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Opportunities and barriers to on-farm composting and compost application: A case study from northwestern Europe

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ABSTRACT

Maintaining and increasing soil quality and fertility in a sustainable way is an important challenge for modern agriculture. The burgeoning bioeconomy is likely to put further pressure on soil resources unless they are managed carefully. Compost has the potential to be an effective soil improver because of its multiple beneficial effects on soil quality. Additionally, it fits within the bioeconomy vision because it can valorize biomass from prior biomass processing or valorize biomass unsuitable for other processes. However, compost is rarely used in intensive agriculture, especially in regions with high manure surpluses. The aim of this research is to identify the barriers to on-farm composting and the application of compost in agriculture, using a mixed method approach for the case of Flanders. The significance of the 28 identified barriers is analyzed and they are categorized as market and financial, policy and institutional, scientific and technological and informational and behavioral barriers. More specifically, the shortage of woody biomass, strict regulation, considerable financial and time investment, and lack of experience and knowledge are hindering on-farm composting. The complex regulation, manure surplus, variable availability and transport of compost, and variable compost quality and composition are barriers to apply compost. In conclusion, five recommendations are suggested that could alleviate certain hindering factors and thus increase attractiveness of compost use in agriculture.

1. Introduction

Input-intensive agricultural practices such as the use of mineral fertilizers, frequent soil tillage, narrow crop rotations, and past shifts in land use (Sleutel et al., 2003, 2006) have led to decreased soil organic carbon (SOC) stocks, biodiversity loss, soil erosion, and pollution of groundwater and air (Kirschenmann, 2010). One of the most important characteristics of soil fertility is sufficient SOC (Aggelides and Londra, 2000; Stamatiadis et al., 1999; Turner et al., 1994; Zebarth et al., 1999), while the SOC content of many croplands in temperate regions is declining (European Commission, 2006; Maes et al., 2012; Sleutel et al., 2003; Van-Camp et al., 2004). Improving and maintaining soil quality and fertility in a sustainable way is thus an important challenge for modern agriculture. Moreover, policymakers (e.g. European Commission, 2012; The White House, 2012) are encouraging rapid development of the bioeconomy, which relies on renewable biomass instead of finite fossil inputs for the production of value-added products such as food, feed, biobased products and bioenergy (OECD, 2013). As a consequence, this development will require a high soil fertility and increases the need for sustainable soil improvers, since fertile soils are the prerequisite to reliably produce the necessary biomass as feedstock for food and biobased products (Meyer-Kohlstock et al., 2013).

Compost application has well-established beneficial impacts on soil quality, soil fertility and the environment. Despite knowledge of these benefits, compost application and compost production on the farm (referred to below as *on-farm composting*) is not a common practice in Flanders (the northern region of Belgium), a region characterized by large manure surpluses. We have evaluated the current challenges regarding on-farm composting and compost application in Flemish agriculture in the context of sustainable soil management. In this paper we (1) critically review the potential

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strengths of compost application, and (2) describe the current compost production and use in Flanders. Next, (3) we analyze the barriers to on-farm composting and compost application, and based on this analysis (4) we formulate a number of preliminary recommendations to alleviate certain barriers. A mixed method approach was used to analyze the case of Flanders, which can be exemplary to other northwestern European regions, in particular Denmark, The Netherlands, North-West Germany, the North-West of France, the Po-valley in Italy and parts of England, which have a similar climate and intensity of agriculture (Sleutel et al., 2007), and the same problems with water quality (Velthof et al., 2014).

2. Review of the characteristics and potential strengths of compost application

To sustainably increase SOC, farmers should change their soil management practices that often rely heavily on the application of mineral fertilizers and intensive soil tillage. Alternative management strategies for increasing or maintaining SOC can include alterations in crop rotation, rotation with temporary grassland, reduced soil tillage, use of (leguminous) green manure crops (cover crops) or the use of organic fertilizers. Examples of such organic fertilizers are farmyard manure, slurry, cut-and-carry fertilizers, digestate and compost. This study analyses on-farm compost use and production because compost has a number of extra benefits compared to other fertilizers and soil improving agents. However, compost application can also be associated with a number of drawbacks such as the risk for greenhouse gas emissions during production (Hao et al., 2001). Furthermore, the benefits and drawbacks might be influenced by climate, soil type, crop succession, feedstock mixture, compost dose, etc. Moreover, the benefits and drawbacks are depending on whether compost replaces other fertilizers or compost is used in addition to fresh manure, organic or mineral fertilizers. It was beyond the scope of this paper to give an extensive overview of all advantages and drawbacks, taking into account all variables and contextual factors for all types of compost application. To compare the benefits and drawbacks of compost with other alternatives, an inclusive study must be conducted taking into account all relevant parameters. However, it is difficult to translate all the aspects of compost production, storage, transport and spreading into economic and particularly ecological values. For instance, cycle closure, carbon sequestration and the related positive effects on the emission of greenhouse gases, water holding capacity or improvement of soil structure are difficult to take into account in assessment methods such as Life Cycle Assessment (LCA) (Obersteiner and Linzner, 2007).

