1.73 flowers. Fresh weight of flower was similar for all the substrates, except for the variant with 40% of wood fiber, where it was the lowest. Plants grown in 100% peat achieved the same visual score as those grown in peat supplemented with 10% or 20% of pine wood fiber. In the variants with 30% and 40% of wood fiber, the visual score was slightly lower.

Irrespective of the substrate type, the additionally fertilized plants produced a significantly ($p \leq 0.05$) greater number of flowers per plant (by 17%), and had greater fresh weight of flower (by 9%) and visual score (by 5%) in comparison with non-fertilized plants (Figure 6A–C).

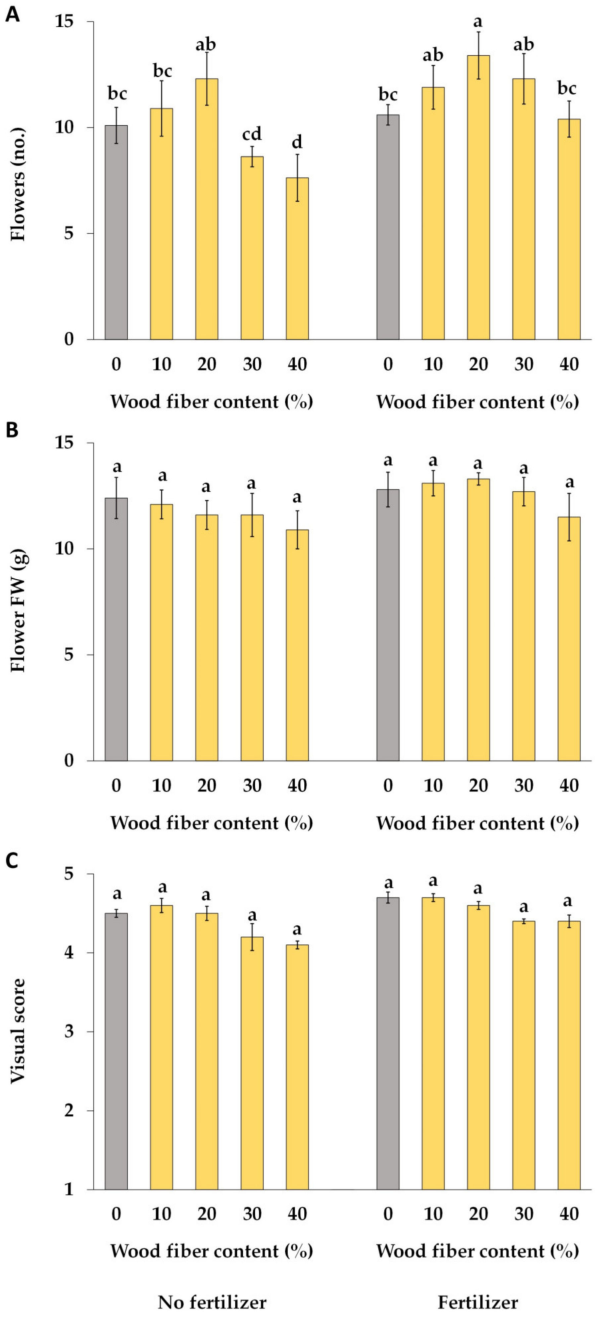

Figure 6. Interactive effects of waste wood fiber substrates and additional fertilization with nitrogen on (**A**) number of flowers, (**B**) fresh weight of flower (FW), and (**C**) visual score of interspecific geraniums. Data are mean ± SD. Different letters above the error bars indicate significant differences for $p \leq 0.05$.

We found a significant interaction between the type of substrate and additional fertilization for the number of flowers per plant (p = 0.018), but there was no interaction for fresh weight of flower (p = 0.574) and visual score (p = 0.091) (Figure 6A–C). The greatest number of flowers was produced by plants grown in peat supplemented with 20% of wood fiber and fertilized (13 ± 1.11 flowers per plant). The least abundant flowering was seen in non-fertilized plants cultivated in peat enriched with 40% of wood fiber (8 ± 1.11 flowers per plant). No chlorosis, leaf drying, or other damage impairing plant quality were observed during growth and flowering (Figure 7).

