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Corn residue inputs influence earthworm population dynamics in a no-till corn-soybean rotation

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ABSTRACT

Temporal dynamics of earthworm populations in temperate agroecosystems are related to climatic and edaphic conditions, agricultural management and crop residue inputs. The amount of crop residue present and its suitability as a food resource for earthworms changes as the material decomposes. A readily-decomposable crop residue (low C:N ratio, low lignin content) may be a transient food resource for earthworms, whereas residues that decompose more slowly could be a persistent food resource to sustain the earthworm populations. Chemical composition of the crop residue and the particulate organic matter (POM) content in soil, a measure of the partially-decomposed residues, are indicators of the food resources for earthworms. The objective of this study was to determine how the quantity and chemistry of crop residues, and the soil POM content, were related to earthworm population dynamics during a two-year field experiment in no-till corn-soybean rotations. The high residue treatment provided an additional 3–5 Mg ha^{-1} y^{-1} in corn residue, compared to the low residue treatment. As hypothesized, earthworm abundance and biomass were strongly affected by the quantity of crop residues left in the agroecosystem after harvest. Greater corn residue inputs in the high residue treatment supported an earthworm community that had similar species composition and age structure, but was nearly twice as large as the earthworm community in the low residue treatment. Soybean residue appeared to be a transient food resource for earthworm populations in the field. Earthworm abundance and biomass were related to the amount of surface residue present, but were not correlated to the chemical composition of crop residue and the soil POM content during this two-year study. Under field conditions, earthworm populations respond to the quantity of residues present as a food resource rather than the chemical composition of the residue.

1. Introduction

The size and activity of soil biota populations in agroecosystems is impacted by crop residue inputs, which can significantly change the edaphic habitat and availability of food resources (Sauvadet et al., 2016). This is especially true for earthworms, whose biomass is typically the largest of all soil biota living in temperate agroecosystems. Generally, agricultural fields with more residues support larger and more diverse earthworm populations than fields with fewer residues (Edwards and Bohlen, 1996). For instance, in a no-till continuous corn system, earthworm abundance increased by 50% after ten years in plots where approximately 8 Mg ha^{-1} $year^{-1}$ of corn stover was retained, compared to plots where corn stover was removed (Karlen et al., 1994). Similarly, earthworm abundance and biomass were, on average, three times higher with residue retention than residue burning in a wheat-lupin agroecosystem (Chan and Heenan, 2006). In another study, Tomlin et al. (1995) found that the mean number of earthworms was 59 m^{-2} under continuous corn, 37 m^{-2} under corn-soybean rotation, and 28 m^{-2} under continuous soybean. They attributed these differences to the quantity of residue produced by each crop in the rotation. After harvesting grain corn, an estimated 5.2 Mg ha^{-1} of residues are left in the field, while 2.9 Mg ha^{-1} of soybean residues remain after harvest, according to estimates of net primary production for the U.S. Midwest (Prince et al., 2001). This supports the notion that more residues will support larger earthworm populations.

The response of earthworm populations to crop residues also depends on their suitability as food resources to support earthworm growth and nutritional requirement, referred to as residue quality. Chemical characteristics such as the C:N ratio and lignin content are major determinants of residue quality because they control the palatability and decomposability of the residue (Hendriksen, 1990; Tian et al., 1997; Curry and Schmidt, 2007). Earthworms grow more and produce more offspring when provided with residues having lower, rather than higher, C:N ratio and lignin content (Bostrom, 1987; Cortez

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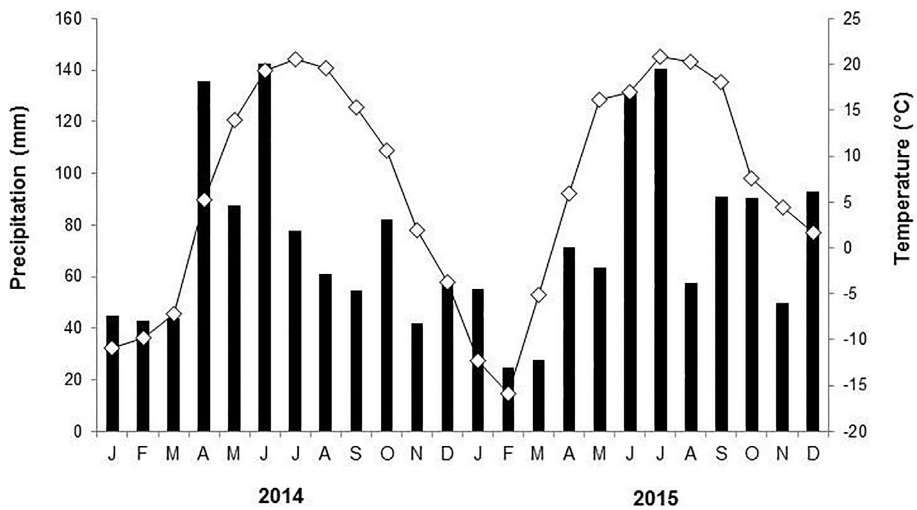

