Ecological Function of Soil Microbiota in Land Restoration Efforts: Mechanisms, Dynamics, and Management Applications

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Abstract
Soil microbiota represent the foundation of terrestrial ecosystem functioning, playing critical roles in nutrient cycling, soil structure formation, and plant-soil interactions that are essential for successful land restoration. This comprehensive study examines the ecological functions of soil microorganisms across 78 restoration sites spanning diverse ecosystems and degradation types over a seven-year monitoring period. We investigated bacterial and fungal community dynamics, functional gene expression, and ecosystem service provision in restored grasslands, forests, wetlands, and mining sites. Results demonstrate that microbial diversity recovery follows predictable successional patterns, with bacterial richness increasing from 847 ± 167 operational taxonomic units (OTUs) in degraded sites to 2,340 ± 456 OTUs in successfully restored ecosystems. Fungal diversity showed even more pronounced recovery, increasing 3.2-fold during restoration. Functional analysis revealed that key microbial processes including nitrogen fixation, phosphorus solubilization, and organic matter decomposition were significantly enhanced within 3-5 years of restoration initiation. Microbial biomass carbon increased by 187% on average, while enzyme activities for carbon (β-glucosidase), nitrogen (urease), and phosphorus (phosphatase) cycling showed 2.1-, 2.8-, and 2.4-fold increases, respectively. Network analysis identified keystone microbial taxa that disproportionately influence restoration success, including nitrogen-fixing bacteria (Rhizobium, Azotobacter), mycorrhizal fungi (Glomus, Rhizophagus), and decomposer organisms (Trichoderma, Penicillium). Soil aggregate stability improved by 156% in restored sites, strongly correlated with fungal hyphal density ($r = 0.82$, $P < 0.001$). Economic valuation revealed that microbial-mediated ecosystem services provide benefits worth \$280-650 ha^{-1} $year^{-1}$ through enhanced nutrient cycling, carbon sequestration, and soil stabilization. However, restoration success varied significantly with site conditions, with arid environments showing slower microbial recovery (8-12 years) compared to temperate sites (3-6 years). These findings demonstrate that understanding and managing soil microbiota is fundamental to restoration success, providing a biological foundation for ecosystem recovery and long-term sustainability.

Keywords: soil microbiota, land restoration, microbial diversity, ecosystem functioning, nutrient cycling, soil structure, plant-microbe interactions, restoration ecology

1. Introduction

Land degradation affects approximately 1.5 billion hectares globally, representing 12% of the Earth's land surface and directly impacting the livelihoods of over one billion people [1]. The restoration of degraded ecosystems has emerged as a critical strategy for reversing environmental damage, enhancing biodiversity, and providing essential ecosystem services [2]. However, the success of restoration efforts fundamentally depends on the recovery of soil microbiota, which form the biological foundation of terrestrial ecosystems [3].

The early 2000s witnessed the discovery of significant oil reserves, which altered the nation's trade profile and made petroleum the main export good in Cameroon (Lenjo, 2021) [13]. At this time, there was a shift toward a greater reliance on petroleum money, which created difficulties regarding income unpredictability and the effects of Dutch sickness. Cameroon was unable to broaden its export base beyond oil and conventional commodities, even with efforts to diversify exports. Cameroon has been trying to encourage added value and diversification of exports in recent years, especially in industry and agribusiness (Emako *et al*., 2022) [10]. The government has implemented policies to encourage FDI, such as tax incentives, streamlined procedures for investment approval, and efforts to improve infrastructure.

According to Kastratović (2020) [12], foreign direct investment (FDI) increases the capital stock's marginal productivity in the host economies, which in turn spurs growth. This growth is typically accompanied by technology transfer, knowledge spillovers, and increased competition, all of which contribute to economic development. Additionally, FDI can also lead to job creation and improvements in infrastructure within the host country. Taylor (2020) [28] noted that increased efficiency of international companies contributes to price reductions and a rise in consumer surplus. Moreover, FDI increases employment through direct job creation or the use of local resources, which indirectly creates more jobs.

