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The effect of thin stillage on the chemical and biological properties of a Chernozem in Western Canada

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ABSTRACT

The aim of the current study was to assess the effects of direct application of thin stillage on soil residual available nitrogen (N) and phosphorus (P) content along with some selected soil chemical (organic carbon, pH, electrical conductivity, metals content) and biological (dehydrogenase activity and microbial biomass) properties after crop harvest in a two-year field study. The experimental treatments included injected TS, broadcasted and incorporated TS and urea fertilizer with 3 application rates equivalent to 50, 100, and 200 kg available N ha^{-1} in addition to a control. Overall, NO_3^--N content in TS treated soil was higher in the second year, but was not significantly different from that of urea treatments. Soil available P content increased in both years, but was greater in the second year, indicating the high release of N and P nutrients through TS organic matter decomposition after application to soil. In selected treatments, microbial biomass was higher in TS than urea treatments, but not significantly different from the control. The other measured soil parameters remained unchanged for both years. This study indicates that application of TS for two years did not contribute to NO_3^--N accumulation in soil beyond the year of application when compared to urea fertilizer. Further studies with longer-term need to be conducted to monitor possible build-up of NO_3^--N and P in soil via carryover of unused inorganic forms and also possibly through increased microbial mineralization.

1. Introduction

Biochemical conversion of starch or sugar crops to produce ethanol also results in generation of thin stillage, a major coproduct associated with this process. This byproduct is a consequence of the fermentation and distillation processes involved in ethanol generation from renewable sources (Mustafa et al., 2000). The fermentation and distillation process of the feedstock results in a product called whole stillage, which contains solids from the used feedstock plus added yeast and liquid from the water added during the process. This whole stillage is then centrifuged to separate the liquid components, called thin stillage, and the solid components termed wet distillers grain. The thin stillage may then be further processed by evaporation to produce syrup which can be blended with wet distillers grain resulting in wet distillers grain with solubles (Bonnardeaux, 2007).

The pressing demand for sustainable energy from renewable sources has resulted in expansion of ethanol production worldwide, and coincidentally the associated byproduct of thin stillage. It has been estimated that each liter of ethanol produced is associated with about 20 L of thin stillage generated (van Haandel and Catunda, 1994). This high volume of thin stillage requires a proper method of utilization that is economically sound and environmentally benign. The evaporation process can help to concentrate thin stillage constituents into a lesser volume. However, this process can have an undesirable impact on the energy balance of ethanol production (Faust et al., 1983). One possible use of thin stillage is to partially or completely replace drinking water for cattle (Mustafa et al., 2000). However; this method is not a commonly adopted practice and may not be able to accommodate the continual rise in thin stillage production, as the rapid growth in ethanol manufacturing is expected to create a surplus of ethanol byproducts (Rausch and Belyea, 2006). Therefore, other alternative utilization avenues need to be sought, including direct application to soil as organic amendment. This possible option can benefit plant and soil by recycling the plant nutrients and carbon that are present in thin stillage. A broad range of organic material (e.g. animal manures, biosolids, composts) application to agricultural soils have already been extensively evaluated, with results showing positive impacts of additions of these materials on various soil properties that far outweighed the negative impacts (Edmeades, 2003; Hargreaves et al., 2008; Diacono and Montemurro, 2010; Quilty and Cattle, 2011). However, effects of

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bioenergy byproducts such as thin stillage on soil chemical and biological properties are not well documented.

A few studies have evaluated the effect of vinasse stillage, a by-product of the sugar industry, addition on soil properties (Gemtos et al., 1999; Singh et al., 2003; Resende et al., 2006; Hati et al., 2007; Tejada et al., 2007; Tejada and Gonzalez, 2005). However, studies examining the impact of thin stillage derived from biochemical conversion of a starch crop, such as corn or wheat on soil chemical and biological properties are still limited. A few short term (2–5 weeks) experiments conducted under growth chamber conditions showed that wheat-based ethanol thin stillage increased plant yield and nutrient supply and did not have a negative impact on soil biological activity (Alotaibi and Schoenau, 2011, 2013; Qian et al., 2011). However, field studies examining effects of repeated application of thin stillage using available application techniques on soil attributes are lacking. Fertilization with thin stillage may contribute to build-up of residual available N and P in the soil as a result of unused plant available forms added in excess of crop demand, and also as a result of continued mineralization of organic forms of these nutrients into inorganic forms. Excess nutrients may pose an environmental risk, especially if rate of nutrients application exceed crop requirements for many years. In addition, the acidic nature of TS and its high salt content may adversely affect soil chemical and biological properties. These possible effects need to be clarified. Therefore, the objective of the current study was to assess changes in some selected soil chemical and biological properties in a Black Chernozemic soil fertilized for two years in the field with TS derived from wheat-based ethanol production.

2. Materials and methods

2.1. Site description

The experimental site was located near the town of Dixonin east-central Saskatchewan, Canada. It is located within a productive agricultural region in Saskatchewan (Stumborg et al., 2007). The predominant soil at the site is classified as a Black Chernozem (Cudworth Association) of clay-loam texture. The average particle-size distribution in the 0–15 cm depth was 30% sand, 23% silt and 47% clay, determined using pipette method (Gee and Bauder, 1986). The study site has a nearly level topography. Prior to the current study, the field was cropped to barley (*Hordeumvulgare* L.). The basic characteristics of the field soil are shown in Table 1.

