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The role of cover crop (*Arachis pintoi* Krapov & Gregory) and *Leucaena leucocephala* (Lam) in soil fertility restoration in Naawan, Philippines: Impacts on nitrogen, phosphorus, potassium, and organic matter

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Abstract

Intensive farming decline soil fertility, resulting decrease in plant production. Land rehabilitation using cover crops like *Arachis pintoi* (Krapov & Gregory) and nitrogen-fixing trees like *Leucaena leucocephala* (Lam) contribute significantly to soil fertility. This study aims to evaluate their effectiveness in improving nitrogen (N), phosphorus (P), potassium (K), and Organic matter levels in degraded land. Conducted in Naawan, Misamis Oriental, Philippines, soil samples collected were analyzed at the Department of Agriculture's Regional Soils Laboratory. Results showed a significant improvement in soil nitrogen (N) levels with *Arachis pintoi* and average phosphorus concentration remained within the normal range. Potassium (K) levels in *A. pintoi* plots generally increased and organic matter content showed an increase but remained below the optimal 5% threshold recommended for plant growth. *L. leucocephala* also demonstrated positive impacts on soil chemical properties. Nitrogen levels increased indicating effective nitrogen fixation. Phosphorus also showed an overall increase while Potassium levels exhibited variability, with some plots showing a decrease and increase. Organic matter content also increased though it did not reach the ideal 5% level. Moreover, significant differences were notable in nitrogen levels. *A. pintoi* resulted in a higher increase compared to *L. leucocephala*. The significant improvement in N levels suggests that *A. pintoi* may be more effective in rapid enhancement of soil fertility.

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Introduction

One urgent environmental problem is land degradation, which is made worse by traditional farming methods. Due to intensive farming techniques, including the use of synthetic fertilizers, monoculture, and continuous tillage, deplete soil nutrients and disrupt its structure (Food Print, 2023). Constant use of inorganic fertilizers may cause negative results such as soil layer hardening due to soil crack effect, and degraded soil physical properties. It is mainly caused by the presence of urea substances (Hasan *et al.*, 2005). Over time, these practices lead to a decline in soil fertility, resulting in a decrease in plant production and an increase in the need for external inputs, which in turn contribute to climate change. Land degradation can also be caused by rapidly growing population that can further put pressure on scarce natural resources. There is a need to feed the growing population, which is why there should be development of more efficient agricultural production systems (Lemage and Tsegaye, 2020). This continuous cultivation may result in soil fertility loss in agricultual landscapes. Furthermore, other factors such as inappropriate cropping systems, excessive nutrient extraction, and adverse weather conditions further accelerate soil degradation, making the restoration of soil health a critical challenge (EOS Data Analytics, 2023).

It is important to address these challenges; one way to address the issue is through land rehabilitation strategies. It focuses on restoring soil fertility and enhancing ecological balance. Among the promising approaches are the use of cover crops and nitrogen-fixing trees, which can improve soil structure and nutrient content. Cover crops such as *Arachis pintoi* (Krapov & Gregory) are known for their ability to enhance soil chemical and physical properties, particularly in acidic and low-fertility soils by improving pH levels and increasing organic matter (Chozin *et al.*, 2018). *A. pintoi* legume has good nutritional value and is suitable to be developed in low-light intensity areas. Additionally, *A. pintoi* mulch is effective in suppressing weed growth, the rate of soil erosion, and maintaining groundwater content (Chozin *et al.*, 2018). This plant is also used in controlling erosion, weeds, and nematodes, as well as increasing soil fertility as animal feed and ornamental plants in some tropical countries (Maswar, 2004). The use of this legume increases carbon fixation in the soil and reduces greenhouse gas emission. Its association with elephant grass can also improve the nutritional value of the silage (Paulino *et al.*, 2012).

Similarly, nitrogen-fixing trees like *Leucaena leucocephala* (Lam. de Wit) contribute significantly to soil fertility through their deep root systems and capacity to fix atmospheric nitrogen which enriches the soil with essential nutrients (Rusdy, 2020). Legume trees species are rich in nutrients and capable of replacing depleted soils, legume trees including *L. leucocephala* have symbiotic relationship with microorganisms like Clostridium and Astobacta which are both capable of trapping atmospheric nitrogen which ends up going back to the soil when they die (Michael, 2019). *L. leucocephala* and other legume shrub species have contributed effectively to the restoration process of abandoned agricultural land. Their presence provides large amount of nitrogen within two years fallow period and may solve soil fertility problem (Lemage and Tsegaye, 2020). Additionally, these species are known to improve soil organic matter, stimulate soil biological activity, and improve soil structure, increase soil aeration, and increase soil water-holding capacity (Sanginga *et al.*, 1988; Kang *et al.*, 1999; Warren and Zou, 2002; Imogie *et al.*, 2008). *A. pintoi* and *L. leucocephala* have similarities when it comes to their capabilities in restoring soil properties.

