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Review paper

Meta-analysis approach to assess effect of tillage on microbial biomass and enzyme activities

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ABSTRACT

Measures of soil biology are critical for the assessment of soil quality under different agricultural management practices. By modifying soil microclimate, tillage exerts the most important control on soil microbial communities. The objective of this study is to assess the effect of tillage on soil microbial biomass and enzyme activities. A meta-analysis was conducted utilizing 139 observations from 62 studies from around the world; the selected effect size (ES) was $\log_n$ of the response ratio (RR), the mean of the tilled treatment divided by the mean of the no-till control. This ES was calculated for seven different microbial properties – microbial biomass carbon (MBC) and nitrogen (MBN), metabolic quotient (qCO_2), fluorescein diacetate (FDA), dehydrogenase (DHA), β-glucosidase, and urease. Microbial biomass, metabolic quotient and enzyme activities were evaluated due their prevalent usage in evaluation of soil quality and use in soil quality indices. Overall, microbial biomass and all of the enzyme activities were greater under no-till compared to tillage. One exception to this was that under chisel tillage, there was no difference in MBC between the tilled plots and no-till. The qCO_2 was greater under tillage than under no-till indicating more active microbes in tilled soil, perhaps compensating for the reduced quantity. In contrast, when looking at only long-term experiments, qCO_2 was similar under both tillage and no-till, which may indicate that eventually microbes in no-till plots become as active as those in tilled plots even with the larger microbial community. The findings of this study illustrate that no-till and even reduced tillage, such as chisel tillage, promote larger microbial communities and greater enzymatic activity.

1. Introduction

The primary purpose of tillage in agricultural systems is to enhance crop production through weed control and seedbed preparation. Tillage systems are described based on the degree of soil inversion and percentage of residues remaining on the soil surface following tillage operations. The use of moldboard plow fully inverts the soil, while less intensive tillage vertically disrupts soil without inversion. Conventional intensive tillage practices leave less than15% residue on the surface while conservation tillage practices leave more than 30% of residue as a soil cover at the time of planting of the next cash crop (CTIC, 2015). The negative effects of tillage on soil erosion, degradation of soil structure, soil macro organisms and loss of nutrients and soil organic matter have led to increasing usage of conservation practices. Currently, conservation agricultural practices, such as non-tillage, are practiced on nearly 155 million hectares worldwide, which comprise 11% of the arable cropland in the world (Kassam et al., 2014). North and South America are the greatest adopters of conservation practices with no-tillage adoption rates of nearly 32% and 45%, respectively (Friedrich et al., 2012).

Management practices influence the soil environment and therefore the habitat of soil microorganisms in various ways. Soil organic matter (SOM) dynamics are highly dependent on the microbial community (Acosta-Martinez et al., 2003; Alvaro-Fuentes et al., 2013). The final product of decomposition that remain in the soil, microbial residues, may be resistant to further degradation

Abbreviations: RR, response ratio; LRR, log response ratio; MBC, microbial biomass carbon; MBN, microbial biomass nitrogen; qCO_2, metabolic quotient; FDA, fluorescein diacetate; DHA, dehydrogenase; β-glu, β-glucosidase.

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thereby protecting SOM through biochemical stability or physical protection within soil aggregates (Six et al., 2006; Jastrow et al., 2007; Schimel and Schaeffer, 2012). Improving the understanding on the rates of decomposition as influenced by management is also fundamental to improve SOM management in cropping systems (Scow, 1997; West and Post, 2002). Crop rotations influence the type and quantity of crop residues being returned to the soils (Karlen et al., 1994; McDaniel et al., 2014); N fertilization increases plant growth and subsequent organic matter inputs and N availability for soil microorganisms and as well as influencing the pH of the soil near the application zone (Geisseler and Scow, 2014). In contrast, tillage can influence microbes by changing both the soil microclimate as well as access to organic matter inputs. The soil microclimate is typically cooler and moister in no-till soils compared to the drier and warmer soils under more intensive tillage (Johnson and Hoyt, 1999; Martens, 2001). Access to organic matter is greater with tillage as organic residues are broken into smaller pieces, which increases the available surface area for microbial colonization (Johnson and Hoyt, 1999; Balesdent et al., 2000). Changes in the soil environment and soil microbial communities as a result of tillage then influences soil quality. The soil biological parameters investigated in this meta-analysis (microbial biomass, metabolic quotient, and enzymatic activities) were selected as they are commonly utilized in assessments of soil quality and as components of soil quality indices (Bastida et al., 2008).

