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Poplar short rotation coppice is not a first choice crop for cattle slurry fertilization: Biomass yield and nitrogen-use efficiency

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ABSTRACT

Little is known about the effect of cattle slurry fertilization on poplar short rotation coppice (SRC). This study addresses the following research questions: (i) is the biomass productivity of poplar SRC responsive to slurry application? (ii) what is the efficiency with which poplar SRC utilizes the N applied in the form of cattle slurry? (iii) does the ratio of carbon (C) to N (C/N) in harvested dry matter vary with rates of N fertilization? Fertilization treatments were: (i) no fertilization (control); (ii) cattle slurry 10 mm, i.e. 10 L m^{-2} (CS10); (iii) cattle slurry 20 mm, i.e. 20 L m^{-2} (CS20); and (iv) industrial fertilizers, consisting in 120 kg N ha^{-1} in the form of urea and 120 kg P_2O_5 in the form of superphosphate (IF). The agronomic efficiency of applied N (AE_N) varied from 5 to 14 kg yield dry matter per kg N applied. The recovery efficiency of applied N (RE_N, kg N uptake per kg N applied) was merely 7.3–10.6%. The physiological efficiency of N uptake (PE_N) was 79–123 kg yield dry matter per kg N uptake. The threshold of 0.6% N, which is considered the guide value for high-quality biomass feedstock for combustion, was exceeded with the treatment CS20 in the first harvest cycle. Overall, our findings suggest that poplar SRC is not a first choice crop for cattle slurry application. In fact, N supply determined poor agronomic efficiency, a modest fraction of the N applied was recovered by the crop, and the rise of N concentration in the harvested biomass was detrimental for the quality of the feedstock product for combustion.

1. Introduction

In the Region Emilia-Romagna, Northern Italy, the management of livestock effluents is a critical issue. This is due to the presence of 1.5 million pigs and 620,000 cows, producing about 10 million Mg of liquid slurries and 5 million Mg of solid manure (Bonazzi, 2009). In the view of reducing the use of the energy-intensive industrial fertilizers, the huge amounts of plant nutrients contained in these effluents can be regarded as a valuable resource. Liquid manure is a complex organic fertilizer, because it supplies, along with nitrogen (N), phosphorus (P), potassium (K) and microelements. However, its rate of application is normally determined on the basis of its N content because this element has major influence of crop yield. A crop suited to receive manure should possess high nitrogen-use efficiency (NUE) in order to reduce N losses and related environmental concerns (Connor et al., 2011). NUE is a complex, comprehensive efficiency that can be thoroughly evaluated by considering the contributions from indigenous soil N supply, the fraction of N applied that is taken up by the crop plant, and the efficiency with which N uptake is converted into crop dry matter production (Cassman et al., 2003).

Because livestock manure is predominantly applied to maize (*Zea mays* L.), there is the need to identify alternative crops, well suited for receiving slurry applications, in areas unsuited to maize cultivation. Poplar (*Populus* ssp.) is a well adapted, widely grown crop in Northern Italy (Spinelli et al., 2011). A recent report of the International Poplar Commission (FAO, 2012) indicates that planted poplars occupy 101,400 ha in Italy, of which 65,900 ha are dedicated to industrial roundwood, 6,100 ha to fuelwood biomass, and 29,400 to environmental protection. In addition, 42,200 ha of indigenous poplar forests are also present in the country, hence the total poplar area in Italy amounts to 143,600 ha.

Short rotation coppice (SRC) of poplar is a well-suited energy crop for Northern Italy. Beside to the high quality of the feedstock product for combustion, poplar can provide valuable environmental services, in particular soil carbon sequestration (Ceotto and Di Candilo, 2011; FAO, 2012; Zenone et al., 2007). Little is known about the effect of cattle slurry fertilization on poplar SRC. Therefore, a

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Table 1
Main chemical and physical characteristics of the soil.

Characteristic		Soil layer	
		0–0.2 m	0.2–0.4 m
Sand (2.0–0.05 mm)	(g kg^{-1})	298	260
Silt (0.05–0.002 mm)	(g kg^{-1})	402	425
Clay (<0.002 mm)	(g kg^{-1})	300	315
pH in water		7.91	7.90
$CaCO_3$ active	(g kg^{-1})	3.25	3.87
$CaCO_3$ total	(g kg^{-1})	20.0	21.0
Walkley and Black SOM	(g kg^{-1})	22.4	17.3
Kjeldahl N	(g kg^{-1})	1.11	0.90
Olsen P	(mg kg^{-1})	26.7	16.8
Exchangeable K	(mg kg^{-1})	460	314

field experiment was devised to address the following research questions:

i) is the biomass productivity of poplar SRC responsive to slurry application?
ii) what is the efficiency with which poplar SRC utilizes the N applied in the form of cattle slurry?
iii) does the ratio of carbon (C) to N (C/N) in harvested dry matter vary with rates of N fertilization?

To answer these questions a field experiment on hybrid poplar (*Populus x canadensis* Moench) SRC was carried out for four years. This experiment belongs to a trilogy of field trials in which the same rates of cattle slurry were applied, in the same location and years, to three energy crops: the herbaceous annual sweet sorghum (*Sorghum bicolor* L. Moench) (Ceotto et al., 2014), the herbaceous perennial giant reed (*Arundo donax* L.) (Ceotto et al., 2015), and the woody perennial poplar SRC. These three energy crops can be cultivated in rainfed condition in Northern Italy, thus they might replace maize when irrigation water is unavailable or too expensive.

