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Research Article
Investigation of Litter Decomposition and Nutrient Release from *Dipterocarpus alatus* Roxb. Ex G.Don. as Affected by Soil Moisture in Ecosystem

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Abstract
Background and Objective: The availability of *Dipterocarpus alatus* in terms of leaf fall per unit area and the degradation to organic and inorganic substances for nutrient cycling by physical, chemical and biological processes have not been found. The purpose of this study was to investigate the rate of *D. alatus* leaf fall per unit area; percent degradation; nitrogen, phosphorus and potassium content and the amount of nitrogen, phosphorus and potassium released. **Materials and Methods:** Mesh fabric was installed around the *D. alatus* tree canopy in Khon Kaen, Roi Et, Yasothon and Mukdahan provinces. Fallen leaves of *D. alatus* were collected in the hot, rainy and winter seasons. To study the rate of degradation and potential for nutrient release, leaves of *D. alatus* were packed in a litter bag and placed on the soil surface in various experimental areas. **Results:** The highest biomass of *D. alatus* leaves fell in summer at Khon Kaen (483.33 g m^{-2}), followed by winter in Yasothon (286.67 g m^{-2}). A higher percentage of *D. alatus* leaf degradation occurred at the end of the rainy season than at the beginning of the rainy season, causing the maximum release of potassium, 2.89-7.5 kg ha^{-1} and the amount of nitrogen released was 0.72-4.93 kg ha^{-1} after 4 months. **Conclusion:** Soil fertility can be increased through organic fertilizer of *D. alatus* which transforms it into organic matter and inorganic substances in soil. Crops around *D. alatus* tree can utilize circulating nutrients especially nitrogen and potassium.

Key words: Biofertilizer, ecosystem, macronutrients, soil fertility, yang

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The above-ground biomass plays an important role in controlling soil erosion, determining nutrient cycling and improving the ecological environment. Above-ground biomass can be decomposed via microorganisms and it also leads to the accumulation of soil organic matter and nutrients through humification. The ecological benefits of *Dipterocarpus alatus* have only been studied in terms of growth and production. Trees have been shown to provide many beneficial effects to agricultural crops grown in association with it as well as to the sustainability of agro ecosystem as a whole through soil fertility enhancement, moisture conservation and erosion control. Leaf litter fall is a mechanism whereby recycle of ecosystem nutrients occurs. Therefore, it is a mechanism which enhances soil fertility. In Thailand, *D. alatus* is a versatile wood as it can be beneficial to almost every part. The ecological benefits of *D. alatus* also include temperature control, shade, wind protection and preventing erosion of the benthic soil. Furthermore, it is found to be beneficial for the growth of mycorrhizal fungi in dry evergreen forest, called rainforest mushrooms that are consumable. Dipterocarpus have symbioses with ectomycorrhizal (ECM) fungi and ECM fungi have been identified from dipterocarp roots by molecular identification, e.g., Thelephoraceae, Russulaceae, Sclerodermataceae, Cortinariaceae, Agaricaceae and Boletaceae[1-5]. The availability of *D. alatus* in terms of leaf fall per unit area and the degradation to organic and inorganic substances for nutrient cycling by physical, chemical and biological processes have not been found. Whether the process of degradation of humus in the ecosystem will be fast or slow depends on the climate, chemical compounds in humus and activities of various microbes in the area[6]. Nitrogen addition increased litter N concentration and thus enhanced litter decomposition by improving substrate quality. This increase, however, was offset by the negative effect of increased soil N, resulting in a diminished effect of increased soil N availability on in situ litter decomposition. The positive effects of improved litter quality slightly out-performed the negative effects of increased soil N. The negative effect of increasing soil N on litter decomposition could be partially explained by reduced soil microbial biomass and activity[7]. Decomposition was significantly faster for litters of a two-species mixture than litters of the single species, but the rate of litter decomposition did not differ much between the two species, suggesting that compositional balance, rather than changes in the dominance between Stipa and Artemisia, is more critical for litter decomposition, hence nutrient cycling in this ecosystem[8]. Litter production occurred throughout the year but the high rate was found during dry period (November-April). The maximum litter fall was in January, 2010, which was 3.6 ton m^{-2} $year^{-1}$ or 34% of total litter fall during a year. The high soil temperature and low soil moisture have resulted in high total litter fall production in this forest. It was found that the litter fall production was positively correlated to soil temperature but negatively correlated to soil moisture. Investigating the litter decomposition reveals that decomposition rate of leaf was higher than branch in all species. The leaf of *D. tuberculatus* has lowest decomposition rate constant. In contrast, the branch of *D. Obtusifolius* shows the highest decomposition. Both compositions of all species were positively correlated to soil moisture and soil temperature[9]. This study therefore focuses on the rate of decomposition of foliar plants, including the amount of nitrogen, phosphorus and potassium release from *D. alatus* leaves in Khon Kaen, Roi Et, Yasothon and Mukdahan provinces, to generate a database for farmers, researchers and academics to promote *D. alatus* plantation and to assess the suitability of *D. alatus* trees as a source of organic matter for the ecosystem.