Composting is a biological process where microorganisms convert organic products into a stable and humus-rich product under controlled conditions, i.e., optimal conditions of moisture and oxygen to facilitate the decomposition process (Bokhorst and ter Berg, 2001; Willekens and Cloet, 2003). Unlike fast-release fertilizers such as mineral fertilizers and slurry, compost contains **large amounts of organic matter**, which enhances the SOC content (Vanden Nest et al., 2014). During three long-term field experiments in Flanders, a significantly higher SOC content was observed when farm compost (made from farmyard residues) (D'Hose et al., 2014; Willekens et al., 2014) and VFG compost (made from vegetable, fruit and garden waste) (Tits et al., 2014) was applied. When mineral fertilizer was applied in a parallel treatment, SOC content decreased. Compost application also improves soil physical properties such as available water content (Curtis and Claassen, 2009; Weber et al., 2007) and aggregate stability (Annabi et al., 2007), which in turn protects the soil against erosion (Diacono and Montemurro, 2010). The organic carbon in compost is more **stable** and resistant to decomposition than in fresh manure or plant residues, where a larger share of the carbon decomposes after application. Compared to an equal amount of farmyard manure applied, twice as much of the applied carbon is retained in the soil when using composted farmyard manure, not taking into account the carbon losses during the composting process (Powlson et al., 2012). In addition to maintaining and improving SOC, compost is also a **source of nutrients**, which reduces the need for other fertilizers. This reduces both the cost of purchasing non-organic fertilizers and can reduce the environmental impact associated with fertilizer production and use. For instance, both D'Hose et al. (2014) and Willekens et al. (2014) observed enhanced plant available potassium contents in soil after repeated compost application. Nevens and Reheul (2003) found that silage maize needed 0–43 kg less mineral fertilizer ha^{-1} on plots with compost application (22.5 Mg ha^{-1}) compared with the plots only receiving mineral fertilizer. One point of consideration is European legislation that limits the supply of nitrogen and phosphorus with the aim of preventing nutrient leaching to ground and surface water. In addition to intercropping systems and soil cover as potential means to limit nutrient leaching, a balance must be found between the supply of nutrients from carbon-rich soil improving fertilizers (for improving soil fertility), and the nutrients supplied from fast-acting fertilizers (for plant nutrition). By adding large amounts of carbon-rich materials (e.g. straw, wood chips) in the composting process, the end product enables adding a significant amount of carbon without adding large amounts of phosphorus and nitrogen. As such, the risk for nutrient leaching is lower than for composts or other organic amendments with a lower carbon-to-nitrogen or carbon-to-phosphorus ratio (Vandecasteele et al., 2014). The nutrients in compost are **released gradually** because they are already fixed in the microbial biomass (Sullivan et al., 1998), unlike the quick release from slurry, farmyard manure and nitrogen-rich crop residues. Compost application therefore helps to prevent nutrient leaching to groundwater (Grey and Henry, 1999; Li et al., 1997) and contributes to soil fertility in the long term. For example, recent research showed that long term amendments of plant-based compost did not increase phosphorus leaching as compared to amendments of dairy farmyard manure (Vanden Nest et al., 2015). Additionally, repeated compost amendments can enhance the **biological diversity** of the soil (D'Hose et al., 2014; Steel et al., 2012) and can decrease the amount and relative abundance of plant-parasitic nematodes (D'Hose et al., 2014). This might reduce the risk of plant diseases and thus the use of pesticides and herbicides. For example, after three years of compost application, the total microbial biomass increased by 27% (Willekens et al., 2014). Moreover, pathogens and weed seeds in the feedstock mixture are suppressed by high temperatures, microbial antagonism and/or competition for nutrients, toxicity from byproducts of organic matter decomposition (e.g., ammonia, sulfides, organic acids, and phenolic compounds), and enzymatic breakdown during the composting process (Wichuk et al., 2011), in contrast to amending the soil through direct application of farmyard residues. Furthermore, a significant **reduction in volume and moisture content** is observed when composting agricultural byproducts (Bernal et al., 2009; Breitenbeck and Schellinger, 2004). This can lead to ecological and economic advantages such as more efficient transport and storage compared to the initial biomass feedstock. The more homogenous and fragmented structure furthermore results in easier spreading compared to other organic fertilizers (e.g. non-composted farmyard manure).

Besides the advantages of compost application on soil quality, compost can play an important role in the **bioeconomy** because its production does not rely on finite inputs. Compost can be produced locally on the farm, and can use biomass that is unusable in