Potential of Slurry from Intensive Dairy Cattle Farms for *Paulownia* and *Populus* Trees, as Organic Fertilizer: I. Effect on Production

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Abstract

Intensive dairy cattle breeding have a relevant social and economic impact in Portugal, particularly in the northern region. This activity generates a high flow of livestock effluents (slurry), rich in important nutrients for plant growth, which can be introduced into forest production systems. These effluents can provide a good alternative to mineral fertilizers, not only from an economic perspective, but also from the point of view of soil fertility resilience. In the present study, the effect of increasing doses of slurry on tree growth was evaluated in clones of *Paulownia* and *Populus*, as they are genotypes that have a high efficiency in the mobilization of soil nutrients and in the capture of CO_2 from the atmosphere, as well as high biomass calorific value. To this end, a demonstration field was installed, where the trees were planted with the compasses of: 2.5 x 1.5 m and 2.5 x 0.75 m, respectively for *Paulownia* and for *Populus*. In the field, the following treatments were performed: T0 - no fertilization, either mineral or organic; T1 - amount of slurry equivalent to 85 kg of N ha^{-1}; T2 - amount of slurry equivalent to 170 kg of N ha^{-1}; T3 - amount of slurry equivalent to 340 kg of N ha^{-1}, either with or without inoculation prior to transplantation, with mycorrhizal arbuscular fungi and plant growth-promoting bacteria. Results evidenced a positive effect of the slurry application, both in the diameter at breast height and in total stand height, showing its fertilizing potential which should later be assessed on the ability to constitute an alternative or, simply, a complement to mineral fertilization.

Keywords: bovine slurry, organic fertilization, *Paulownia* CoT2, *Populus* i214

1. Introduction

Intensive dairy cattle breeding have a relevant social and economic impact in Portugal, particularly in the northern region. This activity generates a high flow of livestock effluents (slurry), rich in important nutrients for plant growth, which can be introduced into forest production systems. These effluents can provide a good alternative to mineral fertilizers, not only from an economic perspective, but also from the point of view of soil fertility resilience.

In fact, these effluents have high levels of macronutrients, such as nitrogen (N), phosphorus (P) and potassium (K), and micronutrients, such as copper (Cu) and zinc (Zn), constituting a valuable resource as an organic fertilizer for soils, increasing its content in organic matter (OM) and available nutrients, while improving its structure. Therefore, the use of slurry as an alternative (or even just as a complement) to mineral fertilization, in agroforestry exploration systems, could be an adequate means of recycling a free polluting product, and avoid, or at least reduce, the use of expensive mineral fertilizers.

However uncontrolled deposition of high amounts of slurry in the soil, as with mineral fertilizers, increases the risk of contamination of surface and groundwater with nitrates, and the ammoniacal formulation of N may also represent a significant environmental risk, due to the volatilisation of ammonia and other compounds that contribute to the aggravation of the greenhouse effect.

All these drawbacks may be true for most organic fertilizers, when managed incorrectly, but it is much more likely for mineral fertilizers, as the N in the former is mostly in the organic formulation and the remaining formulations are slowly leached out by the mineralization process in the soils, as the roots will progressively absorb them physiologically, thus reducing the opportunity for leaching to the ground waters of the more soluble nitric formulations and, likewise, reducing the possibility of ammonia volatilisation to the atmosphere.

Thus, it is of utmost relevance to optimise the fertilizer dosage. To solve this conundrum, the adequate selection of the genotypes of forest species to be used and the adequate fertilizer inputs are the most crucial factors.

As stated by Evangelou *et al*. (2012), “from the environmental point of view, fast-growing tree biomass production replaces non-renewable carbon materials and promotes carbon sequestration and other ecosystem services, such as improvement of soil and water quality, reduction of erosion and increase of biodiversity".

Species like *Paulownia* and *Populus*, are known as fast growing species, suitable for phytoremediation and for the recovery of polluted soils (Macci *et al*., 2013; Macci *et al*., 2016). In a study, carried out by Madejón *et al*. (2016), also working with *Paulownia* and *Populus*, using organic compost to avoid soil fertility loss and to increase biomass production, the researchers concluded that the addition of organic composts to this type of "intensive crops" could be part of the solution of the "waste" disposal, solving the problem of loss of soil fertility as well as production of relevant biomass in marginal soils.

Particularly, with regard to *Paulownia*, the high forage potential of its leaves, which can be used as a source of nutrient-rich food for cattle, allows to complete a cycle of remarkable interest, in a perspective of "circular economy" and, in this way, contribute to a better economic performance of dairy companies.

As far as the poplar is concerned, as it is a silvicultural species of rapid growth that has long been cultivated in Portugal, its choice provides the appropriate reference for measuring the capacity of interaction with organic fertilizers.

In the present report, the effect on tree growth of increasing doses of slurry, either with or without mycorrhizal arbuscular fungi and plant growth-promoting bacteria inoculation, was observed over the first two years (2020 and 2021) after transplanting from nursery to field, of an experimental demonstration forest field, in clones of *Paulownia* and *Populus*.

