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Study of Paulownia's Biomass Production in Mérida (Badajoz), Southwestern Spain

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Abstract Fast-growing forest species have become an alternative to take into account for irrigated land with lower profit margins. The objective of this project is to know the adaptation and biomass yields of the Paulownia crop for biomass and timber production, in the irrigated area of the Guadiana River 'Vegas Bajas' in Extremadura Region, (SPAIN). In 2012, two plots with 4 different Paulownia clones were planted (112, COT2, L1 and X1). One plot has been destined to timber production (T), with a 10-year rotation, grown at 4 by 4m spacing, and the other plot has been destined to biomass production (B), with a 3-year rotation, grown at 3 by 2m spacing. In February 2016, the first rotation stand of the biomass (B) plot was harvested. Clone X1 has showed a significantly lower performance in terms of dry matter production and growth, whilst among the other 3 clones, no significant differences were observed. The total production of the biomass plot was 24280.1kg dry matter ha^{-1}. Average annual total biomass yield was 8093.4 Kg ms ha^{-1} for plot (B).

Keywords Biomass, Fast-growing Trees, Short-rotation Plantation, Paulownia, Timber, Full Random Blocks

1. Introduction

The genus *Paulownia,* original from the rocky and xeric areas of Southeast Asia, is widely distributed throughout the temperate zones of the world, where it is used as a crop [1]. About 50 countries are developing afforestation programs for wood production with some species of this genus, which are characterized by their high yields and their adaptability to different climates and soils [2].

Paulownia has three requirements for its growth [2]:

- Well drained soils, which limits its implantation in clay soils.
- Minimum temperatures below -20ºC
- Minimum annual rainfall or irrigation of 500mm. Most of water must be available during warm season. Stations are reported where 65% of annual rainfall coincides with the growth period of these species.

Its engineering properties, its resistance to pathogens, dimensional stability and a high flash point ensure the quality of the wood for lumber production [3,4].

Its wood is light, soft, straight fiber, slightly knotty and with a glossy luster. Active drying, even at high temperature, does not induce major defects. It has little tendency to warp [5]. Its current uses as saw wood include joinery, carpentry, construction, aviation, packaging, etc.

Paulownia clones are developed in 6-10 years rotations for saw log. In seasons with optimal cultivation conditions, Paulownia trees can reach 10 meters high, with a clean stem of 5 m and a diameter of 22 centimeters in 4 years. In these sites it is common to have trees of 45 to 50 cm of diameter at breast height in 10 years, with biomass yields of 12 m^3 hectare^{-1} year^{-1}. In the United States [6, 7] and other countries, Paulownia is considered as a first class wood, reaching prices even higher than walnut [8]. In Spain the genus Paulownia has been cultivated for the last 10 years, in order to produce timber and biomass. There are studies in which total biomass yields up to 6079 kg dry matter (d.m.) ha^{-1} year^{-1} and with a crown biomass of 4080 Kg d.m. ha^{-1} [9] up to 12 m^3 ha^{-1} year^{-1} [10].

The aim of this study was to evaluate 4 selected *Paulownia* clones in short rotation for saw log and biomass production to compare the biomass yields of these clones in the Guadiana River low basin, in Extremadura Region (Southwestern SPAIN).

2. Materials and Methods

The study began in 2012 with the planting of two plots, one for biomass production B and the other one for timber production T. The study is based on the clones showed in Table 1:

Table 1. Used clones and species that form them

Clon	Specie/s
COT 2	*Paulownia elongata x fortunei*
L1	*Paulownia elongata x fortunei*
X1	*Paulownia fortunei*
112	*Paulownia elongata x fortunei*

In both plots, all the trees were collected at the end of 2012. A biomass production cycle of 3 years was selected, being in February 2016 the first cut of the plot for biomass production (B). In the plot destined to saw log, a cycle of 10 years was provided.

Differences between the four studied clones, in both plots, have been evaluated in a randomized complete block plantation, as shown in Figure 1:

- Plot for Biomass production (B): 8 blocks with 32 trees each (8 trees per clone).
- Plot for timber production (T): 13 blocks with 12 trees each (3 trees per clone).

