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Effects of Maple Sugaring on Leaf Litter Decomposition in Vermont Forests

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Abstract

The purpose of this study was to examine if tapping sugar maple trees alters the decomposition of their leaf litter. To do this, leaf litter collection baskets were placed in tapped and untapped stands of maple trees in Proctor Maple Research Center in Underhill, Vermont. Litter was allowed to collect in the baskets throughout the fall 2016 season, and then the leaves were dried, weighed, and run through a nutrient analyzer. The nutrient analysis yielded percent nitrogen by weight, percent carbon by weight, and carbon nitrogen ratios for each sample. It was found that the leaf litter of untapped samples had significantly more nitrogen and significantly lower carbon nitrogen ratios than the leaf litter collected in the tapped stand. This indicates a likely change in the decomposition of the leaves in each stand, because nutrient ratios have been shown to alter decomposition rates for leaves. One of the implications of slowed decomposition is retarded nutrient cycling, which could lead to a reduction in available nitrogen, a limiting nutrient for sugar maples, in the forest's soil. More research should be done to determine the origin of the difference in nutrients. Additionally, a longer-term study is necessary to monitor the decomposition rates in this forest.

Introduction

Maple syrup constitutes a major industry in Vermont and the greater Northeast (van den Berg, 2013). The syrup is produced by drilling small tap holes into sugar maple trees to collect sap, then distilling the sap into syrup. While existing studies have looked into various ways maple stands adapt to being tapped (Wilmot, 2016), these studies operate on the assumption that nutrient flow and leaf litter decomposition are not significantly altered as a hole is drilled into the tree. With over \$100 million (USD) worth of maple syrup being sold each year in the United States and Canada (Lovett and Mitchell, 2004), it would not be a wise financial decision to ignore the possible negative effects of tapping maple trees on leaf litter decomposition.

Tapped sugar maples are a unique demographic of tree. Once the tree is tapped, a column of nonconductive wood forms above and below the tapping site in an attempt to heal the tree (van den Berg et al. 2013). By virtue of being nonconductive wood, this part of the tree is now unavailable for nutrient storage and transport. Pregitzer et al. (2010) showed that different parts of trees draw their nutrients from different sources. For example, the roots of a maple tree draw their elements, primarily nitrogen, directly from the soil. Alternatively, leaves seem to draw their nitrogen supply from stores within the tree, probably the trunk (Pregitzer et al. 2010). When there is a nonconductive portion of the trunk from tapping, based upon Pregitzer et al.'s (2010) findings, the way leaves draw their nutrients would necessarily be altered and thereby potentially change their nutrient contents. Leaves with reduced nutrient quality will undoubtedly become litter with low nutrient quality.

It has been hypothesized that increased nutrients in litter increases the decomposition rate, but Aerts and Kaluwe (1997) debate this. They argue that it is not the mere presence of nutrients that speeds decomposition, but the ratios in which the nutrients are present. For example, the carbon nitrogen ratio is one of the strongest indicators as to how quickly litter will break down.

Kominsky et al. (2007) found that litter decomposed more quickly when it was composed of more than one species. However, there was not a dramatic increase in decomposition rate as the number of species increased to greater than two.

Maple sugaring stands are most often predominately composed of sugar maple trees and in some areas may be managed to be exclusively sugar maples, which may contribute to a slower rate of decomposition.

The rate at which litter decomposes is important, because the volume of leaf litter can have a negative impact on the plants attempting to grow in the area. If the rate of decomposition is too slow, the litter will build up. This is problematic, because, there is markedly decreased survivorship for young maple trees in areas with large amounts of leaf litter (Patterson et al. 2012).

Past research shows that plants are closely intertwined with the soil in which they grow (Eniver and Hawkes, 2008), and Ross et al (2011) even goes so far as to say that soil nutrients are reflective of the nutrients in past leaf litter. For instance, soil conditions limit what types of plants can grow there and how well they grow. In turn, plants heavily influence soil structure including nutrient content and cycles by decomposing near the base of the tree.

Sugar maples are known for their ability to quickly release nitrogen back into the soils through litter decomposition (Lovett and Mitchell, 2004), and nutrient release rates are highly correlated with the original nutrient quality of the leaves (Tian et al. 1992). Nitrogen is a notable limiting factor for a lot of productivity in maple trees. Slowed decomposition through off balance nutrient ratios would delay the nitrogen that the trees so desperately need from becoming available in the soil, harming the future growth of the trees.