With this, this study aims to evaluate the effectiveness of *A. pintoi* and *L. leucocephala* in rehabilitating degraded land by assessing their impact on soil fertility, bulk density and porosity. Specifically, it will measure the changes in nitrogen, phosphorus, potassium, and organic matter levels before and after planting these species. By comparing these soil components across different treatments, the research seeks to determine the potential of these plants to restore soil health and improve land productivity.

Materials and methods

Study area

The study was conducted in the coastal municipality of Naawan, Misamis Oriental, Philippines. Naawan is a fourth-class municipality situated 62 kilometers away from Cagayan de Oro City. It covers an area of 88.50 square kilometers, representing 2.83% of Misamis Oriental's total land area. The specific study site is located in Barangay Poblacion, Naawan (Fig. 1).

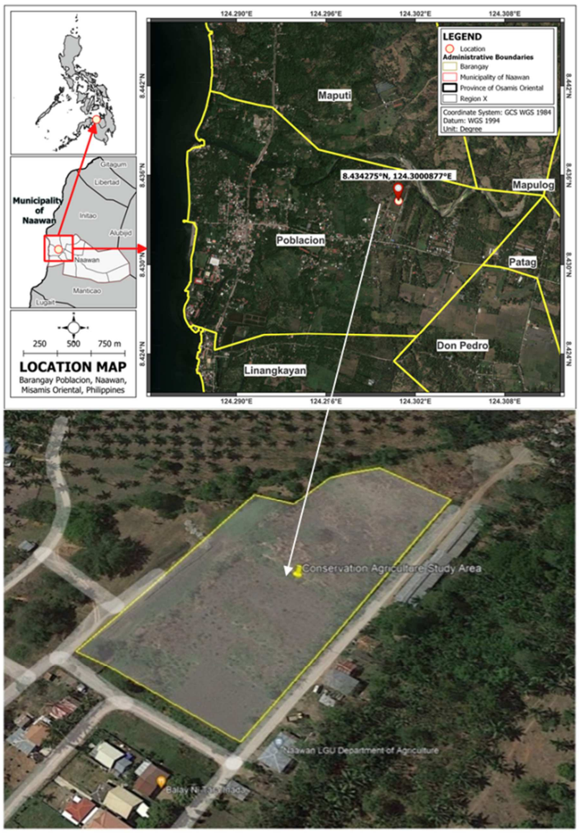

Fig. 1. Location of the study area

This barangay is situated along the barangay road on the mountainous side of the municipality. According to the Philippine Statistics Authority, Naawan had a population of 21,213 in 2015. The land use within two miles of Naawan includes 46% water, 24% forest, and 16% cropland. Within a ten-mile radius, land use includes 51% water, 22% forest, and 27% cropland, while within a 50-mile radius, land use comprises 51% water, 22% forest, and 27% cropland. The predominant soil types in Naawan are sand and loam, specifically sandy loam, which consists of sand, silt, and clay particles. This soil type is known for its favorable drainage characteristics and moderate water-holding capacity, making it suitable for various agricultural activities. Soil acidity in Naawan ranges from nearly neutral to extremely alkaline, with a pH range of 4.5 to above 6.9.

Research design

In this study, a range of techniques and processes were used to measure the landscape soil quality of the study area. In situ and through sample collection for laboratory examination, soil samples were examined. Sample collection and laboratory analysis were used to determine the pH, NPK, and organic matter. Samples were sent to the Department of Agriculture's (DA) IX Regional Soils Laboratory for analysis. The data was examined using statistical methods.

Data gathering

The sample strategy was taken from Ackerson (2018). A composite sample approach was used to collect the samples. Composite samples are made up of individual or subsamples that are combined to create a single composite sample. These samples are typically gathered from different places. By averaging the soil parameters over wider areas, combining many subsamples into a single composite sample reduced the effects of soil variability. A 15 cm hole was dug using a screw auger, and five (5) subsamples were collected in a zigzag pattern to collect soil samples. Five (5) subsamples were collected, and then they were thoroughly combined to create a homogenous mixture. Samples were then properly labeled and kept in plastic bags.

Sample preparation

Parameters such as Nitrogen, Phosphorus, Potassium and Organic matter were sent to DA IX and DA X for analysis. Before samples were sent for analysis, they were air-dried at room temperature with no direct sunlight exposure. Then, they were sieved using a 2mm sieve.

