Research Note / Note de recherche

Variation in Plant Litter Decomposition Rates across Extreme Dry Environments in Qatar

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Decomposition of plant litter is a key process for transfer of carbon and nutrients in ecosystems. Carbon contained in decaying biomass is released to the atmosphere as respired CO_2, a greenhouse gas that contributes to global warming. To our knowledge, there have been no studies on litter decomposition in terrestrial ecosystems in the Arabian peninsula. Here we used commercial teabags (green tea, rooibos tea) as standard substrates to study decomposition rates across contrasting ecosystems in Qatar.

Teabags were buried under and beside Acacia tortilis trees, in depressions with abundant grass vegetation, in saltmarsh without and with vegetation, under Zygophyllum qatarense in drylands, in natural mangrove and in planted mangrove. There were significant site effects across ecosystems on decomposition rate (k), litter stabilisation factor (S), final weight of green tea and final weight of rooibos tea. Mangrove and depressions with grassland had the smallest amounts of remaining green and rooibos tea after the incubation period (69-82 days), while teabags buried under A. tortilis and in saltmarsh without vegetation had the largest amounts. Thus decomposition rates differ among ecosystems in the desert environment. Further multi-year and site studies are needed to identify factors that influence decomposition rates across sites in extreme environments.

Keywords: Arabian Peninsula, carbon turnover, climate change, litter bags, green tea, rooibos tea, teabag index, plant litter decomposition rates

Introduction

Plant litter decomposition plays an important role in the global carbon cycle (Aerts 1997; Aerts 2006). It is estimated that more than 50% of net primary production ends up in the soil (Wardle et al. 2004), while a large proportion is emitted to the atmosphere (Houghton 2007). Decomposition rates of soil organic matter increase with temperature and are more sensitive to changes at lower temperatures than at higher temperatures (Kirschbaum 1995). This affects soil carbon content globally, with values typically being highest in cold regions (Lal 2004). Other important factors affecting decomposition of plant litter are precipitation, substrate, the quality of the plant litter and the organism performing the decomposition (Cornelissen et al. 2007; Gavazov 2010). Models suggest that climate and litter quality explain roughly 60-70% of global litter decomposition rates (Parton et al. 2007). A global study has indicated that in cold, dry regions, climate conditions are more important for decomposition, while in warm, wet regions soil fauna are the main controller (García-Palacios et al. 2013). However, that study did not include any sites from the Arabian Peninsula with its extreme weather conditions. Similarly, another global study (that also lacked data from the Arabian peninsula) showed that climate (actual evapotranspiration) was the best predictor of the decomposition constant (k-value) for litter (Aerts 1997). Mean k-value was positively correlated with actual evapotranspiration, both being highest in the humid tropics (Aerts 1997). On a global scale, climate change is likely to affect decomposition processes, as increased levels of atmospheric carbon dioxide are likely to affect the nitrogen content of litter and as warming will most likely increase decomposition rates (Couteaux et al. 1995; Kirschbaum 1995; Cornelissen et al. 2007).

There have been relatively few decomposition studies in arid environments, despite the fact that these cover about 12% of the total soil surface on earth (Goodall et al. 2009). This is a serious omission, as existing models, which to a large extent focus on precipitation, cannot account for the rapid turnover of organic material in these environments (Vossbrinck et al. 1979; Montaña et al. 1988; Steinberger et al. 1990; Austin and Vivanco 2006). Instead, in arid environments photodegradation (Austin and Vivanco 2006; Barnes et al. 2015; Liu et al. 2015; Huang et al. 2017), soil-litter mixing (Lee et al. 2014; Barnes et al. 2015; Hewins and Throop 2016; Joly et al. 2017) and precipitation pulses (Hamadi et al. 2000; Hewins and Throop 2016; Joly et al. 2017) have been suggested to be important for decomposition. The extreme arid environments of the Arabian Peninsula are particularly under-represented in litter decomposition studies. Mangrove wetlands are somewhat better studied, e.g. a study on litter decomposition in a mangrove in Qatar found an initial mass loss of 68% within the first 108 days, after which the decomposition rate declined (Mahasneh 2001). This is in line with findings by others that early-stage decomposition is faster, with leaching of soluble compounds and decomposition of non-lignified cellulose and hemicellulose (Berg and McClaugherty 2003). However, to our knowledge there are no previous studies on litter decomposition in the extreme arid environment of terrestrial ecosystems in the Arabian Peninsula. Therefore, in the present study we measured the initial mass loss of organic matter and calculated the stabilisation factor S and decomposition rate k across different ecosystems in Qatar, using commercial green tea and rooibos tea as model litters. The teabag index that can be derived from these measurements represent a uniform decomposition value can be compared across ecosystems (Keuskamp et al. 2013; Didion et al. 2016). Our specific objective was to determine whether decomposition rates vary across different ecosystems in the extreme arid environment of Qatar, as warm dry environments may not result in great differences in decomposition rates.

