Influence of INGER and TORDIS Energetic Willow Clones Planted on Contaminated Soil on the Survival Rates, Yields and Calorific Value

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Abstract: The paper presents some forestry aspects of using Inger and Tordis willow clones to obtain woody biomass and remedy degraded soils. The methodological aspects regarding the planting of willow seedlings, the evaluation of the survival rate, the evaluation of the biomass quantity and the enrichment of the soil are analyzed. The results of the experiments showed that the degraded soil decreased the viability rate of the cuttings by 16.6% for the Tordis clone and 35.8 for the Inger clone. The analysis of the soil samples showed that it was enriched in nutrients after 2 years of cultivation, by the decomposition of the fallen leaves on the soil and by the absorption of the substances from the soil. Regarding the amount of biomass, its mass per hectare after the first year of cultivation was 0.64 t/ha for the Inger clone and 0.66 t/ha for the Tordis clone, while the calorific values of 19,376 kJ/kg for Inger and 19,355 kJ/kg for Tordis were good values. The final conclusion of the paper highlights that Osier willow is a viable solution for obtaining energetic biomass and putting it back into the productive circuit of degraded soils.

Keywords: Salix viminalis; Osier willow; Tordis clone; Inger clone; degraded soil; calorific value; biomass

1. Introduction

Fossil energetic resources are depletable in the long run, which is why new solutions to replace them are being looking for. All the more, new and renewable resources are needed, as the classic energetic resources produce greenhouse gases, damage the ozone layer and contribute greatly to the phenomenon of global warming. In this sense, regarding total energetic sources in the near future, renewable energetic sources (RES) become a viable alternative to the classic ones [1–4].

Even though today the fossil coal and fossil gas still have supremacy in energy generation, in 2025 it will be the first time when renewable energies (9900 TWh) will exceed the energy obtained from coal (9700 TWh) and gas (6300 TWh). In the same context, the energy obtained from the sun and wind in 2023 will exceed the energy obtained from fossil gas and, in 2024, will exceed the energy obtained from fossil coal [5]. Biomass is expected to contribute to 9% of the total global renewable energy generation for 2025 [5].

Biomass is usually a vegetable and is obtained from the exploitation and processing of round wood or from various agricultural activities, which results in cereal straw, rice husks, corn cobs and other strains, seed husks and seeds, etc. [6,7]. In recent years, some energetic crops, such as Chinese reed/Miscanthus (Miscanthus giganteus) and energetic willow crops have emerged from the need to identify new energetic solutions [8].

Moreover, a filamentous fungus (Gliocadium roseum) has been discovered in the tropical forests of Patagonia from which diesel fuel can be extracted. Researchers in this field believe that this mushroom could be a new source of green energy on an industrial scale [8].
Osier willow, or Basket willow (Salix viminalis L.), was discovered by Swedish researchers, being cultivated exclusively for energetic purposes, respectively for its large amount of biomass obtained per hectare of 30–50 t/ha, when the twigs were about 4–5–7 m high and had an average moisture content of 50% [7,9]. It is an agricultural plant that is harvested annually with the help of combined equipment that simultaneously harvests the plant and transforms it into chopped biomass. Harvesting is performed after the fall of the leaves because the decomposition of the leaves on the soil until the next year of vegetation acts as a fertilizer and enriches the soil with nutrients. Energetic willow, similar to any other species of willow, grows on wet land and, when this is not possible, the land must be irrigated and fertilized, similar to any other agricultural crop. In the first 3 years of vegetation, this plant grows by about 3.5 cm/day and has an exploitation hope of 22–25 years. It is exploited from with the third year of vegetation, the first 2 years being necessary for a strong rooting of the cuttings and the creation of several shoots in the same cutting. After extensive experiments using germplasm sources from Europe and Russia, Swedish researchers obtained several varieties of willow by hybridization that, due to their special energetic characteristics, are called Osier willow or Basket willow [4]. The clones “INGER” (Salix triandra × Salix viminalis) and “TORDIS” (Salix schwerinii × Salix viminalis), as well as other varieties of Osier willow, were created and accredited by the Swedish company Lantmännen Agroenergi during the last 30–40 years [4,7]. All of these willow species have a fast growth, produce a large amount of wood biomass used for energetic purposes and have a high resistance to diseases and pests. Starting from the third year of vegetation, the energetic willow has an explosive growth, about 14 times higher than the growth of the ordinary willow (Salix alba) in the same conditions of habitat and forest growth [10,11].

