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Impacts of paper sludge and manure on soil and biomass production of willow

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ABSTRACT

Land application of organic wastes to short rotation woody crops (SRWC) can reduce the environmental impacts associated with waste disposal and enhance the productivity of biomass production systems. Understanding the potential impacts of organic amendments however, requires the examination of changes in soil characteristics and plant productivity. This study was conducted to evaluate the effect of paper sludge and dairy manure on biomass production of shrub willow (*Salix dasyclados* SV1) and to determine the impacts of these amendments on soil chemical properties. Treatments included urea, dairy manure and paper sludge separately and in combination, and a control. These materials were applied in the summer of 2005 to two fields of SV1 at different stages of growth: An old field with one year old shoots on a 10 year old root system and a young field which was beginning regrowth after being coppiced at the end of its first growing season. Foliar nutrient concentrations and soil chemical properties were analyzed at the end of the second growing season after treatment application to determine plant response to the fertilization regimes and to determine the effects of fertilization on soil characteristics. Fertilization did not increase biomass production in either field. However, application of the N-poor paper sludge did not reduce yield either. In general, fertilization did not influence soil or foliar chemistry, although there were some exceptions. The lack of response observed in this study is probably related to the nutrient status of the site or losses of applied nutrients.

1. Introduction

The production of short rotation woody crops (SRWC) is projected to be an important source of renewable energy in the coming decades [1,2]. Shrub willow (*Salix* spp.) is an ideal SRWC candidate because it is easy to propagate, has a short breeding cycle, can resprout after multiple harvests, and produces high yields within a few years. Average annual biomass yields in shrub willow biomass crops systems range from 10 to 15 dry Mg ha^{-1} [3–6], but biomass yields can be as high as 27–30 Mg ha^{-1} when crops are fertilized and irrigated [3,7–9]. Maintenance of site conditions over multiple rotations

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requires that nutrients removed in harvested woody biomass be replenished. According to Adegbidi et al. [3], an annual biomass production of 15–26 Mg ha^{-1} annually removes 75–100 kg ha^{-1} of nitrogen (N), 10–12 kg ha^{-1} of phosphorus (P), and 25–40 kg ha^{-1} of potassium (K) in the woody biomass. Kopp et al. [9] obtained an annual biomass yield of up to 16.3 Mg ha^{-1} with the annual application of 336 kg ha^{-1} of N, 112 kg ha^{-1} of P and 224 kg ha^{-1} of K, respectively. Hytonen [10] observed an increase in willow biomass production due to fertilization at annual rates of 100–200 kg ha^{-1} of N, 20–40 kg ha^{-1} of P and 100–200 kg ha^{-1} of K. These studies indicate that nutrient additions to willow production systems can influence biomass yields under certain conditions [11].

The cost of commercial fertilizer is an important component of the inputs needed for the production of willow biomass crops. An analysis of willow biomass crop production in New York State indicated that fertilizer can make up 10–20% of the cost of production over seven rotations [12]. Nitrogen fertilizer input into willow production systems in the US has been estimated to account for 37% of the non-renewable fossil energy input to these systems [13]. By relying on commercial N fertilizers, these systems indirectly require significant inputs of fossil energy and thus decrease both their potential environmental and economic benefits [2,12]. Replacing inorganic commercial fertilizers with organic wastes such as municipal biosolids, paper mill sludge, wastewater and animal manure can increase the farm gate net energy ratio of a willow biomass production system from 1:55 to 1:83 [13] and produce yields comparable to those attained with inorganic sources of N [5]. For example, the application of wastewater sludge to willow biomass crops led to significant increase in biomass productivity on treated plots and recycled residues [14]. In some cases, little or no yield response to fertilization has been reported in willow biomass crops and forestry experiments due to adequate site availability and internal cycling of acquired nutrients [15–17]. Nielsen [18] applied sewage sludge to willow plantations in amounts equivalent to 300 and 600 kg N ha^{-1} and reported that sludge application did not affect biomass production.

Due to increased public concerns about environmental issues and reluctance of farmers to use some organic waste streams for food crop production, SRWC systems have become attractive means for utilizing organic wastes because they direct heavy metals away from the human and animal food chain. The application of organic wastes to SRWCs can provide multiple benefits by making productive use of the waste material as well as providing needed plant nutrients. Organic amendments can also influence various qualities of soil, such as cation exchange capacity (CEC) [19] and improve soil physical properties such as organic matter content and bulk density and water holding capacity [20]. Organic amendments are less expensive and have a lower carbon footprint than commercial fertilizers, yet they have the same potential to supply SRWC systems with the necessary nutrients, particularly on marginal sites where nutrients may be limited. They also help to reduce production costs and to address problems associated with organic waste disposal.

A potential source of organic material for soil amendments is solid waste from the pulp and paper industry. About 85% of the 5.5 million Mg of paper mill sludge produced annually in the U.S. is a byproduct of primary clarification treatment [20–22]. This material consists of expanded fibers of pulverized wood, which is rich in lignin and unused cellulose but low in N and P [23,24]. Disposal of this material presents a problem for the pulp and paper mills. More than half of this primarily organic byproduct is disposed of in landfills or lagoons [25,26]. This method of waste disposal is costly and faces increasingly stringent environmental regulations [27,28]. The regulatory and economic climate favors the treatment of this material through land application to forestry and agricultural systems [29]. Using paper mill sludge as a soil amendment on farmland is an attractive alternative, because it allows for some cost recovery, improves soil properties and recycles some of the carbon into soil [30,31].

A major drawback to the use of paper sludge on SRWC is its low N content [32]. With large contributions of plant fibers, the elemental composition of paper sludge is relatively high in C (30–50%) and low in N (0.1–4%) [32–34]. This high C:N ratio could have detrimental effects on crops [24] by immobilizing soil N [35,36]. Application with a complementary high N organic waste material such as animal manure may relieve these deficiencies while maintaining the soil-building properties of organic residues from paper mill sludge [28]. Animal manure is commonly used as a soil amendment in agricultural systems. Manure has relatively high concentrations of N, typically around 5% of dry matter for dairy cattle and around 9% for swine manure [37], making it a good source of N.

In this study, we explored the use of two common organic wastes, pulp and paper mill sludge and dairy cattle manure, and a combination of the two as soil amendments in a willow biomass crop production system. The primary objective of this study was to compare the effects that sludge and manure applications have on biomass production, foliar nutrient concentrations and soil chemical properties with the effects of commercial fertilizer (urea) and untreated plots. It was hypothesized that: 1) The application of sludge and manure would increase plant growth and biomass production similar to that of commercial fertilizer relative to the control, and 2) sludge and manure treatments would increase CEC, organic matter and the concentration of nutrients in the soil and plant foliage.

2. Materials and methods

2.1. *Description of study sites and experimental design*

The effects of the application of pulp and paper mill sludge and cattle manure on plant growth, biomass production and soil chemical properties were assessed on a willow biomass production system at the State University of New York, College of Environmental Science and Forestry (SUNY ESF) Genetics Field Station in Tully, NY (42° 47′ N, 76° 07′ W). The soil at the site is a Glossoboric Hapludalf of Palmyra series [38]. The parent material is a gravelly sandy outwash derived from limestone, sandstone and shale. Topographically, the site is located on a glacial outwash terrace with a gentle slope of 0–3%. The soil is porous and is well to excessively well drained.

Six treatments were applied, consisting of four organic treatments, one commercial fertilizer (urea), and a control with no additions (Table 1). A target total N application rate of 100 kg ha^{-1} was used for all treatments except the high manure