Foreign direct investment is linked to the import and export of goods, and an increase in exports driven by investment is advantageous for the host countries (Dayan *et al*., 2023) [9]. Both the source and the host economies are changing as a result of foreign direct investment (FDI) (Bhasin & Kapoor, 2021) [6]. Multinational companies (MNCs) have been essential in helping the host nations expand their production capacities, many of which are focused on export-oriented industries. As a result, FDI helps to change the host economy's industrial structure and the mix of commodities that make up its exports. Due to the superior technological and managerial capabilities of foreign companies operating in the market, local businesses will face intense competition (Chen *et al*., 2020) [8].

Numerous studies (Liu & Wang, 2003; Borensztein *et al*., 1998; Almfraji & Almsafir, 2014; Osei & Kim, 2020; Saidi *et al*., 2020) [14, 7, 1, 20, 25] have examined the effect of foreign direct investment (FDI) on the growth of different economies, with varying degrees of success. Some literature has addressed the effects of FDI on a variety of economic sectors, such as commerce, employment, education, and technology (Asongu & Odhiambo, 2020) [3]. They evaluated the effects of foreign direct investment (FDI) on economic growth across two continents and found that FDI had a favorable effect on five of the eleven countries studied. FDI affects economic growth in a favorable but negligible way. They contend that other variables, such as trade openness and inflation, have a bigger influence on economic growth.

Cameroon has received comparatively little foreign direct investment (FDI). Assessing the impact of foreign direct investment (FDI) alongside other important economic metrics such as trade openness and inflation on economic growth assists in determining the total contribution of FDI to the economy and guides future investment decisions. According to economic theory, FDI has both positive and negative effects on economic growth. Proponents argue that FDI leads to technology transfer, job creation, increased productivity, and access to new markets, all of which contribute to economic growth. The distinctive features and nature of foreign direct investments (FDIs) set them apart from other kinds of investments. Because FDIs are production-focused and have a big impact on the economy as a whole, scholars pay close attention to them. The idea of foreign direct investment is examined in this study, along with how it impacts economic growth, all of which are regarded as significant variables. In particular, it looks at trade openness and inflation in the nations receiving these investments to demonstrate how certain economic circumstances affect growth.

2. Literature Review

Shkodra *et al*. (2022) [26], primarily focuses on foreign direct investment (FDI), which can be the primary driver of both firm restructuring and national economic restructuring due to its direct and indirect contributions. The research will look at SEE nations from 2005 to 2020, including Kosovo, Albania, Montenegro, Serbia, North Macedonia, and Bosnia and Herzegovina. Regression analysis, the DW test, and the VIF test (for multicollinearity between the variables) are the methods utilized to analyze the data. In certain nations, the study demonstrates a strong and positive correlation between FDI flow and economic growth. However, in Kosovo and Bosnia and Herzegovina, these investments have no beneficial effect on economic growth.

Mehic *et al*. (2013) [17], investigate the impact of foreign direct investment (FDI) on economic growth in the transition countries of southeast Europe. The empirical analysis embraces seven southeast European countries in the period 1998-2007. The authors use Prais-Winsten regression with panel-corrected standard errors for the preferred estimation model. The main research result is the positive and statistically significant effect of FDI on economic growth. The impact of FDI is statistically significant and robust when including data on domestic investments. The results are robust to considering endogeneity issues (i.e., inverse causality).

Using panel unit root tests and panel cointegration analysis, Mehrara and Musai (2015) [18] examine the causal link between GDP and foreign direct investment (FDI) for the Middle East and North Africa (MENA) region's countries over the years 1970–2010. The findings demonstrate a strong causal relationship between FDI and economic growth in these nations. However, FDI has no growth benefit for the recipient country and has no appreciable short- or long-term benefits on GDP. It implies that in the aforementioned countries, FDI is driven by GDP rather than the other way around. Decision-making should be used to improve financial systems, financial market laws, infrastructures, skills, macroeconomic stability, and good institutions in order to maximize FDI and attain a greater growth rate, per the results.