Energetic willow/Osier willow is a lignocellulosic species, a short rotation crop (SRC) and has an annual vegetative regeneration. This species is characterized by rapid growth and a very high energetic value of 18,810–20,480 kJ/kg. The seedlings are planted in March–April, and before planting they are cut to about 18 cm in length and the roots are kept in water for at least 24 h. Planting is performed mechanically, with 2–3 rows planted simultaneously with a distance of 75 cm between the seedlings and the rows [7,9].

The macroscopic structure of the energetic willow refers to the part visible to the naked eye or with a magnifying glass that has a magnification of maximum 10 times (Figure 1). From a macroscopic point of view, this is a species of deciduous tree with distinct sapwood and heartwood, a density of 500–700 kg/m$^3$, a faded yellow-whitish-reddish color, a coarse texture and is little pronounced. The outer bark is green [11].

Degraded soils refer to those soils on which there have been chemical plants, landfills, or tailings sludge that has been released from wastewater processing. These soils are isolated at the beginning, after which some methods must be found to put it back into the productive circuit, be it for agricultural, fruit-trees, cereals, agro-forestry or other crops. The simplest method is phytoremediation, i.e., the use of plants to remove, transfer, stabilize and destroy contaminants from soil. There are a large number of plants, such as ferns, sunflowers, poplars and willows, that are used to remedy degraded soils. The phytoremediation mechanism includes the extraction of contaminants through the roots, their metabolism in the physiological process and/or their fixation in plant tissues and cells. When using agricultural plants, we must be careful that contaminants do not get into the food of animals or humans [10,12–15]. The largest sources of soil contamination are municipal waste.

Soil degradation may also be due to fires, prolonged droughts, strong winds, invasive vegetation, municipal waste (may contain nonbiodegradable organics and heavy metal such as Pb, Cd or Zn), heavy metal mining, gold mining and industrial activities, especially chemical and/or petrochemical plants. At the level of 1991, it was estimated that about 240 Mha of land chemically degraded, representing 12% of total degraded soils [5,16–19].
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The cultivation of several Salix viminalis clones compared to Salix alba. A quantity of 6.8 kg/year · shrub was found for Salix alba and 4.3 kg/year · shrub for Salix viminalis. It was also found that Salix viminalis absorbed the largest amount of heavy metals from soil, absorbing 84% of Cd, 90% of Cu, 167% of Hg, 190% of Pb and 36% of Zn, and, following the accumulation of heavy metals, the cellulose content increased from 42.09 to 49.69%. Tőzsér et al. [17] studied the possibility of using Salix viminalis for the phytoextraction of metals and other contaminants, such as Al, Ca, K, Mg, Ni, Sr and Zn, from soil. It was found that the average concentration of the chemical elements was the same in the roots and trunk but was much higher in the leaves of the energetic willow.

Saletnik and Puchalski [20] studied the effect of fertilizers (ash and biochar) on the production of wood biomass in the case of Osier willow (Salix viminalis). It was found that, in the case of fertilization with different concentrations of ash and biochar, biomass production values of 2.6 and 3.01 t/ha were highlighted respectively, compared to a control soil that produced 2.29 t/ha. A limiting value was a fertilizer concentration over 3.1 t/ha, which had negative effects on plant growth. Sobczyk and Sobczyk [11] have demonstrated that Salix viminalis is suitable for the phytoextraction of heavy metals from contaminated soils, by its phytoremediation.

Gasecka et al. [21] studied the possibility of applying research conducted in the laboratory in order to decontaminate wastewater contaminated with ions of heavy metals such as copper.

From a study of the bibliography, it is observed that there are consistent studies about energetic willow, about soil degradation and contamination, but very few studies about its planting in situ in degraded soils. Therefore, the main purpose of this research is to plant two clones of energetic willow on degraded and un-degraded land in order to find out the influence of degraded/undegraded soil on the viability of seedlings. The influence of the energetic willow culture on the soil, the amount of biomass obtained after a year of cultivation and the energetic performance of the two clones are some other elements that will be analyzed in the paper.

