Title: A novel method to continuously monitor litter moisture - a microcosm-based experiment

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Abstract

Litter decomposition is a key biogeochemical process that strongly affects carbon and nutrient cycling. Our understanding of the controls over decomposition in arid and semi-arid systems is currently limited by a lack of capability to measure or predict litter moisture. Despite its potential importance in controlling litter decomposition, litter moisture has rarely been continuously monitored due to the technical constraints in doing so. The objective of this study was to test the feasibility of using inexpensive, commercially available relative humidity (RH) loggers (iButtons) to continuously estimate the litter moisture. We incubated two types of litter (conifer and broadleaf) in microcosms and tested RH-litter moisture relationships during a series of dry-down events. The results showed that we could successfully predict litter gravimetric moisture using iButton RH measurements.

Introduction

Litter decomposition is a crucial biogeochemical process which influences the size and residence time of carbon and nutrient pools (Aerts, 1997). Decomposition is generally viewed to be controlled by a combination of abiotic (e.g., temperature, moisture) and biotic (e.g., litter quality) factors that interact to mediate the community composition and metabolic activity of decomposers (Couteaux et al., 1995). Decomposition models based on long-term averages of simple climate parameters (e.g., annual actual evapotranspiration) have generally been successful at predicting decomposition rates in mesic systems globally (Parton et al., 2007). However, these decomposition models have been less successful in drylands (arid and semi-arid systems), where they typically under-predict decomposition (e.g., Parton et al., 2007; Whitford et al., 1981). The disparity between decomposition models and measurements suggests that controls over decomposition in dry systems differ fundamentally from those for wetter systems and/or that unique drivers (e.g., photodegradation and soil-litter mixing) may play a key role in dryland decomposition (e.g., Austin, 2011; Tan et al., 2013; Throop and Archer, 2009).

The idea that controls over litter decomposition differ between mesic and dryland systems is supported by a recent synthesis showing no apparent relationship between annual precipitation and decomposition at sites with <500 mm annual precipitation (Austin 2011). Indeed, several individual studies found positive responses to enhanced annual precipitation in drylands (Brandt et al. 2007; Yahdjian et al. 2006), while others have shown no response to changes within a site to either annual precipitation (Gallo et al. 2009; Vanderbilt et al. 2008) or rainfall pulse size (Austin et al. 2009; Whitford et al. 1986). While the lack of consistent response could be a function of a lack of mechanistic control of moisture over decomposition, this seems unlikely given the ubiquitous control of moisture over dryland ecological processes (e.g., Austin et al., 2004; Wang et al., 2012; Wang et al., 2009). An alternative explanation is that annual precipitation does not reflect biologically-available litter moisture. Surface litter is less buffered by moisture and temperature extremes than subsurface locations (Whitford 2002). Thus, biologically available moisture in surface litter should persist for much shorter time periods following rainfall pulses than would soil moisture. The lack of a consistent relationship between precipitation and decomposition is likely a function of a lack of temporal resolution in exploring these relationships, and not a lack of sensitivity of decomposition to moisture.

The importance of litter moisture in litter decomposition has been suggested in both mesic (Halupa and Howes, 1995; Hudson, 1968) and dry environments (Nagy and Macauley, 1982) but it is rarely measured. The lack of litter moisture measurements is due, in part, to technical constraints to quantification (Ataka et al., 2014; Nagy and Macauley, 1982). Measuring litter moisture content presents a challenge as standard soil moisture probes rely on continuous contact with soil (Wilson et al., 2014) and do not work for thin and discontinuous litter layers that are often found in drylands. However, strong relationships between relative humility (RH) and surface soil moisture exist (Ravi et al., 2004), suggesting the possibility of estimating litter moisture from near-surface RH measurements. An earlier laboratory chamber experiment supports the relationship between litter moisture and RH, although RH was not directly quantified in that experiment (Nagy and Macauley, 1982). The objective of this study is to test the use of a small, inexpensive, and commercially available RH sensor (iButton) to quantify the litter moisture. We designed a microcosm experiment to test the relationships between RH and litter moisture and discuss the possibility of applying this method to field studies.