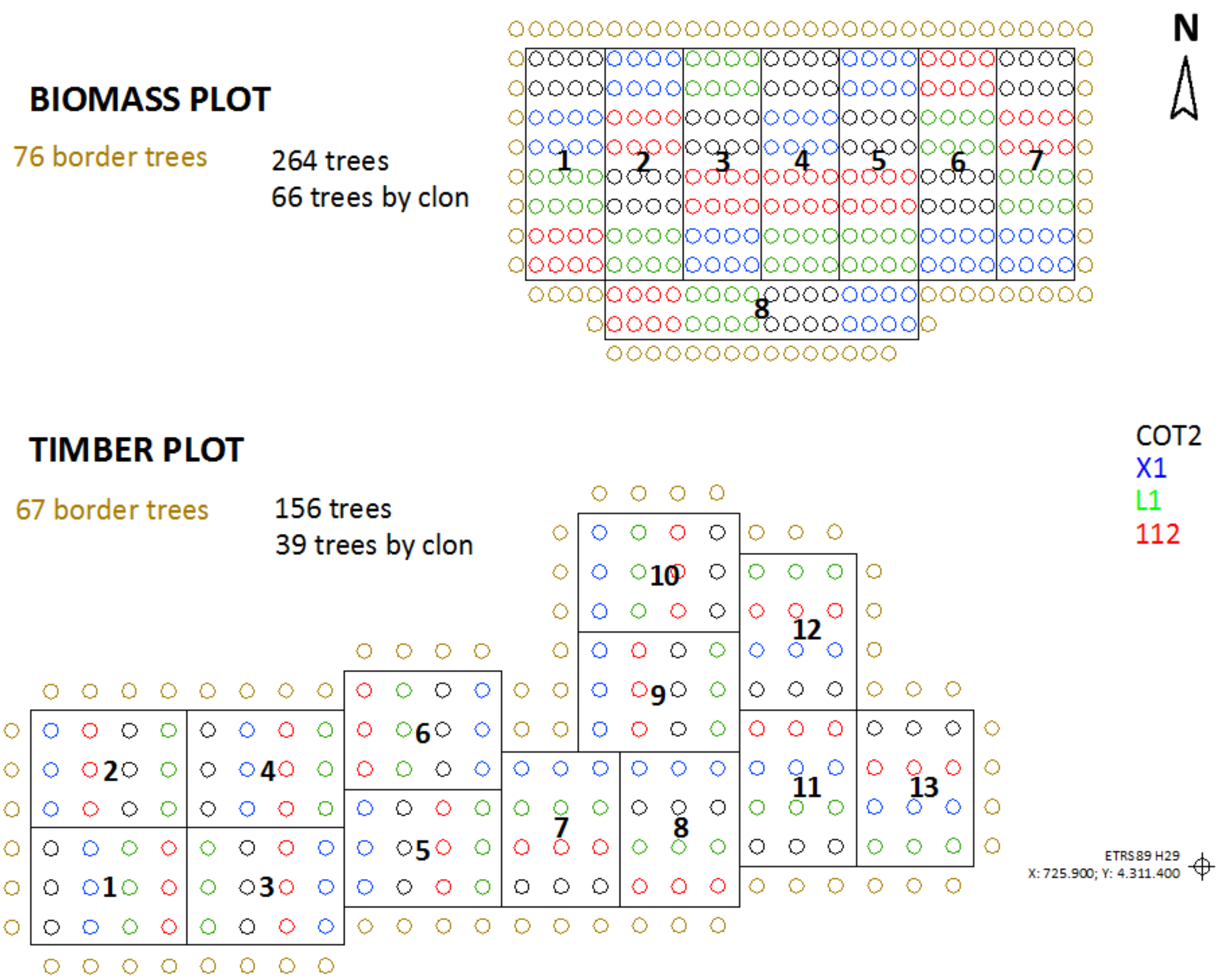

Figure 1. Distribution of the different clones in both plots, above biomass and down timber

2.1. Stablishment

Both plantations are established in Mérida (Badajoz), in the fields of the Cork, Wood and Charcoal Institute (ICMC) of the Technological and Scientific Researches Centre (CICYTEX) of the Extremadura Region (Southwestern SPAIN, ETRS89 H29 X:725.900; Y:4.311.400). The plots have rocky soils of alluvial origin with low organic matter, pH 7,5-8,5. The average annual temperature is 16,9°C and the average annual rainfall is 486 mm.