MATERIALS AND METHODS

Study area: The experiment was conducted in the Khon Kaen, Roi Et, Yasothon and Mukdahan provinces of Northeast Thailand from 2018-2020. The geographical coordinates of Khon Kaen is located at latitude 16.4322° and longitude 102.8236°, Roi Et geographical coordinates are 16.0538°North and 103.6520°East, Yasothon province is located at the place category with the geographical coordinates of 15.7954°North and 104.1419°East and Mukdahan is located at latitude 16.5436° and longitude 104.7024°. A total rainfall of 72.8 mm occurred in winter season, 211.1 mm occurred in summer season and 1,111.9 mm occurred in rainy season during the period of crop growth. The maximum and minimum temperatures were recorded as 34-36 and 24-28°C, respectively.

Leaf fall biomass of *D. alatus* trees: Mesh fabric was installed around the *D. alatus* tree canopy. *Dipterocarpus alatus* trees have a trunk diameter between 100 and 200 cm at a trunk height of 150 cm. Four locations were installed in each province for 6 points per tree. Fallen leaves of *D. alatus* were collected in the hot, rainy and winter seasons. The fresh and dry weights of fallen leaves were taken for further analysis of dry matter weight per area.

Rate of degradation and potential for nutrient release: To study the rate of degradation and potential for nutrient release from *D. alatus* under natural conditions and at the experimental station at different soil moisture levels, soil moisture levels were used at Field Capacity (FC), 40% of FC, 50-60% of FC and 80% of FC, for 4 and 8 months. A total rainfall of 962.20 mm occurred during the period of crop growth. The maximum and minimum temperatures were recorded as 34.88 and 22.67°C, respectively. Leaves of *D. alatus* were packed in a litter bag (nylon mesh 2×2 m mesh, 20×30 cm in size) for 500 g/replication/sample and sewn with nylon thread. The net bag containing the leaves was placed on the soil surface in various experimental areas. The mesh bag sample was collected and cleaned, then dry weight was determined and percent degradation was calculated from the exponential decay model[10].

Macronutrient content: To study the macronutrient content of fallen leaves and rubber balls of *D. alatus*, the amounts of nitrogen, phosphorus and potassium in the fallen leaves and rubber balls of *D. alatus* and the degradation undergone in each period were analyzed by calculating the nitrogen concentration using the Kjeldahl method[11] and the total phosphorus content using the colorimetric method and reporting the nutrient release results per unit area[12].

Statistical analysis: The experiment was carried out in a Completely Randomized Design (CRD) and a combined analysis of data conducted between provinces. Four replications were performed, data were expressed as means. An analysis of variance was conducted on the data obtained for each parameter in each treatment. All analyses were carried out using "Statistica" version 8.0. The Least Significant Differences (LSD) was calculated at p<0.05.