Fig. 1. Monthly precipitation (solid bars) and mean monthly temperatures (diamonds connected by lines) in 2014 and 2015. Data were collected from the Environment Canada weather station (45°25′ N, 73°55′ W), 1.5 km from the agricultural fields in Ste-Anne-de-Bellevue, Quebec, Canada.

and Hameed, 1988; Shipitalo et al., 1988). For instance, Shipitalo et al. (1988) found that earthworms gained on average 68% and 5% of their weight, respectively, when offered alfalfa (C:N ratio of 14) and corn leaves (C:N ratio of 21), while they lost up to 41% of their weight when fed with bromegrass leaves (C:N ratio of 26). Bromegrass leaves were more lignified, as indicated by the aromatic-C content, and appeared to be less palatable for earthworms (Shipitalo et al., 1988). Likewise, the higher palatability of soybean residues was proposed to explain why earthworm populations were 8-fold more abundant and had 5-fold greater biomass under soybean monoculture than corn monoculture (Mackay and Kladivko, 1985). Leguminous crops increase the nutritional value, particularly the N content, of the food resources for earthworms (Hubbard et al., 1999; Fraser et al., 1996), but this beneficial effect could be transient, since legume residues decompose rapidly and may not sustain the earthworm community. This is consistent with the observation of 2-fold more earthworms under continuous corn than continuous soybean (Tomlin et al., 1995). Thus, residues having a low decomposability, such as corn residues, could provide food resources that sustain the earthworm community for a longer period.

Controlled feeding trials in the laboratory provide insight into earthworm preferences, but give little information about the fluctuations in food resources available to field-dwelling earthworms. In agricultural fields, the spatio-temporal variation in food resources for earthworm populations is related to residue management practices (e.g. addition, retention or removal of residues) and the crop sequence (i.e. affecting the residue quality), but also due to physico-chemical changes in the residue during its decomposition. These fluctuations in food resources should be inevitably related to earthworm population dynamics since food controls earthworm growth and reproduction. However, abiotic factors such as temperature and soil moisture are generally considered to regulate earthworm population dynamics in agricultural fields (Gerard, 1967; Daniel 1991; Eriksen-Hamel and Whalen, 2006; Johnston et al., 2014), given the sensitivity of these poikilotherms to temperatures below 5 °C and above 20–25 °C, and their propensity to aestivate or enter a quiescent state in colder and drier soils. Consequently, the contribution of crop residues to the food supply of earthworms in agroecosystems remains poorly understood, particularly with respect to how temporal changes in crop residues are related to earthworm population dynamics.

One way to evaluate how crop residues contribute to the food resources for earthworms is to quantify the particulate organic matter (POM) in soil, a pool of uncomplexed organic matter (53–4000 μm) derived from partially decomposed plant residues (Gregorich et al., 2006) that is a known source of nutrition for earthworms, particularly endogeic species (Abail et al., 2017). As an intermediate product of decomposing crop residue, the physico-chemical properties of POM are consistent in agroecosystems with diverse residue management practices and cropping sequences (St. Luce et al., 2013). Hence, the soil POM content could reflect the food resource available to earthworm populations, particularly the endogeic species that are the numerically dominant earthworms in temperate agroecosystems (Whalen and Fox, 2006).

The objective of this study was to determine how the quantity and quality of crop residues, and the soil POM content was related to earthworm population dynamics during a two-year field experiment. Two adjacent fields, both under a no-till corn-soybean rotation with both phases present each year, were selected for the study. The crop residue input varied during the corn phase of the rotation because corn was produced either for grain or for silage. The field with grain corn-soybean was a high residue-producing system, while the field with silage corn-soybean was a low residue-producing system. We hypothesize that (1) the quantity of crop residues left in the agroecosystem after harvest will determine the abundance and biomass of earthworms, while (2) the temporal changes in residue quality and the soil POM content will be related to earthworm population dynamics.

2. Materials and methods

2.1. Site description

The study was conducted for two consecutive years (2014 and 2015) in two adjacent agricultural fields (50 m apart) at the Macdonald Research Farm of McGill University in Ste-Anne-de-Bellevue, Quebec, Canada (45°25′ N, 73°56′ W). The climate in this region is humid temperate with mean monthly temperatures ranging from −10.8 °C in January to 20.9 °C in July, and mean annual precipitation of 885 mm (Environment Canada, 2017). Daily temperature and rainfall during the study were measured at a nearby meteorological station (Fig. 1). Soil in the agricultural fields was a mixed, frigid Typic Endoquent, classified as a Chicot series sandy-loam, and its general soil physico-chemical characteristics are described in Table 1.

The agricultural fields were in a no-till corn-soybean rotation with one year out of phase, and were managed according to the agronomic norms in this area (Table 2). Two years prior to this study, both fields were grown with alfalfa and managed similarly which made these fields suited to evaluate the effect of crop residues on earthworm populations during the period of our study. According to the type of corn production (silage or grain), each field had a different amount of crop residue