Methods and Study Sites

Study Sites

Qatar lies within the desert belt extending from North Africa to Central Asia and is one of the most arid countries in the world, with average annual rainfall of 78.1 mm, so water is a major limiting ecological factor. The climate is classified in the Köppen system as *BWhsn* (hot desert climate with winter rainfall and high relative humidity). Sporadic rainfall events occur from October to May. Temperature ranges between 35°C and 45°C in summer, and between 15°C and 30°C in winter (December-February).

The test teabags were buried at 10 sites (Table 1) that represent common landscape and vegetation types in the Arabian Peninsula. These were: *Acacia tortilis* (acacia) drylands (two sites), grassland, saltmarsh without vegetation, saltmarsh with vegetation (two sites, dominated by *Salsola* spp.), drylands with the succulent *Zygophyllum qatarense*, two natural mangrove sites (*Avicennia marina* Forsk.) and planted mangrove (*A. marina*) (Table 1). The *Acacia tortilis* drylands had sparse cover of *A. tortilis* trees without undercover vegetation (which sprouts after sporadic rainfall events), so teabags were buried under *A. tortilis* trees and in patches of bare ground just beside the trees. The grassland site was located in a landscape depression, where grasses are abundant after rainfall events, after which they wilt slowly as the soil dries out.

Methods

We followed the teabag index protocol (Keuskamp et al. 2013), and used commercial Lipton green teabags (EAN: 87 22700 05552 5) and Lipton rooibos teabags (EAN: 87 22700 18843 8), made from nylon with a mesh

TABLE 1
List and location of sites in Qatar included in the litter decomposition study.

Location codes	LAT	LONG	Soil type	Vegetation type
Grassland depression	25.37446	51.51617	Sandy loam	Grasses
Saltmarsh with vegetation	25.72942	51.57562	Silty loam	Salsola spp.
Saltmarsh with vegetation	25.69819	51.55212	Silty loam	Salsola spp.
Saltmarsh no vegetation	25.65812	51.54709	Silty loam	No vegetation
Acacia vegetated	25.51005	51.41388	Sandy loam	Acacia tortilis
Acacia bare ground	25.40923	51.45926	Sandy loam	No vegetation
Mangrove	25.73607	51.57624	Marine alluvium	Avicennia marina
Mangrove	25.69730	51.55065	Marine alluvium	Avicennia marina
Planted mangrove	25.66118	51.54853	Marine alluvium	Avicennia marina
Zygophyllum	25.37446	51.51617	Sandy loam	Zygophyllum qatarense

size of 0.25 mm, which allows microorganisms and mesofauna access to the tea but excludes macrofauna (Setälä et al. 1996). Green tea has a high cellulose content and faster decomposition than rooibos tea, which has a high lignin content (Keuskamp et al. 2013).

All teabags were weighed (air-dry, to 0.0001 accuracy) and 46 replicate pairs of green and rooibos bags were buried 8 cm deep in holes at each location, with each bag in a separate hole. The bags were buried between 12 and 20 March 2017 and retrieved between 28 May and 6 June 2017 (incubation duration 68-82 days).

The retrieved teabags were cleared of soil and roots and oven-dried (70°C for 48 h). Due to the fact that the silty soil entered the bags, weight loss of the teabags was then determined by deducting loss on ignition (overnight at 550°C). Four bags had to be removed from the analysis due to damage from invertebrates and foxes, leaving 42 tea bags for analysis.