Materials and Methods

Two microcosm systems made of wooden boxes of 1.5 m (width) x 1.5 m (length) x 0.15 m (height) were built using wood boards. A plastic liner was used inside the wooden boxes to prevent water leaching from the bottom of the microcosm systems and 2 cm soil was placed on the top of plastic liner (Figure 1A). Two types of litter were used, one was mixed broadleaf litter (from a forest dominated by American sycamore, *Platanus occidentalis,* and hickory, *Carya* spp.) and the other was conifer litter (Norway spruce, *Picea abies*). Broadleaf litter and soil were collected from Turkey Foot Nature Park, Zionsville, IN and conifer litter and soil were collected from the Colony Woods neighborhood in Zionsville, IN. Freshly abscised leaf litter was collected from the ground. The litter was kept in their original structure as much as possible. Multiple experiments were conducted with each experiment lasting two to three days, only a single set of the experimental results was presented in figures for clarify. For each experiment, broadleaf litter was in one microcosm and conifer litter was in the other. The broadleaf litter was layered ca. 6 cm deep and conifer litter was ca. 2 cm deep on top of 2 cm of soil. At the beginning of each experiment, the soil and litter layers were brought to field capacity.

Relative humidity (RH) was monitored with iButton temperature and RH loggers (model DS1923-F5#, Maxim, Sunnyvale, CA, USA, temperature range = -55°C to +100°C, RH range = 0 to 100% RH; Figure 1B). This RH sensor type was selected due to its small size, low cost, and lack of requirement continuous connection to an external data logger. These attributes make it a viable option for distributed sampling that would be required to characterize litter moisture in dryland systems with discontinuous and patchy litter layers and plant canopy cover. The iButtons were placed on the litter surface for both litter types. For the conifer litter, iButtons were also placed 1 cm above the litter surface (elevated) to test the influence of iButton position. During each experiment, a subsample of litter (~5 g) from the top 1 cm of the litter layer was collected from each microcosm at hourly intervals between 8:30 am to 6:30 pm. The litter samplings were based on a grid system to avoid duplicated samplings at one location. The gravimetric water content of each collected litter sample was determined by drying the litter at 65^{o}C for 48 hours. The RH at the different locations was monitored using iButtons at one-minute time intervals. These data were averaged to hourly values to match the gravimetric measurements. The relationships between litter moisture (gravimetric water content) and RH at the different locations were analyzed using regression analyses with a significance level of $\alpha = 0.05$ (Matlab 8.2, MathWorks, Natick, MA, USA). The difference of the slopes of RH and gravimetric litter moisture between two litter types was compared using ANOVA. A rain event during one experiment substantially raised the room ambient humidity, allowing comparison of results during different atmospheric conditions.

Results and Discussion

1. Effect of litter types and sensor placement locations

Significant linear relationships between RH and gravimetric litter moisture were found for both conifer litter ($0.68 < r^2 < 0.89$, $p < 0.05$, Figure 2A) and broadleaf litter ($0.56 < r^2 < 0.85$, $p < 0.05$, Figure 2B), indicating the feasibility of using RH monitoring to predict litter moisture. The slopes of the regression equations differed between the two litter types (e.g., 26.3 for conifer and 13.6 for broadleaf litter, $p< 0.05$, Figure 2), suggesting that *a priori* testing is needed to establish the RH-litter moisture relationship for a specific litter. We found that the elevated placements generated weaker relationships between litter moisture than did the surface placements (e.g., lower R^2 values, Supplementary Data), likely because the elevated sensor integrated over a larger area, which is supported by that fact that RH was consistently lower in elevated sensors than surface placements. The optimum locations are likely affected by several factors such as the litter texture and initial water content, underscoring the importance of initial testing before long-term deployment. Due to the increasing recognition of the importance of litter moisture monitoring, two recent studies investigated litter moisture estimates with commercially available capacitance soil moisture probes (Ataka et al., 2014; Wilson et al., 2014); both showed promising results. However, both these methods require close contact of the litter layer and the sensors. Our RH measurement method differs from the soil moisture probe methods since it does not require close contact between the litter layer and the sensors. The RH method may thus be more promising in drylands where litter layers are often thin and discontinuous.

