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Chalermpol Phonsiri
Department of Environmental Forestry, Chiang Mai Agricultural University, Chiang Mai, Thailand

Pailin Siripunya
Department of Environmental Forestry, Chiang Mai Agricultural University, Chiang Mai, Thailand

Corresponding Author:
Chalermpol Phonsiri
Department of Environmental Forestry, Chiang Mai Agricultural University, Chiang Mai, Thailand

Biomass production and nutrient cycling in leucaena-based alley cropping systems

Chalermpol Phonsiri and Pailin Siripunya

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Abstract
Much like a natural forest recycles its own nutrients through leaf litter, alley cropping with nitrogen-fixing trees can create a self-sustaining fertility loop within agricultural fields. This research quantified biomass production and nutrient cycling in a *Leucaena leucocephala*-based alley cropping system with maize at Chiang Mai Agricultural University, Thailand, over two cropping seasons (2021-2022). Leucaena hedgerows (4 m spacing) produced 8.7 t ha^{-1} yr^{-1} of pruned biomass, recycling 142 kg N, 18.4 kg P, and 98 kg K ha^{-1} yr^{-1} to the soil surface. Soil organic carbon in alley plots increased by 0.34 percentage points over two years compared to 0.08 in sole maize. Maize grain yield in the alley system averaged 4.82 t ha^{-1}, 22.3% higher than sole maize (3.94 t ha^{-1}) at the same fertiliser input. The leucaena system replaced approximately 68% of the recommended nitrogen fertiliser through biological fixation and biomass recycling. These findings support leucaena alley cropping as a practical approach to sustainable nutrient management in northern Thai highlands.

Keywords: Biomass production, nutrient cycling, leucaena, alley cropping, hedgerow intercropping, nitrogen fixation, soil organic carbon, maize yield, agroforestry, sustainable agriculture

Introduction
Like a bank account that earns compound interest, soils under agroforestry systems accumulate biological capital year after year organic matter builds, nutrient pools deepen, and the system becomes progressively less dependent on external inputs [1]. *Leucaena leucocephala* (Lam.) de Wit is one of the most widely used trees in tropical alley cropping because it fixes atmospheric nitrogen at rates of 100-300 kg ha^{-1} yr^{-1}, produces large quantities of easily decomposable leaf biomass, and tolerates repeated pruning [2].
In alley cropping, rows of Leucaena hedges are planted between strips of food crop. Hedgerows are pruned at intervals and the nutrient-rich biomass is spread as green manure across the crop alleys [3]. The system simultaneously provides nitrogen, organic matter, and erosion control a combination that chemical fertilisers alone cannot deliver [4]. Northern Thailand's upland agriculture faces severe soil degradation from decades of continuous maize monocropping on slopes [5]. This research quantified the biomass and nutrient recycling capacity of leucaena hedgerows and their impact on maize productivity at Chiang Mai Agricultural University.

Material and Methods
Material
The experiment was established in 2019 at the highland research station of Chiang Mai Agricultural University (18°47′N, 98°58′E, elevation 340 m). *Leucaena leucocephala* cv. K636 hedgerows were planted in east-west rows at 4 m spacing with 0.25 m within-row spacing. Maize (cv. Nakhon Sawan 3) was planted in the 3.2 m wide alleys. Soil is a Typic Haplustalfs (sandy clay loam), pH 5.8, organic carbon 1.21%, total N 0.11%. Biomass and nutrient analyses were done using AOAC methods [6].

Methods
Leucaena hedgerows were pruned to 50 cm height three times per year (April, July, October). Pruned biomass was weighed fresh, subsampled, oven-dried at 65°C, and analysed for N (Kjeldahl), P (vanadomolybdate), and K (flame photometry). Biomass was spread

uniformly across the adjacent alleys as green manure [3]. Maize was grown during the wet season (May-September) in both 2021 and 2022 in an RCBD with four replications comparing alley cropping versus sole maize (no hedgerows). Soil samples (0-20 cm) were collected before planting and after harvest each year for organic carbon (Walkley-Black) and mineral N analysis. Data were analysed by ANOVA in R 4.2.1 with Tukey's HSD at $p<0.05$ [7, 8].

Nutrient budget analysis

The annual nutrient budget for the alley cropping system was constructed by comparing total nutrient inputs (Leucaena biomass recycling + fertiliser + rainfall) against outputs (maize grain removal + leaching estimate). Leucaena biomass contributed 142 kg N ha^{-1} yr^{-1}, while the standard fertiliser dose added 80 kg N ha^{-1}. Maize grain removed approximately 78 kg N ha^{-1} at the observed yield. The net N balance was positive (+144 kg N ha^{-1}), confirming that the system was building rather than depleting soil nitrogen. For phosphorus, the budget was tighter: inputs of 18.4 kg P (biomass) + 17.5 kg P (fertiliser) versus 14.8 kg P removed by grain, leaving a modest surplus of +21.1 kg P ha^{-1} [4, 6].