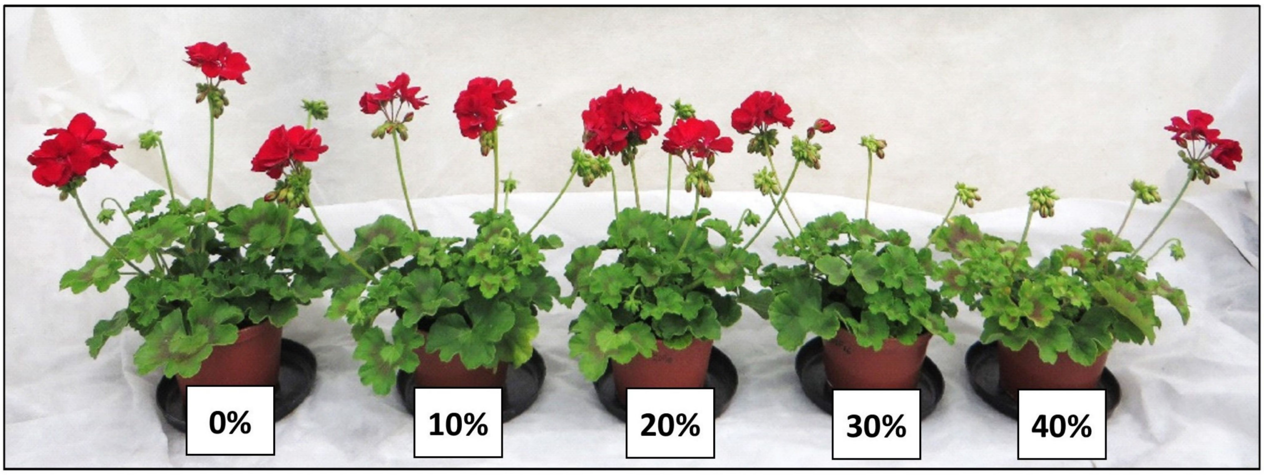

Figure 7. Visual representation of 9-week-old interspecific geranium cv. 'Calliope Dark Red' plants grown in peat-based substrates amended with 0% (control – 100% peat), 10%, 20%, 30%, and 40% waste wood fiber (by volume).

3.3. Effects of Waste Wood Fiber Substrates and Additional Fertilization on Foliar Nutrient Analysis

Leaf content of macronutrients (N, P, K, Ca, Mg, S, and Na) depended significantly on the substrate type (Table 4). As compared with control (100% peat), the plants growing in peat enriched with 20% of pine wood fiber accumulated considerably more N (by 31%) and P (by 33%) in their leaves. The addition of 10%, 20%, and 30% of wood fiber increased also leaf content of Mg and S, and 10% and 20% of wood fiber improved Ca and Na content. Leaf content of K was similar in control plants and those growing in peat with 10% and 20% wood fiber, and it dropped significantly in the substrate with 30% and 40% of wood fiber. Irrespective of the substrate, the fertilized plants accumulated significantly in their leaves more N (by 43.6%), Ca (by 15%), Mg (by 14%), S (by 27%), and Na (by 14%) as compared with non-fertilized variants. P and K content did not depend on additional fertilization (Table 4).

Table 4. Main effects of waste wood fiber substrates and additional fertilization with nitrogen on leaf content of macronutrients (% dry weight) of interspecific geraniums.

