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Soil Column Simulation of Natural Nutrient Flux after Short-term Inundation

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Core Ideas

- Intact soil column flood studies inaccurately capture short-term nutrient flux.
- Filter paper creates barrier to physical disturbance of soil into water column.
- Filters are permeable to dissolved nutrients to chemically flux into water column.
- Cone filters prevent floating soil and organic materials from entering water column.

Abstract: Intact soil column studies have been widely used as laboratory simulations in determining the effects of long-term inundation on nutrient flux in soils, but preliminary studies on total Kjeldahl N (TKN) have shown that physical disturbance associated with current flooding techniques causes an overestimation of TKN flux after short-term inundation. Therefore, the objective of this study was to create a laboratory protocol that would minimize the effect of physical disturbance associated with current flooding procedures. To determine physical disturbance, total P concentrations were measured as a proxy for soil particles. Within 3 h of inundation, results found that total P concentrations in the water column were significantly reduced when using flat or cone-shaped filter paper on the soil surface compared with blanks. By adapting the Collins-filter barrier technique to short-term flooding simulations, we were able to more accurately predict TKN flux to represent a natural real-world response to short-term inundation.

Intact soil column studies have been widely used as laboratory simulations in determining the effects of inundation on biogeochemical responses in soils. Documentation on actual "flooding" procedures, however, are lacking in specific techniques. Although the objectives varied among research studies, laboratory protocols remained standard: "Each core was plugged and flooded" (Chambers, 2012), "[Cores were] filled with site water" (Marton et al., 2012), "Water was carefully added to the aquaria" (van Dijk et al., 2015), or "[Soils were] initially flooded" (Liu et al., 2017). In studies measuring nutrient flux specifically, laboratory simulations are typically conducted to determine long-term effects (weeks or months). When exploring nutrient flux within a short time period (hours or days), however, a large initial spike in nutrients was observed directly following the initial addition of water to intact soil cores. This spike was observed in our preliminary studies measuring the flux of total Kjeldahl nitrogen (TKN) into the water column, where it was hypothesized to be the result of a physical disturbance of soil particles during the addition of water using typical flooding procedures, releasing soil-bound TKN into the water column (unpublished data). Although this spike is often inconsequential for long-term studies that experience higher concentrations overall, a large initial flux of nutrients in short-term inundation studies will more likely negatively skew short-term flooding results with apparent overestimation than what may naturally occur.

Based on observations of our previous studies on TKN, a laboratory simulation study was conducted to distinguish the effects between physical disturbance and natural chemical dissociation of nutrients in response to short-term flooding with overall objectives of (i) designing a laboratory flooding simulation protocol to avoid any physical disturbance and (ii) determining TKN fluxes more accurately following short-term inundation in an intact soil column simulation.

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Abbreviations: TKN, total Kjeldahl nitrogen.

Materials and Methods

Prior to this study, separate intact soil cores were used in a study on TKN flux. Based on observations in our preliminary study, the current experiment was designed to analyze flood simulation techniques in minimizing soil physical disturbance. For this experiment, 12 intact soil cores were collected from the shoreline of Lake Alice, University of Florida Campus, Gainesville, FL, and consisted of fine, flocculent soil particles. Intact samples were collected in 30-cm-long polycarbonate tubes with a 7.3-cm inner diameter by pushing the tubes into the soil to 20-cm depth, removed, and capped on each end. In the laboratory, core tube interiors were cleaned to remove any particulate matter above the soil surface and then saturated to the soil surface with saltwater (EC = 49.9 mS cm^{-1}, pH = 8.34). Saltwater used in the experiment was fresh seawater collected from an offshore location and pumped through the Whitney Laboratory for Marine Bioscience located in St. Augustine, FL. Cores were randomly assigned a laboratory procedure (Fig. 1): filter paper placed flat on the soil surface (e.g., flat), filter paper folded into a cone and placed at the soil surface (e.g., cone), or standard laboratory procedure (nothing on soil surface, e.g., blank). Filter paper (Whatman 41, ashless) was used to work as a barrier to physically disturbed soil particles entering the water column while also being permeable to dissolved nutrients that chemically dissociate from the soil and into the water column (or vice versa). After placement of the assigned laboratory procedure, approximately 10 cm (400 mL) of saltwater was then slowly added to sit on top of each intact soil core. For analysis, 20 mL of water was removed from the floodwater of each tube and stored in scintillation vials with a cap; then 20 mL of saltwater was added back to each tube to maintain a constant volume of floodwater. After the initial sampling (time = 0), this process was repeated after 1 and 3 h. To determine the effectiveness of procedures in minimizing soil physical disturbance, floodwater samples underwent analysis for total P (USEPA Method 365.1; USEPA, 1993).

To confirm the credibility of the filter barrier procedure, TKN was compared between our preliminary flooding simulation (Fig. 2a) and a separate flooding simulation using the cone filter procedure (Fig. 2b, data not shown). Measured concentrations of TKN (actual TKN) were plotted over time, and polynomial best-fit lines of each plot were used to calculate TKN concentrations (predicted TKN) over time. Plots of actual versus predicted TKN concentrations were then used to determine R^2 values, or predictive power.

