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Influence of conservation tillage and glyphosate on soil structure and organic carbon fractions through the cycle of a 3-year potato rotation in Atlantic Canada

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Abstract

Conservation tillage (CT) practices are promising management options for potato (*Solanum tuberosum* L.) production in Atlantic Canada, however, concerns are expressed about the effects of glyphosate [*N*-(phosphonomethyl) glycine] and tillage interactions on soil organic matter and structure. The objective of this study was to compare the effects of a range (from conventional to CT) of tillage practices (with and without glyphosate) on several soil properties over each phase of a 3-year potato rotation [red clover (*Trifolium pretense* L.)–potato–barley (*Hordeum vulgare* L.)], at three sites, over a 5-year period. Four tillage practices were evaluated: (1) autumn mouldboard ploughing followed by spring secondary tillage (conventional tillage treatment); (2) spring mouldboard ploughing followed by secondary tillage; (3) autumn chisel ploughing followed by spring secondary tillage; and (4) spring CT. The temporal variation, influence of tillage, and effect of glyphosate were determined on several soil indicators (phosphatase, microbial biomass C, carbohydrates, organic C, total N, particulate C and N, bulk density and soil structural stability using both dry and wet sieving) at five stages in the 3-year rotation cycle: (1) in red clover phase, after glyphosate application but before autumn tillage; (2) in potato phase, at pre-spring tillage; (3) in potato phase, at pre-ridge tillage; (4) in potato phase, at post-harvest; and (5) in barley phase, at post-harvest. Except for soil bulk density and organic C, there were few clear temporal variations in soil properties. Tillage-induced changes, mainly related to soil loosening depth and inversion, were evident for most of the soil properties at the pre-spring tillage and pre-ridge tillage stages. Periodic and irregular influences of glyphosate were recorded on soil properties at various growth stages. However, these influences were ecologically negligible and related to loss of red clover biomass forfeited by early application of glyphosate in the autumn, rather than a direct effect of the herbicide. There were no glyphosate and tillage interactions. Overall, use of glyphosate in CT and other tillage systems on sandy loam soils had no detrimental effect on soil biological properties and associated processes such as soil aggregation.

Keywords: Potato rotation; Glyphosate; Soil biochemical and biological properties; Conservation tillage; Sandy loam; Atlantic Canada

1. Introduction

Conservation tillage (CT) is an umbrella term used to describe a range of tillage practices that have the potential to reduce soil degradation, relative to some form of conventional tillage (Mannering and Fenster, 1983). A relatively wide array of CT practices are available for cereal and forage production in humid climates (Carter, 1994), but CT practices are less developed for potato production systems. In contrast to grain crop rotations, monoculture or short length

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rotations are generally not permissible for potato production due to disease problems. Furthermore, the type of CT adopted must accommodate specific crop requirements in the rotation that include root crops, especially providing some degree of tillage for the potato phase. In potato production systems, desirable characteristics of CT practices would include maintaining a soil cover during the cool winter period and decreasing the depth and intensity of tillage. Studies conducted in Norway (Ekeberg and Riley, 1996; Riley and Ekeberg, 1998) and Atlantic Canada (Carter et al., 1998; Holmstrom et al., 1999; Carter and Sanderson, 2001) indicate that CT systems are a feasible option for potato production, providing both a reduction in tillage intensity and frequency and similar potato yield and quality as conventional tillage.

Understanding how soils respond to potato management requires an assessment of temporal change in key soil properties. Several studies have been conducted to identify soil measurements that can serve as sensitive indicators to conservation management in cereal crops (Gregorich et al., 1994, 1997; Bolinder et al., 1999). These studies indicated that soil organic C (SOC), particulate organic matter (POM) and microbial biomass C (MBC) would be useful properties to assess soil response. For potato systems, the above parameters plus enzyme activity and wet aggregate stability have also been useful to assess soil response to management (Angers et al., 1999). However, since companion crops in potato rotations are usually grown to support the main cash crop (i.e. potato) information on temporal change in soil indicators would also be of interest (Grandy et al., 2002; Carter et al., 2003a, 2004), especially regarding optimum soil sampling times within the rotation.

Crop health studies in 2-year versus 3-year potato rotations indicated that CT practices will only be successful if they are employed in longer rotations, due to problems with soil-borne diseases (Peters et al., 2004). An integral part of any CT system for 3-year potato rotations (e.g. grain-forage-potato) is the use of autumn-applied herbicide (glyphosate) to remove the forage prior to the potato phase (Holmstrom et al., 1999; Carter and Sanderson, 2001). Herbicide is applied to a full cover of vegetation and thus presumably little glyphosate reaches the soil surface, however, producers have concerns about its influence on soil biological properties and associated processes such as soil aggregation or tilth. Several field studies have been conducted to evaluate the potential effect of glyphosate on soil microorganisms and microbial activity (Heinonen-Tanski et al., 1985; Bliev and Mel'nikova, 1986; Olson and Lindwall, 1991; Hart and Brookes, 1996; Liphadzi et al., 2005). Generally, effects on microbial activity (e.g. C and N mineralization) are both marginal and short-term and would be viewed as ecologically negligible (Domsch, 1984). However, little information is available concerning glyphosate–tillage interactions or possible glyphosate effects on soil properties over time through the cycle of a potato rotation. The timing of glyphosate application in autumn, for instance, could adversely influence the amount of organic C inputs (from above ground forage and root biomass) to the soil, which in-turn could influence soil properties. McLaughlin et al. (2004) argued that soil strength, as indicated by tillage implement draft requirements, was impacted by timing of fall glyphosate application. Furthermore, in sandy soils with relatively high residual P levels (De Jonge et al., 2001), which are common in soils used for potato culture, or sandy soils in cool-season climatic areas (Heinonen-Tanski et al., 1985) glyphosate degradation may be reduced and thus show some soil activity.

Beneficial management practices would advise the shift of autumn primary tillage (common to conventional tillage practices) to the spring, thus, the autumn herbicide treatment would be followed by spring primary and secondary tillage for potato planting. However, in humid regions with a short growing season there can be a reluctance to switch to spring tillage alone as this may result in poor soil conditions in the spring and subsequent delay in potato planting. Thus, in some systems primary tillage is also conducted in the fall shortly after the herbicide application followed by secondary tillage in the spring. Under this scenario there is a concern that combinations of glyphosate (to remove vegetation) plus primary tillage in the fall may adversely influence soil structure and tilth. McLaughlin et al. (2004) showed a trend towards a lower primary tillage draft requirement for glyphosate treated red clover compared to untreated red clover. This offers the benefit of reduced fuel requirements, but may also lead to more intensive soil tillage.

The general objectives of the study were to compare a conventional tillage system for potato production in 3-year rotation against three tillage systems that incorporate various CT characteristics, and to characterize tillage versus glyphosate effects on soil properties throughout the rotation cycle. Carter et al. (2005) presented the crop yield, weed control, crop residue, and soil environmental aspects of the study. In the present study, the responses to tillage practice and use of glyphosate were determined from a range of soil organic fractions, microbial properties, and soil physical properties including soil structure. Specific objectives were (1) to assess the temporal change in some indicator soil properties