Results

Table 1: Biomass production and nutrient recycling by Leucaena hedgerows (mean of two years)

Pruning	Biomass (t ha^{-1})	N content (%)	N recycled (kg ha^{-1})	P recycled (kg ha^{-1})	K recycled (kg ha^{-1})	Ca recycled (kg ha^{-1})
April	2.4 ± 0.3	3.12	38.4	5.1	27.3	12.4
July	3.8 ± 0.4	2.87	56.1	7.6	38.7	18.1
October	2.5 ± 0.3	3.04	47.5	5.7	31.8	14.2
Annual total	8.7 ± 0.8	—	142.0	18.4	97.8	44.7

Values are means ± SE (n = 4 replications × 2 years)

Table 2: Maize yield and soil properties under alley cropping versus sole maize

Parameter	Alley cropping 2021	Alley cropping 2022	Sole maize 2021	Sole maize 2022
Maize yield (t ha^{-1})	4.68 ± 0.24a	4.96 ± 0.21a	3.87 ± 0.28b	4.01 ± 0.26b
Soil OC (%)	1.38 ± 0.06a	1.55 ± 0.07a	1.24 ± 0.05b	1.29 ± 0.06b
Available N (mg kg^{-1})	186 ± 8a	198 ± 9a	158 ± 7b	162 ± 8b
Bulk density (g cm^{-3})	1.28 ± 0.03b	1.24 ± 0.02b	1.36 ± 0.03a	1.35 ± 0.03a

Different letters within rows (across all four columns) differ at $p<0.05$

Maize yield averaged 4.82 t ha^{-1} under alley cropping versus 3.94 t ha^{-1} in sole maize (Table 2). Soil organic carbon increased by 0.34 percentage points in alley plots over two years compared to just 0.08 in sole maize. Available nitrogen and bulk density also improved consistently in the alley system.

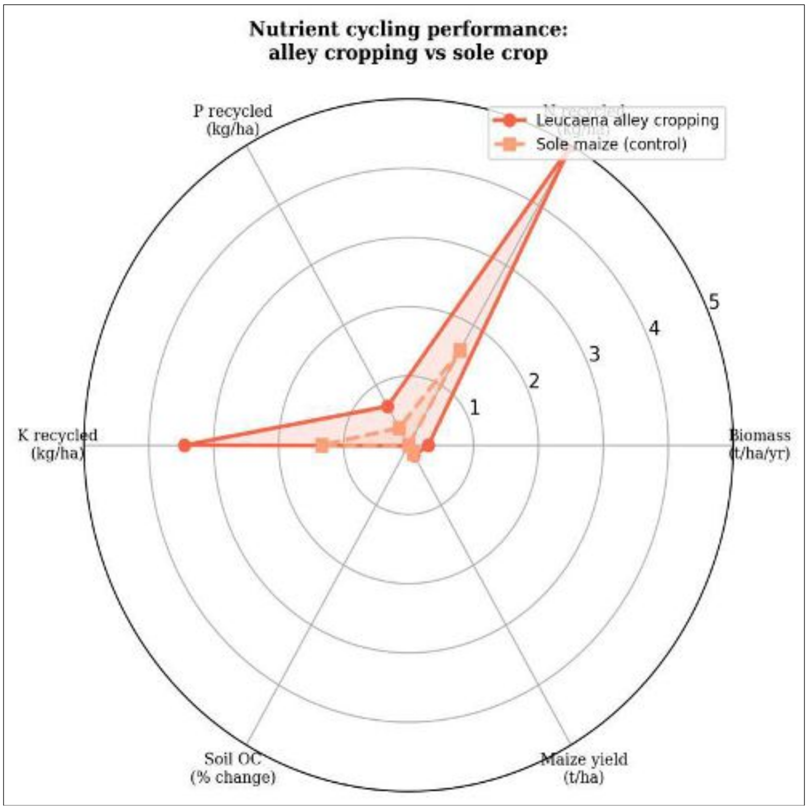

Fig 1: Radar chart comparing nutrient cycling performance of leucaena alley cropping versus sole maize