Experimental Factors		N	P	K	Ca	Mg	S	Na
Wood fiber content (%)	0	1.32 c [1]	0.70 d	2.34 a	1.42 c	0.26 b	0.16 ab	12.6 b
	10	1.59 b	0.78 c	2.13 a	1.66 a	0.35 a	0.18 a	15.1 a
	20	1.73 a	0.93 a	2.25 a	1.61 ab	0.32 a	0.19 a	15.8 a
	30	1.43 c	0.84 b	1.84 b	1.52 bc	0.32 a	0.18 a	13.0 b
	40	1.05 d	0.74 cd	1.43 c	1.12 d	0.26 b	0.14 b	10.3 c
p value		0.001	0.001	0.001	0.001	0.001	0.001	0.001
Additional fertilization	-	1.17 b	0.81 a	2.06 a	1.37 b	0.28 b	0.15 b	12.5 b
	+	1.68 a	0.79 a	1.94 a	1.57 a	0.32 a	0.19 a	14.3 a
p value		0.001	0.657	0.399	0.033	0.042	0.001	0.001

[1] Different letters within each column indicate significant differences ($p \leq 0.05$).

There was a significant interaction between the type of substrate and fertilization for the content of N, P, K, Ca, and Na (Table 5), but not for Mg or S. The plants grown in peat with 20% of wood fiber and additionally fertilized accumulated the greatest amounts of N, P, Ca, and Na among all tested combinations.

Table 5. Interactive effects of waste wood fiber substrates and additional fertilization with nitrogen on leaf content of macronutrients (% dry weight) of interspecific geraniums.

Experimental Factors		N	P	K	Ca	Mg	S	Na
Wood Fiber Content (%)	Additional Fertilization							
0	-	1.22 c [1]	0.67 d	2.27 ab	1.29 c	0.26 a	0.14 a	0.30 de
10	-	1.28 c	0.79 bc	2.27 ab	1.72 a	0.33 a	0.16 a	0.32 de
20	-	1.37 c	0.87 b	2.23 ab	1.32 c	0.29 a	0.17 a	0.33 de
30	-	1.20 c	0.97 a	2.05 ab	1.50 b	0.31 a	0.17 a	0.25 ef
40	-	0.78 d	0.75 cd	1.47 c	1.03 d	0.24 a	0.12 a	0.21 f
0	+	1.42 c	0.73 cd	2.41 a	1.56 ab	0.27 a	0.19 a	0.35 d
10	+	1.89 ab	0.78 bc	2.00 b	1.61 ab	0.37 a	0.20 a	0.73 a
20	+	2.09 a	0.99 a	2.28 ab	1.90 a	0.36 a	0.21 a	0.60 b
30	+	1.67 bc	0.72 cd	1.63 c	1.55 ab	0.33 a	0.19 a	0.65 ab
40	+	1.32 c	0.73 cd	1.39 c	1.21 c	0.27 a	0.15 a	0.49 c
p value		0.001	0.001	0.005	0.001	0.348	0.428	0.001

[1] Different letters within each column indicate significant differences ($p \leq 0.05$).

Leaf content of micronutrients (Fe, Mn, Cu, Zn, and B) significantly depended on the type of substrate and additional fertilization (Table 6). Irrespective of the fertilization, the presence of wood fiber (10–40%) negatively affected Fe content in the leaves as compared with plants grown in 100% peat. On the other hand, amending the substrate with 10% to 40% of wood fiber increased leaf content of Mn, Cu, and B. The use of 20% and 30% of wood fiber also enhanced the accumulation of Zn. Regardless of the substrate type, nitrogen fertilization resulted in a significant increase in the content of Fe (by 20%), Mn (by 17%), Cu (by 22%), Zn (by 16%), and B (by 10%) in the leaves as compared with non-fertilized variants (Table 6).

Table 6. Main effects of waste wood fiber substrates and additional fertilization with nitrogen on leaf content of micronutrients (mg kg^{-1} DW dry weight) of interspecific geraniums.

