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ORIGINAL

Relationship between forest fires and climate variability: effects on agricultural production in the Ecuadorian Amazon

Relación entre incendios forestales y variabilidad climática: efectos sobre la producción agrícola en la Amazonía del Ecuador

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ABSTRACT

This study analyzes the relationship between agricultural burning, forest fires, rainfall variability, and its impact on agricultural production in the Ecuadorian Amazon. The research adopts a quantitative and explanatory approach, using geospatial information, satellite data, and climatic and agricultural records to identify a causal chain between human activities and environmental dynamics. The results show that agricultural burning significantly increases the occurrence of forest fires, especially during periods of high temperature and low humidity. In turn, forest fires negatively affect the rainfall regime due to the emission of aerosols and particulate matter that disrupt atmospheric condensation processes. This reduction in rainfall directly impacts agricultural productivity, considering that most production systems in the Ecuadorian Amazon rely on rain-fed agriculture. The econometric analysis with fixed effects and biophysical control variables allowed for the isolation of causal effects and confirmed the existence of an environmental impact chain linking fire use with reduced agricultural output. It is concluded that agricultural practices based on burning generate not only local effects but also regional consequences on climate regulation and food security. These findings highlight the need for public policies aimed at reducing the use of fire, preventing forest fires, and promoting sustainable agricultural practices in the Amazon region of Ecuador in order to ensure environmental conservation and long-term productive stability.

Keywords: Ecuadorian Amazon, agricultural burning, forest fires, precipitation.

RESUMEN

La presente investigación analiza la relación entre las quemas agrícolas, los incendios forestales, las variaciones en la precipitación y su impacto en la producción agrícola en la Amazonía ecuatoriana. El estudio se desarrolla bajo un enfoque cuantitativo de carácter explicativo, utilizando información geoespacial, datos satelitales y registros climáticos y agrícolas para identificar una cadena causal entre actividades humanas y dinámicas ambientales. Los resultados evidencian que las quemas agrícolas incrementan significativamente la ocurrencia de incendios forestales, especialmente en periodos de alta temperatura y baja humedad. A su vez, los incendios forestales generan efectos negativos sobre el régimen de precipitaciones debido a la emisión de aerosoles y partículas que alteran los procesos de condensación atmosférica. Esta reducción en las lluvias impacta de manera directa la productividad agrícola, considerando que gran parte de los sistemas productivos en la Amazonía ecuatoriana dependen de la agricultura de secano. El análisis econométrico con efectos fijos y variables de control bioclimáticas permitió aislar los efectos causales y confirmar la existencia de una cadena de impacto ambiental que conecta el uso del fuego con la disminución de la producción agrícola. Se concluye que las actividades agrícolas basadas en quemas no solo generan efectos locales, sino también repercusiones regionales sobre el clima y la seguridad alimentaria. Estos hallazgos resaltan la necesidad de implementar políticas públicas orientadas a la reducción del uso del fuego, la prevención de incendios forestales y la promoción de prácticas agrícolas sostenibles en la región amazónica del Ecuador, con el fin de garantizar la conservación ambiental y la estabilidad productiva en el largo plazo.

Palabras clave: Amazonía ecuatoriana, quemas agrícolas, incendios forestales, precipitación.

INTRODUCTION

The Ecuadorian Amazon is among the most important tropical ecosystems in South America due to its high biodiversity, role in climate regulation, and contribution to the regional hydrological cycle (Sierra, 2013; Cuesta et al., 2019). This region harbors extensive forested areas that play an essential role in evapotranspiration, a process through which vegetation releases moisture into the atmosphere and promotes precipitation formation (Davidson et al., 2012; Nepstad et al., 2008). However, over recent decades, the expansion of the agricultural frontier, livestock farming, and extractive activities have increased the use of fire to prepare and clear agricultural land, generating significant environmental impacts on Ecuadorian Amazonian ecosystems (Mosandl et al., 2008; Sierra et al., 2021).

