Productivity and Biometric Characteristics of 11 Varieties of Willow Cultivated on Marginal Soil

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Abstract: In response to the growth in the global population and climate change concerns, questions remain regarding the adaptation of production systems to meet increasing food and energy demands. The aim of the paper is to present the production potential and biometric features of 11 willow varieties bred and cultivated mainly in Europe. The experiment was set up on marginal soil. The research was conducted in 2016–2020 and concerned 11 varieties of willow harvested in a three-year cycle. The dry matter yield of the examined willow varieties ranged from 6.5 to 13.8 Mg ha\(^{-1}\) year\(^{-1}\). Varieties Tur, Sven, Olof, Torhild, and Tordis were characterized by a relatively low level of yield (7.2–8.2 Mg ha\(^{-1}\) year\(^{-1}\)). The highest dry matter yield was obtained for the varieties EkoTur and Zubr, respectively, of 11.5 and 13.8 Mg ha\(^{-1}\) year\(^{-1}\). The assessed varieties differed in both the level of obtained dry matter yield and biometric features. The Zubr variety produced the smallest number of shoots (three), but with the greatest height (4.8 m) and diameter (29.6 mm). Varieties with high production potential develop fewer shoots, but are taller and have a larger diameter than other varieties.

Keywords: SRC; willow; varieties; yield; biometric features; marginal soil

1. Introduction

In response to the growth in the global population and climate change concerns, questions remain regarding the adaptation of production systems to meet increasing food and energy demands, and the identification of the most efficient and sustainable production schemes. Interest in the biobased economy has, therefore, been increased by aligning policies relating to central and interdependent sectors, including agriculture and forestry, food, feed, bioenergy, and bio-chemistry [1,2]. Because the EU’s growing priority for renewable energy sources is driven by increased energy dependency, rising fossil fuel prices, and the desire to protect the environment, the demand for energy from biomass, mainly wood, is increasing. Waste wood from forestry and municipal energy management may in future be supplemented with wood acquired from agricultural land as fuel for power or heating plants [3–6]. Although the primary role of agriculture is food production, a portion of agriculture land has typically been devoted to non-food products, mainly within the framework of emerging technologies. Such uses include the production of bioenergy and various biomaterials [7].

Fast-growing trees for biomass production are proposed as an economical and ecological solution to meet increasing demand for energy, and also for the anticipated shortage of raw materials for wood-based industries [8–11]. One of the short rotation woody coppices (SRWCs) is willow, which has been widely accepted as a renewable energy source. Willow biomass can be converted by a wide range of technologies, such as combined heat and power hydrothermal upgrading, into a variety of energy forms and carriers [12,13]. Willow has several advantages as an SRWC, including a wide range of genetic diversity, easy reproduction, tolerance to a wide range of site conditions, ability to rapidly
regrow after harvests, possibility of harvests in different rotations, and resistance to disadvantageous environmental conditions, e.g., morning frost, wet snow, and strong winds [14–16]. Willow may be taken into account in a concept of extensive agriculture, especially on marginal soils, which are of little use or unusable for growing food crops, soils that are periodically excluded from use, and some fallow lands [6,17].

A significant novelty of this study is the provision of a comprehensive assessment of (1) dry matter yield, (2) biomass moisture, and (3) biometric characteristics of 11 willow varieties, bred and cultivated in various European countries. An additional advantage of the presented results is that the studied varieties were cultivated in commercial plantations on marginal soil.