RESULTS AND DISCUSSION

Leaf fall biomass of *D. alatus* evaluation: A study of the leaf defoliation biomass of *D. alatus* in different seasons and provinces found no seasonal effect on leaf defoliation biomass in *D. alatus*. Defoliation may occur by physiological maturation or due to strong wind or rain. However, leaf defoliation biomass in *D. alatus* varied among provinces. The greatest biomass of leaf defoliation of *D. alatus* occurred in Khon Kaen province, followed by Yasothon, Mukdahan and Roi Et provinces. Generally, leaf defoliation may be caused by deterioration as a result of toxins in the air and water or the lack of essential nutrients for growth, such as nitrogen, which causes yellow leaves and deterioration. Moreover, iron, calcium or stimulation as a result of inappropriate environments, such as drought or flooding, or inappropriate conditions within the plant itself, such as changes in plant hormone levels, result in aging of plant tissues. Therefore, the joint influences of different seasons and provincial areas affect the leaf defoliation biomass of *D. alatus* significantly. The highest biomass of leaf defoliation of *D. alatus* in Khon Kaen province occurred during the rainy season (483.33 g m^{-2}), followed by *D. alatus* in Yasothon province during the winter (286.67 g m^{-2}), *D. alatus* in Khon Kaen province during the summer (228.33 g m^{-2}), *D. alatus* in Mukdahan province during the summer (188.33 g m^{-2}), *D. alatus* in Mukdahan province during the winter (180.00 g m^{-2}) and *D. alatus* in Yasothon province during the summer (174.67 g m^{-2}) (Table 1). In regards with, there was yet previous report related to seasonal and dries evergreen forest to compare the biological mass above ground of Yang Na. There was only a study of investigated the distribution of large trees in diameter at breast height[1]. The study of biological mass above ground of 233 Yang Na trees in the area of 2,400 m^2 showed the total biomass of the Yang Na that was 59.11 trees or 39.40 ton/1,600 m^2. Similar to the total aboveground biomass of Yang na in Plant Genetic Protection Area Ubon

Table 1: Leaf defoliation biomass of *D. alatus*

Treatments	Leaf defoliation biomass (g m^{-2})
Provinces	
Khon Kaen	273.33^{a}
Roi Et	103.50^{c}
Yasothon	196.83^{b}
Mukdahan	160.83^{bc}
Seasons	
Summer	186.58
Rainy	201.88
Winter	162.42
Provinces* seasons	
Khon Kaen+summer	228.33^{bc}
Khon Kaen+rainy	483.33^{a}
Khon Kaen+winter	108.33^{d}
Roi Et+summer	155.00^{cd}
Roi Et+rainy	80.83^{d}
Roi Et+winter	74.67^{d}
Yasothon+summer	174.67^{bcd}
Yasothon+rainy	129.17^{cd}
Yasothon+winter	286.67^{b}
Mukdahan+summer	188.33^{bcd}
Mukdahan+rainy	114.17^{cd}
Mukdahan+winter	180.00^{bcd}
Provinces	**
Seasons	ns
Provinces* seasons	**
CV (%)	37.74

ns: Not significantly different, **Significant difference at $p \leq 0.01$. Different letters indicate a significant difference at $p \leq 0.05$

Ratchathani Zoo, Ubon Ratchathani Province, Thailand was 39.40 tons/1,600 m^2 or 0.03 tons/tree[1]. When compared to other mixed deciduous forests, the amount of biomass was greater. Previously the biomass of natural dipterocarp forests, dipterocarp forest, mixed deciduous forest and Mae Ping National Park demonstrating biomass of 11.56, 15.63, 15.94 and 16.63 ton/1,600 m^2, respectively[1] was observed. Opposite from current results obtained, the total aboveground biomass of Yang na was 30.34 tons/1,600 m^2 or 0.77 tons/tree. Variation in the total aboveground biomass of Yang na may link to the canopy coverage, circumference, height and wood volume which is plentiful and very important for ecology in the study area.

Percentage degradation and nutrient release of *D. alatus*: The percentage of leaf degradation of *D. alatus* at the beginning and end of the rainy seasons revealed that the different seasons and provinces had significantly different effects on the percentage of leaf degradation. The percentage of leaf degradation of *D. alatus* at the end of the rainy season (83.33-95.77%) was greater than at the beginning of the rainy season (77.44-83.89%). Normally, humid conditions will aid in microbial degradation. The province of Khon Kaen had a higher percentage of *D. alatus* leaf degradation than Roi Et, Yasothon and Mukdahan provinces (Table 2). The natural circulation process begins when the leaves, branches, flowers and other parts of the plant fall and land. From there, they gradually decompose into small particles via physical, chemical and biological processes, in which the process of decomposition of fossil plants in the ecosystem occurs quickly or slowly depending on the climate, chemical compounds in humus and the activities of various microbes in the area[6]. Similar to the studied on litter decomposition under climate change in long-term warming relative to differences in soil abiotic properties associated with vegetation type[13]. Results founded that initial decomposition rate was decreased by the warming treatment. Stabilization was less affected by warming and determined by vegetation type and soil moisture. Warming enhances decomposition directly via stimulation of metabolic activity and growth of almost all decomposers[14,15]. Changes in temperature may rapidly affect decomposer activity, while other environmental responses to temperature changes such as plant community composition, litter quantity and quality and soil quality may lag behind[16,17]. This agrees well with the assumption that decomposition is first constrained by soil moisture and secondary by temperature[18]. In contrast with previous studies that warming-induced ecosystem respiration was greatest in drier locations. However, similar to current findings these authors observed considerable variability around the mean values. This could point towards a potentially important role for micro-site differences (such as in microbial communities), irrespective of temperature and moisture[19]. Current findings suggest a potential large role of soil moisture in driving decomposition patterns. Litter can be decomposed via microbial respiration and it also leads to the accumulation of Soil Organic Carbon (SOC) through humification[20,21]. Litter respiration exhibited similar seasonal variation, which was significantly greater in summer (June-August) due to heavy rainfall and higher temperatures than in other seasons with less rainfall and lower temperatures. In this study, complex controls on decomposition that differed among landscape positions and among litter sources was found. Decomposition rates were consistently faster in the lowlands than in the uplands, suggesting an important role of soil moisture in decomposition in this ecosystem.