Damaged sugar maples in established stands would no doubt be a blow for the maple syrup industry. Consequently, it is crucial to better understand the implications of tapping sugar maple trees on their leaf litter decomposition so that improved management strategies can be developed and implemented.

The purpose of this experiment is to examine the validity of the assumption that tapping maple trees does not significantly alter nutrient flow by comparing leaf

litter accumulation and carbon nitrogen ratios of tapped and untapped sugar maple stands. It is hypothesized that there will be a substantial difference in the decomposition of leaf litter from tapped and untapped trees. If, as predicted, there is truly a difference in the decomposition potentials of tapped and untapped leaf litter, significantly different amounts of nitrogen and carbon will be observed from a nutrient combustion analysis.

Materials and Methods

Study Site Description

The Proctor Maple Research Center is a natural research facility affiliated with the Plant Biology Department at the University of Vermont. The Center is located in Underhill, Vermont. The focus of the facility is basic and applied research around sugar maple trees, including how to create an improved maple syrup and understanding the physiology of sap flow. While most of the land is designated for trees that have been tapped for sap collection, there are also some stands that have not been tapped. The areas that were chosen for “tapped” and “untapped” treatments are both near and along the “red line”, in the stands closest to the site’s sugaring house. Both stands had as similar a management history as possible, however, the tapped stand contained some trees that were older than those in the untapped stand. Additionally, the tapped stand was at a slightly higher elevation than the untapped stand, as there was a slope between the two. The tree species compositions of the two stands were similar. The stands, being part of a research forest, had been subjected to some forest management, most notably the felling of some trees in both stands in the year before this study was conducted.

Sampling Units

Ten leaf litter collection baskets were prepared from 16”x13.5”x9” plastic crates. The crates were slotted on the sides and solid on the bottom to prevent any very fine leaf litter from falling out. 4mm black plastic mesh was used to line the sides, but not the bottom of the crate. The sides were lined with mesh so that fine leaf litter would not fall out through the slits in the crate. The 4mm mesh size was chosen because it was large enough to allow some common macro invertebrates to enter the basket and aid with decomposition while still being small enough to retain leaf litter. The mesh was secured to the sides of the basket with plastic zip ties. The baskets were labeled on the outside with letters (A through J) written in permanent marker to denote their study location.

Field Sampling Protocol

On October 12, 2016 at beginning at 10am, leaf litter collection baskets were placed in Proctor Maple Research Center. Baskets A through E were placed in the untapped section. Exact locations for baskets were chosen so that each of the five baskets were within 4 feet of a mature sugar maple tree and so that from one basket the other four could be seen. Areas were chosen where the ground was flatter to prevent the baskets being knocked or blown over by the wind. When the baskets were placed, some leaf litter on the ground was shifted to better place the baskets, however, it was ensured that none of the baskets had external leaf litter reaching high enough up the outside that it could get into the basket.

Baskets F through J were placed in the tapped section. Location selection was similar to that for the untapped section with the major difference being that all baskets were placed within 4 feet of a tapped maple tree (the area also included some untapped maples). At the time the leaf litter baskets were placed, the altitude, geographical coordinates, and the exact distance from nearest maple tree were recorded. All baskets were placed on the same day, within an hour of each other.

When the baskets were placed, the foliage was beginning to turn colors and the first few leaves had just fallen. This timing was selected to ensure that the leaf litter collected was from seasonal leaf loss and not due to other causes of leaf dropping that trees may experience out of the fall season, which may indicate health issues with the trees.

Biweekly monitoring of the baskets was conducted to observe leaf dropping and to ensure that the baskets were not disturbed by wildlife or storms. The baskets were allowed to sit until the November 18, 2016 at 8:30am, after just over 5 weeks in the field, when it appeared that most of the maple trees in the forest had dropped their leaves.

Sample Processing and Laboratory Analysis

Upon collection, the leaves were dried and the dry weight for each sample was recorded. A brief species analysis was done for each sample to ensure that the leaves in the basket accurately represented the species of trees that were observed around the placement location.