2. Materials and Methods

2.1. Experiment Setup

A one-factor field experiment was conducted in 2016–2020 at the Experimental Farm of the Institute of Soil Science and Plant Cultivation—State Research Institute located in Osiny, Poland (51°28′21.34″ N, 22°3′7.65″ E). The experiment was set up on marginal soil. It was a clay soil comprising light clayey sands transformed into light clay at a depth of 70–80 cm, class IV on a VI scale in the Polish classification. The average pH in KCl is 5.5, i.e., it was slightly acidic. The humus content was low at 1.06%. At the time of experiment, the average nitrogen content in soil was 378 mg NO3N kg−1, phosphorus was 224 mg P2O5 kg−1, and potassium was 124 mg K2O kg−1. The content of magnesium in soil was 49 mg MgO kg−1 and calcium was 70 mg CaO kg−1. The content of nutrients in the soil on which the experiments were conducted was at a medium or high (for phosphorus) level. Therefore, the tested plants were optimally supplied with nutrients. The annual sum of precipitation for the locations where the experiment was conducted is 568 mm on average, and the average annual air temperature is 8 °C.

Willow cuttings were planted in April 2016 at a density of 18,000 per ha. The cuttings were planted in two-row strips with rows spaced every 0.75 m apart. The strips were spaced every 1.5 m. The cuttings in each row were planted every 0.50 m. In the first year of vegetation, weeds from plantations were removed mechanically. The research covered 11 varieties of willow (Table 1).

| Variety | Species | Country of Breeding |
|---------|---------|---------------------|
| Gigantea | Salix viminalis | Denmark |
| Inger | S. viminalis x S. triandra | Sweden |
| Linnea | S. viminalis | Sweden |
| Olof | S. viminalis x S. schwerinii | Sweden |
| Sven | S. viminalis x S. schwerinii | Sweden |
| Tora | S. viminalis x S. schwerinii | Sweden |
| Tordis | S. viminalis x S. schwerinii | Sweden |
| Torhild | S. viminalis x S. schwerinii | Sweden |
| Ekotur | S. viminalis | Poland |
| Tur | S. viminalis | Poland |
| Zubr | S. viminalis | Poland |

The cultivation area of each variety was 270 m²; moreover, for the varieties located on the edge of the field, an additional strip of plants (2 rows) was planted in order to eliminate the edge effect. The total area of the experimental field was 3150 m². After the first year of vegetation, in January 2017, a maintenance cut was made. Willow biomass was harvested in January 2020 after three years of vegetation. In the year the plantation was established, mineral fertilization was applied in the dose of 30 kg ha−1 N, 60 kg ha−1 P2O5, and 90 kg ha−1 K2O. After maintenance, a cut of 80 kg ha−1 N, 60 kg ha−1 P2O5, and 90 kg ha−1 K2O was applied. No pesticides were used on the plantation.
2.2. Yield and Biometric Analysis

After three years of vegetation, in January 2020 the biomass yield and their biometric features of the tested willow varieties were determined. For this purpose, 5 whole plants of each variety were harvested in 5 replications, giving a total of 25 plants. Each of the replicates was randomized, then 5 consecutive plants in a row were harvested. No samples were taken from the edge of the experimental field to eliminate the edge effect. Sampling was performed manually using a chainsaw. Each plant was weighed immediately after harvest. Two shoots with average values of biometric features were taken from each plant and ground for determination of the share of dry matter. In the laboratory the biomass humidity was determined with the drying method at 100 °C for a period of 14 days. Dry matter yield was determined from the ratio of fresh matter yield and and dry matter content. The yield from the area of 1 ha was calculated from the product of the actual density and the unit weight of plant.

Measurements of biometric parameters of the tested plants were also performed. The following were determined: number of shoots per plant, diameter of plant shoots at a height of 15 cm, and Ø (mm) and height of shoots (m).

2.3. Statistical Analysis

The results were subjected to analysis of variance for a single factor (ANOVA) using the software Statistica v13.3 (TIBCO Software Inc., Palo Alto, CA, USA). The significance of differences between varieties for the variable, such as dry matter yield, number of shoots for plant, plant height, and shoot diameter was identified using the NIR test ($p < 0.05$). Cluster analysis was performed using the method of $k$ means. The grouping variables were dry matter yield, number of shoots per plant, plant height, and shoot diameter. Initial cluster centers were established on the basis of a random selection of $k$ observations using a standardized distance measure (Euclidean distance). A $k$-fold cross-validation was used to determine the number of clusters.

