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Manure derived biochar can successfully replace phosphate rock amendment in peatland restoration

Rémy Pouliot [a, *, 1], Sandrine Hugron [a, 1], Line Rochefort [a, 1], Stéphane Godbout [b], Joahnn H. Palacios [b], Elisabeth Groeneveld [a, 1], Isabelle Jarry [a, 1]

[a] Peatland Ecology Research Group (PERG) and Centre d'Études Nordiques, Université Laval, 2425 Rue de l'Agriculture, Quebec City, Québec, G1V 0A6, Canada

[b] Institut de Recherche et de développement en agroenvironnement (IRDA), 2700 Rue Einstein, Quebec City, Québec, G1P 3W8, Canada

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ABSTRACT

Phosphate rock fertilization is commonly used in peatland restoration to promote the growth of *Polytrichum strictum*, a nurse plant which aids the establishment of *Sphagnum* mosses. The present study tested whether 1) phosphorus fertilization facilitates the germination of *P. strictum* spores and 2) biochar derived from local pig manure can replace imported phosphate rock currently used in peatland restoration. Various doses of biochar were compared to phosphate rock to test its effect directly on *P. strictum* stem regeneration (in Petri dishes in a growth chamber) and in a simulation of peatland restoration with the moss layer transfer technique (in mesocoms in a greenhouse). Phosphorus fertilization promoted the germination of *P. strictum* spores as well as vegetative stem development. Biochar can effectively replace phosphate rock in peatland restoration giving a new waste management option for rural regions with phosphorus surpluses. As more available phosphorus was present in biochar, an addition of only 3–9 g m^{-2} of pig manure biochar is recommended during the peatland restoration process, which is less than the standard dose of phosphate rock (15 g m^{-2}).

1. Introduction

According to SER (2004), ecological restoration comprises all the processes which help the recovery of a degraded, damaged or destroyed ecosystem. Plants, especially *Sphagnum* mosses, poorly recolonize vacuum-milled peatlands without active human intervention, even many decades post-abandonment (Poulin et al., 2005), making peatland ecological restoration necessary. The main goal of peatland ecological restoration is to restore the long-term function of the carbon sink by promoting, as short-term goals: 1) the development of a moss carpet dominated by *Sphagnum*, which will allow the formation and the accumulation of peat and 2) the return of the diplothelmic hydrological layers (Graf et al., 2012; Rochefort, 2000; Sliva and Pfadenhauer, 1999; Vasander et al., 2003) which regulate the processes of decomposition and nutrient sequestration.

A restoration approach called the moss layer transfer method, developed in the 1990s, has successfully allowed the return of plant communities dominated by *Sphagnum* mosses in North American bogs (Poulin et al., 2012). This approach typically includes six steps: 1) site preparation to remove biological crusting and redistribute water, 2) harvesting of donor plant fragments, 3) spreading donor vegetation, 4) mulch application, 5) blocking drainage ditches and 6) phosphorus fertilization (Graf et al., 2012; Quinty and Rochefort, 2003; Rochefort and Lode, 2006).

The interest of phosphorus fertilization is to accelerate the establishment of *Polytrichum strictum* Brid., a pioneer species that can tolerate the harsh conditions found on bare peat surfaces. An important role played by *P. strictum* during the first 2–3 years post restoration is to reduce wind erosion and frost heaving, two important barriers to *Sphagnum* moss establishment (Groeneveld and Rochefort, 2005; Quinty and Rochefort, 2003). *P. strictum* stabilize the peat surface with its rhizoids and acts as a nurse plant by creating humid microclimates favorable to *Sphagnum* moss establishment on bare peat (Groeneveld et al., 2007). Once established, *Sphagnum* mosses eventually outcompete *P. strictum*, which gradually decreases in abundance (Rochefort et al., 2013). Depending on the circumstances, the growth of *Sphagnum* mosses can be enhanced by phosphorus fertilization (Aerts et al., 1992; Baker and

* Corresponding author.
E-mail address: remy.pouliot.1@ulaval.ca (R. Pouliot).
[1] http://www.gret-perg.ulaval.ca.

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Boatman, 1990; Li and Vitt, 1994; Limpens et al., 2004) or not (Ferland and Rochefort, 1997; Sottorcornola et al., 2007). However, until now it has not been possible to separate direct positive effects of fertilizer on *Sphagnum* moss growth from indirect positive effects via the promotion of nurse species such as *P. strictum* on restored peatlands.

The decision to fertilize or not depends on the balance between frost heaving risks (need for *P. strictum* as a nurse plant and soil stabilizer) versus the risk of invasion by non-peatland invasive species (Sottocornola et al., 2007). Where frost heaving risks outweigh those of invasion by undesirable species, a low dose of 15 g m^{-2} granular phosphate rock is recommended (Quinty and Rochefort, 2003). A higher dose would increase *P. strictum* cover (linear positive effect, Sottorcornola et al., 2007). However, a 30% *P. strictum* cover threshold should not be exceeded in restored peatlands because above this level it competes with *Sphagnum* moss rather than promoting its establishment (González et al., 2013). In addition, even if fertilization is known to increase growth of *Polytrichaceae* mosses after its establishment (Chapin and Chapin, 1980; Sottocornala et al., 2007), no studies indicate whether the phosphorus acts on spore germination or vegetative fragment regeneration for the specific bog species *P. strictum*.