Once the analysis was completed, the dried leafs were ground first with a mortar and pestle to break up bigger leaf pieces so that they could be further processed. At this time, twigs were removed. A TRIPP grinding machine was used to further grind the leaf litter into a fine powder. To obtain the Carbon Nitrogen ratios of the samples, a nutrient analysis was performed using a FlashEA nutrient analyzer. To prepare the samples for the analysis, each sample had to be weighed and wrapped in a capsule. For each capsule, a sheet of foil was pressed into the shape of a cup. 15-18mg was weighed out in the “cup”, with the exact weight being recorded. Once the sample was in the “cup”, the top of the foil was pinched together and pressed down to form a disc shape with the powder sample inside. For each basket, three subsamples were run through the nutrient analyzer to ensure there were not any significant effects from the subsampling. Wheat flour and powdered tomato leaves were used for quality control standards and run before, twice in the middle, and at the end of the unknown samples. The carbon and nitrogen contents were known for both the flour and tomato leaves so that percent recovery for those known samples could be calculated.

Data Structure

The resulting data consisted of distance from the nearest maple, geographic coordinates, elevation, and total mass of dried leaf litter collected at each sampling site. The laboratory analysis gave percent nitrogen by weight, percent carbon by weight, and a carbon nitrogen ratio for each subsample.

Statistical Analysis

Statistical analyses were run in R Studio and ANOVAs were performed to determine statistical significance of the data. Quality control samples were evaluated using R Studio. R Studio was further used to calculate means and standard deviations for nutrient content in the leaves and to create figures. Means and standard deviation were calculated for each individual basket from the triplicate samples, as well as for each treatment type. The locations of the leaf litter collection baskets were also plugged into a Geographical Information System Program, ESRI, to help highlight any potentially confounding characteristics of the two stands.

Results

The percent recoveries of nitrogen for the quality control samples had percent differences ranging from 0-14% different from the known content. The percent recoveries of carbon for the quality control samples had percent differences ranging from 0-10%. In both cases, there was one outlying sample, the first sample run, which had a larger percent difference. Excluding that sample, the percent recoveries fell into an acceptable range, meaning that there was less than 10% deviation from expected recovery.

The mean nitrogen contents for untapped treatment baskets A, B, C, D, and E were 1.208%, 1.180%, 1.246%, 1.157%, and 1.161% respectively. The mean nitrogen content for the untapped treatment overall was found to be 1.190% with a standard deviation of .033. The mean nitrogen content for the tapped treatment baskets, F, G, H, I, and J were .984%, 1.051%, 1.049%, 1.168%, and 1.079% respectively with the tapped treatment having an overall mean of 1.126% and standard deviation of .0596. An ANOVA comparing the nitrogen contents of the tapped and untapped treatments yielded a p-value of .0066 (Figure 1).

The mean carbon contents for untapped treatment baskets A, B, C, D, and E were 48.130%, 49.182%, 48.261%, 48.752%, and 48.081% respectively with an overall mean for the treatment of 48.481% and a standard deviation of .423. The mean carbon contents for the tapped treatment baskets F, G, H, I, and J were 50.290%, 46.747%, 48.870%, 47.884%, and 48.834% respectively. The overall mean carbon content for the tapped treatment was 48.527%, and the treatment had a standard deviation of .0596. When the carbon contents of the two treatments were compared with an ANOVA, the found p-value was .943 (Figure 2).

The mean carbon nitrogen ratios for untapped treatment baskets were 39.85:1, 41.68:1, 38.74:1, 42.15:1, and 41.42:1 respectively. The mean ratio for the untapped treatment was 40.768:1 with a standard deviation of 1.276. The mean carbon nitrogen ratios for tapped treatment baskets F, G, H, I, and J were 51.12:1, 44.49:1, 46.58:1, 41.01:1, and 45.27:1 respectively. The mean ratio for the tapped treatment was 45.693:1 with a standard deviation of 2.99. An ANOVA test

comparing the ratio of the untapped baskets to those of the tapped yielded a p-value of .023.

ANOVA tests comparing the untapped and tapped treatments for mass of leaves once dried (Figure 3), elevation at which litter was collected, and distance of the basket from the nearest maple tree gave p values of .184, .126, and .295 respectively.