2. The potential application under the field conditions

To test the applicability of using the RH monitoring method under the field settings, we analyzed data from a rainy period when the indoor RH changed dramatically following a rainfall event, increasing from ca. 15% to 50% (Figure 3E). After the rainfall event, the relationships between RH and gravimetric litter moisture were much weaker than during the drier days (Figure 2) for both types of litters (Figure 3A and C). However, after removing the room RH effect by subtracting the ambient room RH values (measured at locations far from the microcosms) from litter RH values, strong relationships existed between RH and gravimetric litter moisture in both types of litters (Figure 3B and D). This indicates that the RH monitoring method is applicable under variable moisture conditions but that litter RH values must be corrected for fluctuations in ambient RH. The effects from other meteorological factors such as wind and solar radiation require further investigation under the field conditions.

In summary, we demonstrate that litter moisture can be predicted from litter surface RH based on a microcosm experiment using two types of litter. The RH monitoring method has the potential to be applied under field conditions if the ambient RH is monitored simultaneously. Potential future improvements to this method include a consideration of the effects of soil-litter mixing, which may buffer litter moisture (Lee et al., 2014), and a test of the effects of meteorological variables such as direct precipitation, wind, and solar radiation on RH-litter relationships.

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Figure 1. The microcosm experimental setup (A) and a photo of iButtons and iButton data reader (B). The US quarter is for scale.

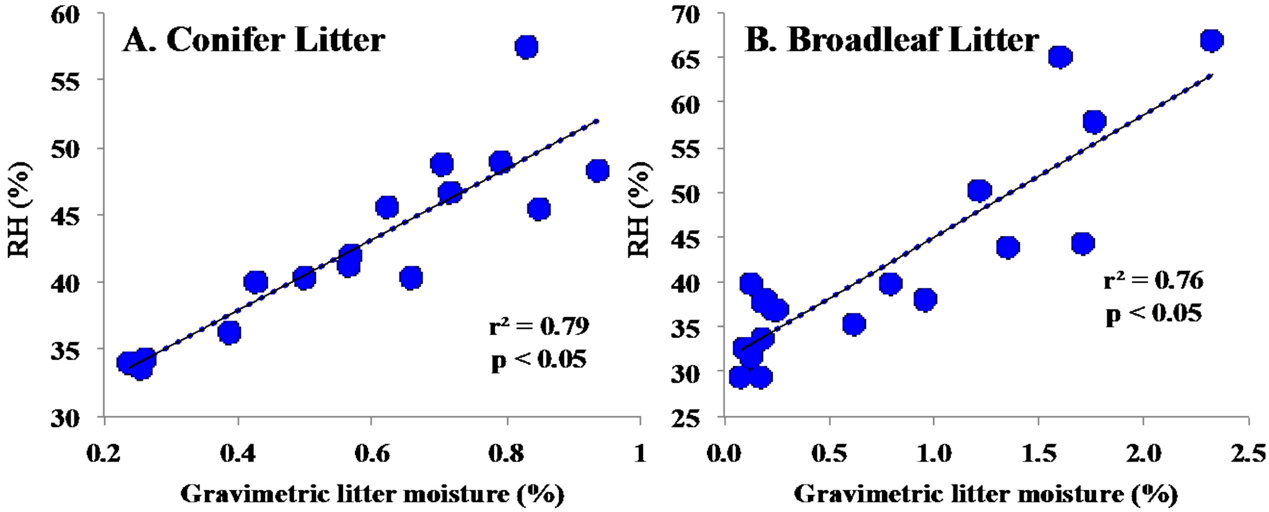

Figure 2. The relationship between relative humidity and gravimetric litter moisture for conifer litter (A) and broadleaf litter (B).