Pig manure biochar could be an alternative fertilizer to phosphate rock during peatland restoration. Indeed, the content of available phosphorus in biochar is thought to be larger than in phosphate rock. However, no information is available to confirm this assumption. The biochar can be produced from several biomasses (wood, agricultural crop residues or animal manure) through a pyrolysis process. In this process, the biomass is heated at relatively high temperature (350 °C–750 °C) in an oxygen free environment, converting it into a carbonized solid fraction (biochar) and a gas fraction which subsequently can be partly converted by condensation into bio-oil (Bridgwater, 2003). Current applications of biochar include the amendment of agricultural soils for improving crops yield, the treatment of gaseous or liquid effluents, the use as bio-fuel and as a carbon sequestration material (Demirbas et al., 2006; Gaunt and Lehmann, 2008; Lehmann, 2007; McHenry, 2009; Navia and Crowley, 2010; Sun et al., 2014; Uzoma et al., 2011).

Two main advantages arise from the conversion of pig manure to biochar for use as fertilizer in peatland restoration. First, biochar produced from animal manure feedstock generally contains more phosphorus than biochar from lignocellulosic biomass (Ro et al., 2010). Therefore, less fertilizer is needed for an equivalent dose of phosphorus. Second, the conversion adds value to a by-product present in excess in some areas. Because of regulations limiting the amount of manure that can be spread, the supply of manure for use as fertilizer often exceeds demand in areas with a high concentration of swine production. Consequently, many farms are required to adopt new disposal practices. Converting the excess manure into biochar is a solution with environmental, technical and economic benefits for swine producers. Biochar is drier, lighter and more resistant to decomposition than the raw material from which it is derived, thereby facilitating the storage, management and long-range transport for use outside the animal production areas. However, the use of biochar as a fertilizer during peatland restoration has never been tested.

The first objective of the present study was to determine if the phosphorus acts on spores or fragments of *P. strictum* (in a growth chamber), the hypothesis being that it acts on both. The second objective was to test the effectiveness of biochar as a substitute for phosphate rock fertilization during peatland restoration. First, a preliminary study was carried out in order to estimate the available P in the biochar as compared to phosphorus rock. Second, two experiments were carried out to test the effects of biochar 1) on *P. strictum* in a growth chamber experiment and 2) on a small-scale peatland restoration experiment in a greenhouse. The hypothesis was that more available phosphorus would be present in biochar, and as a result, a lower dose could be used compared to phosphate rock to obtain the same effects on plants.

2. Material and methods

2.1. Germination of P. strictum spores

This experiment was conducted in Petri dishes and aimed to verify the effects of phosphorous fertilization on the germination of *P. strictum* spores. Six doses of phosphorus (phosphoric acid – H_3PO_4) were tested: 0, 0.14, 0.25, 1, 20 and 100 mg of P L^{-1}. The experiment was designed as a completely randomized design with five repetitions.

Capsules of *P. strictum* were collected in a peatland located in eastern Québec, Canada (47°49′N and 69°28′W). The spores of six capsules were mixed with 45 ml of water (for an approximate ratio of 367 000 spores/ml). Five drops (32 μl each) were placed in each Petri dish which had been filled beforehand with sterilized horticultural peat. Petri dishes were watered with a five-time diluted modified Rudolph solution (Campeau and Rochefort, 1996) to which was added the appropriate volume of H_3PO_4 to achieve the wanted concentrations of phosphorus. Petri dishes were then sealed with paraffin to minimize water loss. The treatment with 0.14 mg of P L^{-1} corresponded to the amount of phosphorus in the modified Rudolph solution. In the control without phosphorus, the stock solution normally used with KH_2PO_4 was changed for a solution with KOH to maintain the same amount of potassium. Petri dishes were placed in a growth chamber (photoperiod = 14 h) where the temperature was maintained at 25 °C during the day and 22 °C during the night. After 45 days of growth, the number of leafy gametophytes was recorded in each Petri dish.

2.2. Production of biochar from pig manure and evaluation of P availability for dose determination

The biochar used in this study was produced using a pyrolysis system with a feedstock consisting of the dried solid fraction of pig manure. The solid fraction came from a growing-finishing barn using an under slat separating system (perforated belt). This solid fraction was then dried with the SHOC[MD] process, a bio-dryer that dries and sanitizes organic sludges to create a final product that is free of pathogens and offensive odors. This product was then pyrolized at 500 °C for 1.5 h.

Chemical characteristics of the biochar obtained from pig manure and of the phosphate rock were analyzed at the Research and Development Institute for the Agri-Environment (IRDA) laboratory (Quebec City, QC, Canada) (Table 1). Despite the phosphate rock contained close to five times more of total P than in biochar, the major portion is unavailable to the plants. In opposite, biochar contains a higher proportion of available P (close to six times more) than in phosphate rock. The obtained concentrations were used in order to choice the fertilization doses for the following experiments.

2.3. P. strictum fragment regeneration in Petri dishes

This experiment was carried out in Petri dishes and aimed to test a wide range of biochar doses on *P. strictum* fragments. It was designed as a completely randomized experiment and included a control treatment without phosphorous fertilization, three doses of phosphate rock including the reference dose typically used in restoration and six doses of biochar. Based on the results of the preliminary P availability tests, the biochar doses contained