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Changes in soil chemical properties with flooding: A field laboratory approach

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ABSTRACT

Phenolic compounds, which can affect the availability of soil nitrogen (N) for plants, may accumulate in the soil under flooded conditions. The objective of this study was to determine if short-duration floods (i.e., 3 vs. 5 weeks) with varying flow rates (i.e., stagnant vs. flowing) would affect soil inorganic-N or polyphenolic content under field conditions. Our study site was an outdoor research facility used for evaluating flood tolerance of various plant species. Flood conditions (i.e., timing, depth, duration, and flow rate) at this facility can be manipulated making it ideal for a field-based investigation of the effects of flooding on soil chemical and environmental properties. Four flood treatments (non-flooded control, 3-week-flowing flood, 5-week-flowing flood, and 5-week stagnant flood) were implemented in May–June, 2005. Soil redox potential, pH, temperature, volumetric water content and dissolved oxygen were monitored over the course of the flood treatments with automated sensors. Pre- and post-flood soil samples were collected and analyzed for inorganic-N content, total N, total organic C, and total soluble polyphenolics. Sensor data revealed a decrease in redox potentials and dissolved oxygen with flooding; however, differences between flood treatments were not significant. Both 5-week flood treatments developed anaerobic soil conditions within 12 days of inundation; anaerobic conditions were maintained for these treatments until dry-down. Soil conditions in the 3-week-flowing treatment remained generally in the suboxic range. Significant differences in soil temperature, volumetric water content and pH were not observed. Flooding affected soil inorganic-N in that NO_3–N decreased under 5-week flood treatments and increased under 3-week-flowing and control treatments. Losses in soil NO_3–N were nearly 4 times greater for the 5-week-stagnant treatment than the 5-week-flowing treatment. Trends included all flood treatments (including the control) showing increases in soil NH_4–N and most flood treatments (all except the 5-week-flowing) showing decreases in soil polyphenolic content. Changes in soil NH_4–N and polyphenolics, as well as TN, TOC and C:N ratio with flooding were not significant. Short-duration floods in this facility, therefore, did not result in the accumulation of polyphenolics in the soil. Other changes in soil chemistry, such as TN and TOC were minimal and not significant despite development of anaerobic soil conditions.

1. Introduction

Past research suggests that anaerobic soil conditions due to inundation will result in reduced nutrient availability for riparian plants. Availability of N in particular may decline due to either increases in denitrification and nitrate reduction (Baldwin and Mitchell, 2000; Vepraskas and Faulkner, 2001), or decreases in effective N concentration due to altered residue decomposition (Baldwin and Mitchell, 2000; Baker et al., 2001; Schuur and Matson, 2001; Neatrour et al., 2004). Shifts in microbial metabolism to anaerobic mechanisms under saturated soil conditions results in an overall decrease in decomposition of residues; lignin and polyphenolic decomposition in particular are adversely affected.

The accumulation of lignin and phenolics in the soil may lead to a decrease in plant-available N. Phenolic compounds may bind with proteins or amino acids in the soil to form recalcitrant humic-N polymers that are resistant to microbial conversion or plant uptake (Gaunt et al., 1995; Browaldh, 1997; Inderjit and Mallik, 1997; Hattenschwiler and Vitousek, 2000; Suominen et al., 2003; Kruse et al., 2004; Schmidt-Rohr et al., 2004). Soluble polyphenolic compounds, which have a higher protein binding capacity than

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insoluble polyphenolic compounds (Mafongoya et al., 1998; Mungai and Motavalli, 2006), may leach out of the soil, contributing to N loss from the system over and above their influence on N mineralization (Mungai and Motavalli, 2006).

Investigations of the decline in productivity of multi-cropped rice systems offer evidence that phenolic compounds accumulate under flooded conditions and that subsequent N deficiencies occur. Declines in yield of continuously cropped, irrigated rice systems have been reported since 1982 (Cassman et al., 1995). Cassman et al. (1995) investigated possible causes for these declines and they found no evidence for zinc, potassium or phosphorous deficiencies. Results, however, suggested a decrease in available N despite no changes in total soil N. Other studies have indicated similar changes in soil N (Gaunt et al., 1995; Olk et al., 1996; Schmidt-Rohr et al., 2004). NMR spectroscopy work by Olk et al. (1996) and Schmidt-Rohr et al. (2004) lend support to the role of phenolic compounds in the decrease of N availability.

Field-based experiments frequently produce results different than similar laboratory manipulations. For example, while Olk et al. (1996) observed yield declines in rice systems that were associated with decreased effective soil N, they were unable to link this decreased N availability to the accumulation of phenolic compounds in the soil under field conditions. Soil properties, such as texture and pH, may affect the relationship between phenolic compounds and N mineralization by influencing the residence time of phenolic compounds in the soil and by affecting their ability to bind N (Whitehead et al., 1982; Inderjit and Mallik, 1997; Ohno, 2001).