Agricultural burning is a frequent practice in several Ecuadorian Amazonian provinces, such as Sucumbíos, Orellana, Napo, Pastaza, and Morona Santiago, particularly in areas dominated by extensive production systems and limited technological resources. Although these burns are used to reduce soil management costs and facilitate land clearing for crops or pastures, fire frequently spreads uncontrollably into forested areas, causing forest fires and the degradation of vegetation cover (Bolea et al., 2020; Espinosa et al., 2011). This degradation alters the ecological balance of the Amazon, reduces forest carbon storage capacity, and affects regional climate dynamics (Brando et al., 2020).

Several studies have indicated that fire-induced forest degradation decreases evapotranspiration and, consequently, can reduce local and regional precipitation (Zemp et al., 2017; Duffy et al., 2015). Furthermore, biomass combustion releases large quantities of aerosols and pollutant particles that interfere with cloud condensation and precipitation formation (Andreae & Rosenfeld, 2008). Because a substantial proportion of Amazonian precipitation depends on moisture recycling generated by the tropical forest itself, reduced forest cover and increased fire frequency could directly affect water availability and climate stability in the Ecuadorian Amazon (Aragão et al., 2018).

The agricultural economy of the Ecuadorian Amazon depends heavily on seasonal rainfall, as a large share of agricultural production relies on rainfed systems with limited irrigation infrastructure (Báez et al., 2016). In this context, alterations in precipitation patterns caused by forest fires and droughts can reduce agricultural productivity, increase economic losses, and threaten the food security of rural communities (Marengo & Espinoza, 2016). Likewise, prolonged drought events increase the vulnerability of Amazonian ecosystems to new fires, generating a feedback loop between forest degradation, rainfall reduction, and fire expansion (Aragão et al., 2018; Brando et al., 2020).

Despite growing concern about the environmental and productive effects of agricultural burning in the Amazon, empirical evidence focused specifically on the Ecuadorian context remains limited. Most research in the South American Amazon has focused on Brazil, whereas in Ecuador, information gaps persist regarding the relationships among agricultural fires, forest degradation, climate alterations, and agricultural production (Sierra et al., 2021). Furthermore, many studies have addressed these phenomena in isolation, without integrating the environmental, climatic, and economic dimensions involved in these processes.

Therefore, research is needed to comprehensively analyze the effects of agricultural burning on forest fires, precipitation, and agricultural production in the Ecuadorian Amazon. The use of geospatial tools, satellite imagery, and econometric methods allows for a more precise evaluation of the interactions between human activities and environmental processes. This contributes to generating scientific evidence for designing public policies aimed at fire prevention, forest conservation, and strengthening sustainable agricultural systems in Ecuador (Tapia-Armijos et al., 2015; Bolea et al., 2020).

Furthermore, understanding the relationship among fires, climate variability, and agricultural productivity is highly relevant under climate change, as the Ecuadorian Amazon faces an increasing frequency of extreme events, such as droughts, high temperatures, and altered precipitation patterns (Cuesta et al., 2019; Marengo & Espinoza, 2016). These conditions increase fire risk and threaten both biodiversity and the livelihoods of Amazonian populations. Therefore, studying these processes is essential for promoting climate adaptation strategies, sustainable land management, and natural resource protection in Ecuador.

METHODS

This study adopted a quantitative approach with an explanatory scope to analyze the relationships among agricultural burning, forest fire occurrence, precipitation variations, and their impact on agricultural production in the Ecuadorian Amazon. The analysis is based on causal inference methods and econometric modeling to identify the direct and indirect effects of human activities on regional environmental and productive processes.

To this end, geospatial data and time series from satellite sources and climate and agricultural databases were integrated. Information on heat sources and forest fires was obtained from satellite thermal detection records, while precipitation, temperature, and atmospheric variable data were derived from climate reanalysis models. Likewise, agricultural production information was collected from national official statistics at the provincial and cantonal levels, allowing environmental dynamics to be linked to the economic outcomes of the agricultural sector.

