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Effect of Differently Matured Composts from Willow on Growth and Development of Lettuce †

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Abstract: Soil amendments from peats, brown coals and composts produced from segregated biodegradable waste or biomass from fallow land can increase soil fertility and improve soil productivity. The aim of the study was to determine the possibility of using willow (*Salix viminalis* L.) biomass composts as a substrate component in horticulture. The objects of the research were composts produced from willow carried out in a pile under aerobic conditions. The addition of hay and mineral nitrogen (Nmin) was used to improve process efficiency. In order to verify the type and determine fertilizing value, basic chemical parameters were analyzed (pH, total contents of C, N and P) and a pot experiment was established to analyze the germination and growth of lettuce (*Lactuca sativa* L.). Changes in pH, an increase in total nitrogen content (TN), phosphorus (TP) and a decrease in TOC was observed in the investigated samples. Results of the experiment showed that the highest yield was obtained from the pots with the mixture of willow, hay and Nmin. Matured composts significantly stimulated the germination and growth of the test plants. It can be concluded that the addition of hay and Nmin significantly improved composting process and increased the fertilizing value of the investigated composts.

Keywords: composts; maturity; willow; fertilizing value

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1. Introduction

In recent decades, a significant decrease in humic substances (HS) content in terrestrial environments (especially cultivated areas), due to increased mineralization of organic matter, has been observed [1]. This phenomenon is very strongly observed in intensively used agroecosystems, especially in horticulture in the cultivation of vegetables, ornamental and fruit plants, mushroom plantations, nurseries, orchards and forestry [2]. The consequences of these adverse changes are a rapid reduction in soil fertility and productivity, and a catastrophic impact on crop production and the conservation values of terrestrial ecosystems [3]. Current trends and guidelines related to the functioning of sustainable agricultural production point to the need to radically reduce the use of fertilisers or peat-based components [4,5]. Many studies have clearly shown that inappropriate and excessive peat extraction for agricultural and energy purposes has led to very negative environmental consequences [6,7]. It is therefore proposed that peatlands be considered as protected areas and that peat be considered as a global natural and/or strategic resource [8]. In order to reduce the negative effects of environmental changes, improve soil quality and increase soil organic matter (SOM) content, relevant guidelines, programmes and projects have been developed [9–11]. The most likely solutions seem to be those suggesting the use of sustainable tillage and the introduction of organic or organic-mineral soil conditioners produced from exogenous organic matter (EOM). In this context, use materials and production and cultivation technologies that meet society's current [12] and future needs for food, feed production, environmental quality and human health and maintain agriculture's acceptable impact on the environment. Furthermore, modern fertility management should be based on a comprehensive, long-term and integrated approach [13] rather than the more short-term approach used in conventional farming.

The use of alternative sources of EOM are also highly recommended: selected 'green waste', biodegradable municipal waste or biomass from the cultivation of various plant species, with a particular focus on the concept of using biomass from the cultivation of energy willow as a substrate for compost production [11,12]. However, the quality and usefulness of the organic matter input is a consequence of the quality of the substrates used, the rate and the direction of the transformation. Furthermore, in terms of yield potential, the sum total of all organic matter present in the soil must be taken into consideration, including interactions occurring at different times [13,14]. This applies in particular to residues at different stages of decomposition, substances newly synthesised as a result of microbiological/chemical reactions and the biomass of soil micro-organisms (edaphic). Although research work on willow biomass processing has been carried out for many years, information on mineralisation and humification processes during composting is still inconclusive [15,16]. Undoubtedly, increased recycling of organic residues as fertilisers and soil additives in field and horticultural crops avoids both the use of non-renewable resources, energy expenditure and landfilling of biodegradable materials [17]. Therefore, a detailed understanding of the transformations of organic matter and mineral components contained in composted willow will help to develop methods of producing composts with the most favourable technical parameters, useful for agricultural and natural purposes and safe for the environment [8,14,16,17].

The aim of this study was to analyze selected chemical properties of composts produced from energy willow (*Salix viminalis* L.) as well as to determine their influence on germination and growth of lettuce (*Lactuca sativa* L.).

2. Materials and Methods

The objects of the research were composts (Figure 1) produced according to semi-dynamic open pile system [18,19] in three variants:

- variant A: composts produced from willow chips (diameter of approx. 2.5 cm, obtained from 3-year-old plants);
- variant B: willow mixed with hay (extensive meadows: 50% grasses, 25% legumes and 25% other herbaceous plants);
- variant C: willow mixed with hay and mineral (ammonium nitrate 34% N) nitrogen fertilizer (Nmin).