2. Materials and Methods

In order to establish the influence that the contaminated land had on the viability of the energy willow seedlings, two energetic willow crops from the Inger and Tordis clones were established on two distinct lands, one of these being contaminated and the other uncontaminated. The creation of an energetic willow plantation in the area of the
former chemical plant located in Tarnaveni (Romania) had two main objectives, on the one hand the improvement of the properties of the soil contaminated with heavy metals, and on the other hand the production of wood biomass for energetic purposes. In this way, the two energy willow clones, Inger and Tordis, were planted in March 2014; the genetic material was in the form of cuttings with a length of 18–20 cm in ties of 50 pieces that were provided by the company S.C. Kontrastwege S.R.L. (Miercurea Ciuc, Romania) [4], and this was authorized at a national level for the marketing of planting material. It took about 14,000 cuttings/ha because the distance between cuttings per row was 50 cm, and the distance between adjacent rows was 75 cm (Figure 2).

![Planting scheme of energetic willow cuttings.](image)

**Figure 2.** Planting scheme of energetic willow cuttings.

The planting was performed mechanically with the help of a machine that performed the simultaneous planting of two adjacent rows (Figure 2). The turning area of the machine at the ends was taken into account as well as the existence of additional spaces at the edges of the cultivated field. Growth conditions were specific to the plains of Southeast Europe, with a temperate continental climate, average annual temperatures of 10–11 °C and an average annual rainfall of 630 mm/year. The same average values of the meteorological conditions were in the period considered, from March 2014 to March 2015. No fertilizers or irrigation were administered for this growing period of *Salix viminalis* in the first year after planting.

Collecting data on the survival rate of cuttings in both contaminated and uncontaminated land involved a comprehensive inventory of energetic willow cultivation in the two areas, by successively traversing each row of plants and visually identifying the condition of each cutting. We started from the hypothesis that, in such conditions, there will be different mortality situations, from one land to another, depending on the nutrients in the soil or, especially, the contamination of the land, because the planting conditions on the degraded/undegraded land were identical. To determine the degree of viability, a methodology for the integral analysis of all seedlings was adopted, specifying the total number of survivors and the number of seedlings planted in the previous year. In this analysis it was considered that a specimen survived if it entered the vegetation, i.e., if it generated shoots, and that, at the opposite end, a specimen did not survive if it was dry and did not generate shoots or was not found on the planting site when collecting data from the field. A number of 48 rows were inventoried on both types of land and clone, which meant that there were a total number of 29,485 twigs belonging to the Inger clone and a similar number to the Tordis clone. The calculation ratio of the survival rate was as follows (Equation (1)):

\[
SR = \frac{n_t - n_d}{n_t} \times 100 \text{%}
\]

where \(n_t\) is the total number of seedlings considered and \(n_d\) is the number of dead seedlings.
The determination of the influence exerted by the energetic willow culture on the soil properties was performed, in the case of the contaminated land, by comparing the soil characteristics before planting and after the second year of vegetation. In order to establish the influence that an energetic willow crop located in contaminated soil has on soil properties, some soil samples were taken, both in the year of the establishment of the crop and two years later, both in the last decade of March. The samples were taken using the classical method, from 3 soil profiles arranged in a grid with a side of 1 m, from several depth levels to a maximum depth of 1.2 m. The soil samples were mixed and homogenized for each depth range, thus making an average, from which quantities of about 1 kg each were then taken, packed in plastic bags for transport to the analysis laboratory and labeled with the sampling depth range and area. The 6 soil samples were brought to and analyzed in the laboratory. Thus, the modified Kjeldahl method (ISO 11261) and, implicitly, the Kjeldahl apparatus were used to determine the total nitrogen content of a soil sample, including ammoniacal nitrogen, nitrates, nitrites, and organic nitrogen. The principle of this method is based on the wet mineralization of the organic matter contained, by boiling with concentrated sulfuric acid (H\(_2\)SO\(_4\)) in the presence of a catalyst (potassium sulphate, copper sulphate and titanium dioxide or another type of catalyst). Nitrogen from organic matter and ammoniacal nitrogen in the soil remained as ammonium sulfate in the sulfur extract. The ammonium was separated by distillation in an alkaline medium (10 mol/L NaOH) and absorbed into a boric acid solution; this was followed by a titration with a sulfuric acid solution of known titer. The general relationship used in soil pedological studies to determine the nitrogen index is as follows (Equation (2)):