3. Results and Discussion

The dry matter yield of the tested willow varieties harvested in the three year cycle ranged from 6.5 Mg ha$^{-1}$ year$^{-1}$ for the Tora variety to 13.8 Mg ha$^{-1}$ year$^{-1}$ for the Žubr variety (Figure 1). The highest dry matter yield was obtained for the varieties Ekotur and Žubr, respectively, of 11.5 and 13.8 Mg ha$^{-1}$ year$^{-1}$, which are bred at UWM in Olsztyn.

![Figure 1. Dry matter yield (Mg ha$^{-1}$·year$^{-1}$) of tested willow varieties. * Explanations: data marked with the same letters do not differ significantly at $\alpha = 0.05$.](image)
The Žubr variety obtained a significantly higher result than all other varieties. In second place in this respect was the variety Ekotur. The yield of Žubr variety was 51% higher than the average for varieties and 84–112% higher than the worst varieties. Žubr variety also yielded 20% higher than the second-best variety. Variety Ekotur yielded 26% higher than the average and 76% higher than the weakest variety (Table 2).

**Table 2.** Matrix of differences (%) between yields of dry mass of tested varieties of willow.

| Variety | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|
| Tora (1) | −10 | −13 | −17 | −19 | −20 | −33 | −34 | −38 | −43  | −53  | −28  |
| Tur (2)  | 11  | 15  | 19  | 15  | 19  | 15  | 19  | 15  | 19   | 15   | 19   |
| Sven (3) | 15  | 18  | 15  | 15  | 18  | 15  | 18  | 15  | 18   | 15   | 18   |
| Olol (4) | 21  | 21  | 21  | 21  | 21  | 21  | 21  | 21  | 21   | 21   | 21   |
| Torhild (5) | 24  | 24  | 24  | 24  | 24  | 24  | 24  | 24  | 24   | 24   | 24   |
| Tordis (6) | 26  | 26  | 26  | 26  | 26  | 26  | 26  | 26  | 26   | 26   | 26   |
| Gigantea (7) | 49  | 49  | 49  | 49  | 49  | 49  | 49  | 49  | 49   | 49   | 49   |
| Inger (8) | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50   | 50   | 50   |
| Linnea (9) | 62  | 62  | 62  | 62  | 62  | 62  | 62  | 62  | 62   | 62   | 62   |
| Ekotur (10) | 76  | 76  | 76  | 76  | 76  | 76  | 76  | 76  | 76   | 76   | 76   |
| Žubr (11) | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112 | 112  | 112  | 112  |

Average yields of dry matter (9.7–10.5 Mg ha\(^{-1}\) year\(^{-1}\)) were obtained for the varieties Gigantea, Inger, and Linnea. Varieties Tur, Sven, Olof, Torhild, and Tordis were characterized by a relatively low level of yield (7.2–8.2 Mg ha\(^{-1}\) year\(^{-1}\)). Results obtained from Olof, Torhild, Tordis, Gigantea, Inger, and Linnea varieties were close to the average value, with a deviation of up to 15%. The results of this group of varieties were from 5% to 62% better than those of the three lowest yielding varieties. Within this group Inger yielded 25% higher than Olof. Three varieties yielded much lower than average, Tora (−28%), Tur (−20%), and Sven (−18%). These varieties yielded about half as much as the Žubr variety. Despite the wide range of results, there were no statistically significant differences between the varieties Tora, Tur, Sven, Olof, Torhild, and Tordis.