Discussion

The hypothesis that there is a substantial long-term effect from tapping a maple tree on leaf litter decomposition is supported, but not proven, by this study. The decomposition of tapped compared to untapped sugar maple leaf litter is currently relatively poorly understood. However, it is important to look further into as it has been shown that these nutrient ratios in turn affect the decomposition rates of leaf litter and nutrient cycling on the floors of tapped sugar maple stands.

Nitrogen and Carbon Contents

There was a very significant difference in the nitrogen percentages between the tapped and untapped trees, with a p-value of .0066. While the carbon concentrations themselves were not observed to be significantly different, the very large difference in nitrogen contents made the carbon nitrogen ratios significantly different between the two treatments as well.

Carbon Nitrogen Ratios

The results showed carbon nitrogen ratios ranging from 38.738:1 to 51.117:1 with a mean for untapped trees of 40.77:1 and a mean for tapped trees of 45.69:1. According to Trautmann and Krasny (1997), sugar maples are relatively high in carbon and typically have a carbon nitrogen ratio of 52:1. Lovett and Mitchell (2004) agree, finding that maples have relatively little nitrogen stored in their wood and leaves when compared to other northeastern hard woods. Neither stand had as high of a carbon nitrogen ratio as Trautmann and Krasny (1997) suggest. This could either be due to carbon depletion or increased nitrogen in the trees' leaves.

One possible cause of carbon depletion in tapped trees is from the sap collection. Sugar maple sap is preferred for syrup making due to its relatively high concentration of sugars. All those carbohydrates are coming from what the tree had stored in its trunk, which reduces the carbon available for the leaves.

Based upon the fact that the carbon contents were almost identical across the treatments, it is much more likely that increased nitrogen is the cause of the altered ratios in this case. The carbon concentrations of the tapped trees may have been

able to return to a comparable amount through photosynthesis throughout the spring, summer, and extended fall seasons.

Possible Sources of Nitrogen

Previous work by Pregitzer et al (2010), has shown that maple leaves tend to show a time lag in their nutrient contents. The leaves pull their nutrients from stores in the trunk of the tree rather than directly from the ground. That means that the ratios found in this study represent the nutrient content of the trunk, which is reflective of soil conditions at least two years prior to the collection of the leaf litter. According to its management plan, Proctor Maple Research Center does not add synthetic nitrogen to their soils, so fertilization regimes cannot provide the easy explanation to this increased nitrogen concentration in the untapped trees' leaf litter.

Without data on nitrogen concentrations in the soils, it is difficult to pinpoint what might be causing the difference in nutrients. If the untapped soils also had a significantly greater concentration of nitrogen, it could be theorized that the higher content in the leaves was merely reflective of increased soil concentrations. From there, it could be theorized that the additional nitrogen came to be in the soils of the untapped stand because it is at the bottom of a slight slope and that runoff from a storm event had increased the soil nutrients in that area.

If soil nutrient concentrations were not significantly different, it would be left to assume that the untapped trees were taking up and storing more nitrogen. In that scenario, it would be reasonable to suppose that additional nitrogen could be taken up and stored in these untapped trees because they do not contain nonconductive channels in their trunks, like tapped trees have. If all the wood in their trunks is conductive, there is more room in which nutrients can move and be stored.

Nitrogen Content Implications

In either case, there is a significant difference in percent nitrogen by weight to be addressed. One concern that frequently accompanies increased nitrogen concentrations is a greater mass of leaf litter (Aerts and Caluwe, 1997). An especially thick litter layer can suffocate undergrowth and smaller maple trees (Patterson et al. 2012). However, there was not a significant difference observed in

the masses of leaf litter between the two treatments. In fact, the mean dried leaf litter mass was greater for the tapped treatment than for the untapped treatment (though still not significantly). This was not an expected result, because the untapped treatment had the higher nitrogen content.

While increased nitrogen has, in previous studies, been seen to increase leaf litter, nitrogen has also shown to be valuable in the long-term decomposition of the litter. When there is more nitrogen in the leaf litter, decomposition by nitrifying bacteria has a faster rate (Aerts and Caluwe, 1997). Therefore, in a forest as old as Proctor Maple Research Center, where all the trees in the stands studied were mature, the threat of suffocation by leaf litter is less pertinent. What is more important is how quickly the nutrients in the leaf litter can be made available again.

