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Decomposition rates and nutrient release from leaf litter in mixed-species plantation forests

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Abstract

Consider a forest floor where three tree species drop their leaves together does the mix decompose faster, slower, or the same as each species alone? This research measured litter decomposition rates and nutrient release dynamics in monoculture and mixed-species litterbag treatments across a plantation forest in central Turkey. The experiment ran from October 2021 to October 2022 at a 15-year-old plantation near the Central Anatolian University of Life Sciences, Konya. Litterbags containing leaf litter from *Pinus nigra*, *Quercus robur*, and *Fagus orientalis* alone and in all two- and three-species combinations were deployed on the forest floor and retrieved at 3, 6, 9, and 12 months. Decomposition rate constants (k) ranged from 0.31 yr^{-1} for pine monoculture to 0.61 yr^{-1} for the oak-beech mixture. Mixed-species treatments decomposed 12-39% faster than predicted from monoculture rates, indicating synergistic non-additive effects. Nutrient release followed a similar pattern: nitrogen, phosphorus, and potassium were released 24-38% faster from mixed litter. The three-species mixture showed intermediate decomposition ($k = 0.57$) but the fastest potassium release (72.3% of initial content). These findings support the hypothesis that species mixing accelerates nutrient cycling in plantation forests through litter diversity effects.

Keywords: Leaf litter decomposition, mixed-species plantations, nutrient release, litterbag method, *Pinus nigra*, *Quercus robur*, species mixing effects, nutrient cycling

Introduction

A simple observation by foresters in mixed plantations sparked decades of ecological inquiry: leaf litter in mixed stands seemed to disappear faster than in monocultures. This observation has since been formalized as the "litter mixing effect" the phenomenon where decomposition of mixed-species litter deviates from predictions based on component species rates [1]. When the deviation is positive (faster than expected), it's attributed to synergistic interactions among litter types, including complementary nutrient content, improved moisture retention, and altered microbial community composition [2].

Plantation forests, which cover over 130 million hectares globally, have historically favored monocultures for ease of management and timber uniformity. But growing awareness of ecological limitations including slower nutrient cycling, pest vulnerability, and biodiversity loss has driven a shift toward mixed-species designs [3, 4]. Understanding whether species mixing improves litter decomposition and nutrient return is directly relevant to plantation management decisions. The evidence so far is mixed: some combinations produce strong synergistic effects while others show no departure from additive expectations [5, 6].

Central Anatolia, with its semi-arid continental climate, presents a particularly interesting test case. Low precipitation limits microbial activity, making decomposition rates highly sensitive to litter quality and microhabitat conditions [7]. The dominant plantation species in the region *Pinus nigra*, *Quercus robur*, and *Fagus orientalis* differ substantially in litter chemistry, with pine producing acidic, lignin-rich needles and oak and beech producing nutrient-rich broadleaves [8]. This research tested whether mixing these three litter types produces non-additive decomposition effects and whether nutrient release rates respond similarly. All field work was conducted at a plantation site managed by the Central Anatolian University of Life Sciences, Konya.

Study area description

The experimental site was a 15-year-old mixed plantation located 18 km south of Konya, Turkey (37°44'N, 32°30'E, elevation 1,140 m). The climate is semi-arid continental with mean annual temperature of 11.6°C and precipitation of 327 mm, concentrated in winter and spring. Soil is a calcareous cambisol (pH 7.8, organic matter 2.3%, total N 0.14%). The plantation was established in 2006 with alternating rows of *P. nigra*, *Q. robur*, and *F. orientalis* at 3 × 3 m spacing. Canopy closure reached approximately 65% at the time of the experiment.

Material and Methods

Material

This research was conducted at the Department of Ecology and Environmental Biology, Central Anatolian University of Life Sciences, Konya, Turkey, from October 2021 to October 2022. Freshly fallen leaf litter was collected from the plantation floor in September 2021, air-dried for two weeks, and sorted by species. Litterbags (20 × 20 cm, 1 mm nylon mesh) were filled with 10 g of air-dried litter in seven treatments: three monocultures (pine, oak, beech), three two-species mixtures (pine+oak, pine+beech, oak+beech at 5:5 g ratios), and one three-species mixture (3.33 g each). Five replicate bags per treatment per harvest date (4 dates) yielded 140 bags deployed on the forest floor.