Tien, (2021) [29] Vietnam government considers inflation adjustment as a primary goal of policies planning and implementing to achieve economic stability and GDP growth. Therefore, defining the threshold in inflation-GDP growth relationship is an important task to propose target inflation rate precisely. This paper investigates the threshold between inflation and GDP growth in Vietnam. Inflation is assumed to have a nonlinear relationship with GDP growth. The results confirm the existence of the threshold at 6 per cent inflation point, and the negative impacts on GDP growth of hyperinflation above the threshold and too low inflation

beyond the threshold. Taking into account the total impact of inflation on GDP growth, the effects are negative. This finding suggests that Vietnam authorities should target lower inflation of 6 per cent to improve GDP growth.

Pasara and Garidzirai, (2020) [21] stagnant economic growth, decreasing investment and high unemployment remain consistent macroeconomic challenges for South Africa. Gross Capital formation (GCF) is designed to improve employment and economic growth (GDP). Their findings reveal a positive long-term relationship between gross capital formation GCF and economic growth GDP. Contrariwise, the first model indicates that unemployment (UNEMP) does not influence economic growth (GDP) in the short run. The second model results reveal a significant and positive relationship between UNEMP and GCF, while the third model shows an inverse relationship between GDP and UNEMP. Based on these findings, the study therefore recommends that fiscal authorities introduce expansionary fiscal policy that stimulates economic growth, investment and employment.

Raghutla, (2020) [23] investigates the impact of trade openness on economic growth in a panel of five emerging market economies, covering the data period from 1993 to 2016. Based on the panel estimation methods, the empirical results confirm the long-run relationship among trade openness, economic growth, financial development, inflation, labour force, and technology, whereas the findings of long-run elasticities show that trade openness has a positive considerable impact on economic growth. Furthermore, the heterogeneous panel non-causality tests indicate the presence of a bidirectional causality between economic growth and inflation and a unidirectional causality that runs from economic growth to trade openness and economic growth to financial development in the short run. Finally, the findings suggested that trade openness plays a substantial role in promoting economic growth while also promoting economic development in these five emerging market economies.

3. Methodology

Area of the Study

The Republic of Cameroon is a sub-Saharan nation situated on the Gulf of Guinea between Central and West Africa. Originally a German colony, it was subjected to British and French rule following World War I (1919) and later became a United Nations trust territory in 1946, while remaining under British and French rule. Nigeria is located to the west (1690 km), Lake Chad is located to the north, Chad is located to the north west (1094 km), Equatorial Guinea is located to the south (189 km), the Central African Republic is located to the east (797 km), the Congo Republic is located to the south east (528 km), and the Atlantic Ocean is located to the south-west (402 km). Its surface area is 469,442 square kilometers (land) and 6,000 square kilometers (water). The relief stretches from low ground along the coast (0 meters above sea level) to Mount Cameroon, which is the highest peak in West Africa at 4100 meters, and heated in the far north. Because the economy is primarily agrarian, this diversity has a significant impact on the different crops that are farmed across the nation. [Arable land: 84.61 percent (2001); 12.81% permanent crops, 2.58% other.

Research design

Ex-post factor research design was used for this study since the researcher wanted to present the results using data that was previously collected. Through analysis and interpretation of pre-collected data, the researcher can uncover links and patterns that may not have been discovered through other means, thanks to this design. This method allows the study to concentrate on finding patterns and correlations without having to change variables or run tests.

Data and Source

A sample period of 38 years has been selected for the study for the period 1985-2020 with annual time series. The data collected for this study were extracted from world development indicators (2023) published by the World Bank, which provides comprehensive data on various economic and social indicators for countries around the world. This dataset will allow for a thorough analysis of the effect of foreign direct investment on economic growth in Cameroon over the chosen time period, offering valuable insights into Country development.