Carbon Nitrogen Ratio Implications

Nutrient ratios are especially important for sugar maples because they play a substantial role in nitrogen cycling through the decomposition of their litter (Lovett and Mitchell, 2004). These ratios contribute to the initial rate of decomposition (Aerts and Caluwe, 1997).

In this case, since the untapped stand has lower carbon nitrogen ratio, it is expected that these nutrients will more rapidly be returned to the soil and be available for the trees again, because of sugar maple's rapid nitrification (Lovett and Mitchell, 2004). This is especially important because, in sugar maple stands the majority of the carbon sequestered in the soil comes from leaf litter (Ross et al. 2011) and sugar maples are incredibly influential in nitrogen cycling through leaf litter decomposition (Lovett and Mitchell, 2004).

For the tapped stand, the nutrients may stay trapped in immobilized forms in the leaf litter for comparatively longer, potentially leading to further nutrient depletion in both the tree and future litter.

Species Effect

As expected, there was no significant difference found in the distances the baskets were placed from the nearest maple trees. Therefore, it appears that distance from the nearest tree did not have a measurable impact on either the amount of leaf litter collected, or the nutrient ratios observed in the litter. Leaves of

the three most prominent trees in the area, sugar maple, yellow birch, and paper birch, were found in each basket, meaning that it is unlikely that the species composition of the leaves contributed to other results (Kominsky et al. 2007). Furthermore, yellow birch and sugar maple trees have similar chemical structures and decomposition patterns, indeed Ross et al. (2011) has gone so far as to propose the two species can be analyzed together for nutrients. This further suggests that in this case species composition of the leaf litter did not play a significant role. Even though there was a small slope between the two treatment locations, no significant difference was found in elevation between the two sites.

Macroinvertebrates

Unfortunately, no macroinvertebrates were recovered in the leaf litter collection baskets. This is most likely due to how high above the top of the ground leaf litter the openings in the baskets were. The bottom inch of the sides of the baskets were made of solid plastic and impenetrable by macroinvertebrates and leaf litter. The baskets were intentionally placed so that the openings in the baskets were above the top of the leaf litter outside the baskets. This was done to ensure that no older leaf litter could enter the baskets through the mesh sides, however this decision ultimately appears to have excluded macroinvertebrates from the baskets. Therefore, no consideration can be given to the importance of macroinvertebrates in this study, although they are known to greatly influence decomposition.

Recommendations

Further research on this topic should expand the focus to include soil and root interactions as well. Soil pH and nutrient concentrations could provide critical insight on where the nutrients in the leaves came from. Different equipment that more easily allows macroinvertebrates to enter the collection baskets should be used. Ideally, future studies would also be able to collect and analyze leaf litter, soil, and macroinvertebrates over several years rather than just one season. Given that nitrogen's most important role is in long-term decomposition, a study with a longer timeline should be conducted to determine if there is more of a clear effect of nitrogen on sugar maple leaf litter decomposition.