Experimental Factors		Fe	Mn	Cu	Zn	B
Wood fiber content (%)	0	156 a [1]	118 d	4.52 d	20.7 b	47.3 d
	10	139 b	135 c	5.55 a	20.0 c	62.9 b
	20	152 ab	149 b	5.35 b	22.2 a	62.7 b
	30	148 ab	164 a	5.41 b	22.5 a	67.9 a
	40	122 c	133 c	4.94 c	19.0 d	54.7 c
p value		0.001	0.001	0.001	0.001	0.001
Additional fertilization	-	130 b	129 b	4.64 b	19.3 b	56.3 b
	+	157 a	151 a	5.66 a	22.4 a	61.9 a
p value		0.001	0.005	0.001	0.001	0.043

[1] Different letters within each column indicate significant differences ($p \leq 0.05$).

There was a significant interaction between both investigated factors for the content of Fe, Mn, Cu, and Zn (Table 7), with an exception of B. The highest amounts of Fe, Mn, Cu, and Zn were detected in the leaves of plants grown in peat supplemented with 20% of wood fiber and fertilized with nitrogen.

Table 7. Interactive effects of waste wood fiber substrates and additional fertilization with nitrogen on leaf content of micronutrients (mg kg^{-1} DW dry weight) of interspecific geraniums.

Experimental Factors		Fe	Mn	Cu	Zn	B
Wood Fiber Content (%)	**Additional Fertilization**					
0	-	147 cd [1]	116 ef	3.91 g	17.7 f	44.0 a
10	-	130 ef	129 de	5.26 bc	19.4 e	60.4 a
20	-	124 f	125 def	4.66 e	19.9 de	60.7 a
30	-	143 cde	164 ab	4.97 d	22.5 b	65.3 a
40	-	106 g	112 f	4.42 f	17.0 f	51.1 a
0	+	165 ab	121 ef	5.14 cd	23.6 a	50.6 a
10	+	149 cd	140 cd	5.85 a	20.6 cd	65.3 a
20	+	179 a	173 a	6.03 a	24.5 a	64.7 a
30	+	153 bc	165 ab	5.85 a	22.5 b	70.6 a
40	+	138 def	154 bc	5.45 b	20.9 c	58.3 a
p value		0.001	0.001	0.001	0.001	0.230

[1] Different letters within each column indicate significant differences ($p \leq 0.05$).

4. Discussion

Our study showed a considerable potential of using waste wood fiber as a substrate component in the cultivation of interspecific geraniums. The plants growing in peat substrate supplemented with 10% or 20% of wood fiber reached a similar leaf greenness index, flower weight, and visual score, as those cultivated in traditional peat-only substrate.

At 20% of wood fiber, interspecific geraniums produced a greater number of flowers than when growing in the peat alone. The possibility of using wood fiber as an alternative to peat in the cultivation of zonal pelargonium, i.e., the species from which interspecific geraniums are derived was demonstrated in earlier studies by Jackson and Bartley [33]. They obtained plants of similar quality when growing them in control conditions of 100% peat and peat enriched with pine fiber at 10%, 20%, 30%, and 40% (by volume). The plant growth significantly depended on the origin, particle size, and shape of the fiber. The plants of *Petunia* × *hybrida* grown in peat mixed with pine wood fiber (30%) produced dark-green foliage and a marketable flower number similar to those growing in 100% peat [17]. A substrate containing 25% or 50% (*v*/*v*) wood fiber was also found effective in the cultivation of *Prunus laurocerasus* and *Thuja plicata* [16].

The addition of wood fiber reduced fresh weight of the above-ground part as compared with 100% peat substrate. Ornamental plants grown in the substrate enriched with wood products are usually smaller and more compact, which may in fact improve their decorative value and may be an alternative for growth retardants that exert negative effects on the environment [34].

Our study demonstrated at amendment of 40% share of wood fiber was unfavorable for interspecific geraniums, as it strongly limited their growth and delay of flowering. This might be due to immobilize fertilizer N and reduce N uptake by plants, different physical properties of the substrate that may have reduced water availability, and possible phytotoxicity of compounds present in the wood material [35]. Fresh bark or sawdust of conifers may, under certain conditions, limit plant growth due to their high content of metabolites with negative allelopathic effects on plants [36].