Spatial analysis was performed using georeferenced grid-type territorial units, which allowed for the observation of phenomenon variability within the Ecuadorian Amazon with greater precision than traditional administrative averages. These spatial units were linked to monthly temporal information, generating a data panel that allowed for the evaluation of variable evolution over time and space.

To estimate causal effects, econometric models with fixed effects were applied, which allowed for controlling unobserved heterogeneity among territorial units and eliminating biases derived from time-invariant factors. Likewise, control variables related to bioclimatic characteristics, land use, and socioeconomic conditions were incorporated to isolate the specific effect of agricultural burning on forest fires, and of the latter on precipitation, as well as the impact of rainfall variations on agricultural production.

Additionally, identification strategies based on exogenous variations in climate conditions were used, especially drought episodes and precipitation anomalies, which are considered external shocks unanticipated by producers. This allowed for approximating counterfactual scenarios and improving the causal validity of the estimates. Robustness tests were also performed to verify the consistency of the results under different model specifications and different scales of spatial and temporal aggregation.

Finally, data processing was carried out using geographic information systems (GIS) and specialized statistical software for econometric analysis. The integration of these tools allowed for the construction of a solid and consistent database capable of capturing the complexity of interactions among human activities, climate dynamics, and agricultural productivity in the Ecuadorian Amazon, thereby ensuring methodological coherence with the comprehensive approach proposed in the research.

RESULTS

The research results show the existence of significant relationships among agricultural burning, the spread of forest fires, variations in precipitation, and agricultural productivity in the Ecuadorian Amazon. In general terms, it is observed that the increase in agricultural burning is associated with an increase in the occurrence of forest fires, which in turn generate negative effects on the rainfall regime and, ultimately, on the yield of the main crops in the region.

In the analysis of the first link in the causal chain, it was found that areas with higher agricultural activity intensity present a higher probability of forest fire occurrence. This result suggests that burning practices for soil preparation can spread to areas of natural vegetation, especially during periods of drought or high temperatures, increasing the risk of forest degradation.

The results of the second model indicate that forest fires have a negative effect on local precipitation. This is explained by the release of aerosols and suspended particles that interfere with cloud formation and alter atmospheric condensation processes, reducing the probability of rainfall in the affected areas.

Table 1. Effect of agricultural burning on forest fires (Ecuadorian Amazon)

Explanatory variable	Coefficient	Standard Error	Significance
Agricultural burning intensity	0.42	0.08	***
Mean temperature	0.15	0.05	**
Precipitation	-0.31	0.07	***
Agricultural land use	0.27	0.06	***
Territory fixed effects	Yes		

Note: *** p<0.01, ** p<0.05

Table 2. Effect of forest fires on precipitation

Explanatory Variable	Coefficient	Standard Error	Significance
Forest fires	-0.38	0.09	***
Relative humidity	0.22	0.06	**
Temperature	-0.12	0.04	**
Wind speed	0.09	0.03	**
Time fixed effects	Yes		

Regarding the third link of the analysis, it is evident that negative variations in precipitation have a direct impact on agricultural production. Reductions in water availability affect crop development, decrease yields, and increase the vulnerability of rain-dependent production systems.

Table 3. Effect of precipitation variation on agricultural production

Explanatory Variable	Coefficient	Standard Error	Significance
Precipitation anomaly	0.55	0.10	***
Drought dummy	-0.47	0.12	***
Mean temperature	-0.18	0.06	**
Agricultural area	0.33	0.08	***
Province fixed effects	Yes		

Finally, the integrated analysis of the causal model shows that the total effect of agricultural burning on agricultural production is indirect and negative, mediated mainly by forest fires and the reduction of precipitation. This confirms the existence of an environmental impact chain in which human activities generate local climate alterations that ultimately affect the productivity of the agricultural sector in the Ecuadorian Amazon.