Figures

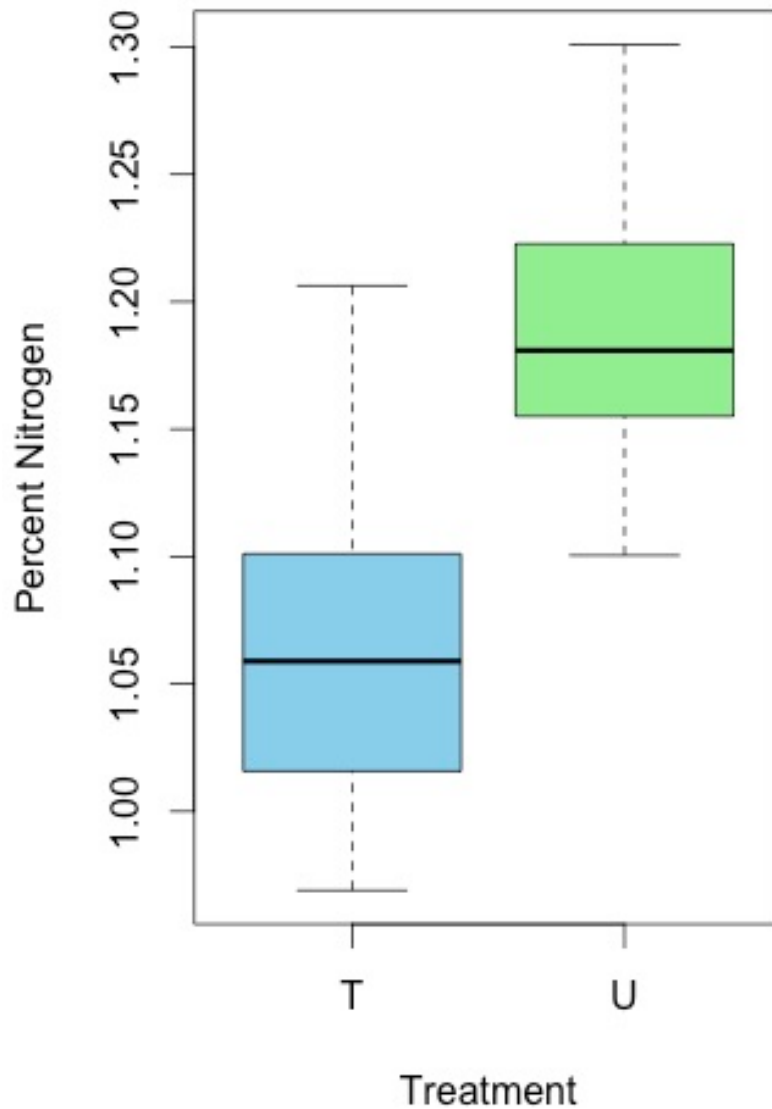


Figure 1: This is a box plot showing a comparison of the percent nitrogen by weight for each of the treatments. T on the Treatment axis represents the tapped treatment, and U on the Treatment axis represents the untapped treatment.

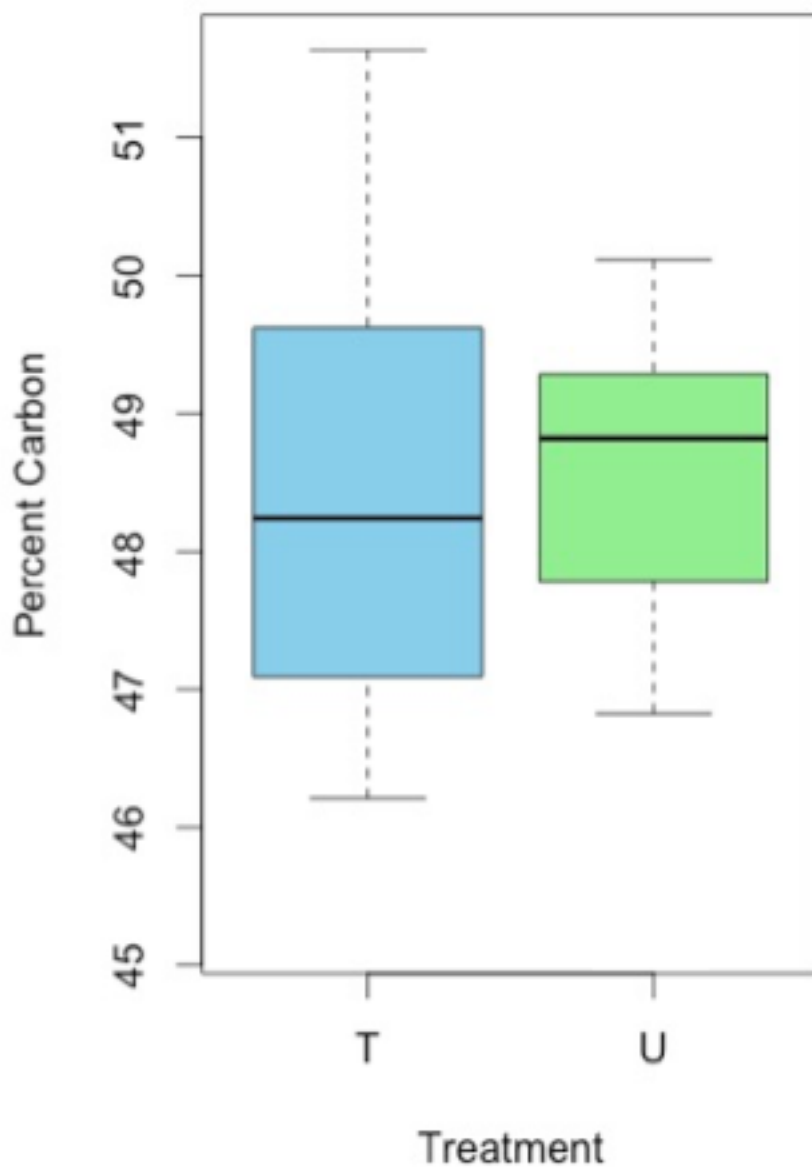


Figure 2: This is a box plot showing a comparison of the percent carbon by weight for each of the treatments. T on the Treatment axis represents the tapped treatment, and U on the Treatment axis represents the untapped treatment.