Reported biomass yields of willow harvested in a three-year cycle, depending on the location and variety, ranged from 6.4 to 20.0 Mg ha\(^{-1}\) year\(^{-1}\), and were generally similar to those obtained in our own research [15,18,19]. Stolarski et al. [16] compared 15 willow varieties and genotypes in a field experiment. As in the current research, the authors showed that the Žubr variety produces a very high dry matter yield, which, depending on the location, ranged from 18.0 to 20.3 Mg ha\(^{-1}\) year\(^{-1}\) in a three-year rotation. This yield was higher than that obtained in our own experiment (13.8 Mg ha\(^{-1}\) year\(^{-1}\)) because the willow was grown on better-quality soils. It should be noted that regardless of the soil conditions, the Žubr variety yield was clearly the highest. In the study of Stolarski et al. [16] in relation to the Žubr variety, the dry matter yield of the next three varieties was lower by 13%, and for the next five by 17%. The yields obtained in our own research were also similar to those obtained in other parts of Europe, which in the UK ranged from 4.9 to 15.4 Mg ha\(^{-1}\) year\(^{-1}\). It should be noted that the highest yields were obtained from Ashton Stott and Ashton Parfitt varieties (15.4 and 13.9 Mg ha\(^{-1}\) year\(^{-1}\), respectively) grown in the UK, which were not included in the own research [20–22]. In contrast, the yields obtained in Scandinavia were lower and ranged from 6.9 to 7.7 Mg ha\(^{-1}\) year\(^{-1}\) in Sweden and 3.1 to 8.6 Mg ha\(^{-1}\) year\(^{-1}\) in Denmark, depending on the variety and site [23,24]. Furthermore, studies conducted in the USA and Canada indicate that the dry matter yields of willow genotypes were significantly differentiated both in terms of genotype and site. The dry matter yield of willow in these studies ranged from 3.5 to 13.6 Mg ha\(^{-1}\) year\(^{-1}\) [25,26].

The factor that determines the quality of willow biomass and, indirectly, the level of the yield, is biomass moisture during harvest. For the studied varieties, it was very diverse and ranged from 42.3–42.9% for the varieties Olof, Torhild and Tora, to 50.1–51.4 for the varieties Žubr, Linnea, Inger,
The varieties Tordis, Ekotur, Sven, and Gigantea were characterized by the average level of humidity (46.5–49.3%). In studies conducted in north-eastern Poland, humidity of willow biomass during harvest, depending on the variety, ranged from 47.5% to 52.0% [27].

The assessed varieties differed in both the level of the obtained dry matter yields and biometric features (Table 3).

Table 3. Biometric features of tested willow varieties.

| Variety | Number of Shoots for Plant | Plant Height (m) | Shoot Diameter (mm) |
|---------|----------------------------|------------------|---------------------|
| Gigantea | 8.4 a *                     | 3.3 d            | 15.6 f              |
| Inger   | 7.7 ab                      | 3.2 d            | 17.1 def            |
| Linnea  | 6.8 b                       | 3.4 d            | 18.5 cde            |
| Olof    | 7.1 b                       | 3.3 d            | 17.8 cdef           |
| Sven    | 5.1 c                       | 3.5 cd           | 18.4 cde            |
| Tora    | 5.0 c                       | 3.5 cd           | 19.9 bc             |
| Tordis  | 4.9 c                       | 3.9 bc           | 19.3 bcd            |
| Torhild | 6.7 b                       | 3.1 d            | 16.3 ef             |
| Ekotur  | 4.9 c                       | 4.1 b            | 21.7 b              |
| Tur     | 6.5 b                       | 3.1 d            | 15.7 f              |
| Zubr    | 2.9 d                       | 4.8 a            | 29.6 a              |
| **Average** | **6.0**                     | **3.6**          | **19.1**            |

*Explanations: data marked with the same letters do not differ significantly at α = 0.05.