The north side of the field was selected for the production of biomass and the south side for timber production. In both plots, a drip irrigation installation was carried out, which also allowed the fertirrigation. The water was analyzed, highlighting the chlorine content (288 mg l^{-1})

Table 2. Plot surface, number of trees and spacing

Plot	Area (m^2)	Number of trees	Number of border trees	Spacing
(B) Biomass	2048	264	74	3x2 m
(T) Timber	3836	168	71	4x4 m

Herbaceous vegetation was eliminated before the tillage. A full and crossed tillage has been carried out with a subsoil of up to 80cm.

Because of rabbits in the area protectors were installed with a Ø 22cm and a height of 33cm. After the resprouting in February 2013, the protectors were removed once the plants surpassed their height, to favor a uniform and vigorous regrowth.

Both plots were fertirrigated with a drip irrigation system, with 2 self-compensating drippers of 4l h^{-1} per tree. A Hunter X Core irrigation programmer was installed, connected to the existing irrigation system, to control the irrigation in both plots, assisted by a solar and rain sensor (Solar-Sync of Hunter), which regulates the irrigation time according to Humidity and radiation. The water comes from a well located at the ICMC. In addition, a venturi was installed for the fertilization.

2.2. Stand Management

The plantation was weeded with mechanical weed control machine. Later, in order not to damage the roots, herbaceous control was done by chemical treatments (Glyphosate and Oxyfluorfen), when necessary.

During the first year, pest damage was observed in very young plants due to *Stagonomus bipunctatus*, also known as rice bed bug or pudding. It was controlled by the combined use of Imidacloprid and 3% Cipermetril accompanied by 1% Methylclorpirifos.

Along 2013 there were some trees of the B plot that were affected by *Phytophthora citrophthora*, which was isolated in the necrotic tissues. A phosphite treatment with Fosetyl aluminum was applied to soil [12], which proved very effective, since there were no more cases of attack by that fungus during 2014 or 2015. After the first cut in February 2016, some sprouts were affected again, because of this treatment with Phosphites was repeated, resprouting all affected trees.

The irrigation dose was calculated based on evapotranspiration of the area and the needs of the plant. Irrigation dose was increased with the growth of the trees in the different plots, from 1 hour daily (6 days a week) the first year, to the current 2.5-3 hours (20 to 25 liters per tree), 4 days a week during the summer (around 6000 m^3 $ha^{-1}year^{-1}$).

In both plots 500 kg ha^{-1} of a 15-10-15 (N-P-K) fertilizer was applied from the beginning of June 2012 until June 2014. Humic and fulvic acids were added to improve the structure and soil exchange capacity. Since then (June 2014) a richer Nitrogen formulation of 15-5-5 + 3% Organic Matter has been applied.

Only the plot for the production of wood (M) was pruned to avoid bifurcations of the shaft and to produce a clean shaft of branches. In 2014 and 2015 shoots and branches on the shaft where eliminated of the up to a maximum of 2/3 of the tree height.

2.3. Measurements and Analysis

The evolution of the total height was monitored, with measurements at the beginning and at the end of each growing period (only in plot T), and a biweekly or weekly follow-up of the measurements of the breast height diameter was carried out in both plots.

On the other hand, in February 2016, all the trees of the B plot were cut at the end of the first production cycle (3 years). After being cut down, all the trees were individually weighed, using a hook scale and a small crane. Later, they were chipped with a whole-tree chipper and samples from each clone were taken.

Moisture content was calculated according to ISO 18134-1:2015 (Solid biofuels. Determination of moisture content. Oven dry method. Part I: Total moisture). A slice of each stalk was removed after being cut. Slices were weighed individually (wet matter) and dried in a stove for 48 hours at 105 ºC to obtain the dry weight. Ash content was determined with the chips sampled, according to ISO 18122:2015 (Solid biofuels. Determination of ash content). C,H,N, S were measured using an elementary analyser Tru-Spec CHN Leco 4084, according to the standards ISO-16948 and ISO 16994 for biomass analysis. The Cl content in ash was determined with the titration method in accordance with ISO 16994. The chemical composition of ash in the *Paulownia* biomass was determined with an Inductively Coupled Plasma–Optical Emision Varian-715ES ISO 16968 (determination of trace elements: Cu, Pb, Cr, Ni, Zn, Mn, Cd). Calorific value was determined according to ISO 18125 (Solid biofuel: Determination of calorific value).—Data analysis was performed using the statistical software R [12], and