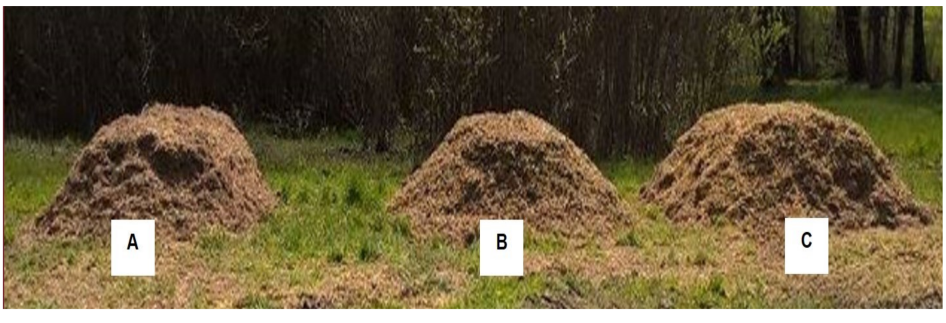

Figure 1. Different willow compost variants: (**A**)—variant A (willow chips); (**B**)—variant B (willow chips:hay, mass ratio 1:1 in d.m); (**C**)—variant C (willow chips:hay:Nmin, mass ratio 1:1:0.04 in d.m).

The prepared substrates were piled up in piles of approx. 4 m × 2.0 m × 1.2 m (L × W × H). The composts were regularly turned to aerate and homogenise the composted mass.

Samples for analysis were taken from the piles at different maturity stage (after 1, 32, 71 and 167 days), then air-dried and ground, then ground mechanically to a diameter of 2.0 mm. Basic properties of the analysed composts were investigated according to the most important chemical parameters for product qualification and compost quality assessment in EU countries: total organic carbon, total nitrogen and total phosphorus contents [19].

2.1. Basic Chemical Analyses

In collected materials the following determinations were performed: pH in 1 mol KCl dm-3, content of total organic carbon (TOC) and total nitrogen (TN) using Vario Macro Cube CN analyser (Elementar Analysensysteme GmbH, 63505 Langenselbold Germany), content of total phosphorus (TP) by MP-AES 4200 analyzer (Agilent, Santa Clara, CA, USA) after mineralisation (m:v = 1:10) of the samples in perchloric acid (72% $HClO_4$ by mass).

2.2. Vegetation Experiments

To determine the potential use of composts [20], a preliminary vegetation study was performed, including a two-stage pot experiment: the effect of composts at different maturity stages on germination (stage 1) and initial growth (stage 2) of lettuce (*Lactuca sativa* L.). The experiments were conducted in the experimental rooms of the Institute under conditions eliminating the impact of abiotic factors and with access to even natural light. A randomized complete block method was used with the following parameters: 20 seeds per pot in 3 replicates (Stage 1) and 3 seedlings per pot in 3 replicates (Stage 2) for each variant, respectively. During the experiment the influence of two factors were investigated: the type of composting variant and the compost maturity stage.

2.3. Statistical Analyses

The results obtained from chemical analyses and vegetation experiments were statistically processed using Statistica 13 software. Differences among objects were checked according to Tukey's test at the significance level <0.05.

3. Results and Discussion

The results presented in this paper are based on mean values obtained during chemical analyses and resulting from the vegetation experiment.

3.1. Changes in pH, TOC, TN and TP Contents in the Studied Compost Samples

Changes in pH during composting indicate the intensity of biochemical processes. Values of pH in the range 5.5 to 8.0 are considered the most optimal, while the final product should be neutral or slightly acidic [21–23]. The analysis of the obtained results (Figure 2, Table 1) indicates too high acidification of the tested composts. Regardless of the variants used, the lowest value of this parameter was found in the initial materials: pHKCl from 4.16 to 5.12 (variants A and B, respectively). Additionally, statistical analysis (Table 1) showed significant differences between the tested samples.

However, it should be noted that the dynamics of these changes differed between the composting variants. They result mainly from the composition of the composted biomass and the intensity and direction of the organic and mineral components transformations [18–20]. These phenomena are determined by the biodegradability of the substrates used and the conditions of the composting process [24,25].