\[
IN = \left( H \times V_{Ah} \right) \div 100
\]  

where IN is the nitrogen index; \( H \) is the humus content, on a dry basis [%]; and \( V_{Ah} \) is the degree of saturation calculated compared to the hydrolytic acidity of the soil.

It can also determine the amount of total nitrogen, on the base of 6 samples, using the following relationship:

\[
WN = \left( P - M \right) \times c(H_2SO_4) \times MN \times 100 \div m
\]  

where \( WN \) is the total amount of nitrogen [%]; \( P \) is the amount of sulfuric acid obtained by titrating the sample [ml]; \( M \) is the amount of sulfuric acid found at the titration of the control sample [ml]; \( c(H_2SO_4) \) is the sulfuric acid concentration (0.01 mol/L); \( MN \) is the molecular mass of nitrogen (14.007 g/mol); and \( m \) is the mass of the soil sample (0.5 g).

The obtained results can also be expressed in g/kg, when wood samples were dried in the oven at 105 °C for several hours.

For the organic carbon content in the soil, an indirect titrimetric method was used, namely the Schollenberger-Jackson method, which is based on the high temperature oxidation of organic carbon by the use of chromic acid (as oxidizer) and sulfuric acid. A Cecil photo-colorimeter was used to determine the phosphorus content in the 6 soil samples, and an atomic absorption spectrometer to determine sodium and potassium. Sodium (Na) and potassium (K) were determined with a flame atomic absorption spectrometer. Atomic absorption spectrometry (AAS) is part of the UV–VIS method and is based on measuring the radiant power absorbed by a population of free atoms. The samples had to be atomized by heating, after which the electrothermal evaporation took place.

Methodology for biomass estimation of the two clones was unitary. The amount of biomass was determined primarily in the form of the wood mass of the twigs harvested at the end of the second year of vegetation for each cutting, after which the entire plant was extrapolated from each row level. Based on the dry mass of a twig, the number of twigs on a row and the number of rows per hectare, the total mass of biomass per hectare could be determined. The final expression was in t/ha.
Additionally, in the same context, the density of the obtained twigs was determined, the calculation relation being the following (Equation (4)):

\[
D_t = \frac{(4 \times m)}{(\pi \times D^2 \times l)} \times 10^6 \text{ [kg/m}^3\text{]} \tag{4}
\]

where \(D_t\) is the total density of the willow twig, on a dry basis, in kg/m\(^3\); \(m\) is the dry mass of the pieces taken into account, in g; \(d\) is the diameter of the willow twig, in mm; and \(l\) is the test tube length, in mm.

As the willow twigs were thin, the amount of total biomass was determined, and also separately, for bark and wood, taking into account the average bark thickness (Figure 3). This was helpful in determining the amount of bark and wood biomass, expressed in m\(^3\).

![Figure 3. Macroscopic structure of energetic willow shoots: 1—bark; 2—xylem; 3—pith; l—the length of the seedling; d—inner diameter of the wooden part of the twig; D—outer diameter of the willow twig.](image)

This time, if we take into account the total volume of the shoot and the inner diameter of the xylem area, the calculation relationship for determining the bark density (dry basis) will be as follows:

\[
D_b = \frac{(4 \times m)}{(\pi \times l \times (D^2 - d^2))} \times 10^6 \text{ [kg/m}^3\text{]} \tag{5}
\]

where \(D_b\) is the density of the twig bark, in kg/m\(^3\); \(m\) is the mass of the bark sample, in g; \(D\) is the outer diameter of the twig, in mm; and \(d\) is the inner diameter of the xylem area, in mm.