Stabilisation factor $\boldsymbol{S}$ (i.e. the fraction of the labile material that is not decomposed, but stabilises after three months) and decomposition rate, k, were calculated according to Keuskamp et al. (2013) based on the equation:

$W(t) = ae^{-k1t} + (1- a)*K_2 = ae^{-k1t} + (1- a)$

where W is weight, a is decomposable fraction (where S + 1 - a), t *is* time (days incubated), K_1 is decomposition rate of the labile fraction (steep part of the curve) and K_2 is decomposition rate of the recalcitrant fraction, assumed to be 0 during short incubations of less than 3 months. a was determined initially for green tea:

$S = 1- a_{green}/H_{green}$

and, assuming that stabilization was similar for green and rooibos tea, a_{roo} was calculated as:

$a_{roo} = H_{roo}\,(1 - S)$.

where H_{green} and H_{roo} are the hydrolysable fraction of green and rooibos tea, respectively, determined in laboratory extractions (Keuskamp et al, 2013).

Subsequently, k can be calculated from:

$$W(roo) = a_{roo}\, e^{-kt} + (1 - a_{roo})$$

Statistical Analyses

The data were not normally distributed, so we used the conservative non-parametric Kruskal-Wallis test to analyse the effect of site on stabilisation factor S, decomposition rate k, mass loss of green tea and mass loss of rooibos tea. All analyses were performed in IBM © SPSS © Statistics Version 24.

Results and Discussion

Across ecosystems, we found a significant site effect on decomposition rate ($p=0.011$), litter stabilisation factor ($p=0.001$), final weight of green tea ($p=0.001$) and final weight of rooibos tea (p 0.001) (Figure 1). The mangrove and grassland depression sites had the smallest amounts of remaining green and rooibos tea after the incubation period in soil, while teabags buried under *A. tortilis* and in saltmarsh without vegetation had the largest amounts. Rapid litter turnover and high k values in mangrove have also been reported in other studies (Tam et al. 1998; Li and Ye 2014). As expected due to differences in the 'litter' quality, rooibos tea (high lignin content) had higher remaining mass after the incubation period than green tea at all sites. The faster decomposition of green tea (high cellulose content) across all sites is in line with the suggestion that litter quality is one the major controllers of litter decomposition (Cornwell et al. 2008; Zhang et al. 2008; Li et al. 2011; Bradford et al. 2016). Water availability has also been suggested to be an important controller of litter decomposition on local scale in deserts and semi-arid regions (Couteaux et al. 1995; Zhang et al. 2008; Joly et al. 2017), with drier sites having lower k values (Gholz et al. 2000). A previous study in the Al Barriyya Desert (Palestine) found that decomposition rates were significantly higher during the short rainy winter period than in the dry period (Hamadi et al. 2000). Experimental water addition in semi-arid Inner Mongolia also significantly increased k values (Liu et al. 2006), while warming and experimental rainfall reduction significantly decreased litter decomposition in dry Mediterranean grassland (Almagro et al. 2015). In Qatar, water availability is likely to be an important controller of decomposition, as the country has an extreme arid environment with only sporadic rainfall events and with no permanent freshwater bodies. This was reflected in our data, as drier acacia sites had lower *k* values than mangrove sites, which were wetter. While sporadic local rainfall events could thus be expected to temporarily increase the decomposition rate at drier sites in Qatar, global warming accompanied with decreased rainfall could potentially decrease litter decomposition in the longer term. Our study was conducted during the dry spring-early summer period, so further long-term studies are needed to capture sporadic rainfall events.