The obtained results of TOC content, the applied willow processing technology and the origin and quality of substrates used allow one to qualify the studied products as composts [16,19]. In all investigated samples a decreasing trend in TOC content (Figure 3a, Table 1) was observed. The dynamics of these changes showed statistically significant differences between the variants used in the experiment. In the initial phase of composting

TOC ranged from 478.9 to 404.1 g kg^{-1} (variants A and C. respectively), while in mature materials it ranged from 375.0 to 458.4 g kg^{-1} (variants B. C and A. respectively).

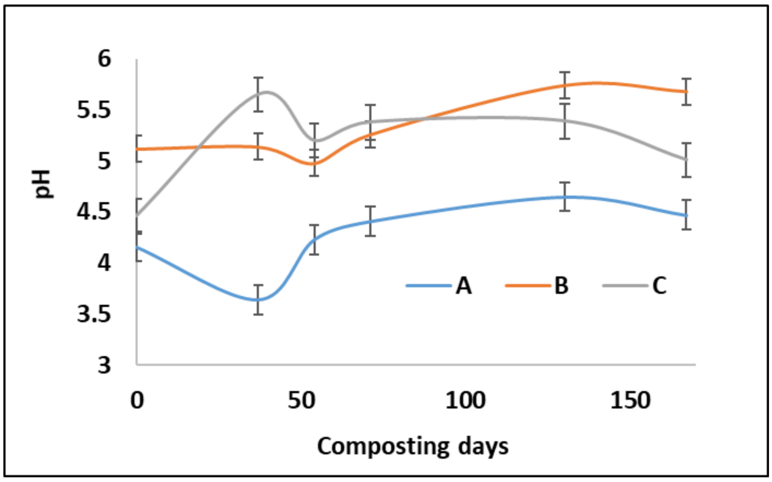

Figure 2. Changes in pH_{KCl} during composting of willow chips.

Table 1. Changes in basic chemical parameters of differently matured composts produced from willow.

Variant	Composting Days							
	1	St. Dev.	32	St. Dev.	71	St. Dev.	167	St. Dev.
					pH			
A	4.16 ^{a}	0.07	3.64 ^{a}	0.12	4.41 ^{a}	0.13	4.47 ^{a}	0.13
B	5.12 ^{b}	0.09	5.14 ^{a}	0.08	5.26 ^{b}	0.16	5.68 ^{b}	0.17
C	4.46 ^{c}	0.16	5.65 ^{ab}	0.17	5.38 ^{b}	0.16	5.01 ^{c}	0.15
					TOC g kg^{-1}			
A	478.9 ^{a}	14.37	469.6 ^{a}	14.09	455.6 ^{a}	13.67	458.4 ^{a}	13.75
B	431.4 ^{b}	12.94	409.1 ^{ab}	12.27	425.4 ^{b}	11.25	374.9 ^{b}	11.25
C	404.1^{c}	12.12	403.3 ^{b}	12.10	399.1 ^{b}	11.24	374.8 ^{c}	11.24
					TN g kg^{-1}			
A	4.30 ^{a}	0.12	4.54 ^{a}	0.14	5.59 ^{a}	0.17	6.71 ^{a}	0.20
B	6.90 ^{b}	0.20	8.343 ^{b}	0.24	9.57 ^{b}	0.28	13.39 ^{b}	0.39
C	9.78 ^{c}	0.29	27.70 ^{c}	0.81	36.66 ^{c}	1.10	50.06 ^{c}	1.46
					TP g kg^{-1}			
A	1.36 ^{a}	0.05	1.26 ^{a}	0.04	1.33 ^{a}	0.05	1.39 ^{a}	0.05
B	1.12 ^{b}	0.04	1.12 ^{b}	0.04	1.55 ^{b}	0.05	1.77 ^{b}	0.06
C	0.92 ^{c}	0.04	1.60 ^{c}	0.06	1.36 ^{a}	0.05	1.03 ^{c}	0.04

Means followed by the same letter are not significantly different at $p < 0.05$ (ANOVA).

The most intensive decrease in TOC content was observed in variant B (enriched with hay) especially in the first 30 days of the experiment. For compost enriched with nitrogen fertiliser, (variant C), similar phenomena were observed between 30 and 70 days of composting and in the stabilisation phase (Figure 3a). In the variant containing only willow (variant A), the decrease in TOC content was most intense up to day 71 and then stabilisation was observed. The results obtained indicate willow as a highly resistant to bio-transformation processes and should be considered a structuring material and a potential source of organic carbon in the case of increased microbial and chemical activity of the environment [2,12]. Furthermore, it should be noted that hay and Nmin significantly stimulated the composting process, as evidenced by the variable activity of TOC decomposition during the experiment. The processes observed are in line with previous studies on composting of wood or wood waste [26–28]. However, most studies indicate that the best way to achieve appropriate quality for this type of compost is to use chemical and biological stimulating agents. Furthermore, it has been shown experimentally that composting wood without additives is a long-term process, which may consequently negatively affect the ecological and economic aspect of the production of these composts.