During the density analysis it was necessary to know the dry mass of the biomass obtained when *Salix viminalis* is harvesting, in this sense first determining the moisture content of some samples, by using the classical gravimetric method. Then, from the general relation of the absolute moisture content, the absolutely dry mass was extracted when the wet mass of the shoots and their moisture content were known in order to determine the total amount of dry wood biomass (Equation (6)), as follows:

\[
m_0 = 100 \times m_{MC} \div (100 + MC) \text{ [t]} \tag{6}
\]

where \(m_0\) is the absolutely dry mass of biomass, in t; \(m_{MC}\) is the mass at a certain moisture content, in t; and MC is the moisture content of biomass, on a dry basis, in %.

In general, the calorific value of wood biomass is defined as the amount of heat produced by a certain wood mass, which is why it is expressed in kJ/kg or MJ/kg. As wood is a porous material and absorbs moisture, the calorific value can be a higher (HCV) or gross calorific value (GCV) and a lower (LCV) or net calorific value (NCV). Experiments on the calorific value of biomass resulting from energetic willow were performed on XRY-1C Oxygen Calorimetric Bomb (Shanghai Geological Ltd., Shanghai, China), installed with its own work software and expression of results [22–24]. The difference between the two
types of calorific value is given by the latent heat of vaporization [25]. The specimens used in this test had rectangular shapes, with a mass of 0.6–0.8 g, such as to be included in the crucible of the calorimetric bomb, which has a frustoconical shape with a base of 10 mm. These 10 pieces for each determination were dried at 105 °C, in a Memmert laboratory oven (Germany), in order to eliminate the main factor of diminishing the calorific value, which is moisture content. The calorimetric installation includes several parts, the main part being the calorimetric bomb, in which the wood piece and technical oxygen are introduced at a pressure of 30 bar. The combustion process is initialized by two electrodes, a nickel wire 10 mm long, 0.1 mm thick and a spiral 4 mm in diameter, and an 8-mm cotton wire that connects the wooden test tube and the nickel wire [26]. The three distinct and successive periods of the test (fore, main and after), with a total duration of about 40–50 min, were viewed on a computer screen, and at the end of the test the two values of calorific value, test duration and temperature values, were given for each period of the test. The calculation relation used by the calorimetric installation software was the following (Equation (7)):

\[ HCV = \left( K \times (T_f - T_i) - H_s \right) \div m \ [kJ/kg] \]  

where \( K \) is the calorimeter constant, \( T_f \) is the final temperature in the calorimeter, in °C; \( T_i \) is the initial temperature of the calorimeter, in °C; \( H_s \) is the amount of additional heat resulting from the burning of nickel and cotton yarn, in kJ; and \( m \) is the mass of the sample from the calorimetric bomb, in kg.

The calorific value (CV) of wood biomass (expressed at 0% moisture content of wood on a dry basis) is a constant of each wood species and is slightly higher than the upper and lower calorific value [6,27–29]. This value of calorific value, independent of the value of moisture content, can be determined according to the previous value with the following relation (Equation (8)) [9]:

\[ CV = \frac{HCV_{MC}}{100(100 - Mc)} + \frac{2.44 \cdot Mc}{100 - Mc} \ [kJ/kg] \]  

where \( CV \) is the calorific value of dry mass, in kJ/kg; \( HCV_{MC} \) is the superior calorific value of moist wood, in kJ/kg; and \( Mc \) is the moisture content, on a dry basis, in %.

As a piece of wood cannot be absolutely dry and due to the fact, that in a calorimetric bomb, about 3 mL of distilled water is used to absorb some acids, HCV and LCV values will always result. That is why relation (8) is used, which determines the calorific value for dry conditions, namely for a moisture content of 0%. In order to know the calorific value per unit of volume, which is often necessary in energy calculations and evaluations, the following relationship can be used (Equation (9)):

\[ CD = CV \cdot D_{w,b} \cdot 10^{-6} \ [MJ/m^3] \]  

where \( CD \) is the calorific density, in MJ/m³; \( CV \) is the calorific value, in kJ/kg; and \( D_{w,b} \) is the density of wood or bark, in kg/m³.

