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Subsoil application of compost improved sugarcane yield through enhanced supply and cycling of soil labile organic carbon and nitrogen in an acidic soil at tropical Australia

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ABSTRACT

Organic amendments are mostly carried out on the soil surface layer to mitigate the decline in sugarcane soil health, however, the effects of subsoil application of composts on soil carbon (C) and nutrient dynamics and sugarcane yield are largely unknown. A 4 years field trial was conducted at Maryborough, Australia, to investigate the effects of subsoil application of compost on soil C and N cycling, associated biological processes and sugarcane productivity. The trial included four subsoil (ca. 25 cm) amendment treatments of control (CK, without amendment); gypsum (GP); compost (CP); and mineral fertilizer (FE). Overall, the compost treatment increased concentrations of soil NH_4^+-N by 30% and NO_3^--N by 40% at subsoil (10–25 cm) amendment layer. Soil microbial biomass C and N at the 0–10 cm depth were also significantly higher in the compost treatment than the other treatments. The CO_2 respiration in the compost and fertilizer treatments, were significantly higher than in the control and gypsum treatments at the subsoil amendment depth. The compost treatment had greater β–glucosidase activities than other treatments at the 10–25 cm soil depth. In addition, subsoil application of compost increased inputs of hot water extractable organic C (HWEOC) by 30% and N (HWETN) by 70% at the application depth, but did not affect total soil C and N contents. The HWEOC and HWETN pools were positively related to the cumulative sugarcane yield during the 4 years cropping cycle. The subsoil application of compost increased the supply of organic C and N for microbial community, enhanced nutrient cycling processes, improved soil environmental conditions and soil health for sugarcane growth and thus increased sugarcane productivity.

1. Introduction

Sugarcane is one of the most important commercial plants, and considered as a main source of sugar production worldwide. Sugarcane cultivation in Australia is concentrated along the east coast of Queensland (Renouf et al., 2010). Many sugarcane-growing regions in Australia have suffered from yield decline in the past decades. A long-term study by Garside et al. (2005) have shown that long-term monoculture, soil structural decline through compaction and excessive tillage, and the depletion of soil organic matter are the main contributors to the sugarcane yield decline. To address the declining soil health of sugarcane soils, organic soil ameliorants including compost (Jindo et al., 2016; Min et al., 2003) and mill mud (the residual mud and fiber removed from the raw juice stream by clarification and rotary vacuum filters; Qureshi et al., 2002) are increasingly used by farmers to improve soil organic matter content. Organic amendments may also increase soil nutrient (e.g. nitrogen (N)) availability for plant growth (Rezaei Rashti et al., 2017). Ryals et al. (2016) indicated that grassland amendment with composted green waste increased plant production without changing plant communities. Further, they suggested that green waste compost amendment would support sunflower growth even in copper contaminated sandy loam soil. In addition, Kumar et al. (2010) have shown that composted sugarcane residue is useful for sustaining high crop yield and reducing soil nutrient depletion.

The application of compost has been considered as an efficient way to improve soil physical, chemical and biological properties (Cassman et al., 1996; Fernandez-Hernandez et al., 2014; Medina et al., 2015). Calcino et al. (2009) reported that Bedminster compost increased

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sugarcane yield as well as soil N, calcium (Ca), magnesium (Mg), potassium (K) and copper (Cu) levels. Stoffella and Graetz (2000) also indicated that compost with sugarcane filter cake (the residue of the filtration of sugarcane juice) would enrich soil humic content and macro- and micro-nutrients such as N, P, K and Ca. In addition, Hernandez et al. (2014) suggested that the application of compost incorporating cow manure, alperujo and olive prunings would increase both crop yield and soil fertility. The scientific knowledge regarding the impact of compost on soil chemical, physical and biological properties as well as soil health in Australian sugarcane fields remain essentially unstudied. The potential impacts are likely to vary according to soil types, climatic conditions and the composition and properties of the compost (Goyal et al., 2005).

Most of sugarcane soils in northern Queensland are impacted by acidity and Al^{3+} toxicity (Hamza and Anderson, 2003). This can be addressed through gypsum or lime application. Rossato et al. (2017) has suggested that soil structure can be improved with surface application of gypsum, while, gypsum application may also cause K^+ and Mg^{2+} leaching to deeper soil profile. To avoid the disadvantages of surface soil amendments, such as NH_4^+, K^+ and Mg^{2+} leaching, subsoil gypsum amendments became an alternative field management practice. Deep ripping has been considered a common way to deliver organic amendments to the subsoil (Chen et al., 2014). However, little work has been done on the impacts of subsoil application of composts on long-term soil fertility and sugarcane crop yield. It has been suggested that amending subsoils would increase plant nutrient use efficiency and yields as plant roots can have a better access to the nutrients applied in the subsoil (Hall et al., 2010; Li et al., 2015). Moreover, gypsum subsoil application may increase the concentration of Ca^{2+} in the root zone without leaching K^+ and Mg^{2+} from top soil.

Soil health decline has become one of the main concerns to farmers in the recent years, since it affects soil productivity and long-term sustainability. The key indicators of a healthy soil can include microbial biomass C and N, microbial activity and the ratio of bacteria and fungi in microbial communities in addition to other physical (e.g. soil structure) and chemical (e.g. soil pH and nutrient availability) indicators (Schloter et al., 2003). It has also been reported that the soil microbial community plays a vital role in soil C and nutrient cycling (Estrada-Bonilla et al., 2017). Microbial activity has been suggested to be an important indicator of the impact of field management practices on soil health (Van Bruggen and Semenov, 2000). Compost application can increase soil C and nutrient transformation by providing substrate for microbial utilization (Fauci and Dick, 1994). This study aimed to investigate the longer-term impacts of subsoil compost application in comparison with mineral fertilizer and gypsum on the chemical and biological properties of sugarcane soil. The underlying hypothesis was that subsoil application of compost to sugarcane cropping system would increase the supply of soil labile organic matter, thereby increase microbial activity and nutrient (e.g. N) cycling processes and improve sugarcane yield.