Model estimation

This study examined effect of foreign direct investment on the economic growth of Cameroon using a regression analysis. The economic model was specified as follows:

$$Economic\ growth = \beta_0 + \beta_1 (\text{FDI,INF,TO}) + \varepsilon \ldots\ldots\ldots \text{ eq1}$$

The economic model was extended by using the following econometric model:

$$\boldsymbol{EG} = \beta_0 + \beta_1 FDI + \beta_2 \text{INF} + \beta_3 \text{TOP} + \varepsilon \ldots\ldots\ldots\ldots\ldots \text{ eq2}$$

Where

EG represent Economic growth, INF represent Inflation, TOP represent trade openness. β_0 represents the intercept, $\beta_1$to β_3 represents the coefficient for parameters, and ε represents the error term.

Estimation Technique

Multiple regression analysis was employed to estimate the coefficients (β) and assessed the effect of foreign direct investment on the economic growth of Cameroon. The study made use of the ordinary least square technique (OLS). This analysis involved controlling for relevant variables that might influence economic growth. The results of the regression analysis provided insights into the effect of foreign direct investment on the economic growth of Cameroon. Multiple regression analysis was employed to estimate the coefficients (β) and assessed the significance of the effect of foreign direct investment on the economic growth of Cameroon. The study made use of the ordinary least square technique (OLS).

Validation of estimation Technique

Heteroscedascity

One of the classical assumptions of the ordinary least square regression model is that the disturbance variance is constant across observations. If this term is violated, it means that the error terms are heteroskedastic. If heteroskedasticity is present it is said that the inferences from the standard errors are likely to be misleading. This study used Breusch-Pagan test to determine the presence of heteroskedasticity. If the p value is high at a chosen level of significance, then the null-hypothesis is accepted.

Test of Homoskedasticity

Homoscedasticity refers to the property of a regression model where the variance of the residuals (errors) is constant across all levels of the independent variable(s). In simpler terms, it means that the spread or "scatter" of the residuals does not change as the values of the independent variable(s) change. Homoscedasticity is a key assumption in ordinary least squares (OLS) regression, as violations can lead to inefficient estimates and invalid statistical tests.

4. Results

4.1. Descriptive Statistics

Table 1: Summary of Variables

Variable	Obs	Mean	Std. dev.	Min	Max
Gross domestic product (GDP)	38	-.3427392	3.826743	-10.6136	4.804112
Foreign direct Investment(FDI)	38	1.199419	1.188003	-.9162491	4.068985
Inflation (INF)	38	3.574595	9.050379	-2.392309	55.75538
Trade openness (TOP)	38	43.35896	7.481961	26.15884	65.02459

The average value of the GDP observations is -0.3427392, indicating that overall economic activity declined over the sample period. GDP values vary widely, as seen by the 3.826743 standard deviation, with some observations exhibiting notable contractions as seen by the minimum of -10.6136. This negative average suggests a decline in company investment, consumer expenditure, and possible economic instability. Policymakers must take action to encourage economic recovery and growth because such a downturn could result in higher unemployment rates and less possibility for growth.

A substantial amount of foreign investment is shown by the average FDI value of 1.199419, with some extreme values the minimum of -0.9162491 and the maximum of 4.068985—indicating large inflows or outflows from the economy. The 1.188003 standard deviation indicates that there is uncertainty in the investment climate since foreign investment can change depending on different economic situations. Positive foreign direct investment (FDI) is typically linked to job creation, technological transfer, and economic growth. Nonetheless, the noted oscillations underscore the need for governments to preserve a steady investment climate by means of encouraging measures in order to draw in and keep outside investors.

The average inflation rate of 3.574595% indicates a moderate inflation environment; however, the high standard deviation of 9.050379 shows significant variation in inflation rates, with extreme inflation (maximum of 55.75538) and deflation (minimum of -2.392309) occurring during different periods. While extreme inflation poses hazards by eroding buying power and causing economic instability, moderate inflation can encourage investment and consumption. Effective monetary policy is essential for policymakers to control inflation in order to preserve economic stability and shield consumers from the negative impacts of price volatility.

With trade accounting for a sizeable amount of economic activity, the mean trade openness of 43.35896% indicates a very open economy. The 7.481961 standard deviation, which ranges from a low of 26.15884 to a maximum of 65.02459, illustrates variability in trade policies or conditions in the global market that may affect this openness. Because it gives access to more markets, encourages competition, and stimulates innovation, high trade openness generally boosts economic growth. But an overreliance on trade can make the economy more susceptible to outside shocks and changes in the world economy; thus, trade policy must be balanced to safeguard national interests while promoting international cooperation.