From a statistical point of view, the main parameters, such as arithmetic mean, maximum and minimum values and standard deviation, were highlighted by using the facilities offered by Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Additionally, the Minitab 18 statistical program, especially the statistical graphs of it, was used for statistical analysis and the processing of the experimental results (Minitab LLC, State College, PA, USA). In the statistical processing of the experimental results, a confidence interval of 95% and an error of type \( \alpha \) equal to 0.05 were used, thus obtaining a probabilistic interval of the analyzed values, with upper and lower limits.

3. Results and Discussions

The experimental results will refer explicitly to the survival rate of the planted cuttings, the amount of biomass, soil enrichment and the calorific value of the obtained biomass.
3.1. Seedling Survival Rate

The comparison made in terms of the survival rate between the sample lots on contaminated land in Tarnaveni (Romania) and contaminated land in Ozun (Romania) locations led to a low differentiation between the two clones (Figure 4).

![I-MR Chart of Inger](image)

Figure 4. Survival rate of the Inger clone on contaminated land.

In general, any Individual-Moving Range (I-MR) sawtooth graph is composed of two simple diagrams, the first one representing the individual values, with the above analysis, and the second sawtooth diagram representing the displacement of the values, such that we have the zero-control line as the lower limit. In order to obtain the second diagram (for moving range), the average of the values was subtracted from each individual value, thus obtaining another series of 42 positive values, which were distributed between the control limits of 0 and 4.34%. Therefore, in this last case (Figure 4), we have a new average of 1.32%. In both cases, most of the values are within the control limits, strengthening the character of the statistical normality of the values. The second part of the diagram in Figure 4 shows that the values obtained for the differential points 20, 21 and 23 are sensitive and measures will have to be taken to remedy them.

For a comparative analysis between the two clones, Inger and Tordis, planted on contaminated and uncontaminated land, the graph in Figure 5 was made, where it is clearly seen that the survival rate is better on contaminated land and is higher in the Tordis clone than the Inger clone from this point of view. To see if the means of the two groups of values for the two considered clones differed significantly, a one-way ANOVA test was performed, and it was found that the two means did not differ in a confidence interval of 95%. The survival rate is almost 50.2% better in the case of favorable land, which, in the case of contaminated land, can only be explained by losses resulting from planting, i.e., when they enter into vegetation (excluding subsequent costs of biological material and complete). However, these losses will be offset by the recovery of land unsuitable for other crops, which will be returned to the agricultural or forestry production circuit. Similar values were observed by other authors [30–34].
3.2. Evaluation of the Amount of Biomass after One Year of Culture

According to the elaborate methodology, the research determined both the amount of total dry biomass and the amount of bark, because the bark could have energetic properties different to that of wood. First, the dry mass of each twig extracted as a sample from the total samples was determined, depending on their diameter measured at 100 cm from the ground. The value of the Pearson $R^2$ determination coefficient was taken into account, choosing the highest value, i.e., in the case of Figure 6 the coefficient was $R^2 = 0.91$ for bark, and was $R^2 = 0.99$ for wood). Among the linear, exponential, logarithmic, polynomial and power approximations, it was found that the exponential function has the highest predictability of values.

When the dried biomass was determined for each rod, it was found that there is a model with the highest predictability, with a Pearson coefficient of $R^2 = 0.91$, which corresponded to a diameter of 60 cm above the ground, but good results were obtained for diameters below 60 cm and between 60–80 cm and linear and polynomial models, with coefficients of determination between 0.92–0.93. The culture scheme was $0.75 \times 0.45 \times 1.5$, which means a there was a distance of 0.75 m between rows, a distance of 1.5 m between two adjacent rows and a distance of 0.45 m between two shoots. The experimental analysis determined a dry biomass amount of 0.64 t/h for the Inger clone and 0.66 t/h for the Tordis clone. Compared to these data, other authors [34–37] found values of 9.43 g/shoot for the Canastota clone and 47.13 g/shoot for the Tully clone, also for one-year crops of Salix viminalis. Beyond these, energetic willow crops can provide large amounts of biomass up to 3.5–4.6 t/ha [38–40] when entering the crop after 2 years (which means an increase of 5.4–7.2 times), because, after cutting, the shoots at each cutting will have more shoots and larger diameters, which does not happen after the first year of cultivation. By simplifying the working methodology and using the average per dry sample of 34.62 g/shoot, the total amount of biomass would have been at a level of 485 kg/ha. This result is consistent with the results obtained by the authors of [41,42], who obtained a result of 436 kg/ha after the first year of cultivation. Additionally, another important conclusion can state that the biomass obtained in the first year of vegetation in which the shoots are small and non-vigorous and the amount of biomass are 8–10 times lower than that obtained at maturity, could be added to the other benefits brought by this plantation.
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to the amount of bark, because the bark could have energetic properties different to that of wood. First, the dry mass of each twig extracted as a sample from the ground. The value of the Pearson R² determination coefficient was taken into account, as the total samples was determined, depending on their diameter measured at 100 cm from the nearest shoot. In the Inger clone, the determination coefficient was R² = 0.99 for wood and R² = 0.91 for bark. Among the linear, exponential, logarithmic, polynomial and power approximations, it was found that the exponential function has the highest predictability, with a Pearson coefficient of R² = 0.91, which corresponds to the curve