Agricolae package [13], to perform a comparison test of means of the studied parameters diameter and weight. With the measurements of diameters and weights corrected for moisture content, a parametric test of comparison of means was made. The accomplishment of this type of test requires the verification of three previous hypotheses: independence of the data, normality in the distributions and homoscedasticity. The first one was obtained with the design of the test in random blocks, the normality was verified through Kolmogorov-Smirnov test. Finally the homoscedasticity was verified through the Bartlett test to verify the homogeneity of variances for both variables. Subsequently a comparison of means test was performed: the Welch test for unequal variances and the Tukey´s Honest Significant Difference test.

3. Results

Only the plot for biomass production has been evaluated, because the plot for timber production has not been cut yet, so its production has not been currently evaluated.

Measures are summarized in the following tables and figures (tables 3 and 4, figures 2 and 3):

Table 3. Summary of measurements

	Units	No.	Mean	S.D.	Min.	Max.
Diameter	mm	244	106.3	13.6	51.2	136.6
Wet weight	g	244	40.2	11.3	7.2	70.8
Dry weight	g	244	14.6	4.0	2.6	24.4

N= Number S.D. Statistical Deviation

Table 4. Summary of diameters (mm) per clone

	No.	Mean	S.D.	Min.	Max.
112	61	110.5	11.1	84.7	133.7
COT2	61	110.3	10.2	81.8	134.3
L1	61	110.6	10.2	91.0	136.6
X1	61	93.6	14.3	51.2	121.6

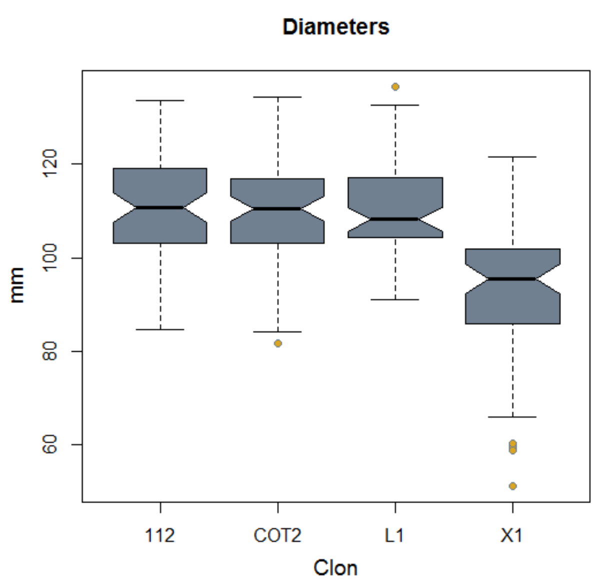

Figure 2. Diameters at breast height (mm) per clone

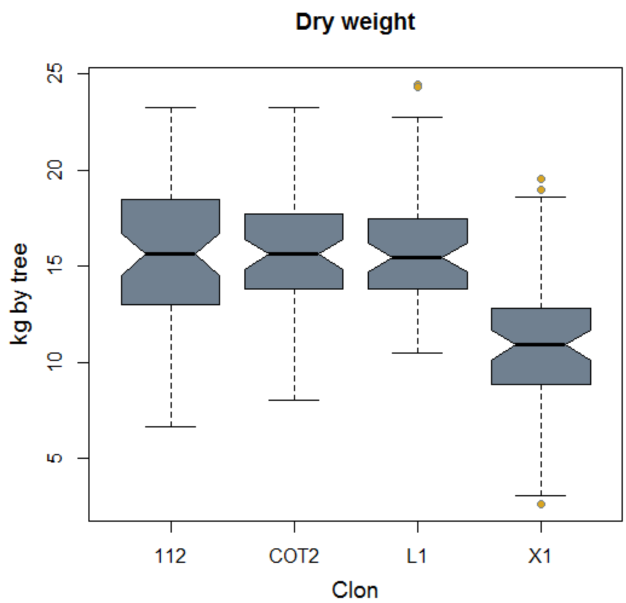

Figure 3. Dry weight (kg) per clone

Table 5. Summary of dry weight (Kg) per tree of each clone

	N	Mean	S.D.	Min.	Max.
112	61	15.6	3.6	6.7	23.2
COT2	61	15.9	3.1	8.0	23.3
L1	61	16.1	3.5	10.5	24.4
X1	61	10.9	3.6	2.6	19.5

In Figures 2 and 3 the distribution of the measurements of diameter and dry weight of each clone are shown, respectively. These distributions show a possible differentiated behavior of clone X1. In addition, the normality test of Kolmogorov-Smirnov verified the normality of both distributions.