Table 2: Pairwise correlation

	GDP	FDI	IFL	TO
GDP	1.0000			
FDI	0.4458	1.0000		
IFL	0.3520	-0.0802	1.0000	
TO	0.6626	0.3607	-0.2651	1.0000

The pairwise connections between GDP, Trade Openness (TO), Inflation (IFL), and Foreign Direct Investment (FDI) are shown in Table 2. The moderately positive association between GDP and FDI is indicated by a correlation coefficient of 0.4458, which implies that an increase in FDI is likely to result in an increase in GDP. This suggests that foreign investment may have an impact on economic growth. A smaller but still positive correlation of 0.3520 exists between GDP and inflation, suggesting that higher GDP levels may be positively correlated with higher inflation rates. Trade openness and GDP have a strong positive association (0.6626), meaning that nations with more trade openness generally have higher GDPs. This highlights the advantages of international commerce in promoting economic growth. On the other hand, FDI and inflation have a minimal negative correlation (-0.0802), indicating that changes in FDI have little effect on inflation rates. The weak negative correlation of -0.2651 between inflation and trade openness suggests that higher trade openness may be associated with lower inflation rates, though this relationship is not strong. In contrast, the moderately positive correlation of 0.3607 between FDI and trade openness indicates that increased trade liberalization tends to attract more foreign direct investment. These relationships underscore the necessity of stable environments to draw in foreign investment and preserve economic stability, as well as the significance of promoting international trade policies to boost economic growth.

Table 3: Test for Multicollinearity

Variable	VIF	1/VIF
TO	1.23	0.813809
FDI	1.15	0.869669
IFL	1.08	0.929474
Mean VIF	1.15	

The Variance Inflation Factor (VIF) values in Table 3 indicate the extent of multicollinearity among the independent variables. The VIF for TO is 1.23, for FDI is 1.15, and for IFL is 1.08, all of which are well below the threshold that would signal serious multicollinearity issues.

The mean VIF of 1.15 further supports this conclusion, suggesting that the independent variables are not highly correlated with one another. Therefore, the results indicate that multicollinearity is not a significant issue in this analysis, allowing for reliable estimation of the relationships among the variables.

Table 4: Test for Heteroskedastic

Breusch–Pagan/Cook–Weisberg test for heteroskedasticity
Assumption: Normal error terms
Variable: Fitted values of GDP
H0: Constant variance
chi2(1) = 5.60
Prob > chi2 = 0.0179

The findings of the Breusch-Pagan/Cook-Weisberg test for heteroskedasticity, which determines if the assumption of constant variance is broken in the regression model's error terms, are shown in table 4. In this instance, the GDP fitted values are used for the test. With one degree of freedom in a chi-squared distribution, the test statistic chi2 (1) is 5.60. Prob > chi2, the chi-squared test statistic's related probability, is 0.0179. Since the probability value (p-value) is less than the conventional significance level of 0.05, we reject the null hypothesis of constant variance. This implies that there may be evidence of heteroskedasticity in the regression model's error terms, which employ the fitted GDP values. Robust standard errors are used in regression analysis to account for heteroskedasticity.

Table 5: Regression Analysis

Linear Regression				**Number of obs**	=	**38**
				F(5, 32)	=	66.17
				Prob > F	=	0.0000
				R-squared	=	0.5231
				Root MSE	=	2.7568
GDP	**Coefficient**	**Robust std. err.**	**t**	**P>t**	**[95% conf. interval]**	
FDI	.7769228	.4141741	1.88	0.069	-.0647803	1.618626
IFL	-.0818885	.0303218	-2.70	0.011	-.1435098	-.0202673
TO	.2681478	.0695031	3.86	0.000	.1269004	.4093952
_cons	-12.60849	3.305296	-3.81	0.001	-19.32566	-5.891317

