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Fertilizer potential of slurry from intensive dairy cattle farms in Intensive production forestry systems

Abstract

Intensive dairy cattle breeding has 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 intensive production forestry systems. These effluents can provide a good alternative to mineral fertilizers, not only from an economic perspective but, particularly, from the point of view of environmental protection. In the present study, the effect of increasing doses of slurry on tree growth, either with or without mycorrhizal arbuscular fungi (AMF) and plant growth-promoting bacteria (PGPB) inoculation, was evaluated in clones of *Paulownia* CoT2 and *Populus* i214, as they are genotypes that have a high efficiency in the mobilization of soil nutrients (namely N) and in the capture of CO_2 from the atmosphere, as well as high biomass calorific value. For this purpose, a demonstration field trial was installed, occupying an area of 14,607 m^2, 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 Poplar. Prior to transplantation to the field, some plants were inoculated with AMF and PGPB. 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}, both with and without inoculation. Results revealed a significant and positive effect of the slurry application, both in the diameter at breast height (DBH) and total stand height (TH), showing its high fertilizing potential, and, on the other hand, there was no increased contamination by nitrates and by pathogenic microorganism in the leachates for the experimental doses of slurry. Therefore, we can conclude that, under the experimental conditions, the slurry resulting from the intensive exploitation of cattle constitutes an alternative to exclusively mineral fertilization in intensive production forestry systems, either by increasing the production of biomass or by the absence of contamination of aquifers by nitrates and pathogens.

Keywords: bovine slurry, organic fertilization, paulownia, poplar, aquifers contamination

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Introduction

Intensive dairy cattle breeding has 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 intensive production forestry 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 environmental protection.

The uncontrolled deposition of high amounts of leachate in the soil increases the risk of contamination of surface and groundwater with nitrates. The excess of nitrogen (N) is also reflected in the release of high concentrations of volatile compounds with unpleasant odours, such as ammonia and other nitrogenous gases that contribute to the greenhouse effect.

These effluents have high levels of macronutrients, such as 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. In this way, the application of slurry can be a good alternative, or complement, to mineral fertilizers in agroforestry intensive systems.

On the other hand, the use of these compounds for enhancement of the productivity of biomass production systems might be a solution to reduce environmental impacts associated with the disposal of cattle effluents. Species like *Paulownia* sp. and *Populus* sp., are known as fast growing trees suitable for phytoremediation and for recovering polluted soils.[1,2] As stated by Evangelou et al.[3] "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, reduced erosion and increased biodiversity".

In a study, carried out by Madejón et al.[4] also working with Paulownia and Poplar, 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 biomass in marginal soils. In another study, carried out by Quaye et al.[5] the team was unable to obtain positive, and significant, results, attributing these results to the "nutrient status of the site or losses of applied nutrients". In the present study, the effect of increasing doses of slurry on fast-growing trees biomass production, either with or without mycorrhizal arbuscular fungi (AMF) and plant growth-promoting bacteria (PGPB) inoculation, was evaluated in clones of Paulownia and Poplar, as they are trees that have a high efficiency in the mobilization of soil nutrients (namely N) and in the capture of CO_2 from the atmosphere, as well as high biomass calorific value.

Materials and methods

For this purpose, a demonstration field trial was installed in Penafiel (North of Portugal), occupying an area of 14,607 m^2, 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 CoT2 (*Paulownia elongata* x *Paulownia fortunei*) and for Poplar i214 (*Populus deltoides* x *Populus nigra* [*Populus* x *euramericana* (Dode) Guinier]) clones.

The choice of tree species was based on the fact that they are species that have a high efficiency in the mobilization of nutrients from the soil (namely N), in the capture of carbon dioxide from the atmosphere (contributing to the fight against climate change) and whose biomass holds a high calorific value. On the other hand, the leaves of these species have a high forage potential and can be used as a source of nutrient-rich food for cattle. Therefore, these species, which generates biomass for energy purposes and as a source of food for livestock, will contribute to a better economic performance of dairy companies.

Prior to transplantation to the field 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, facilitating their transplantation and establishment in the field.