The average long-term annual precipitation and temperature for this area is 373 mm and 0.7 °C respectively (Stumborg et al., 2007). Monthly cumulative rainfall and mean air temperature over the two growing seasons and the 30-yr average are summarized in Fig. 1. The climate data were retrieved from a weather station located at Humboldt approximately 5 km from the experimental site (Environment Canada, 2012).

The field experiment was established in fall 2008. The experimental setup was a randomized complete block design with 10 treatments repeated 4 times. The experimental treatments included: injected thin stillage (INJTS), broadcasted and incorporated thin stillage (BRTS) and banded urea for comparative purposes, each of which was applied at three rates: low (L), medium (M) and high (H). A control (unfertilized, unamended) was included for comparison. The three rates of TS application were: 16,800, 33,600 and 67,200 L ha^{-1}, intended to provide approximately 50, 100 and 200 kg available N ha^{-1}, respectively, based on an assumption that about 60% of the total N in thin stillage would be available during the course of the year (Qian et al., 2011). The three rates of conventional fertilizer urea (46-0-0) applied for comparison were 50, 100 and 200 kg N ha^{-1}. Plot dimensions were 3 by 9 m in blocks that were spaced apart by 27 m. Plots received the same treatments in both 2009 and 2010.

Table 1
Selected soil properties at the start of the field study in fall 2008 in samples collected from control plots at 3 depths.

Property	Soil depth (cm)[a]		
	0–15	15–30	30–60
NO_3^--N (μg g^{-1})	7.0 ± 0.3	4.8 ± 0.2	5.1 ± 0.3
NH_4^+-N (μg g^{-1})	4.3 ± 0.3	5.0 ± 0.1	5.0 ± 0.5
Avail. P (μg g^{-1})	5.1 ± 1.0	1.9 ± 0.0	2.0 ± 0.1
Avail. K (μg g^{-1})	275 ± 23	128 ± 15	115 ± 3
OC (%)	2.8 ± 0.2	1.3 ± 0.2	0.7 ± 0.1
pH	8.0 ± 0.1	7.8 ± 0.1	7.9 ± 0.03
EC (dS m^{-1})	1.5 ± 0.8	3.7 ± 0.7	4.8 ± 0.2
Sand (%)	29.7 ± 0.5	19.4 ± 3.3	22.8 ± 3.3
Silt (%)	23.6 ± 3.0	26.3 ± 1.8	22.4 ± 2.1
Clay (%)	46.7 ± 3.5	54.2 ± 5.1	54.8 ± 1.2

[a] Values presented are means followed by standard error.

2.2. Treatment application

The thin stillage utilized in this study is a byproduct of bio-ethanol production from wheat grain feedstock. It was provided by the Pound-Maker Agventures ethanol plant located at Lanigan, Saskatchewan. The collection, delivery and application of the thin stillage were carried out by the Prairie Agricultural Machinery Institute (PAMI, Humboldt, SK). Application of treatments to the field took place in the preceding fall (1st week of October) of each growing season. For the injection method of application, thin stillage was applied using the PAMI liquid slurry injector truck. The TS was agitated as it was pumped into the PAMI injector truck. The injector truck is equipped with modified Bourgault low disturbance injector disc coulters spaced 30 cm apart. The TS was applied in bands behind the coulter at an average depth of 8–10 cm. For the broadcast and incorporation method, the injectors were lifted above the soil surface to get TS applied on the soil surface in a band, followed by immediate incorporation with a chisel plow cultivator using one pass with 30 cm sweeps on a 20 cm row spacing, followed by harrowing. During TS application to soil and for both years, several samples were collected at the injector opening, mixed to yield a homogenous representative sample and stored in the freezer (−20 °C) until analysis for chemical composition. The analysis of TS was conducted at a commercial laboratory (ALS Laboratory Group, Saskatoon, SK). Basic characteristics of TS applied for each year are provided in Table 2. Commercial granular urea fertilizer (46-0-0) was banded into the soil using PAMI's plot drill at an 8 cm depth with knives on a 20 cm row spacing.

The field was seeded to Lillian variety hard red spring wheat (*T. aestivum*) and BrettYoung 719 Roundup Ready variety canola (*Brassica napus* L.) in the seasons of 2009 and 2010, respectively. Information regarding planting and harvesting details and crop related parameters measured and their response to treatment application were previously reported by Alotaibi et al., 2014.

2.3. Soil sample collection

The first soil sample collection occurred immediately after layout of the experimental plot in fall of 2008 for initial soil characterization of the study site. For this purpose, soil samples were collected only from the control plots at three soil depth increments (0–15, 15–30 and 30–60 cm). To evaluate treatments effects on residual soil available N and P and some selected soil chemical and biological properties, soil samples were collected immediately after crop harvest at the end of growing seasons before freeze-up (mid October) for both years from all plots. A hydraulic punch truck was used to collect soil cores (3 per plot), which were separated into different soil depths increments: 0–15, 15–30 and 30–60 cm in the first year whereas in the second year the samples were collected at 0–15, 15–30, 30–60 and 60–90 cm depths. The triplicate soil samples collected from each depth were mixed