The Bartlett test was employed to verify the homogeneity of variances for the diameter and dry weight variables. In the case of the diameters per clone the result of this test gives a p-value of 0.02071, which means the homogeneity of variances is rejected with a probability of 95%. This result entails to compare the means of the diameters using the Welch test, for unequal variances. However, in the dry weight variable the p-value is 0.5869, so it is accepted the hypothesis of the homogeneity of variances which allows to perform a comparison analysis of Tukey's multiple means.

3.1. Comparison of Means of Measurements of Diameters.

The test is performed for each pair of clones. The results are reflected in the table 6

Table 6. Summary of diameters (mm) per clone

Comparative clones	p-value	Signification level
112 - COT2	0.8946	
112 - L1	0.9871	
112 - X1	3.952e-11	***
COT2 - L1	0.8766	
COT2 - X1	2.636e-11	***
L1 - X1	1.431e-11	***

3.2. Comparison Analysis of Means Measurements of Wood Weight at 0% Moisture

The analysis of the dry weight variance shows a high significance (p-value ≈ 0), so all clones have not the same behavior in terms of their dry weight production. This variable is submitted to the HSD test, to compare unpaired means.

On the other hand, it has been verified that membership of a given block does not act as a differentiating factor in the production of biomass.

Table 7. HSD test result

Clone	Mean	Group
L1	16.07	a
COT2	15.90	a
112	15.62	a
X1	10.93	b

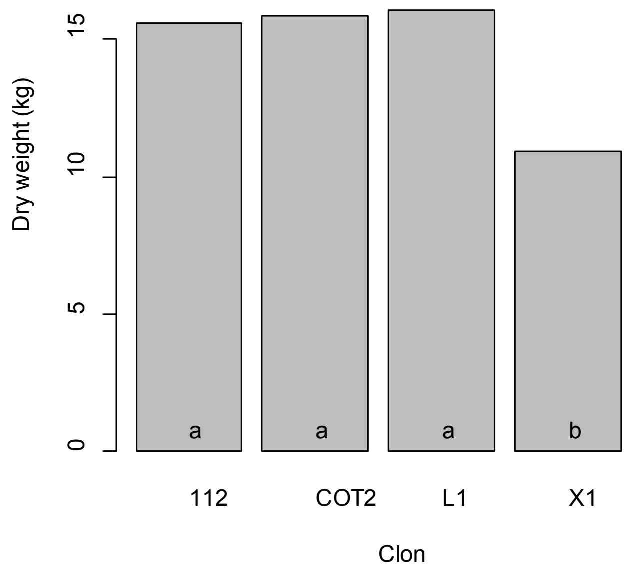

Figure 4. Groupated dry weight means (kg)

The results obtained conclude that clone X1 has a significantly lower dry biomass production than the other three tested clones.

3.3. Analysis of the Biomass Composition for Different Clones after Chips

Splinter samples were taken from the different clones attempting to represent all parts of the tree, obtaining mean values. They are showed in Tables 8 and 9.

Table 8. Elemental analysis and calorific values

					ELEMENTAL ANALYSIS[4]				CALORIFIC VALUE[5]	
CLONE	%HUMIDITY[1]	%ASH[2]	%O[4]	%Cl[3]	%C	%N	%H	%S[3]	LCV (Kcal/kg)	HCV (Kcal/kg)
X1	64.85	1.95	44.05	0.07	47.31	0.41	6.04	0.01	4414	4731
COT 2	62.79	1.96	42.51	0.12	51.56	0.45	5.60	0.02	4425	4718
112	63.02	1.51	46.07	0.14	46.01	0.21	5.89	0.00	4341	4650
L1	63.55	1.85	45.66	0.08	45.89	0.27	6.04	0.00	4437	4753

1: UNE-EN ISO 18134-1, **2**: UNE-EN ISO 18122, **3**: UNE-EN ISO 16994, **4**: UNE-EN ISO 16948, **5**: UNE-EN ISO 18125.