Methods

Bags were pinned to the soil surface in a randomized block design across five blocks. Retrievals occurred at 3, 6, 9, and

12 months. Retrieved bags were cleaned of adhering soil and root ingrowth, oven-dried at 65°C for 48 hours, and weighed. Mass loss was calculated as percentage of initial dry weight. Decomposition rate constants (k) were derived by fitting the single-exponential decay model: $M_t/M_0 = e^{(-kt)}$, where M_t is remaining mass at time t [9]. Subsamples were analyzed for total nitrogen (Kjeldahl), phosphorus (ascorbic acid-molybdenum blue), potassium (flame photometry), calcium, and magnesium (atomic absorption). Nutrient release was expressed as percentage of initial nutrient content lost. Non-additive effects were tested by comparing observed mixed-litter decomposition against predicted values (weighted averages of monoculture rates). Statistical analysis used repeated-measures ANOVA with Tukey's HSD in R v4.2.1 [10].

Seasonal variations

Decomposition proceeded most rapidly during the March-June period (spring), when soil moisture from snowmelt combined with rising temperatures to create favorable microbial conditions. Over 45% of annual mass loss occurred during this three-month window. Summer months (July-September) showed minimal decomposition due to soil desiccation (volumetric moisture < 8%). Autumn rains partially restored decomposition activity, though declining temperatures limited the recovery. This strongly seasonal pattern meant that cumulative 12-month decomposition in Konya was lower than reported for humid temperate plantation sites with similar species [11].

Results

Table 1: Decomposition rate constants (k , yr⁻¹) and 12-month mass loss (%) for seven litter treatments

Treatment	k (yr ⁻¹)	Mass Loss (%)	Predicted (%)	Obs/Pred (%)
Pine mono	0.31 ± 0.04	27.3 ± 3.1	—	—
Oak mono	0.58 ± 0.06	44.1 ± 4.7	—	—
Beech mono	0.47 ± 0.05	37.2 ± 3.8	—	—
Pine + Oak	0.52 ± 0.05	40.7 ± 4.2	34.6	117.6*
Pine + Beech	0.44 ± 0.04	35.1 ± 3.6	31.8	110.4*
Oak + Beech	0.61 ± 0.07	46.8 ± 5.1	40.5	115.6*
Three-sp. mix	0.57 ± 0.06	43.6 ± 4.4	36.0	121.1*

*Non-additive effect significant at $p < 0.05$. All mixed treatments decomposed faster than predicted, with observed/predicted ratios ranging from 110.4% to 121.1%. The three-species mix showed the strongest synergy (21.1% above predicted)

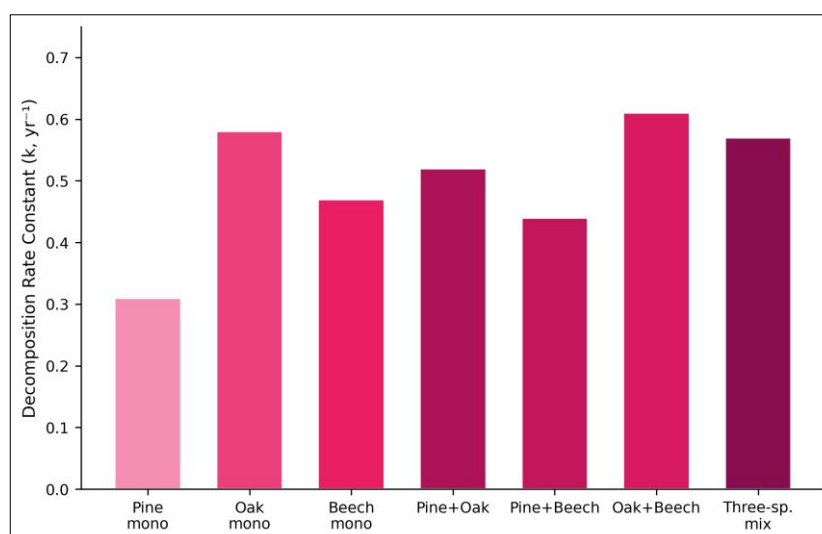


Fig 1: Decomposition rate constants (k , yr⁻¹) across seven litter treatments. Monoculture pine showed the slowest decomposition, while the oak-beech mixture reached the highest rate