The experimental demonstration forest field was installed 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:

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

In order to monitor the nutritional and microbiological composition of the leachates, in the different treatments, a network of lysimeters was installed (Figure 1) at a depth of 2m. The cattle slurry used on the experiment was chemically analysed each year (2019 and 2020), for N, in order to estimate the amounts to be applied in each treatment, to respect the amounts choose to be tested, as well as for the main characteristics, considered in the EU legislation (Table 1), and the values determined were all within the limits allowed for its use in agricultural soils. Increasing rates of slurry were applied, for continuous bands (the blocks), maintaining blocks that were not submitted to the treatment (T0), in order to evaluate the effect of treatments on the various parameters under evaluation. Thus, 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 provide 170 kg of N ha^{-1}; T3 - quantity of slurry, in order to supply 340 kg of N ha^{-1}, both with and without inoculation.

Figure 1 Installation of lysimeter aboveground for leachate collection.

Table 1 Chemical characteristics analysed for the slurry used in 2019 and 2020, in the field experiment with *Paulownia* CoT2 (*Paulownia elongata* x *Paulownia fortunei*), and Poplar i214 (*Populus deltoides* x *Populus nigra* [*Populus* x *euramericana* (Dode) Guinier]), clones

Characteristic	Year		Method used for the determination
	2019	2020	
Moisture	97%	96%	EN 13040:2007
Dry matter	3.30%	4.00%	Calculation by weight difference
pH(H2O) (25°C)	7.7	7.2	EN 13037:2011
Electric conductivity (25°C)	17.5 mS/cm	16.6 mS/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 (P2O5)	0.07%	0.09%	EN 13650:2001
Total potassium (K2O)	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
Chlorid (Cl-)	0.20%	0.07%	PE-117-LQARS/ LAF (Ed. n° 1)
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

Slurry application was done three times throughout the year, in spring, in summer and in autumn. Within the blocks, in each treatment, there were selected and marked nine plots of trees for

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biometric evaluation. The trees were monitored from the point of view of biometric parameters, in 2019 and 2020, for Total Height (TH) and Diameter at Breast Height (DBH), in order to assess the increase in growth associated with slurry application rates. For that purpose, the measures taken each year were subtracted from the measures from the previous year, to evaluate the increments that resulted in each treatment. The experimental data were analyzed for variance by the General Linear Model (GLM) and means separation was performed using Tukey's Honestly Significant Difference (HSD) test at $p \leq 0.05$.

Results and discussion

Although treatments with and without inoculation of AMF+PGPB were included in the design of the experimental field, the fact is that the latter type of treatments was located in an area that proved to be particularly sensitive to waterlogging, significantly compromising the fidelity of the statistical results. The growth parameters of Paulownia trees (Table 2) were significantly affected by the treatments, in all the cases, except for DBH, in the mycorrhizal trees plot. Means in the same column with the same small letter do not differ significantly ($p \leq 0.05$), as judged by the Tukey test.

Table 2 Mean values for *Paulownia* growth increases, with respect to DBH and TH of trees, for each treatment of increasing rates of slurry, without and with the mycorrhizal arbuscular fungi and plant growth-promoting bacteria inoculation

Treatment	DBH (cm)	TH (m)
T0	1.79 bcd	1.47 bc
T1	2.79 a	2.47 a
T2	2.50 ab	1.83 ab
T3	2.23 abc	1.28 bc
T0 inoculated	1.14 cd	0.68 c
T1 inoculated	0.76 d	0.50 c
T2 inoculated	1.78 abcd	2.86 a
T3 inoculated	1.88 abcd	2.87 a

Considering the treatments without inoculation, there was a significant positive effect of the treatment either for DBH and TH, from the T0 to the T1. From then on, these parameters systematically decreased, albeit by a non-significant margin. This might be attributed to the higher amount of slurry used in the treatments T2 and T3, which could have been excessive. Considering the treatments with mycorrhizal, there was no significant effect in what concerns the DBH, but there was a significant increase of TH from T0 and T1 to T2 and T3.