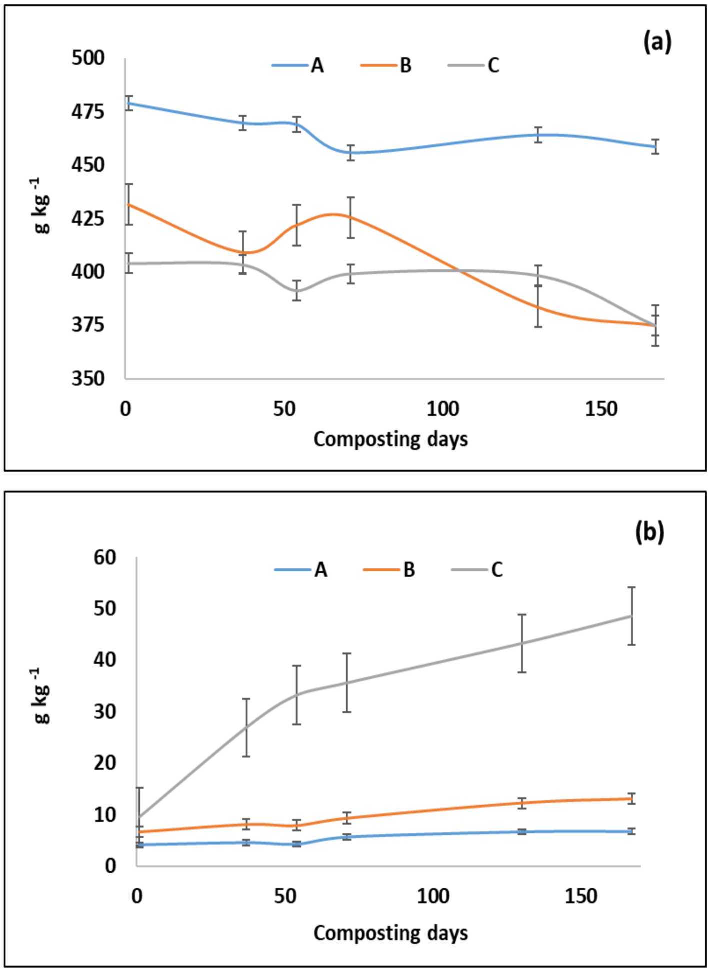

Figure 3. Changes in: (**a**) TOC and (**b**) TN during composting of willow chips [g kg^{-1}].

Total nitrogen content is an obligatory chemical parameter for the classification of compost as a potential product for soil application [19,29]. Furthermore, many authors [30,31] indicate the importance of determining TN, and the proportion of TOC and TN in both the substrate and the final product. Analysis of TN contents (Figure 3b, Table 1) showed a significant increasing trend in all tested composts, especially in variants enriched with hay and nitrogen fertilizer. The highest quantitative changes of TN from 9.78 g kg^{-1} in the initial material to 50.06 g kg^{-1} in the final product, were observed for variant C. It should also be noted that the most beneficial changes in TN content were observed in the variants enriched with hay and Nmin, which—with relation to the intensity of TOC transformations (Figure 3a,b)—indicates the necessity of supplementing wood substrates with materials containing significant amounts of N [32–34].

In the studied composts (Figure 4, Table 1), the TP contents ranged from 0.92–1.36 g kg^{-1} in the initial materials (variants C and A) and 1.03–1.77 g kg^{-1} in the final products (variants C and B. respectively).

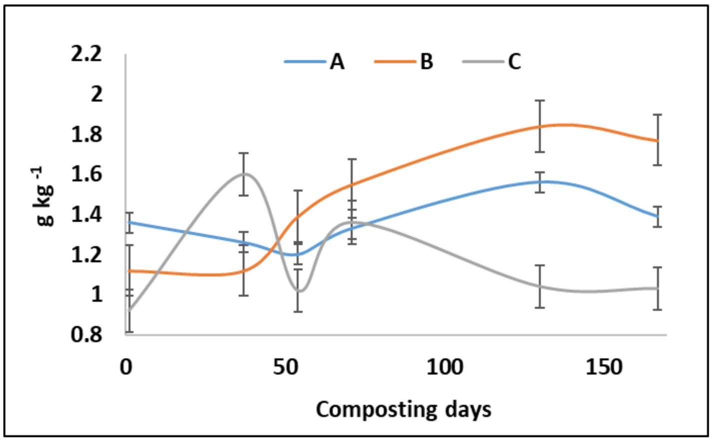

Figure 4. Changes in total phosphorus content [g kg^{-1}] during composting.