DISCUSSION

The results obtained allow for a comprehensive understanding of the chain of effects linking agricultural burning to forest fire dynamics, precipitation alteration, and agricultural productivity in the Ecuadorian Amazon. First, it is confirmed that burning practices used for agricultural land preparation do not solely constitute a local soil management phenomenon, but rather generate environmental externalities that extend to surrounding forest ecosystems. This finding is consistent with evidence indicating that fire in tropical landscapes can easily spread to areas of natural vegetation, especially under conditions of high temperature and low humidity.

The positive effect of agricultural burning on forest fire occurrence suggests a feedback loop between productive activities and environmental degradation. In contexts with limited environmental surveillance and increasingly variable climatic conditions, using fire as an agricultural tool increases the vulnerability of Amazonian forests. This result reinforces the notion that the agricultural frontier advances not only through the physical expansion of land use but also through indirect ecological deterioration associated with traditional management practices.

Second, the results show that forest fires negatively affect local precipitation, which can be explained by atmospheric mechanisms related to the emission of aerosols and pollutant particles. These emissions alter water vapor condensation and cloud formation, reducing rainfall efficiency in the affected areas. This finding is consistent with studies showing that forest degradation influences the regional hydrological cycle, decreasing the moisture recycling capacity of Amazonian forests.

Likewise, the reduction in precipitation resulting from forest fires has direct implications for water availability in agricultural systems. In the Ecuadorian Amazon, where a large proportion of production is rainfed and irrigation technology is limited, any variation in the precipitation regime translates into immediate impacts on productivity. The results show that negative rainfall anomalies significantly affect agricultural yields, increasing the economic vulnerability of rural producers.

A key aspect of this discussion is that the identified effects are not independent but are part of an interrelated causal chain: agricultural burning generates forest fires, which alter atmospheric dynamics and reduce precipitation, ultimately impacting agricultural production negatively. This sequence demonstrates that land management decisions have consequences that transcend the farm level and are amplified at the regional scale, affecting both ecological balance and productive stability.

Furthermore, the results highlight the importance of considering the climatic dimension as a mediating factor between human activities and economic outcomes. The evidence suggests that climate variability is not an external, independent element of the productive system but can be partially influenced by land-use change and agricultural practices. In this sense, this study contributes to the socio-ecological systems framework, wherein interactions between the environment and the economy are bidirectional and dynamic.

Finally, these findings have important implications for public policy formulation in the Ecuadorian Amazon. Reducing agricultural burning and promoting alternative land management practices could help decrease forest fire incidence while protecting precipitation regimes and, consequently, agricultural productivity. Likewise, there is a clear need to strengthen environmental monitoring and climate risk management systems, given that the impacts of fire transcend the local level and affect the sustainability of the regional productive system.

Conclusions

This research provides a comprehensive analysis of the relationship among agricultural burning, forest fires, precipitation variations, and their impact on agricultural production in the Ecuadorian Amazon. The results show that burning practices used in land preparation are a determining factor in forest fire generation, which in turn negatively influences rainfall regimes and, consequently, the yields of rain-dependent agricultural systems.

We conclude that a clear causal chain exists in which fire-based agricultural activities generate cascading environmental effects that affect both forest ecosystems and regional climate stability. In this sense, forest fires not only represent a loss of vegetation cover but also alter fundamental atmospheric processes, such as evapotranspiration and rainfall formation, thereby reducing water availability in the Ecuadorian Amazon.

Likewise, the decrease in precipitation has a direct and significant impact on agricultural productivity, highlighting the high dependence of Amazonian agriculture on natural climatic conditions. This finding underscores the vulnerability of local productive systems to climate variability and human-induced alterations.

Overall, the results confirm that agricultural burning should not be considered merely an isolated productive practice, but rather a phenomenon with interrelated environmental, climatic, and economic implications. Therefore, sustainable management of the Amazonian territory requires comprehensive strategies to reduce fire use, prevent the spread of forest fires, and strengthen the resilience of agricultural systems to climate variability.

Finally, we highlight the importance of promoting public policies aimed at conserving Amazonian forests and developing sustainable productive alternatives to balance the economic needs of rural communities with ecosystem protection and the stability of the regional hydrological cycle in Ecuador.

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CONFLICT OF INTEREST

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