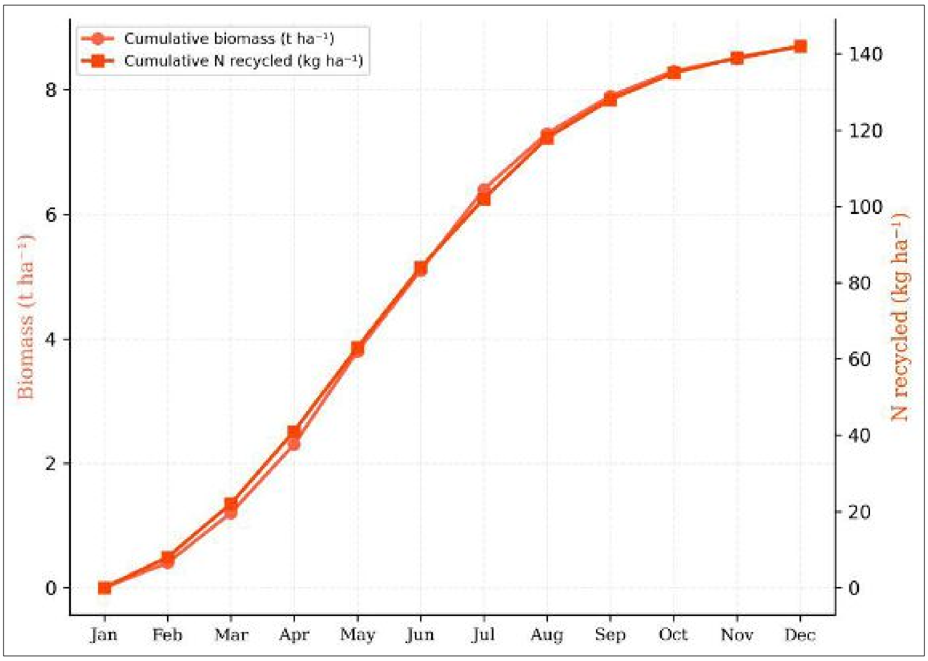

Fig 2: Cumulative biomass and nitrogen recycling by Leucaena hedgerows over the annual cycle

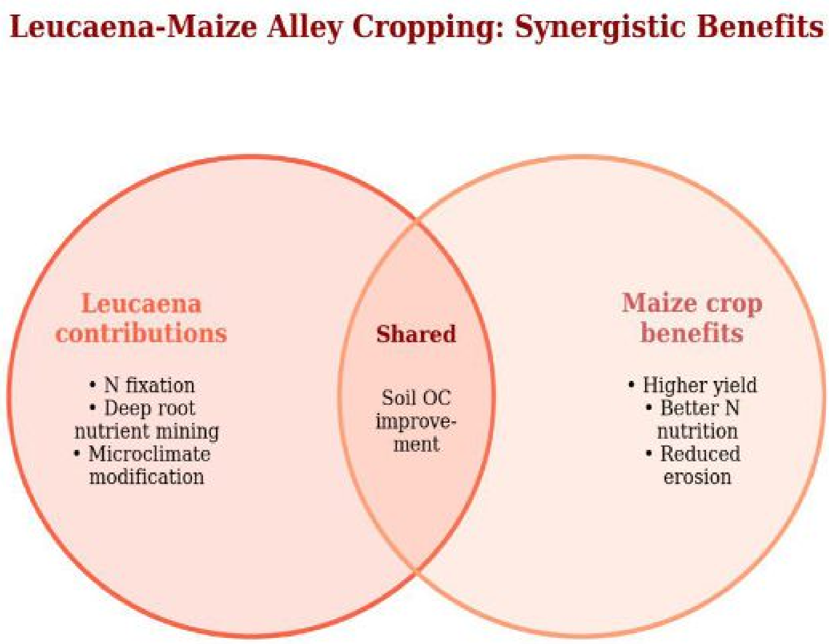

Fig 3: Venn diagram showing synergistic benefits of Leucaena-maize alley cropping

Discussion

The 142 kg N ha⁻¹ yr⁻¹ recycled by Leucaena biomass is within the range reported for similar alley cropping systems in Southeast Asia (100-200 kg N) but at the higher end, likely due to the three-pruning regime and favourable rainfall at the Chiang Mai site [2, 3]. The 22.3% maize yield advantage of alley cropping occurred even though both systems received the same fertiliser dose, confirming that the extra nitrogen and organic matter from Leucaena provided benefits beyond what mineral fertiliser alone could deliver [4]. The improvement in bulk density (from 1.36 to 1.24 g cm⁻³) reflects better soil aggregation from continuous organic matter addition [1]. Two seasons of data provide a good indication but longer-term monitoring is needed to confirm whether the system reaches a steady state or continues accumulating carbon.

Conclusion

Leucaena hedgerows produced 8.7 t ha⁻¹ yr⁻¹ of biomass, recycling 142 kg N ha⁻¹ and replacing approximately 68% of recommended nitrogen fertiliser. Maize yield was 22.3% higher in the alley system and soil organic carbon increased by 0.34 percentage points over two years. The system is well suited to the northern Thai uplands where soil degradation from continuous monocropping is a growing concern.

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