When comparing the treatments with and without inoculation, the highest value for DBH was found in the treatments T1, and the lowest was found in the treatment T1 inoculated. The same behaviour was observed for the TH, although, in this case, the worst results were obtained in the treatment T0 inoculated and T1 inoculated.

These discrepancies can be justified by the fact that the blocks where the mycorrhizal plants were planted was subject to long lasting waterlogging, despite the installation of a draining network on the ground, before planting, since Paulownia trees are sensitive to excessive soil moisture. In fact, Berdón et al.[6] studying several clones of Paulownia, concluded that this species demands conditions of well drained soils, with good aeration, not clayey, and not flooded, although the trees need water during the growing period.

The growth of Poplar trees (Table 3), either for DBH, or for TH, was significant till the highest rate of slurry used, showing a continuous response to the increasing rates of the treatments, in both cases (without and with mycorrhizal). The regular behaviour, of the increase registered for the measures made, as a reflection of the treatments, is an indication of the adaptability of this species (a riparian species) to the conditions of the soil and to the organic compounds applied, confirming its high efficiency in the assimilation of N. Means in the same column with the same small letter do not differ significantly ($p \leq 0.05$), as judged by the Tukey test. When comparing the behaviour of both species (Figure 2), it is evident that the *Populus* is much well-adjusted to the prevalent edaphic conditions.

Table 3 Mean values for *Populus* growth increases, with respect to the DBH (cm) and the TH (m) of trees, for each treatment of increasing rates of slurry land use, and the mycorrhizal arbuscular fungi and plant growth-promoting bacteria inoculation

Treatment	DBH (cm)	TH (m)
T0	2.07 c	2.50 cd
T1	2.23 bc	2.46 d
T2	2.59 ab	2.70 bcd
T3	2.91 a	3.52 a
T0 inoculated	2.40 abc	2.82 bcd
T1 inoculated	2.22 bc	3.00 abc
T2 inoculated	2.41 abc	2.73 bcd
T3 inoculated	2.48 abc	3.10 ab

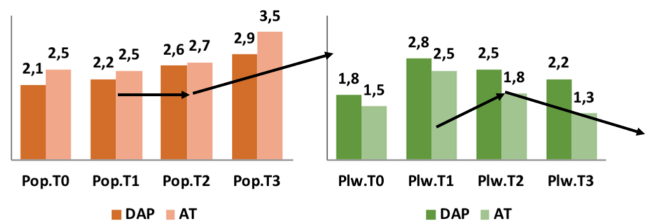

Figure 2 Average values of the increase, from 2019 to 2020, of DAP and TH, for Paulownia and Poplar (from Menino et al.[7]).

Also, Macci et al.[2] found lowest growth for *Paulownia*, when compared to *Populus*, suggesting that the "environmental conditions" were not adequate, or the best, for this last species, which complies with Berdón et al.[6] (*op. cit.*). With regard to the results verified for the leaching of nitrates, in the plots with slurry application, in any of the tested allocations, the values recorded were not higher than those verified for the plots without slurry application, standing in all situations below the limits referred to in the European directive for Nitrate Vulnerable Zones. Similar results were obtained for the total counts of coliforms and *Escherichia coli* in leachates, which were in all cases below the limits allowed in irrigation water.

Conclusion

The results revealed a significant and positive effect of the slurry application in both species, either in the diameter at breast height (DBH) or in total stand height (TH), showing its high fertilizing potential and, thus, providing an alternative to chemical fertilization. No less relevant is the fact that, for any of the slurry supplies tested, there was no contamination of nitrates and/or pathogens in the water collected in the lysimeters and, on the other hand, there was a high fixation of N in the soil. With regard to Poplar, the results are consistent with a high capacity to take advantage of the fertilizing potential of slurry, under current experimental conditions (riparian environment). This is evident in the graph of Figure 2, where the capacity to take advantage of the progressive endowments of slurry is evident. On the other hand, with regard to Paulownia - a species with antagonistic environmental requirements to those verified in the present experimental situation - the results verified here are not conclusive, given the specific hydraulic conditions to which it was submitted, which were far from adequate for its culture.

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Conflicts of interest

The author declares there is no conflict of interest.

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