2. Materials and methods

2.1. Site characterization and agronomic details

The experimental site is located in Anzola dell'Emilia (Bologna), in the alluvial plain of Po Valley, Northern Italy (Lat. 44° 32′ N, Long. 11° 11′ E, 38 m a.s.l.). The soil of the site is a silt loam, classified as Udifluventic Haplustepts fine silty, mixed mesic (Soil Survey Staff, 2003). Main soil characteristics are reported in Table 1. The climate is temperate sub-continental, owing to the relatively long distance from the sea of about 200 km. The average long-term annual rainfall for the location is about 740 mm.

The fertilization experiment was carried out during four years, from 2008 to 2011, on a poplar (*P. x canadensis*, Moench, clone I-214) plantation established in 2002. The clone I-214 was selected for its high productivity and widespread diffusion, 77% of total planted poplar in Italy (FAO, 2012).

The preceding crop was winter wheat. After the wheat harvest, the soil was ploughed at 0.30 m depth during the summer and subsequently refined with a rotary harrow during the winter to prepare a favourable soil bed conditions for poplar establishment.

The poplar plantation was managed as SRC with a harvest cycle of two years. The poplar clone was propagated using stem cuttings of 200 mm length and 15–22 mm of diameter. The planting density was 0.93 plants per square meter, resulting from rows distance of 1.8 m, and plant distance within row of 0.6 m. After transplantation the crop was fertilized with 120 kg N ha^{-1} in the form of urea and 52 kg P ha^{-1} in the form of superphosphate.

Aiming to facilitate crop establishment, the experiment was irrigated three times during the year 2002, applying a water volume of 40 mm per irrigation. In the successive years the poplar plantation was not irrigated, as it is usually managed in the Region. During the first growing season weeds were controlled mechanically. Pest populations of the leaf beetle *Chrisomela populi* L. were controlled every summer with the pyrethroid insecticide Bifenthrin (2 L ha^{-1}).

Prior to the beginning of the fertilization experiment, the poplar plantation was harvested in December 2003 (end of the growing seasons 2002–2003), February 2006 (end of growing seasons 2004–2005) and February 2008 (end of the growing seasons 2006–2007). Immediately after the first and second harvest, December 2003 and February 2006 respectively, crop was fertilized with 120 kg N ha^{-1} in the form of urea and 52 kg P ha^{-1} in the form of superphosphate.

Fertilization treatments, applied annually in the period from 2008 to 2011 (four years), i.e. from the seventh to the tenth year of crop stand, were: (i) no fertilization (control); (ii) cattle slurry 10 mm, i.e. 10 L m^{-2} (CS10); (iii) cattle slurry 20 mm, i.e. 20 L m^{-2} (CS20); and iv) industrial fertilizers, consisting in 120 kg N ha^{-1} in the form of urea and 52 kg P ha^{-1} in the form of superphosphate (IF). The plots of the unfertilized control have received no fertilization since February 2006, two years prior to the application of treatments, hence remained without fertilization for a time span of 6 years.

With the treatment IF, P was applied along with N to compensate the possible advantage of P applied with cattle slurry. Mineral K fertilization was disregarded because the soil of the site is high in exchangeable K (Table 1). Lanyon and Smith (1985) indicated that K supply is not worthwhile when K concentration in the arable soil is greater than 150 mg K kg^{-1}.

Cattle slurry and industrial fertilizers were applied on soil surface without any previous tillage. In the area of the Po Valley, animal slurries are normally applied on soil surface and there is no legal obligation to inject them into the soil. However, injection of animal slurry into the soil would be hardly possible in case of poplar, owing to the presence of belowground biomass (i.e. stumps and roots). The cattle slurry was collected from an open-air lagoon and transported to the field with a slurry tank. During field distribution, operated manually, the slurry has been maintained in agitation in the tank to assure uniformity of composition, and sampled to determine N, P and K content. The sample was collected during distribution on the plots, stored in a plastic container and analyzed in the same day. Standard analytical methods for the determination of nutrients content of manure were used in agreement with Cottenie (1979). Cattle slurry treatments were applied on 28 May 2008, 25 June 2009, 25 June 2010 and 27 June 2011. While the volume of applied slurry with CS10 and CS20 were kept constant across years, the composition of slurry varied determining different rates of N and P application between years. The amounts of N and P applied annually, and accumulated for each harvest cycle, with the individual treatments are indicated in Table 2.

The total area of the poplar plantation is about 3000 m^2. The experimental plots were established in the inner part of the poplar plantation with the purpose of avoiding edge effects. The individual plot consisted in three rows (i.e. 3 × 1.8 m = 5.4 m width) and 6 m length, including 10 plants, hence 5.4 × 6 = 32.4 m^2. At the end of the 6 m length of the plot, three plants were eliminated in each row to create a corridor of 1.8 m between plots. The three rows of each plot were separated by one row (1.8 m width) to attenuate the interference of fertilization treatment between plots. The experimental design was a randomized block with three replications.

2.2. Crop measurement

During the experiment the crop was harvested twice: in March 2010 (first harvest cycle, growing seasons 2008–2009) and in March 2012 (second harvest cycle, growing seasons 2010–2011). The