The varieties Ekotur, Tordis, Tora, and Sven developed five shoots per plant, and Tur developed six. The varieties Gigantea and Inger had, on average, eight shoots per plant, and Linnea and Olof had seven. Those four varieties had the highest number of shoots per plant. The height of the shoots of the studied varieties also varied. The Zubr variety achieved the longest shoots, with an average length of 4.8 m. The varieties Ekotur, Tordis, Tora, and Sven grew shoots ranging from 3.5 to 4.1 m. Other varieties developed shoots 3.2 to 3.4 m long. The diameter of the shoots was significantly differentiated. The lowest value of this parameter (15.6–16.3 mm) was recorded for the Gigantea, Tur, and Torhild varieties. In addition to the Zubr variety, the Ekotur, Tora, and Tordis varieties had the largest shoot diameter (19.3–21.7 mm). The Zubr variety, which was characterized by the highest dry matter yield, produced the smallest number of shoots (three), but had the greatest height (4.8 m), and the biggest diameter (29.6 mm). The second highest yielding variety, Ekotur, was also characterized by a small number of shoots, good height, and large diameter of shoots. However, the trend changed for the next three varieties—Gigantea, Inger, and Linnea—which also had a high yield level (9.7–10.5 Mg ha\(^{-1}\) year\(^{-1}\)). These were characterized by the highest number of shoots throughout the experiment. Linea had seven shoots on average, and Inger and Gigantea had eight. All three varieties were similar in height, but the diameter of the shoots differed. The higher yielding varieties had the thickest shoot diameter. The closest to the average values of these parameters were Tordis and Tur, however, they yielded much lower than average. Olof and Torhild varieties developed the same number of shoots as Linea, however they obtained much lower height and thickness, so the yield of these varieties was lower than the average and by almost 6 Mg ha\(^{-1}\) year\(^{-1}\) lower than the yield of the best variety. Low yielding varieties, Tora and Sven, were characterized by a small number of shoots and average values of their height and thickness, and Tur had a high average number of shoots but small height and diameter. The presented results concerning biometric features of willow varieties are similar to those obtained by other researchers. They also confirm the thesis that parameters of those features are significantly different, depending on the variety [18,28–31]. It should be emphasized that both the varieties included in the current research and those presented by other authors are characterized by more favorable values and relationships of biometric features compared to wild forms of willow growing in natural stands [32,33].
Characteristics of the features of individual varieties allow for a reliable selection of varieties most appropriate to biomass yield. Due to the growing interest in diversification of crops to compensate for other crops' flaws, mixed crops are often used. For this purpose, clusters of varieties that have similar biometric characteristics were distinguished. Different mixtures of varieties may contain varieties with the same characteristics, or varieties with extremely different parameters, depending on the purpose of cultivation. The cluster analysis confirmed that the tested willow varieties can be categorized in terms of the level of yield and biometric features into three clusters (Table 4).

Table 4. Yield of biomass and biometric features of willow crops in separated clusters.

| Cluster | Variety            | DM Yield (Mg ha\(^{-1}\) year\(^{-1}\)) | Number of Shoots for Plant | Plant Height (m) | Shoot Diameter (mm) |
|---------|--------------------|----------------------------------------|----------------------------|-----------------|---------------------|
| 1       | Ektur, Zubr        | 12.6                                   | 4.0                        | 4.5             | 25.7                |
| 2       | Gigantea, Inger, Linnea | 10.0                                  | 7.7                        | 3.3             | 18.5                |
| 3       | Olof, Sven, Tora, Tordis, Torhild, Tur | 7.6                                   | 5.8                        | 3.4             | 17.9                |

The first cluster includes the Zubr and Ektur varieties, which stand out primarily because of a high yield, obtained through specific biometric features. Both varieties were characterized by an average low number of shoots but had large height and diameter. It was also shown in other studies that the highest dry matter yields are obtained from plants that develop a small number of shoots, but were tall and had a larger diameter [16,34]. By comparison, a relatively high yield was obtained by varieties from the second cluster, which were characterized by completely different biometric characteristics. Gigantea, Inger, and Linnea varieties had an average of 26.7% shorter shoots and 28.0% smaller diameter of shoots than the varieties from the first cluster, which was compensated for by a large number of shoots. Furthermore, plants from the second cluster were a group combining the characteristics of varieties from the first and third cluster. The third group of varieties was characterized by parametric features that were highly similar to the second cluster, but with a much smaller number of shoots, resulting in the lowest yield of the three mentioned clusters. The results obtained suggest that for energy purposes, varieties from the first cluster are definitely preferred. Large biomass obtained from less numerous shoots can provide proportionally more wood in relation to bark. For purposes other than energy production, for example, as a substrate for the extraction of active substances, varieties with a higher proportion of bark in the yield could be preferred [35]. Ideal for this purpose would be varieties from the second cluster, which have a large number of shoots and provide a relatively high yield. In contrast, the lowest yielding varieties could have a higher content of active substances, which would reduce the importance of total biomass yield. The productivity of individual varieties in terms of substrates used for different purposes should be further investigated.