Wetland and Conservation Reserve programs have resulted in an increased focus on preservation and restoration of riparian wetlands in Midwestern states in the USA. In 1999, the University of Missouri Center for Agroforestry established an outdoor research facility for evaluating flood tolerance of potential species for riparian buffers and afforestation of bottomland sites. Because flood conditions (timing, depth, duration, flow rate, etc) can be controlled, this facility is ideal for a field-based investigation of the effects of flooding on soil chemical properties, such as inorganic-N and soluble polyphenolic levels. The primary objective of this study was to determine if short-duration floods (i.e., 3 vs. 5 weeks) with varying flow rates (i.e., stagnant vs. flowing) would affect soil inorganic-N or polyphenolic content. Secondarily, soil environmental properties, such as volumetric moisture content, temperature, pH, redox potential and dissolved oxygen content, were monitored to determine the relationship between changes in soil environmental conditions and changes in soil chemical properties with flooding. We predicted that longer duration floods and/or stagnant flood conditions would result in more anaerobic soil conditions as measured by redox potential and dissolved oxygen content. Those treatments with the lowest redox potentials were expected to have decreases in soil NO_3–N and increases in soil NH_4–N and polyphenolic content.

2. Methods

2.1. Study site

This study was conducted at the Flood Tolerance Laboratory (FTL) at the Horticulture and Agroforestry Research Center (HARC) in New Franklin, Missouri (USA) (39° 0′ 0″ N, 92° 46′ 0″ W) (Fig. 1). The FTL is an outdoor research facility constructed on a wide terrace floodplain adjacent to Sulphur Creek. A limestone-covered county road runs on the north side of the research facility, allowing access. The FTL consists of twelve 6 m × 180 m parallel channels and a retention pond. Soil removed in the creation of the pond was used to create berms (2 m high and 6 m wide) between the channels; this allowed for minimal disturbance to the soils within the channels. However, channels have been disked or rototilled prior to plantings. Generally tillage is shallow (i.e., to a depth of 4″) and is concentrated in the portions of the channels that will be planted that season. Soil samples for this study were taken from areas in the channels that were not planted with experimental species. However, a number of "weedy species" became established during the growing season. These species were generally wetland adapted species (i.e., able to tolerate frequent flooding and/or soils with poor drainage) that were common to the Sulphur Creek floodplain. Identified species included Pennsylvania smartweed (*Polygonum* sp.), yellow nutsedge (*Cyperus esculentus* L.), curly dock (*Rumex* sp.) and cinquefoil (*Potentilla* sp.). Soils in this floodplain are generally classified as Nodaway silt loam, occasionally flooded (fine-silty, mixed, superactive, non-acid, mesic Mollic Udifluvents).

Fig. 1. Aerial photograph taken in 2004 of the Flood Tolerance Laboratory at the Horticulture and Agroforestry Research Center in New Franklin, MO (USA). Sulphur Creek is located along the tree-lined corridor in the left and upper portions of the photo. A lime-stone county road borders the facility to the right; the pump house and retention pond are at the bottom of the photo.

Each channel can be manipulated independently of adjacent channels to allow for various flood treatments (i.e., changing depth, flow rate and duration of flooding). Water is pumped underground from the retention pond to the inlet end of the channels, and in flowing-flood treatments, water circulates between the pond and the channels, flowing from the inlet to the outlet (pond) end. Flow rate for flowing flood channels is such that water within the channels is replaced once per 24 h.

2.2. Flood treatments and environmental monitoring

Flood duration and flow rate are expected to affect the development of anaerobic soil conditions which in-turn should influence soil inorganic-N and polyphenolic levels. Movement (i.e., flowing conditions) should maintain higher oxygen levels in the flood water, thereby increasing the diffusion of dissolved oxygen into the soil. On the other hand, longer flood durations should result in a greater depletion of soil oxygen and thus the development of more reduced soil conditions than floods of shorter duration. Four flood treatments at the FTL were evaluated: (i) 3 weeks of flowing water maintained at 15 cm (3WF), (ii) 5 weeks of flowing water maintained at 15 cm (5WF), (iii) 5 weeks of stagnant water maintained at 15 cm (5WS), and (iv) no flood or control. The experimental design was a randomized complete block with three blocks arranged in a north–south direction; each block contained each of the four treatments. Flooding was initiated on May 23, 2005; 3WF channels were drained on June 13th, and 5WF and 5WS channels were drained on June 27th.

Prior to the 2005 flood season, electronic sensors to monitor changes in soil volumetric water content, temperature, redox