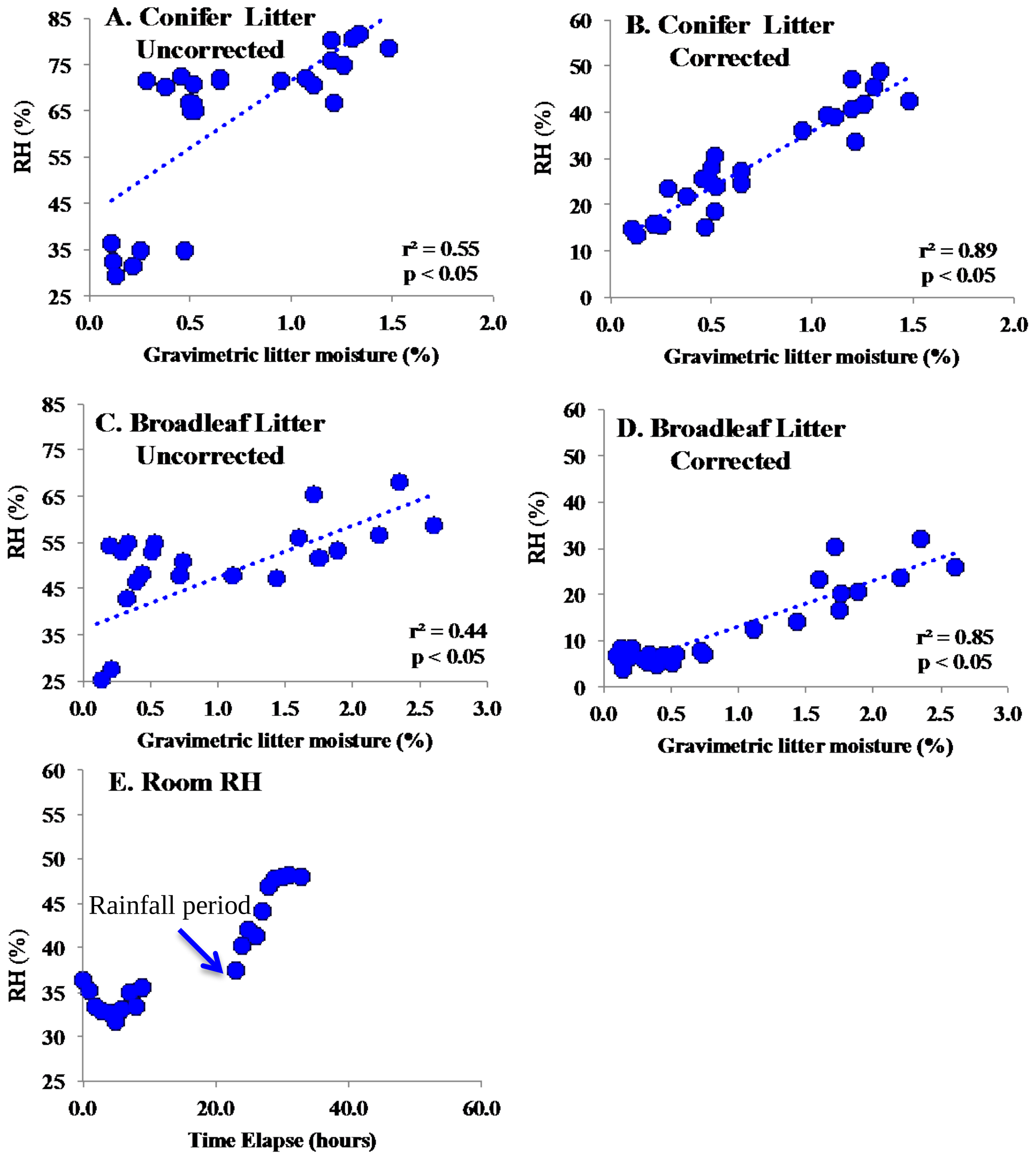

Figure 3. The relationship between relative humidity and gravimetric litter moisture for conifer litter under uncorrected (A) and corrected condition (B); and for broadleaf litter under uncorrected (C) and corrected condition (D) during a raining period. The correction is based on the relative humidity dynamics of the control (i.e., ambient room relative humidity, (E)) during the measuring period.