The biometric features of different varieties of the willow *Salix viminalis* L. differ due to its crossbreeding with other species of willows. In the case of the willow, several dozen hybrid varieties are available on the European market. The most frequently cultivated domestic varieties are Start, Sprint, Turbo, Tur, Bison, and Ektur. In Poland, Swedish varieties of Torhild, Sven, Olof, Gudrun, Tordis, Tora, and Inger are also often cultivated. Due to the high variability of yields of individual varieties in following years, it is recommended to use mixtures of several different clones in cultivation [35–37]. Different varieties, in addition to the clusters of similar varieties distinguished in the current work, may have different yield levels depending on the geographical location of cultivation, soil type, and cultivation technology used. It cannot be precluded that climatic differences, in addition to the progression of climate warming, will result in changes in the productive potential of varieties. The key in this aspect will be the sum and distribution of precipitation and the average summer temperatures. Willow is quite predictable in this respect: the biomass yield is linearly related to the annual total precipitation. In many regions, recent years have been dominated by periods of dry years with annual perception below 600 mm, interrupted by years of very large amounts of precipitation. Therefore,
regardless of location, drought-resistant varieties will be preferred. In this case, features such as strong development of the root system will be crucial, probably at the expense of the aboveground biomass in the first years of cultivation. As average temperatures increase, the pressure of diseases and pests will become more severe, so high-yielding varieties could be unreliable in some years. On the basis of previous studies, no impact of climate change on willow cultivation in Poland has been observed to date. In the conditions of north-eastern Poland, the best yielding varieties were Ekotur (17.8 Mg ha\(^{-1}\) year\(^{-1}\)), ˙Zubr (15.9 Mg ha\(^{-1}\) year\(^{-1}\)), and Start (16.7 Mg ha\(^{-1}\) year\(^{-1}\)), which coincides with the results obtained in the current experiment. It may prove that the climatic gradient of the Polish area is of little importance for the selection of varieties [35–37].

In the current paper we focus on the cultivation of willows on marginal land. Such areas will have some production limitations, which will directly translate into the yield and its quality. In Poland, land is marginalized for various reasons. In more than half of the cases, the reason for abandonment of land is low soil productivity potential, caused by low humus content, low fertility, and poor water holding capacity [38]. On such soils, the highest yielding varieties with favorable biometric features may be found to be weaker than on soils which are optimal for the production of willow. Furthermore, good quality soils are also often located in marginal areas. Most commonly, good soils in Poland are abandoned for organizational reasons. In this category, most of the land is set aside in the vicinity of large cities and main roads. This land was abandoned, among other reasons, as a result of industrial transformations. This often leads to extension of the distance from the farm to the field due to the construction of a highway, which eliminates local roads. It is possible to use such land for willow cultivation, however, management of these fields will be limited due to the long distance from the farm. There is also potential in degraded and polluted land, on which willow cultivation can be carried out successfully, however, use of its yield will be limited to energetic and technical purposes. In the current study, it was pointed out that the most productive varieties of willow have also obtained a decent yield on marginal soils. However, it should be remembered that the plantation was professionally cared for and carried out with the best scientific knowledge. Many of the key measures that are provided in experimental plantations are often lacking in commercial crops [36]. On marginal land, often some kind of agrotechnical negligence occurs, so it is advisable to select varieties that require as little input as possible. For example, harvesting may be delayed by organizational problems and therefore the production cycle may be extended by an additional year. It is often observed that hybrid varieties, designed for high yields, can cope less well with environmental pressure and the consequences of agrotechnical negligence. It is also unclear how the tested varieties would survive without any fertilization and chemical protection on poor soils. Rich soils can ensure the survival of plantations without fertilization and even allow a decent yield. On marginal soils, such cultivation can carry a risk of failure [35,39].