2. Materials and Methods

The experimental demonstration forest field, occupying an area of 14,607 m^2, was installed in 2019 in the region of Penafiel (North of Portugal) in a compact soil, derived from granites, which are prone to waterlogging during the autumn and winter periods and characterized by a low internal drainage capacity. For this reason, it was necessary to remove the top layer (to a depth of about 50 cm), install a drainage pipe system, cover with a gravel layer of about 20 cm, and top with the previously removed soil.

A sample of the resulting Anthrosol - according with FAO classification (IUSS-FAO, 2006) - was analysed for selected properties, according to the methods used routinely in the laboratories of the "National Research Institute of Agriculture and Veterinary", in Oeiras (Portugal), presenting the following physicochemical characteristics:

• Texture		sandy-loam;
• pH (H_2O)	6.4	slightly acid
• organic matter	17.6 g kg^{-1}	medium level;
• N Kjeldhal	0.9 g kg^{-1}	medium level;
• P_2O_5 (extractable)	54.1 mg kg^{-1}	medium level;
• K_2O (extractable)	131 mg kg^{-1}	high level.

The trees were planted with the compasses of: 2.5 x 1.5 m and 2.5 x 0.75 m, respectively, for *Paulownia* CoT2 (*Paulownia elongata* x *Paulownia fortunei*), and for poplar i214 clones (*Populus deltoides* x *Populus nigra* [*Populus* x *euramericana* (Dode) Guinier]).

Prior to transplantation to the field, and as a complement to the main purpose of this demonstration display, some plants were inoculated with mycorrhizal arbuscular fungi (MAF) and plant growth-promoting bacteria (PGPB), which, associated with trees, are supposed to enhance a greater supply of nutrients and a greater resistance to diseases, preparing them for transplantation and healthier establishment.

The cattle slurry used on the experimental display was chemically analysed, each year after transplantation (2020 and 2021), for N (for the calculation of the quantities to be applied in each treatment) as well as for the main characteristics considered in the EU legislation, and the results were the following:

• Moisture	97%	96%	EN 13040:2007
• Dry matter	3.3%	4.0%	Calculation by weight difference
• pH(H_2O) (25°C)	7.7	7.2	EN 13037:2011
• Electric conductivity (25°C)	17.5 mS/cm	16.6mS/cm	EN 13038:2011
• Total nitrogen (N)	3260 mg L^{-1}	3124 mg L^{-1}	Bremner & Mulvaney, 1982
• Organic matter	2%	3%	EN 13039:2011
• Total phosphorus (P_2O_5)	0.07%	0.09%	EN 13650:2001
• Total potassium (K_2O	0.17%	0.16%	EN 13650:2001
• Total calcium (CaO)	0.20%	0.17%	EN 13650:2001

• Total magnesium (MgO)	0.08%	0.07%	EN 13650:2001
• Total boron (B	0.93 mg kg^{-1}	0.85 mg kg^{-1}	EN 13650:2001
• Total sodium (Na)	0.09%	0.05%	EN 13650:2001
• Chlorine (Cl^-)	0.20%	0.07%	PE-117-LQARS/LAF (Ed. nº1)
• Total copper (Cu)	2.33 mg kg^{-1}	2.86 mg kg^{-1}	EN 13650:2001
• Total zinc (Zn)	12.1 mg kg^{-1}	16.7 mg kg^{-1}	EN 13650:2001
• Total nickel (Ni)	<33.3 mg kg^{-1}	<33.3 mg kg^{-1}	EN 13650:2001
• Total chromium (Cr)	<16.6 mg kg^{-1}	<16.6 mg kg^{-1}	EN 13650:2001
• Total lead (Pb)	<33.3 mg kg^{-1}	<33.3 mg kg^{-1}	EN 13650:2001

In the field, the following treatments were performed: T0 - without slurry application; T1 - quantity of slurry in order to supply 85 kg of N ha^{-1}; T2 - quantity of slurry in order to supply 170 kg of N ha^{-1}; T3 - quantity of slurry in order to supply 340 kg of N ha^{-1}; all of them with and without inoculation. Slurry application was done, in continuous bands, three times throughout the year, namely in spring, summer and autumn.

The treatments without inoculation were included in blocks with eight plots with nine trees each. The treatments with inoculation were included in blocks with eight plots with six trees each.

Biometric data for diameter at breast height (DBH) and trees total height (TH) were recorded for all trees in all plots, in order to assess the Growth Increase (GI) for each treatment. For that purpose, the measures registered in 2021 were subtracted from the measures registered in the previous year to evaluate the increments that resulted for each treatment.

The experimental data were analyzed for variance by the General Linear Model and means separation was performed using Tukey's Honestly Significant Difference test at $p \leq 0.05$.