Each composite sample was divided into 4 quarters, and the 1st and 4th quarters were selected and weighed, amounting 1 kilogram. The samples were then sent to the laboratory for analysis.

Data analysis

Two-way Analysis of Variance was done to see the significant differences on soil parameter; Statistical Package for the Social Sciences (SPSS) was used as statistical analysis. A relationship is significant if the P-value is less than the alpha value of 0.05.

Results and discussion

The results indicate a significant improvement in soil nitrogen (N) levels with *A. pintoi*. Table 1 shows the chemical properties of the soil before planting the plant species in different plots. Initially, the soil had a low N concentration (0.06 %, SD= 0.02), but after 3 months of planting, the N content ((1.35 %, SD= 0.10) increased from an average of 0.06% to 1.35% surpassing the normal range. This increase is consistent with Zhang *et al.* (2009), who emphasize the importance of nitrogen for plant growth and metabolism. The substantial rise in N can be attributed to the nitrogen-fixing ability of *A. pintoi*, which enhances soil fertility through biological fixation. Phosphorus (P) levels in the soil with *A. pintoi* varied, with one plot (B4P3) falling below the normal range while another (B2P1) exceeded it. However, the average phosphorus concentration remained within the normal range (38.98 ppm, SD= 23.82) after 3 months (42.11 ppm, SD= 26.14), indicating an overall improvement.

Table 1. Chemical properties before planting

Treatment	Plots	N	P	K	OM
		(%)	(ppm)	(ppm)	(%)
	Normal range	0.2-0.5	30-60	180-300	>5
Control	B1P3	0.04	22.53	304.86	0.89
	B2P3	0.07	29.6	318.24	1.42
	B3P1	0.08	36.77	309.94	1.54
	B4P2	0.04	17.03	347.36	0.81
Arachis pintoi	B1P2	0.04	37.93	224.44	0.81
	B2P1	0.08	72.5	348.4	1.57
	B3P2	0.07	27.76	235.15	1.42
	B4P3	0.04	17.72	280.2	0.85
Leucaena leucocephala	B1P1	0.07	18.81	210.37	1.38
	B2P2	0.05	49.41	379.09	0.95
	B3P3	0.07	13.63	210.36	1.4
	B4P1	0.04	20.7	336.67	0.72

Table 2. Chemical properties after 3 months

Treatment	Plots	N	P	K	OM
		(%)	(ppm)	(ppm)	(%)
	Normal range	0.2-0.5	30-60	180-300	>5
Control	B1P3	1.28	14.35	188.5	2.55
	B2P3	1.3	18.3	212.5	2.6
	B3P1	1.3	39.45	380	2.6
	B4P2	1.3	25.55	347	2.6
Arachis pintoi	B1P2	1.35	30	323.5	2.7
	B2P1	1.48	78.2	410.5	2.95
	B3P2	1.25	42.65	291.5	2.5
	B4P3	1.33	17.6	275	2.65
Leucaena leucocephala	B1P1	1.28	28.3	194.5	2.55
	B2P2	1.4	40.85	313.5	2.8
	B3P3	1.35	32.45	240.5	2.7
	B4P1	1.22	33.15	521.5	2.45

Table 2 presents the chemical properties of the soil after 3 months of planting the *A. pintoi*. Results show that potassium (K) levels in *A. pintoi* plots generally increased (272.05ppm, SD= 56.34 to 325.13ppm, SD= 60.37), with most plots falling within the ideal range. Organic matter (OM) content (1.16%, SD= 0.39) showed an increase (2.70%, SD= 0.19) but remained below the optimal

5% threshold recommended for plant growth (Meshram *et al.*, 2016).

Despite this, the increase in OM suggests a positive effect of *A. pintoi* on soil organic content over a short period. In addition, Table 3 showed the results for the bulk density and porosity both species. According to Mukhopadhyay *et al.* (2019), a bulk density of a value equal or below 1.3 gcm^{-3} is good, between 1.3 gcm^{-3} and 1.55 gcm^{-3} is fair, and above 1.8 gcm^{-3} is not favorable. While for soil porosity the requirement for plant growth typically range from 40% to 60% (Cai *et al.*, 2024). *A. pintoi* shows that the p-value is 0.052, which is little higher than the accepted threshold of 0.05. While the p-value for porosity is 0.048, which is indicates that there is a significant difference. Although the bulk density results are not statistically significant, the p-value is close to 0.05, implying that *A. pintoi* may still have a subtle effect on soil compaction. Further research may reveal more about its long-term effects on bulk density. Furthermore, the significant difference in porosity suggests that *A. pintoi* is actively altering soil structure. This could be owing to its rooting patterns or ability to form soil aggregates, both of which can help with soil aeration, water retention, and root penetration.