The yields of individual varieties will also be quite different depending on the cultivation technology used. Disease and insect resistance are also important. To obtain the highest yield of biomass, a three year cycle is optimal, in which the highest yields are obtained by Ekotur and ˙Zubr varieties. In Poland the cultivation was tested in harvest cycles ranging from annual to over five years. It was indicated that some willow varieties, considered as low yielding, may yield quite well in longer cultivation cycles. The experiment was also conducted with plant density modifications. The smallest stocking density is used in the Eco-Salix system, where willow is planted from large stakes in a small stocking density of less than 10,000 per ha. In the Eco-salix system, the best yielding variety was UWM 043. A very large planting density of about a hundred thousand individuals per ha was also tested in case of seedlings from annual offshoots, planted mechanically. In the case of the cultivation of willow grown in high density (48,000–96,000 per ha), there was a significant decrease in yield in the long-term perspective for all varieties tested (Tur, Turbo, UWM 046, UWM 200, and UWM 095), however, the UWM 095 variety provided the most stable yield. Depending on the height of the harvest cycle, the highest yield was obtained from Tora and 1023 clone in a one year cycle, Tur and 1054 clone in a two year cycle, ˙Zubr in a three year cycle, and Ekotur and 1058 clone in a four year cycle [35,36,40].
The biomass yield depends not only on the biometric features, but also on the physiological characteristics of the plant. In this case, the characteristics of resistance to diseases, e.g., rust caused by *Melampsora sp.*, which can reduce the biomass yield by up to 40%, may be crucial. Resistance to willow rust was obtained in most varieties with high yield potential, however, other biological limitations remain. An important and often underestimated feature is the resistance of willows to pests, whose pressure may increase with climate warming. Unfortunately, pest-resistant willow species are characterized by very slow growth in comparison to the willow *Salix viminalis* L., whereas hybrids between species do not provide satisfactory resistance and yield [41]. Obtaining resistance features, which reduces the pressure of pests, can be supported by molecular techniques. Gene identification and gene transfer application in industrial plants is less controversial than in the case of food plants. Modification of willow varieties can have a positive impact on mitigating the effects of climate crisis, allowing substantial amounts of carbon dioxide to be sequestered in the crop biomass. By comparison, the genetic purity of wild populations of willows, which can easily cross-pollinate with modified crops, cannot be assured. It is unlikely that elaborate and expensive genetic engineering methods will be applied to the willow breeding process because willow is not considered to be an important crop for the human economy [41].

A high level of biomass yield is crucial if willow is converted to energy production. However, the use of lower yielding varieties for industrial cropping is also possible. Willow is grown for various purposes, including traditional wicker products. In this case the yield of dry matter is not as crucial as the quality of the material, so short and shrubby varieties could be preferred. However, varieties often damaged by pests will be avoided. The content of active substances is another feature of the varieties, not necessarily related to the yield. In this case, varieties with a higher proportion of bark in the biomass, i.e., varieties that are vigorously shrubby, will be preferred for medicinal and cosmetic products. An important branch of the economy in the future may be natural construction, due to its growing interest. It also uses products from willow plantations in addition to other industrial crops. In this case, high yield does not have to be a key value, which should relate to the strength and durability of the obtained material [35,41].

4. Conclusions

This study provides an assessment of the productivity and biometric features of some of the most common willow varieties in Europe. The presented results clearly show that the key element that determines the production effects is the appropriate selection of varieties. Varieties with high production potential develop fewer shoots, but are taller and larger in diameter than other varieties. The obtained results also indicate that it is possible to effectively use marginal land for production purposes other than food production, including, for example, the cultivation of willow intended for industrial purposes.

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