The initial study in which the teabag index was developed was able to distinguish differences in decomposition rate (*k*) and stabilisation factor (*S*) between ecosystems on a global scale after an incubation period of ca. 90 days (Keuskamp et al. 2013). Here we show that the method also works well on a smaller regional scale, as we were able to distinguish differences in both *k* and *S* between different ecosystems in Qatar. In fact,

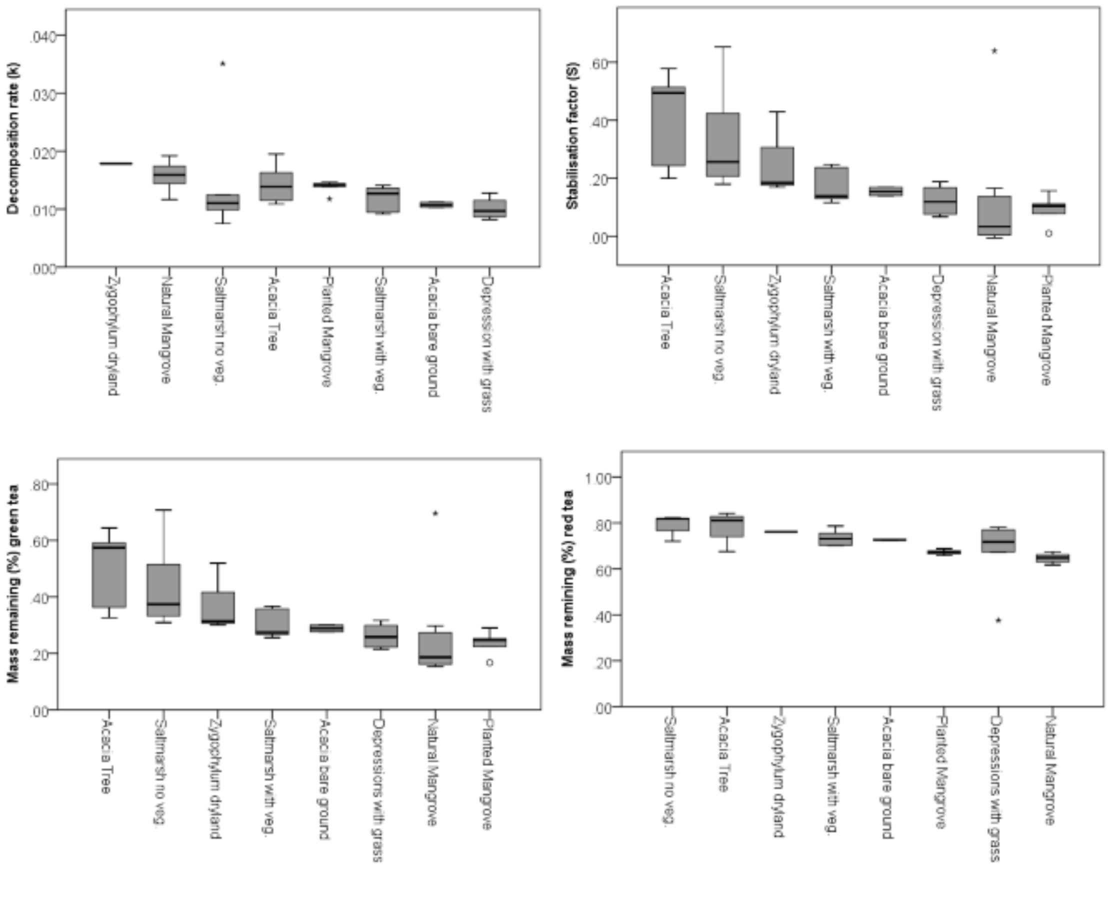

FIGURE 1

Box plots of decomposition rate k, stabilisation factor S and mass loss of green and rooibos tea for different ecosystems in Qatar, where k represents the short-term dynamics of litter decomposition and S is indicative of long-term carbon storage. Calculations were based on incubation periods of between 69 and 82 days. Labels indicate ecosystems. Box plots show the 10th -90th percentiles of the data.

our results show that there is considerable variation in *k*, *S* and mass loss of litter between local dryland ecosystems, and that the teabag index is suitable for studies on litter decomposition in arid environments. The *k* and *S* values for mangrove and the arid *Acacia* and *Zygophyllum* sites were in line with values reported for mangrove in Florida and for desert soils in China (Keuskamp et al. 2013). However, in order to gain a better understanding, experimental multi-year and multi-site studies are needed to identify factors that influence decomposition rates across ecosystems in the extreme environments of the Arabian peninsula.

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