\[
y = 1.627e^{0.2211x}
\]

R² = 0.9156

The curve is in the form of the letter “S”, called the Cumulative Distribution Function (CDF), explains how appropriate the real points of density of this cumulative empirical curve are, respectively, and it is observed that the experimental values respect the statistical principle of normality.

Regarding the effective density of dry willow twigs, and by using Equation (4), an average value of 507.3 kg/m³ was found (Figure 7) in the case of the Inger clone and 508.2 kg/m³ in the case of the Tordis clone. Taking into account the mean value, the standard deviation value and the 95% confidence interval, a range of Salix viminalis density values of 423.7–590.9 kg/m³ was found for the Inger clone and very close to it for the Tordis clone.

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Often, we need the volumetric expression of the amount of dry biomass, in order to be able to size the silos or other storage spaces. Based on the mass quantity of Salix viminalis biomass, on the effective density of willow twigs and also on biomass loosening coefficient in the form of chopped biomass of 3.2 [25,43–45], a biomass volume of 12.89 m³/ha was obtained after the first year of cultivation in the case of the Inger clone and 13.31 m³/ha in the case of the Tordis clone [7,46–48].

Figure 6. Bark mass (a) and wood dry mass (b) for willow twigs, depending on their diameter.
3.3. Soil Enrichment

The results obtained in the research regarding the influence of an energetic willow culture on soil were made by comparative pedological analysis of the soil, before planting and two years after planting in contaminated soil. Before planting the energetic willow, the contaminated soil was weakly alkaline in the first 30 cm and strongly alkaline in the next 40 cm. In the same soil, the humus content was reduced, i.e., 2.76% at the surface in the first 20 cm, with a mull humus, the carbon/nitrogen ratio was 11.43, with a low nitrogen and potassium content and an average phosphorus content (Table 1). The sodium content increased from surface to depth, being 188.5 ppm at 20 cm depth and 543.7 ppm at 60 cm, with these values being well above the upper value of 22.5 ppm specified by other researchers in the field [49,50]. The soil analysis after two years of energetic willow cultivation shows a weakly alkaline reaction in the first 30 cm and a moderately alkaline reaction in the next 40 cm.

Table 1. Soil features before and after planting.

| No. | Soil Features     | Before Planting | After Two Year of Planting |
|-----|-------------------|-----------------|-----------------------------|
| 1   | pH                | 8.1             | 8.3                         |
| 2   | Humus content     | 2.76            | 3.60                        |
| 3   | C/N ratio         | 11.53           | 13.06                       |
| 4   | Sodium, ppm       | 188.5           | 35.21                       |
| 5   | Carbon content, ppm | 1.60           | 2.09                        |
| 6   | P content, ppm    | 25              | 80                          |
| 7   | K content, ppm    | 76.33           | 107.21                      |

The soil had a low content of mull humus, with a C/N ratio of 13.06, an average nitrogen content and a high content of phosphorus and assimilable potassium. If a comparison between the soil characteristics before and after planting is made, there is an increase in the content of nitrogen, phosphorus and potassium. There was also a considerable decrease in the sodium content by 12.6%, a value much closer to the maximum allowable limits found by other authors [51-53] and demonstrated by its absorption in the energy of willow.
biomass. In addition to these, it was found that the humus content increased at the soil’s surface, this being justified by the decomposition of fallen leaves and partially decomposed at the soil surface, which also led to a 14.2% increase in the C/N ratio.