Moreover, the dynamics of TP content changes were significantly different depending on the maturity of the compost and the composition of the composted mass [8,24,35]. Based on the results obtained, it must be stated that in all variants, the total values of C, N and P were low compared to other types of composted biomass [25,31,33]. However, it should be taken into consideration that an assessment based on the total content of selected macro- and micro-nutrients is only relevant to determine the category of the product tested [19] and is not sufficient to estimate its potential and actual nutrient supply ability. According to a recent studies [36,37], products resulting from the biological treatment (e.g., composting) of woody or wood-like substances were characterised by relatively low contents of available nutrients, which significantly reduces their potential use as fertilisers. Furthermore, most of the tested composts produced from wood-based components showed an inappropriate share of biologically active forms in relation to the total content of selected nutrients, which significantly limited the estimation of the optimal fertiliser dose. Therefore, modification of substrates used for the production of willow biomass composts by introducing substances improving chemical parameters in the final products should be considered.

3.2. Results of the Pot Experiment

Although the examination of selected chemical properties allowed the tested composts to be qualified to the appropriate group of substances used for soil application, a two-stage vegetation experiment was conducted to assess their suitability as potential growing media.

3.2.1. Influence of Investigated Composts on Lettuce Germination

The results of the first stage of the pot experiment (Figure 5a, Table 2) indicated differences in the influence of the investigated composts on the germination of lettuce.

Table 2. Number of lettuce seedlings (*Lactuca sativa* L.) after 20 days of incubation (number per pot, mean values).

Variant	Composting Days			
	1	**32**	**71**	**167**
A	10	9	10	12
B	14	15	15	13
C	0	9	12	14
Control		8		

•—significant at $p < 0.05$; LSD = 5.00 (ANOVA).

Figure 5. Vegetation experiment: (**a**) Stage 1–germination and (**b**) Stage 2–growth of lettuce (*Lactuca sativa* L.).

Although the number of germinated seeds in the control sample (8 seeds) was lower than in all tested composts, 9–15 (variants A, C and B, respectively), a significant correlation (Table 2) was found for variant B (all samples) and variant C (material after167 days of composting).

Furthermore, the lack of significant effect on germination regardless of composting time for variants A (all samples) and C (samples after 1, 32 and 71 days of composting) may indicate the effect of an inhibitory factor present in these composts. Based on previous studies [15,20,36,38], low pH value and too high TOC/TN ratio (> 20) seem to be the most probable, especially for samples of variant A. Gariglio et al. [20,38] found that substrate containing non-composted willow sawdust significantly inhibited lettuce seed germination in comparison to variants with composted materials. Based on changes in the germination index (Gi) values, they showed that the composting process reduced the negative effect of untreated willow. Furthermore, the most optimal germination parameters were found in media containing willow composted for a minimum of 40 days. On the contrary, in substrates containing longer composted material, the observed effects were not statistically significant. It can therefore be deduced that the germination-inhibiting compounds contained in willow are eliminated during the composting process and are not present in the mature material. Similar results were obtained in the experiments conducted by Duddigan et al. [36] and Adamczewska-Sowińska et al. [15]. Application of composts from wood-based substrates did not result in an increase in the number of germinated plants, suggesting the lack or limited effect on the germination. Furthermore, the use of Nmin-enriched compost variants in these experiments did not result in a statistically significant effect on the germination of the test plants.

3.2.2. The Influence of Investigated Composts on Lettuce Growth and Yield

Although organic additives usually stimulate emergence and improve plant growth and development [39–41], the use of wood or bark composts may not result in a positive yield-forming effect. The results obtained in the second stage of the pot experiment (Figure 5b, Table 3) showed the lettuce yields obtained from the variant C samples after 1, 71 and 167 days of composting (4.70, 10.37 and 5.55 g pot^{-1}, respectively) were significantly higher than the yield of the control: 2.17 g pot^{-1}. Moreover, the other samples tested did not significantly influence the growth and yield of lettuce, regardless of the variant used and the duration of composting. Furthermore, the application of compost from variant A in pot experiments (Tables 2 and 3) did not significantly improve either germination or yield of the test plant.