2. Materials and methods

2.1. Site description

The experimental site was located in the Yerra (25° 33′ 44″ S, 152° 33′ 24″ E), 17 km southwest of Maryborough, Queensland, Australia with yearly mean rainfall of 1138.0 mm and mean temperature of 21.2 °C. The area is classified as Brown Dermosol according to Australian Soil Classification (Isbell, 2016). The corresponding soil type in USDA classification is Ultisol (Soil Survey Staff, 2014). The structure of the subsoil limits water permeability and plant growth. It may also provide a toxic environment for sugarcane roots due to the high levels of acidity and Al. Prior to the experimental setup; a Mungbean (*Vigna radiate*) crop was grown on the site for one season and harvested in April 2012. The harvested Mungbean stubble was applied to soil as mulch and retained on the soil surface until the site was cultivated for sugarcane planting in July 2012. Soil A-horizon (0–15 cm soil depth) had a sandy clay texture and the clay content was 28%. It has contained 75 mg kg^{-1} available P and 1.3% organic carbon with a pH of 6.1 and EC of 0.5 dS m^{-1}. Soil B-horizon (15–30 cm soil depth) had a sandy clay texture and the clay content was 33%. The pH value in B-horizon was 4.8 and EC was 1.8 dS m^{-1}. It has also contained 13 mg kg^{-1} available P and 0.9% organic carbon.

The field trial had a randomized plot design with four sugarcane rows (1.7 m wide by 30 m long) in each plot. Lime (2 tonnes ha^{-1}) was surface applied to the A horizon across the entire experimental area one year before the establishment of the trial. The experiment consisted of four treatments: 1) no subsoil amendment as control (CK); 2) subsoil application of gypsum (10 tonnes ha^{-1} equal to 2250 kg Ca and 3 kg Na ha^{-1}) as calcium enriched treatment (GP); 3) subsoil application of compost (10 dry tonnes ha^{-1} equal to 146 kg N, 39 kg P, 97 kg K, 44 kg Mg and 194 kg Ca ha^{-1} with pH value of 6.9; CP) and 4) subsoil application of mineral fertilizer (36 kg N ha^{-1}, 12 kg P ha^{-1} and 44 kg K ha^{-1}, Incitec Pivot blends; equivalent to total nutrient contents of applied compost; FE). Amendments were applied to the subsoil (20–25 cm depth) two weeks before sugarcane (variety KQ228) plantation using a modified deep ripper with a 10 cm diameter tube attached to the back of the ripper tine. The dry weight composition of applied compost consisted of 23% wood chips; 35% chicken manure and 42% sugar mill filter press plus ash. The plots were managed as normal commercial crop for the duration of the experiment and same amount of nutrients (110 kg N ha^{-1}, 10 kg P ha^{-1} and 120 kg K ha^{-1}) has been applied to the plant, 1st, 2nd and 3rd ratoons (a practice of growing a crop from the stubbles of previous crop) in all treatments. Sugarcane, 1st, 2nd and 3rd ratoon crops were hand harvested at 1 m^2 areas (with four randomly picked replicates per plot) at 2013, 2014, 2015 and 2016 respectively.

The deep (0–60 cm) soil sampling from each treatment was carried out on sugarcane rows in December 2016 with 4 replicates per plot. The soil cores were randomly sampled with an auger of 7.5 cm in diameter and were divided into four layers of 0–10 cm, 10–25 cm, 25–40 cm and 40–60 cm depth. The collected fresh soil samples were sieved (< 2 mm) prior to laboratory analyses. A portion of the sieved soil samples were air-dried for chemical analysis, while the rest of sieved soil samples were stored at 4 °C before biochemical analyses within 2 weeks after sampling.

2.2. Soil physicochemical analysis

The soil sand, silt and clay contents were measured by a modified hydrometer method (Day, 1965). Electrical conductivity (EC) and pH (1:5 soil:water ratio) of soil samples were measured using a glass electrode (Rayment and Lyons, 2011). Soil mineral N (NH_4^+-N and NO_3^--N) was extracted by 2M KCl at a 1:4 ratio of soil to extractant using an end-over-end shaker for 1 h, filtered by a Whatman 42 filter paper (Rayment and Lyons, 2011) and concentrations of NH_4^+-N and NO_3^--N were measured by a SEAL AA3 Continuous Segmented Flow Analyzer (SEAL Analytical Limited. USA). Total C (TC) and N (TN) contents of soil samples were measured by dry-combustion method using a LECO CNS-2000 analyzer (LECO Corporation, MI, USA). Cation exchange capacity (CEC) of soil samples were measured by the silver-thiourea method (Pleysier and Juo, 1980) using an inductively coupled plasma optical emission spectrometer (ICP-OES; Perkin Elmer; Optima 8300). Hot water extractable organic C (HWEOC) and hot water extractable total N (HWETN) were measured using the method described by Chen et al. (2000). Briefly, 4.0 g (oven-dry equivalent) of fresh soil was incubated with 20 mL of water in a capped falcon-tube at 70 °C for 18 h. After incubation the tubes were shaken on an end-over-end shaker for 5 min and filtered through a Whatman 42 filter paper (Whatman Ltd., Maidstone, UK), followed by a 0.45-μm filter membrane. Concentrations of organic C and total extractable N in the filtrate were