Table 9. Heavy metal analysis

	ANALYSIS ICP-OES[6]						
CLONE	Cu (ppm)	Pb (ppm)	Cr (ppm)	Ni (ppm)	Zn (ppm)	Mn (ppm)	Cd (ppm)
X1	3.65	0	0.48	0.6	9.34	5.03	0.25
COT 2	6.01	0	0.54	0.8	8.98	8.03	0.10
112	4.67	0	0.41	0.81	8.80	4.27	0.22
L1	8.67	0	0.63	1.22	10.88	5.03	0.22

6: UNE-EN ISO 16968

4. Discussion

The membership of the given block in the plot B does not determine the biomass production. Therefore, the dry biomass production of X1 clone is significantly lower than the other three tested clones according the results obtained. Furthermore, X1 is the only clone of the *Paulownia fortunei species*, and the other studied clones are of the *Paulownia elongata x fortunei* species.

Significant differences are not found among biomass production of clones 112, COT2 or L1.

The total production of plot B was 24280.1 kg d.m ha^{-1}. 8093.4 Kg d.m. ha^{-1} $year^{-1}$ for the total of the plot with the sum of the 4 clones. According to Del Cerro [14], clone 112 was studied and its production was 6079.13 kg d.m ha^{-1}. (in 17 months) or, what is the same, 4291.15 kg d.m ha^{-1} $year^{-1}$, under planting, irrigation and subscribes similar conditions. In another study, Jimenez Bocanegra *et al.* [15], obtained between 1.7-14 Tn d.m ha^{-1} in 2 years (0.85-7 Tn d.m ha^{-1} $year^{-1}$.) with clone COT2 with similar experimental conditions. The difference in the productions may be due to edaphoclimatic conditions and the different coppicing cycle.

The results obtained from the tests carried out in plot B, from the determinations of moisture, ash, oxygen, chlorine, elemental analysis (C, H, N and S), calorific value and minority elements, in the *Paulownia* chips, appear in tables 8 and 9. All values obtained satisfy the solid biofuels regulation for wood chips class B1 [16], except chlorine. The water used in irrigation comes from a well with a high content of chlorine (153 mg l^{-1}) and other elements, exceeding the levels of drinking water in Merida (46 mg Cl l^{-1}). However, another sample of *Paulownia* chips from another CICYTEX experimental plot, at La Orden Experimental Farm in Guadajira (Badajoz), was irrigated with water from the channel used by farmers on their plots and it has got a lower value Chlorine content (0.01%) than the previous sample, meeting the standard of solid biofuels (maximum limit 0.05%). Kasamaky [17] obtained similar values in the characterization of the *Paulownia* biomass. Values of HCV are located in the range of 4200 and 4400 Kcal kg^{-1} depending on the analyzed clone, while the ash percentage is around 2%. The analysis carried out by the Renewable Energy Research Institute "IER" [18] also presented similar values.

5. Conclusions

The *Paulownia* plantations are viable in the area of "Las Vegas Bajas del Guadiana". These conditions are extrapolable to areas of Extremadura Region (Southwestern SPAIN), as long as the conditions of the soils are well aerated, not clayey, without flooding for long time and good availability of irrigation in the early years. Subsequently, although the irrigation may not be necessary, they advantage the growth and development of this species. Chlorine is easily assimilable by the clones in study, remaining in the wood after the cut, so that can be a conditioning in certain areas with water rich in this element.

Considering the results, the similar behavior of clones L1, COT2 and 112 has been observed in their growth in diameter, as well as in biomass yield. These clones are significantly higher than clone X1, it means that these three clones are better adapted to the studied area. Therefore, the choice of any of these clones cannot be made on the basis of their biomass production or growth, under the conditions of cultivation and station quality in which this test was performed.

The total production of the plot for biomass production was 24280.1 kg m.s. ha^{-1} with a three years coppicing cycle, that is 8093.4 Kg m.s. $ha^{-1}year^{-1}$ for the total plot.

On the other hand, from the sanitary point of view, these *Paulownia* clones show a good behavior against pests, although they are more sensitive in the first stages of growth. It is clear the sensitivity to the attack of some pathogenic fungus of agricultural origin like *Phytophthora citrophthora*, for which the application of phosphites to soil could be an effective treatment.

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