Table 3. Lettuce yield obtained from seedlings after 20 days of experiment (grams per pot, mean values).

Variant	Composting Days			
	1	32	71	167
A	1.22	1.83	1.13	1.35
B	0.86	1.98	2.09	2.15
C	4.78	1.97	10.37	5.55
Control	2.17			

•—significant at $p < 0.05$; LSD = 2.52 (ANOVA).

Many authors indicate [12,39,42–44] that the effect on plant growth under the influence of organic additives may differ depending on the quality of the additive used. Analysing the data in Table 3, it can be assumed that the main factors limiting the stimulating effect of the studied composts on plant yield are low content and probably low bioavailability of basic nutrients. Experimental results conducted by Duddigan et al. [36] have shown that using growing media containing only wood-based composts did not increase yields compared to control media. Gariglio et al. [20,39] reported a significant increase in yield of test plants on substrates with composted willow sawdust only compared to non-composted material. Furthermore, the results of the study by Adamczewska-Sowińska et al. [15] indicated a negative effect of using substrates of composted willow only, on the quantity and quality characteristics of test plants. However, in all these experiments, the use of Nmin-supplemented variants had a stimulating effect on the quality and quantity of the yield obtained. Therefore, most authors suggest the use of composting as a method of processing willow for agricultural purposes, and also recommend enriching the substrate with nutrients, especially nitrogen. Thus, with reference to studies on composts from wood-based substrates [15,20,39,44], the evaluation of the effect on yield is extremely complex and requires understanding of many factors. Therefore, application of such composts as a single amendment may not result in a change in yield [38,39,45,46].

4. Summary and Conclusions

Both the results of chemical analyses and vegetation experiments indicate the potential usefulness of willow composts as an alternative fertiliser product [25,27,28]. This is particularly important in terms of carbon sequestration [5,14] and stabilization [5,8,9,46–48] of soil organic matter by low-cost, widely used and effective methods of wood-based substance management. While the use of semi-dynamic composting in open piles to process this type of substrate is widely accepted, the most discussed and controversial seem to be the physicochemical parameters [23,46,47] and the effect of the obtained product on plant growth and development. Optimisation of the substrate composition by using suitable additives enriching the willow chips with mineral compounds seems to be the most reasonable solution [15,20,36,39]. Moreover, in order to improve the yield-forming properties, the use of the obtained product in combination with other organic or mineral-organic additives should be considered [38,45]. Therefore, further research on improving the properties of willow-based composts should focus on developing the most effective ways to stimulate the composting process using chemical, microbiological and technical methods [29,30].

Based on the results of the preliminary studies, the following conclusions can be drawn: (1) Willow chips can be a substrate for the production of alternative fertilizer products and/or growing media; however they require appropriate organic and mineral additives and optimized composting conditions; (2) Despite the use of organic and mineral additives, all tested composts contained low quantities of C, N and P; (3) Chemical simulation through the addition of compounds containing macro- and micronutrients, especially nitrogen, is necessary to optimise willow-based compost production processes; (4) The results of vegetation experiments showed that regardless of the maturity stage, composts made of willow chips without additives (variant A) had an inhibitory effect on germination. growth and yield of lettuce; (5) Considering the results of preliminary chemical tests and vegetation experiments, the use of the tested composts as a single amendment or growing medium is not recommended; (6) The study demonstrated the validity of using both the results of chemical properties and vegetation experiments to verify the quality and suitability of the tested composts; (7) Some of the results obtained during the preliminary research were used to prepare a patent application.

5. Patents

Some of the results obtained for variants A and C: chemical properties, germination test, were used in patent application No. P.435103 registered on 28 June 2020 in the Polish Patent Office. A legal procedure is currently underway.

Author Contributions: Conceptualization J.B., E.J. and J.S.; methodology J.B., A.K.-H. and E.J.; validation E.J., J.S. and K.A.-S.; formal analysis J.B. and E.J.; investigation J.B., A.K.-H. and E.J.; resources J.B., E.J. and J.S.; data curation E.J., J.B.; writing—original draft preparation J.B.; writing—review and editing J.B., E.J., K.A.-S.; visualization J.B. and E.J.; supervision E.J. and J.S.; project administration E.J. and J.B. All authors have read and agreed to the published version of the manuscript.

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