Reviews by Johnson and Hoyt (1999) and Martens (2001) have both reported greater microbial abundance under no-till soils with a more favorable microclimate compared to soils under conventional tillage; similar results were reported by Kaschuk et al. (2010), Das et al. (2014), and (Balota et al., 2004). The degree to which microbial biomass increased under no-till compared to conventional tillage differed greatly, however, with a 17% increase reported by Das et al. (2014) and a 98% increase reported by Balota et al. (2004). While microbial biomass is often reported to be greater under no-tillage systems, no differences due to tillage have also been reported in de Gennaro et al. (2014). Despite a relative consensus of greater amounts of microbial biomass C under no-till, measures of microbial activity vary much more widely. Microbial activity measured through the metabolic quotient (microbial respiration/microbial biomass or qCO2) was reported smaller under no-tillage compared to conventionally tilled systems (Balota et al., 2004) suggesting that microbes are more active under conventional tillage. On the other hand, Babujia et al. (2010) found no differences between conventional tillage and no-till practices. Other approaches used to understand microbial activity is through quantification of the functional role microbes play in the cycle of nutrients. Typically, this has been quantified through the rates of enzymatic activity. However, understanding of their dynamics in soil systems as influenced by tillage is less clear and contradictory (Gil-Sotres et al., 2005; Laudicina et al., 2012).

Evaluating the effect of tillage on microbial biomass and activity with a meta-analysis approach will provide a quantitative analysis of the global response of microbial soil characteristics to different tillage practices. A meta-analysis is a statistical method of combining results from multiple data sets to evaluate the magnitude of the effect size as well as patterns of response and sources of heterogeneity (Gurevitch and Hedges, 1999; Borenstein et al., 2009; Koricheva et al., 2013). With this approach, we can also evaluate other possible sources of variability simultaneously influencing microbial properties. We expect minimally disturbed or no-tillage soils to have a larger microbial community as evidenced by greater microbial biomass C (Johnson and Hoyt, 1999; Balota et al., 2004; Das et al., 2014). Further, the reduced rates of soil disturbance are expected to reduce microbial enzymatic activity likely linked to slow rates of C and N mineralization from SOM. Specifically, the objectives of this study were to use a meta-analysis approach to 1) determine the effect size of tillage compared to no-till on microbial biomass and enzyme activities involved in the C and N cycles and 2) evaluate the influence of other sources of variability on the magnitude and direction of the effect size.

2. Materials and methods

2.1. Data collection and database

Data was collected through a process of data mining of the scientific literature using Thomas Reuters Web of Science v.5.16.1. We looked for peer-reviewed articles evaluating the effect of soil management practices on microbial biomass and activity. Keywords used for the initial search included “microbial biomass”, “microbial activity”, and “soil management”. This initial search produced 1242 articles, which were further refined by including “tillage” as another keyword to 380 articles. The literature search was restricted to peer-reviewed papers that were published between January 2000 and December 2014. The reference list from review papers on soil organic matter dynamics and soil microbial properties were further scrutinized to select additional peer-reviewed articles that had not been picked up by the initial search. Fig. 1 shows a flow chart illustrating the steps in data collection.

To construct the database, results from a publication were included if it met the following criteria for quality control and to ensure appropriate data collection: 1) Studies reported results on a minimum of one of the following soil biological parameters: microbial biomass (measured through chloroform-fumigation extraction (CFE), chloroform-fumigation incubation (CFI) or phospholipid fatty acids (PLFA) and microbial activity (measured through metabolic quotient and enzymatic activity of fluorescein diacetate (FDA), dehydrogenase, β-glucosidase, and urease) as affected by at least a no-till control and an alternative type of tillage used as treatments, 2) Articles reported data collected from field trials in grain-based studies, 3) Articles had clear specifications of experimental design and a minimum of two replications, 4) Articles included details on the length of the study, 5) Information on the location of the experimental site was provided so that additional environmental characteristics such as mean annual temperature and precipitation and soil texture could be obtained either from the same article or from additional secondary sources. A total of 62 peer-reviewed journal articles were included in the database. Multiple treatment pairs from the same study were included as separate observations when they could be categorized within separate subgroups for one or more moderating variables. A total of 137 treatment pairs were extracted; however, each treatment pair provided data for only a few microbial parameters evaluated within this study. The number of observations for each microbial property differed with 89 for microbial biomass C (MBC), 46 for microbial biomass N (MBN), 29 for metabolic quotient (qCO_2), 19 for fluorescein diacetate (FDA), 43 for dehydrogenase (DHA), 53 for β-glucosidase (β-glu), and 19 for urease. The locations for the studies included were far-ranging, and there were a minimum of three studies on every