Table 2: Percentage of leaf degradation of *D. alatus*

Treatments	Leaf degradation of *D. alatus* (%)
Provinces	
Khon Kaen	87.89^{a}
Roi Et	86.95^{ab}
Yasothon	84.72^{b}
Mukdahan	80.39^{c}
Seasons	
Beginning of rainy	80.06^{b}
End of rainy	89.92^{a}
Provinces* seasons	
Khon Kaen+beginning of rainy	80.00^{cd}
Khon Kaen+end of rainy	95.78^{a}
Roi Et+beginning of rainy	78.89^{d}
Roi Et+end of rainy	95.00^{a}
Yasothon+beginning of rainy	83.89^{b}
Yasothon+end of rainy	85.56^{b}
Mukdahan+beginning of rainy	77.44^{d}
Mukdahan+end of rainy	83.33^{bc}
Provinces	**
Seasons	**
Provinces* seasons	**
CV (%)	2.33

**Significant difference at $p \leq 0.01$. Different letters indicate a significant difference at $p \leq 0.05$

The study of macronutrients such as nitrogen, phosphorus and potassium in the leaves and rubber balls from various provinces in the summer found no significant difference in the nitrogen content of leaves of *D. alatus* in different provinces (Table 3). The exception was phosphorus and potassium, which was more likely to be found in the leaves of *D. alatus* from Khon Kaen province. Rubber balls had more potassium than nitrogen and higher phosphorus than potassium was found in the leaves of *D. alatus*. After 4 months, under different climatic conditions in different provinces, the nitrogen and potassium content of *D. alatus*

Table 3: Macronutrient contents of leaves and rubber balls of *D. alatus*

Provinces	N (%)	P (%)	K (%)
Leaves			
Khon Kaen	0.89[a]	0.08[a]	0.59[a]
Roi Et	0.85[a]	0.08[a]	0.33[b]
Yasothon	0.86[a]	0.09[a]	0.47[ab]
Mukdahan	0.90[a]	0.03[b]	0.45[ab]
F-test	ns	**	*
CV (%)	6.41	14.70	28.97
Rubber ball			
Khon Kaen	0.75	0.05	1.13
Roi Et	0.45	0.05	1.08
Yasothon	0.71	0.04	1.13

ns: Not significantly different, *Significant difference at $p \leq 0.05$, **Significant difference at $p \leq 0.01$. Different letters indicate a significant difference at $p \leq 0.05$

Table 4: Macronutrients released from the leaves of *D. alatus* after 4 months

Provinces	N (%)	P (%)	K (%)
Khon Kaen	0.18	0.04[ab]	0.26
Roi Et	0.07	0.04[ab]	0.25
Yasothon	0.13	0.05[a]	0.38
Mukdahan	0.15	0.01[b]	0.18
F-test	ns	*	ns
CV (%)	65.37	54.42	42.31

ns: Not significantly different, *Significant difference at $p \leq 0.05$. Different letters indicate a significant difference at $p \leq 0.05$

Table 5: Percentage of degradation of *D. alatus* leaves from different provinces at various soil moisture levels after 4 and 8 months