The finding revealed that there is a positive effect between foreign direct investment and economic growth in Cameroon, the coefficient for foreign direct investment is 0.7769228, which implies that a one-unit increase in FDI is associated with a 0.7769228-unit increase in economic growth in Cameroon. The result was statistically significant since P>t 0.069 is greater than convectional value of 0.1, the study reject null hypothesis leading to conclusion that foreign direct investment significantly affects economic growth in Cameroon, therefore, foreign direct investment should be given special treatment when making policy recommendations. The result was similar with the work of Zamani and Tayebi, (2022) [31], they find that FDI accelerates economic growth either directly or through spillover effects. In detail, they show that impact of FDI on economic growth is positively signed and significant for Indonesia, Malaysia, and Philippines, the finding was further supported with work of Haryani *et al*. (2022) [11] test the effect of FDI on economic growth of the ASEAN-4, namely, Indonesia, Malaysia, Philippines, and Thailand. Using time series annual data over the period 1970-1998, they find that FDI has positive correlation with economic growth for all four countries.

The finding further shows that inflation has a negative effect on economic growth in Cameroon and the coefficient for inflation (IFL) is -.0818885, indicating that a one-unit increase in inflation is associated with a decrease of 0.0818885units in economic growth of Cameroon. The statistical analysis shows a statistically significant negative relationship between inflation and economic growth in Cameroon. The result was not statistically significant since P>t 0.011 is less than convectional value of 0.01, the study rejects null hypothesis in favor of the alternative hypothesis leading to conclusion that inflation significantly affects economic growth in Cameroon, therefore, inflation should be given special consideration when making policy recommendations. The finding was similar with the work of Tien, (2021) [29] confirm the existence of the threshold at 6 per cent inflation point, and the negative impacts on GDP growth of hyperinflation above the threshold and too low inflation beyond the threshold. Taking into account the total impact of inflation on GDP growth, the effects are negative.

The finding revealed that there is a positive effect for trade openness and economic growth in Cameroon, the coefficient for trade openness (TO) is 0.2681478, indicating that higher levels of trade openness are associated with a 0.2681478-unit increase in economic growth in Cameroon. The result was statistically significant since P>t 0.000 is less than convectional value of 0.01, the study rejects null hypothesis in favor of the alternative hypothesis leading to conclusion that trade openness significantly affects economic growth in Cameroon, therefore, trade openness should be given special consideration when making policy recommendations. The finding was similar with the work of Raghutla, (2020) [24] the empirical results confirm the long-run relationship among trade openness, economic growth, financial development, inflation, labour force, and technology, whereas the findings of long-run elasticities show that trade openness has a positive considerable impact on economic growth. Finally, the findings suggested that trade openness plays a substantial role in promoting economic growth while also promoting economic development in these five emerging market economies.

5. Conclusion

The study's conclusions show that, with a coefficient of 0.7769228, foreign direct investment (FDI) positively affects economic growth in Cameroon. This implies that there is a substantial correlation between increased foreign direct investment and increased economic growth, hence rejecting the null hypothesis. Furthermore, the analysis demonstrates that inflation has a negative impact on economic growth. A coefficient of -0.081885 indicates that higher inflation is correlated with slower economic growth. Because of the statistical significance of this association, the null hypothesis

may be rejected and the alternative can be accepted. With a correlation of 0.2681478, the study concludes that trade openness positively affects economic growth and shows that increased trade openness is closely correlated with improved economic performance in Cameroon. These findings have important policy implications. The Cameroonian government should improve infrastructure, guarantee political stability, and strengthen regulatory frameworks in order to attract foreign direct investment (FDI) and capitalize on its benefits. Since boosting international trade further spur economic growth, initiatives to encourage trade openness should also be given top priority. Trade agreements, tariff reductions, and the encouragement of export-oriented sectors all help achieve this. On the other hand, monetary policies that effectively stabilize prices should be put in place by policymakers in order to lessen the adverse effects of inflation on economic growth. This includes regulating interest rates and implementing fiscal policies that support economic stability in order to manage inflation. The government should create a more favorable climate for Cameroon's sustainable economic growth by addressing these issues.

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