Table 3. Bulk density and porosity in each treatment

Treatment	Bulk density			Porosity		
	Before planting (gcm^{-3})	3 months (gcm^{-3})	p-value	Before planting (%)	3 months (%)	p-value
Control	1.44	1.21		45.76	54.47	
	1.46	1.30		45.01	50.78	
	1.42	1.31		46.53	50.54	
	1.31	1.31		50.54	53.32	
Average	1.407	1.28	0.041	46.96	52.28	0.013
Std. Dev	0.067	0.048		2.466	1.928	
Arachis pintoi	1.52	1.23		42.55	53.61	
	1.37	1.32		48.22	50.17	
	1.37	1.21		48.22	54.44	
	1.41	1.37		46.75	48.48	
Average	1.417	1.282	0.052	46.435	51.675	0.048
Std. Dev	0.070	0.075		2.681	2.820	
Leucaena leucocephala	1.42	1.24		46.40	53.29	
	1.40	1.30		47.26	50.78	
	1.37	1.27		45.17	52.17	
	1.42	1.41		46.32	46.67	
Average	1.403	1.305	0.034	46.288	50.728	0.034
Std. Dev	0.023	0.074		0.858	2.893	

L. leucocephala also demonstrated positive impacts on soil chemical properties. Nitrogen levels increased (1.31%, SD= 0.08) from the baseline (0.06%, SD= 0.02) average of 0.06% to 1.31% after 3 months, indicating effective nitrogen fixation and a notable enhancement in soil fertility. This finding aligns with previous studies showing that *L. leucocephala* contributes to increased nitrogen levels in the soil (Radrizzani *et al.*, 2011). Phosphorus results showed that only one plot (B1P1) did not meet the normal range (which is >6), while the others fell within it (25ppm, SD= 16.13), reflecting an overall increase (33.69ppm, SD= 5.23) in P levels. Potassium levels exhibited variability, with some plots (B1P1 and B2P2) showing a decrease, while others (B3P3 and B4P1) increased. Nevertheless, all plots remained within the normal range for K from (231.53ppm, SD= 87.77) to (317.50ppm, SD= 144.56). Organic matter content increased (2.63%, SD= 0.16) from (1.11%, SD= 0.33) in soils with *L. leucocephala*, though it did not reach the ideal 5% level. The observed increase suggests that *L. leucocephala* positively affects soil OM content, contributing to long-term soil health improvements. In addition, the p-value for both bulk density and porosity for *L. leucocephala* is 0.034, this indicates that this plant has a significant impact on the quality of soil. The statistically significant results for bulk density and porosity show that *L. leucocephala* has a quantifiable and significant effect on soil structure, and generates looser, more porous soil, which could be extremely valuable for enhancing soil health in agricultural or natural settings. This also means that *L. leucocephala* is a good candidate for improving soil structure in degraded or compacted soils especially in agricultural system.

In comparison, both *A. pintoi* and *L. leucocephala* significantly improved soil nitrogen levels, with *A. pintoi* slightly outperforming *L. leucocephala* in this aspect. For phosphorus, *A. pintoi* had more variability, with some plots falling below the normal range, whereas *L. leucocephala* showed a more consistent increase in phosphorus levels. In terms of potassium, *A. pintoi* generally maintained or increased K levels, while *L. leucocephala* showed mixed results with some plots decreasing. Both species enhanced organic matter content, but neither reached the recommended 5% level, though both showed positive changes. Moreover, while it has little effect on bulk density, *A. pintoi* exhibits a strong influence on porosity, which may be advantageous for enhancing soil aeration and water infiltration. This could suggest that *A. pintoi* slightly enhances soil structure without significantly changing soil compaction. Contrarily, *L. leucocephala* has a considerable effect on bulk density as well as porosity, indicating a more profound influence on soil structure. This could imply that *L. leucocephala* depending on the particular experimental settings, either loosens the soil, boosting porosity, or compacts it, decreasing porosity.

Conclusion

Based on the research findings, planting *A. pintoi* and *L. leucocephala* in a degraded land significantly improved soil nitrogen, phosphorus, potassium, and organic matter. *A. pintoi* resulted in higher increase in nitrogen compared to *L. leucocephala,* but the latter showed more stable increase in phosphorus and organic matter. Although there is an increase in the organic matter in every plot neither of them reached the recommended 5% level. Both had little effect on bulk density, but *A. pintoi* exhibited a stronger influence on porosity. This can be advantageous for the enhancement of soil aeration and water infiltration. *L. leucocephala* also either loosens the soil or compacts it. Overall, this research shows the positive effect of these two plant species in enhancing the soil quality in degraded land. It entails effective use for land rehabilitation.

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