	Degradation (%)	
Soil moisture (%)	4 months	8 months
80 of FC	82.50[a]	85.83[a]
50-60 of FC	82.42[a]	84.17[ab]
40 of FC	79.58[ab]	83.25[ab]
Field capacity (FC)	78.16[b]	80.42[b]
F-test	*	ns
CV (%)	2.48	3.20

ns: Not significantly different, *Significant difference at $p \leq 0.05$. Different letters indicate a significant difference at $p \leq 0.05$

leaves were not significantly different. The amount of nitrogen released was between 0.07 and 0.18% (or a volume of 0.72-4.92 kg ha^{-1}), the potassium released was between 0.18 and 0.38% (or a volume of 2.89-7.5 kg ha^{-1}) and the amount of phosphorus released was only 0.16-0.98 kg ha^{-1}. Moreover, these values tended to be higher in Yasothon, Khon Kaen and Roi Et than in Mukdahan province (Table 4). Previous studies in Kanchanaburi province, the nutrient content of dominant tree species has the highest Ca in leaf litter. Rainfall had a highly significant ($p<0.01$) effect on the litter decomposition rate. Deadwood is a reservoir of macro elements such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg), which ultimately end up in the soil. Current study confirmed the influence of deadwood decomposition on the physical properties of soils. Organic matter released from decomposing wood penetrates the soil, thereby altering its physical properties. Decomposition of dead plant matter is an important process that regulates nutrient circulation (nutrient cycling) and organic production[22]. In the first phase of degradation, the amount of potassium is greatly reduced, followed by that of nitrogen and phosphorus. The phosphorus content tends to decrease because phosphorus is immobilized by the increasing number of decaying microbes while the degradation of remains and other elements is weight loss. This causes slow release of phosphorus, then the release of potassium and nitrogen. Previous studies indicate a beneficial effect of alder wood decomposition on surface soil levels. More decomposed alder wood releases more nitrogen compounds to the soil, which is reflected in the biochemical activity of the soils and component circulation. Alder as a sparse species can bind free nitrogen in symbiosis with bacteria in the root, which through decomposing leaves and wood enter the soil[23]. In addition, it was found that the nitrogen content and the ratio of carbon to nitrogen is a factor that affects the rate of decomposition; if the plant leaves have a low carbon and high nitrogen content, they will be rapidly degraded[24].

Effects of soil moisture levels on the percentage degradation of *D. alatus*: In the experiment to study the percentage of leaf degradation under various soil moisture levels, it was found that soil moisture had a significant effect on the percentage of leaf degradation (Table 5). With soil moisture between 50 and 80%, leaf degradation exceeded 80% over 4 and 8 months. The stimulation of nutrient loss under elevated CO_2 was associated with the increased soil moisture, the higher leaf litter quality and the greater soil acidity[7]. However, the percentage degradation of *D. alatus* leaves at each soil moisture level from 4-8 months was not significantly different. General experiments also found a high rate of plant leaf decomposition within 14 weeks, reaching 64.62±0.42% by the sixth week. After the humus falls to the ground, it will decompose to form inorganic substances due to the derivative activity of microbes[25]. In the initial stage, the decay will be rapid but later will tend to stabilize and decomposition will be slow and gradual for months or years. Although earthworms and termites play a very important role in the decomposition activity of tropical plants in the tropical forest and cause rapid decay in the tropics[26], there are also 2 major groups of microbes involved in the degradation of organic matter, namely mould and bacteria. By releasing a type of enzyme called extracellular enzymes or exoenzymes, they digest larger plant molecules and then absorb them through their cell walls[27]. Microbial activity on the forest floor depends on the type of microorganisms and the amount of microbes in each area, which differ according to the climatic and chemical factors in the area, such as soil moisture and temperature. The microbes work well, resulting in a very high degradation rate of debris, especially during the first 1-4 months, which is the rainy season.

CONCLUSION

The *D. alatus* trees in Khon Kaen during the rainy season have the greatest biomass of leaf fall (483.33 g m^{-2}), followed by Yasothon province in the winter (286.67 g m^{-2}). The percentage degradation of *D. alatus* leaves at the end of the rainy season was greater than in the beginning, causing the maximum release of potassium, nitrogen and phosphorus, in addition to protect wind and chemical spray around rice fields or field crops. These biomasses used as a carbon sources to produce an organic fertilizer because the leaves of *D. alatus* in various areas are high in nitrogen content and rubber balls contain a high amount of potassium.

SIGNIFICANCE STATEMENT

This study discovered the biomass of *D. alatus* as a carbon sources to produce an organic fertilizer that can be beneficial for nitrogen and potassium. This study will help the researchers to uncover the ecological benefits of *D. alatus* in terms of the rate of decomposition and the amount of macronutrients released that were not able to explore. Thus a new theory to generate a database for farmers, researchers and academics to promote *D. alatus* plantation and to assess the suitability of *D. alatus* trees as a source of organic matter for the ecosystem.

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