The use of wood fiber as a substrate component requires additional N fertilization due to immobilization of nitrogen in substrates of this type [37]. According to Wright et al. [24], plants grown in substrates containing wood materials require about 100 mg L^{-1} more N to achieve growth and quality similar to plants grown in peat-based substrates. In general, geraniums belong to “heavy feeders” and require substantial and regular nitrogen fertilization during their growth and flowering [38]. In our study on interspecific geraniums, all variants were from the beginning of the experiments supplemented with about 272 mg L^{-1} N. To counteract possible immobilization of N in the substrate, some variants were additionally fertilized with calcium nitrate. We found that the additional fertilization enhanced market quality of interspecific geraniums vs. the non-fertilized plants, as manifested in improvement of all assessed growth and flowering parameters except SPAD.

Although plants grown in the substrate containing 10% and 20% of wood fiber and additionally fertilized produced dark green leaves and looked well, N content in their leaves was lower than the standard range provided by Biamonte et al. [38] for *P.* × *hortorum* and *P.* × *hederaefolium*. N deficiency symptoms were observed in the plants growing in the substrate with 40% of wood fiber. The possible reason for low concentrations of N could be its immobilization [26]. It may be also due to the time of sampling, which occurred at full bloom when the plants already finished their intense vegetative growth [37]. It seems that extra fertilizer N (> 100 mg L^{-1}) can need during production of plants grown in peat substrates amended with waste wood fiber. The content of P in the leaves of interspecific geraniums exceeded the recommended optimum range for *P.* × *hortorum* and *P.* × *hederaefolium* [38], which may be due to slightly acidic pH of the substrates. P is not toxic to plants and it does not evoke symptoms of phytotoxicity even at large doses [39]. The content of K in the leaves of interspecific geraniums was lower than recommended for geraniums [38], particularly in the plants grown in the presence of 40% wood fiber, both in N fertilized and non-fertilized variants. Typical symptoms of K deficiency were not observed in the plants. Leaf content of Ca and Mg fell within the optimum range for *P.* × *hortorum* and *P.* × *hederaefolium* [38]. The content of S was similar to that reported by Krug et al. [40] for young and mature plants of *P.* × *hortorum*. Moreover, the concentration of micronutrients such as Fe, Mn, Cu, Zn, and B was similar to that recommended for geraniums by Biamonte et al. [38] and Krug et al. [40].

There are many methods for producing wood-based materials, and numerous factors affect their structure and parameter repeatability during the manufacturing process [33]. There are also many types of machines that process wood into smaller-sized components [41]. Each component of the substrate processed in different ways is a unique material. This means that different components of wood mixed with peat in the same proportions will in fact yield different products with variable effects on plant growth, flowering, and nutrient elements content [42].

5. Conclusions

The growing ecological awareness strongly highlights the necessity of sustainable development in every branch of global economy, including ornamental horticulture. This study of interspecific geraniums used wood fiber as a substrate alternative for commonly used high peat, the natural resources of which are limited and non-renewable. Our research demonstrated that wood fiber constituting industrial waste may be used in the cultivation of interspecific geraniums if its share in the peat substrate does not exceed 20%. Plants grown in such a substrate maintain high visual score, have intensely green leaves and bloom similarly effectively as those grown in 100% peat. Additional fertilization with nitrogen improved plant growth and nutrition.

Author Contributions: Conceptualization, A.Z.; methodology, A.Z.; formal analysis, A.Z., J.S.N., and W.K.; investigation, A.Z., P.S., J.S.N., and W.K; data curation, A.Z; writing—original draft preparation, review and editing, A.Z. and P.S.; visualization, A.Z.; funding acquisition, A.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable

Informed Consent Statement: Not applicable

Data Availability Statement: The data presented in this study are available within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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