Fig. 1. Laboratory procedures: (a) filter paper flat on soil surface, (b) filter paper shaped into a cone on soil surface, and (c) nothing on soil surface. Cone preventing soil sediment and organic material from floating into water column of intact soil core; (d) side view of cone in floodwater and (e) overhead view of water columns of cone (left) and blank (right).

Results and Discussion

In soil, P's affinity for binding with particle surfaces makes it a reliable proxy for the amount of soil particles that flux into the water column on flooding. After 3 h of inundation, total P concentrations were significantly higher in the floodwater of blank soils (266.50 µg L^{-1}) compared with flat and cone procedures (67.84 and 66.27 µg L^{-1}, respectively; Fig. 3). In addition to larger total P concentrations, blank soils also had the largest standard error among replicates, further indicating the inconsistencies of standard soil column procedures.

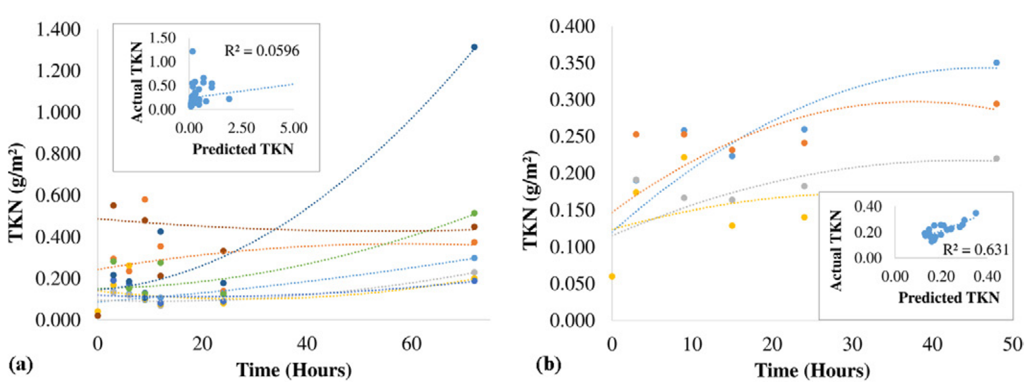

Fig. 2. Soil core replicates of total Kjeldahl N (TKN) concentrations over time. Inserted graphs are predicted vs. actual TKN concentrations with R^2. Predicted values calculated from polynomial best-fit lines. (a) Soil cores without cone filters; (b) soil cores with cone filters.

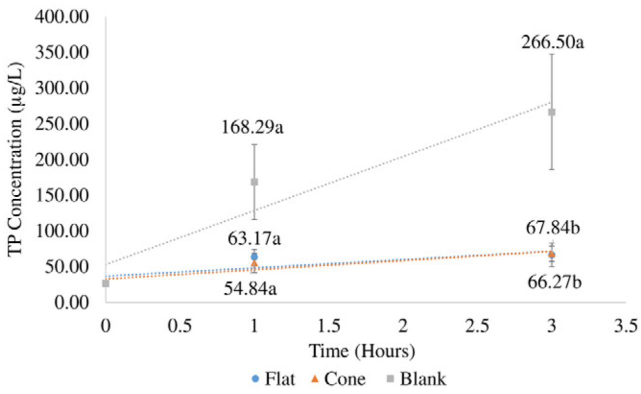

Fig. 3. Total P (TP) concentrations in floodwater above soils following flat, cone, and blank procedures. Points represent average and standard error of four replicates per procedure.

Results of this study illustrate that both flat and cone procedures significantly reduce the physical impact of flooding; however, soil type should be considered in evaluation. For example, Fig. 1d–e illustrate the ability of cones to prevent organic materials from the soil core, and any associated nutrients, from floating into the water column and potentially skewing flux data related to chemical effects of inundation. Therefore, the use of the cone procedure, hereafter referred to as the Collins-filter barrier technique, is recommended in future intact soil column short-term inundation studies.

After confirming the ability of the Collins-filter barrier technique to reduce physical disturbance, TKN data was analyzed to evaluate the effectiveness of the technique to predict TKN concentrations (data not shown). From our preliminary study, a large initial spike in TKN (Fig. 2a) resulted in a large overestimation of TKN concentrations compared with actual concentrations (actual vs. predicted TKN, $R^2 = 0.06$). In comparison, by using the Collins-filter barrier technique (Fig. 2b), the initial spike in TKN was reduced, allowing for a best-fit line to more closely predict TKN concentrations over time (actual vs. predicted TKN, $R^2 = 0.63$). The improvement in predictive power of TKN shown in Fig. 2 demonstrates that the Collins-filter barrier technique can be successfully used in future short-term inundation studies on nutrient flux.

Conclusion

Intact soil column studies allow for the simulation of inundation in a controlled environment, but current flooding procedures may cause a false overestimation of nutrient flux into the water column due to physical disturbance during the flooding process. By adapting the Collins-filter barrier technique to short-term flooding simulations, physical disturbance of soil particles is significantly decreased, allowing for more accurate measurements of TKN concentrations in the floodwater. This technique will, therefore, more accurately represent natural chemical nutrient flux response to short-term inundation, thus allowing better estimation of potential nutrient fluxes in real-world flooding events.

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