3.4. Calorific Value

The calorific value of the wood obtained from the two Inger and Tordis clones of the energetic willow (in the form of pellets specially made for this test) was differentiated on the biomass resulting from the wood and the other obtained from the bark. The values of wood biomass for the two clones had a very small difference (Figure 8); the Inger clone had a high calorific value of 19,376 kJ/kg, 0.1% higher than the Tordis clone. From this point of view, it can be concluded that the two clones have the same energy value and can be used to obtain wood biomass. However, a one-way ANOVA was used, and it was found that there were no differences between the mean values of the two clones in the confidence interval considered.

![Probability Plot of HCV Inger, LCV Inger](image)

**Figure 8.** Probability plot of calorific value for Inger (a) and Tordis (b) clones.
The graph in the previous Figure 8 was made for an error of 0.05 and a normal distribution of values. The framing of the experimental values between the two control limits shows us the normality of the distribution once again, but the best element is the Anderson–Darling (AD) parameter with values of 0.198/0.219 in the case of Figure 8a and 0.557/0.206 in the case of Figure 8b, these values being higher than the error taking into account of 0.05. By taking into account the 95% confidence interval (for ±2 s, where s is the standard deviation of the values determined using the Minitab 18 program) and the arithmetic mean, it was possible to determine the limiting intervals of the calorific value, as follows:

- For the Inger clone: HCV = (18,906–19,846) kJ/kg; LCV = (18,328–19,208) kJ/kg;
- For the Tordis clone: HCV = (18,801–19,909) kJ/kg; LCV = (18,091–19,171) kJ/kg.

The calorific value of the bark obtained from the two clones did not have significant differences, which is why the graph of the calorific value is presented only for the Inger clone (Figure 9).

The calorific value of the dried bark obtained from the two clones was much lower than that of the dried wood; the calorific value of the wood of the Inger clone was with 2.49% higher than that of the bark and with 2.38% higher than that of the Tordis clone. As other authors have specified, the bark has a calorific value almost equal to that of the wood due to the higher ash content and lower lignin content. In this sense, an ash content of 3.9% for bark and 2.2% for wood without bark was obtained [9,54]. Additionally, the calorific value for energy willow falls into the category of firewood from hard species, such as beech and hornbeam [6,7], which exceeds that of lower coals, such as peat, lignite and brown coal, but is lower than that of high-calorific coals, such as anthracite and coke [6]. Additionally, close calorific values were obtained both for shredding and from briquettes and pellets, the conclusion being that if appropriate drying conditions of energy biomass are ensured, it can be used directly (in the form of firewood or shredding properly) without the additional costs of compaction in briquettes or pellets. Additionally, another important conclusion is that the biomass resulting from the exploitation of energetic willow should not be separated in the form of bark and wood, and can be used together, because they have appropriate calorific values [25].

![Empirical CDF of HCV Bark, LCV Bark](image_url)

**Figure 9.** Calorific value of the energy willow bark, Inger’s clone.
4. Conclusions

1. Energetic willow can be used in all countries, but it is especially suitable in developing countries where there are uncultivated, arid, contaminated or other lands with low productivity.

2. The survival rate was favorable for the Tordis clone, with a 38.4% increase on contaminated land, which recommends the use of the Tordis clone on contaminated land.

3. The amount of biomass obtained after the first year of cultivation was 0.64 t/h or 4.03 m$^3$/ha in the case of the Inger clone and 0.66 t/ha or 4.16 m$^3$/ha in the case of the Tordis clone.

4. The phytoremediation action of the soil was demonstrated by decreasing the sodium content and increasing the C/N ratio.

5. The calorific powers of the two clones were almost similar the obtaining results having reliable intervals with small differences.

6. The use of Salix viminalis for the remediation of some contaminated lands represents a beneficial activity both for the land and through the contribution of wood biomass with superior energetic properties.

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