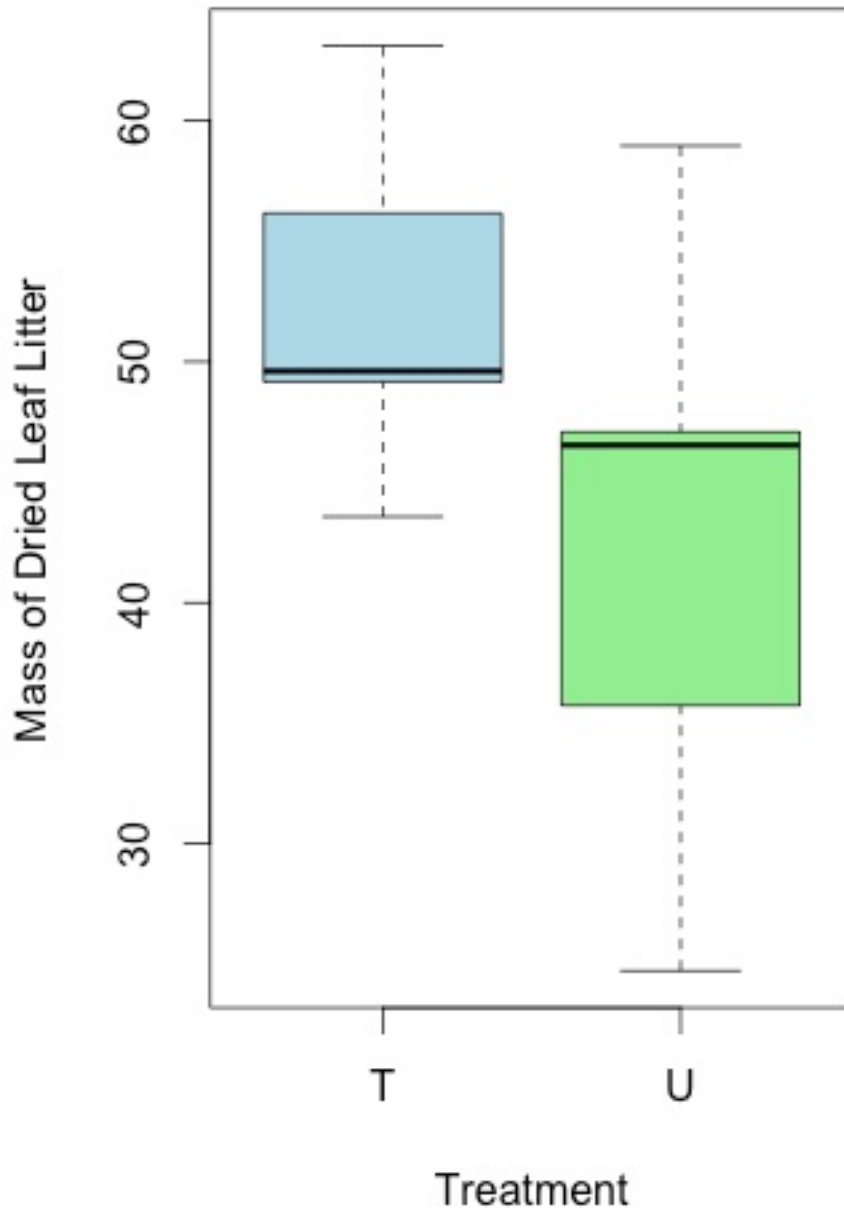


Figure 3: This is a box plot showing a comparison of the mass of the leaf litter collected for each of the treatments once it was dried. T on the Treatment axis represents the tapped treatment, and U on the Treatment axis represents the untapped treatment.

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