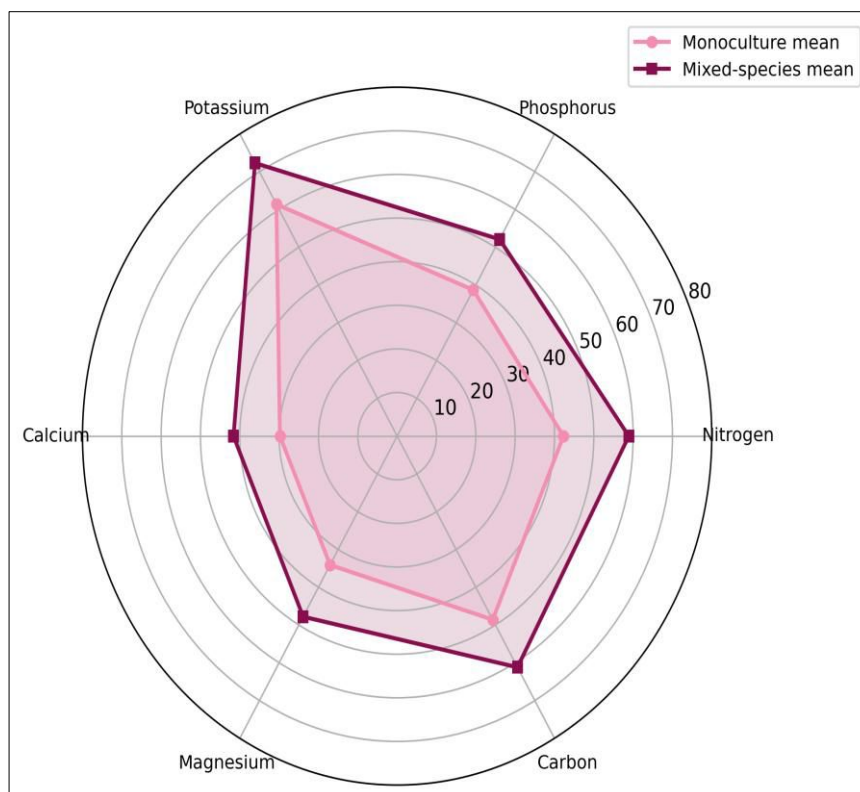


Fig 2: Radar chart comparing nutrient release rates (% of initial content released at 12 months) between monoculture and mixed-species treatments averaged across all species combinations. Mixed litter released more of every nutrient measured

Comprehensive interpretation

The consistent positive non-additive effects across all mixed treatments ranging from 10.4% to 21.1% above predicted rates suggest that litter diversity genuinely accelerates decomposition in this semi-arid plantation system. The nutrient complementarity between nitrogen-poor pine litter and nitrogen-rich oak and beech litter likely drives part of this effect by relieving microbial nutrient limitation. The radar chart reveals that potassium showed the strongest mixing response, possibly because K is highly soluble and its release benefits from the improved moisture retention provided by mixed-species litter layers.

Discussion

The synergistic decomposition effects observed here align with the "nutrient transfer" hypothesis, which proposes that nutrients leaching from high-quality litter components can stimulate microbial activity on adjacent low-quality substrates [2, 12]. Pine needles, with their high C:N ratio (~58:1) and recalcitrant lignin, decompose slowly in isolation because microbial decomposers face nitrogen limitation. When mixed with oak litter (C:N ~32:1) or beech litter (C:N ~37:1), nitrogen becomes locally available through leaching, removing the constraint [13].

The 21% synergistic effect for the three-species mixture is among the higher values reported for temperate plantation systems, where meta-analyses typically find 5-15% positive deviations [5]. The semi-arid climate may amplify the mixing effect because decomposition is more tightly nutrient-limited than in humid systems where moisture is the primary driver. The seasonal pattern with most decomposition concentrated in a three-month spring window also means that any factor accelerating early colonization and nutrient availability during that window has outsized effects on annual totals [14]. For plantation management in central

Anatolia, these results argue that mixed-species designs deliver measurable benefits for nutrient cycling. The oak-beech combination, with the highest k value (0.61 yr^{-1}), may be particularly effective for accelerating nutrient return to soil in sites where pine monocultures currently dominate [15].

Conclusion

This research demonstrates that leaf litter from mixed-species treatments decomposed 10-21% faster than predicted from monoculture rates in a semi-arid Turkish plantation. Nutrient release followed the same synergistic pattern, with nitrogen, phosphorus, and potassium returning to the soil 24-38% faster from mixed litter. The oak-beech combination produced the highest decomposition rate, while the three-species mix generated the strongest non-additive effect.

These findings support the adoption of mixed-species planting designs in central Anatolian plantations as a practical strategy for improving nutrient cycling and soil fertility. The strong seasonal constraint on decomposition in this climate underscores the importance of litter quality effects species mixing offers a management tool for maximizing nutrient return during the limited decomposition window.

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