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Research Paper

Potential biogas and methane yield of maize stover fractions and evaluation of some possible stover harvest chains

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With a yearly global production of about 75 million tonnes of dry matter (DM), maize stover remains a major untapped agricultural resource. While its use as a feedstock for biogas production has been well studied, the methane potential of separate single stover fraction begs further analysis. This study evaluated the composition of maize cobs, husks, leaves, and stalks and the potential of those components to produce biogas and methane. These analyses allowed an estimate of the preferred maize stover harvest chain conditions for quantity and quality. Methane yields from the fractions ranged between 206.6 and 307.0 l_N kg^{-1} VS, with husks being the most productive. In total, our estimates suggest that these fractions produce about 3000 m^3 ha^{-1} of methane from the biogas conveniently collected by different harvest chains.

1. Introduction

Global maize production has increased by more than 40% in the past ten years, reaching 863 Mt (USDA, 2013a) in 2013. In Europe alone, 2013 maize production totalled 64.6 Mt, with an increase of 10% from 2012 (USDA, 2013a). The most recent forecast from the USDA indicates that 2014 European maize production will increase beyond that of 2013 (USDA, 2014). These elements indicate that grain maize production will probably continue to increase in the coming years and maize residues production as well. The management of this huge amount of biomass and its environmentally friendly use has to be taken into account.

The maize is harvested by combines, which separate kernels from the rest of the plant and collect grains in the tank. In good harvesting conditions, stalks and leaves are left directly on the ground below the head, while ears and a small amount

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of stalks and leaves above ear insertion enter the threshing and cleaning system for grain separation. After grain separation, cobs, husks, stalks and leaves, broken and partially chopped, are discharged to the ground from the straw walker and sieves, forming a windrow just behind the combine rear wheels (Gramig, Reeling, Cibin, & Chaubey, 2013). Cobs, husks, leaves and stalks, commonly called stover, are important residues of maize processing.

Stover harvest takes place in a second pass by a shredder, which can allow collection of up to 70–80% of the material left on the ground, depending on operating conditions (Sokhansanj, Turhollow, Cushman, & Cundiff, 2002). The shredder has to be kept at a proper distance from the ground, to reduce the stover losses and, at the same time, to avoid soil particle collection. The collected stover can be baled in round or square bales or ensiled, depending on the intended use.

Several studies have indicated that the heterogeneous composition of maize biomass impacts enzymatic hydrolysis and degradability (Bootsma & Shanks, 2005; Duguid et al., 2009; Li, Xu, Liu, Fang, & Wang, 2014; Mourtzinis et al., 2014;). Most authors agree that maize grains represent 50–53% of the plant (dry weight basis), depending on agricultural practices and climate conditions. A similar consensus exists in the stover composition literature. Sokhansanj, Mani, Tagore, and Turhollow (2010) reported that for every 1 kg of dry maize grains, about 0.15 kg of cobs, 0.22 kg of leaves, 0.14 kg of husks, and 0.50 kg of stalks are produced. Zych (2008) two years earlier found similar values, with a slightly higher percentage of cobs and leaves and a lower percentage of husks and stalks. Actually, these residues have several applications. Maize cobs are used as building materials and for activated carbon (Cao, Xie, Lv, & Bao, 2006; Pinto et al., 2012), leaves serve as a source of fermentable sugars and fibre for paper (Shinners & Binversie, 2007), and stalks, leaves, and husks are transformed into bio-fertilizers or livestock litter (Chen et al., 2010). Although these residues are part of some productive processes, a mere 6% of the total is usually collected and removed from the field (Sokhansanj et al., 2002). It is more common practice to leave stover on the ground surface to be buried into the soil where it becomes a source of organic matter (OM) and nutrients for the following crops. It has been estimated that worldwide approximately 204 Mt of dry matter (DM) is returned to the ground each year through maize residues (Sorensen et al., 2009). Clearly, crop residues play an important role in protecting and improving soil quality. At the same time, the negative soil quality effects of residue removal and crop productivity have been significant topics in long-term research (Mann, Tolbert, & Cushman, 2002), while in the last few years, maize residues removal for energy production has become a major subject of interest (Monforti, Bódis, Scarlat, & Dallemand, 2013; Zhang, Ghaly, & Li, 2012; Zych, 2008).

Taken in aggregate, the literature indicates that stover collection systems must be designed with the goal of optimising biomass production and maintaining crop residues for soil sustainability. To do so, requires removing the maize stover portion with the highest fermentable sugar content. Harvest chains capable of collecting single maize fractions are in common use for cobs and the lower stalk. In the case of the other fractions, prototypes are being studied for a variety of purposes, as well as for energy production.

The main uses for maize residues in energy are ethanol production (Lamsal, Wang, & Johnson, 2011) and thermochemical conversion, such as gasification and pyrolysis (Ioannidou et al., 2009; Kumar, Wang, Dzenis, Jones, & Hanna, 2008). In the monthly WASDE report released on November 8 2013, the USDA World Agricultural Outlook Board estimated that 118 Mt of maize were used to produce ethanol and co-products of ethanol during the 2012–13 marketing year (USDA, 2013b). Recently, the interest in biogas production from maize stover has also increased. As reported in several papers (Li, Zhu, Wan, & Park, 2011; Yuan et al., 2011; Zhang et al., 2012), maize residues have the potential to be used as alternative feedstocks in anaerobic digestion (AD) plants for biogas production.

Anaerobic digestion (AD) is a clean technology that allows biogas production through organic matter degradation; the biogas produced can then feed a co-generator of combined heat and power (CHP) to obtain electrical and thermal energy. In contrast to other kinds of renewable energies, when crop residues are used to produce biogas, the organic matter (OM) removed by the field is returned to the soil at the end of the process through digestate application, thus avoiding the risk of soil OM depletion. Although some researches have been published on the use of maize stover in biogas plants, detailed data on biogas and methane production from maize stover fractions remains scarce. Detailed information on the relative energy value of maize fractions might prove useful to balance OM soil removal with the use of the residues as feedstocks for energy production. Furthermore, such data might inform approaches to new harvesting machinery prototypes.

This research aimed to analyse potential biogas and methane yields of maize stover fractions to identify the most efficient producer among them and inform the development of harvesting systems designed for energy production. In addition, we estimated the amount of maize residue collected using three different harvest chains. This allowed us to estimate the energetic value of maize residue fractions in m^3 of methane and electric energy from a surface of 4.5 ha.

2. Materials and methods

2.1. *Maize stover fractions collection*

Different maize residues (FAO class 600) were collected after the grain harvest at a farm close to Novara, Piemonte, Northwest Italy. Cob, husk, stalk, and leaf residues were separately collected after grain harvest. The residues were subsequently dried and chopped with an electric shredder to a particle size of 15–20 mm, and then stored under vacuum until the AD batch trials started. A grain sample from the same field was also collected to allow comparison of the known highest methane-yielding fraction of the maize plant with the methane yields of the other stover fractions. The maize grains were not manipulated for the biogas production trials.

Liquid separated solid fraction of digestate was collected in an agricultural biogas plant (fed with animal manure and maize silage) and used as inoculum for the AD batch trials.