3. Results and Discussion

The average GI recorded for both species in the treatments without inoculation were as shown in Table 1, with values that can justify the following considerations:

With regard to DBH, the treatments with slurry, in both species, always showed a higher value than those recorded for the treatments without slurry, although only by a statistically significant margin for treatment T1, in the case of *Paulownia*, and for treatments T2 and T3, in the case of poplar.

This is also true for the data recorded for TH in the case of *Paulownia*. In the case of poplar, the effect of fertilizer only becomes significant in the T3 treatment, although here in an exuberant way.

Although not significant, the pattern of response to fertilizer for the two species under consideration was the opposite, being decreasing in the case of *Paulownia* and increasing in the case of poplar.

Table 1. Mean values for *Paulownia* and *Populus* GI, from 2020 to 2021, with respect to DBH and TH of trees, for each treatment without mycorrhizal inoculation

Treatment	DBH (cm)	TH (m)
Paulownia T0	1.79 c	1.47 d
Paulownia T1	2.79 ab	2.47 c
Paulownia T2	2.50 abc	1.83 cd
Paulownia T3	2.23 abc	1.28 d
Populus T0	2.07 bc	2.50 bc
Populus T1	2.23 bc	2.46 c
Populus T2	2.59 ab	2.70 c
Populus T3	2.91 a	3.52 a

Means in the same column with the same small letter do not differ significantly ($p \leq 0.05$), as judged by the Tukey test.

It seems, therefore, legitimate to conclude that, under the present experimental conditions, while *Pawlownia* reacts to slurry fertilization at lower doses and does not benefit from higher doses of the fertilizer, the poplar needs successively higher doses, which is not fully in agreement with what has been verified by Ceotto *et al.* (2016) who, in their research on the effects of cattle slurry on poplar, conclude that this species had a poor nitrogen (N) use efficiency.

Despite only evidenced in the significance of the data recorded in the TH for the T0 treatment of both species, there was a significantly more positive performance of the poplar. This fact is in line with what is generally recognized. Nevertheless, Macci *et al*. (2016) found lowest growth for *Paulownia*, when compared to *Populus*, although these authors recognise that in their study the "environmental conditions" were not adequate, or the best, for this species, as it is the case in the present study.

Even though the land had been worked to increase its internal drainage, this proved insufficient, as the climatic conditions during the experimental period were not the most favourable for Paulownia. As Berdón *et al*. (2017) concluded, after studying several clones of *Paulownia*, this species demands conditions of well drained soils, with good aeration, not clayey. This is particularly noticeable in the results verified in the experimental set-up for evaluating the effect of inoculation in GI, since its location was much more unfavourable as far as waterlogging was concerned.

On the contrary the poplar, being a riparian species, is better equipped to face situations of excess water, which can be seen in the data for both parameters recorded in table 2.

Table 2. Mean values for *Paulownia* and *Populus* GI, from 2020 to 2021, with respect to the DBH and TH of trees, for each treatment of increasing rates of slurry land use, with mycorrhizal inoculation

Treatment	DBH (cm)	TH (m)
Paulownia mycorrhized T0	1.14 bc	0.68 b
Paulownia mycorrhized T1	0.76 c	0.50 b
Paulownia mycorrhized T2	1.78 ab	2.86 a
Paulownia mycorrhized T3	1.88 ab	2.87 a
Populus mycorrhized T0	2.40 a	2.82 a
Populus mycorrhized T1	2.22 a	3.00 a
Populus mycorrhized T2	2.41 a	2.73 a
Populus mycorrhized T3	2.48 a	3.10 a

Means in the same column with the same small letter do not differ significantly ($p \leq 0.05$), as judged by the Tukey test.

As can be seen in this last table, no significant differences were recorded for both parameters measured for the poplar. This was not the case for *Paulownia* where significant differences, with regard to the data recorded for both parameters, showed significant differences. Here the DBH recorded for T1, although by a non-significant margin, was lower than that for T0 itself, differing from the other treatments by a significant margin. As far as trees TH is concerned, in addition to a relationship between T1 and T0 identical to that for DBH, the differentiation for the more generous slurry endowment treatments was significant; in this case the pattern of response to slurry application was opposite to that seen in the treatments without inoculation, with conspicuously and significantly higher values for treatments T2 and T3.

Given the soil and climatic conditions prevailing during the two years of the trial, the data verified for the trial with inoculation of MAF and PGPB are inconclusive.

4. Conclusions

Concerning the main hypothesis that justified the present study, the results revealed a significant and positive effect of the slurry application, either in the diameter at breast height (DBH) or in the total stand height, showing the high fertilizing potential of this organic compost and, thus, providing an alternative to chemical fertilization and to uncontrolled disposal of highly polluting waste.

Under the present experimental conditions, while *Pawlownia* reacted to slurry fertilization at lower doses and does not benefit from higher doses of the fertilizer, poplar showed an opposite pattern, with a positive response to increasing slurry inputs.

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