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Original Article

Decomposing the maize productivity gap: evidence from Oaxaca-Blinder for chemical and organic fertilizers in Ecuador

Descomponiendo la brecha de productividad del maíz: evidencia desde Oaxaca-Blinder para fertilizantes químicos y orgánicos en Ecuador

Daniela Alexandra García Chamba[1] ✉, Alexandra Maribel Ordoñez Valdiviezo[1] ✉, José Vicente Ordóñez Yaguache[1] ✉

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[1] Universidad Nacional de Loja. Facultad Jurídica, Social y Administrativa. Av. Pío Jaramillo Alvarado y Reinaldo Espinosa. Código postal: 110150. Loja, Loja, Ecuador.

Correspondence: jose.ordonez@unl.edu.ec

Abstract

This study analyzes the productivity gap in soft maize between producers using chemical and organic fertilizers in Ecuador and its relationship with productive characteristics from the 2024 Continuous Survey of Agricultural Area and Production [ESPAC]. The analysis covered 895 producers across 13 provinces. The estimates were obtained without applying sampling expansion factors; therefore, the results correspond to the analyzed sample and should not be interpreted as population-level estimates. The empirical strategy combines Ordinary Least Squares [OLS] with HC1 heteroskedasticity-robust standard errors and a threefold Oaxaca–Blinder decomposition with bootstrapping. Average productivity was 1.81 TM ha^{-1} among producers using chemical fertilizers and 1.30 TM ha^{-1} among those using organic fertilizers, representing a descriptive difference of approximately 38%. In the extended model, the use of chemical fertilizer was associated with 35.8% higher productivity than in the organic-fertilizer group, while irrigation was associated with a 24.1% difference; both associations were statistically significant. The Oaxaca–Blinder decomposition identified a total gap of −0.281 log points in the Organic − Chemical orientation, equivalent to −24.5%. The explained component was 0.041 log points, with a 95% confidence interval that included zero; the unexplained component was −0.305 log points and differed significantly from zero, whereas the interaction component was −0.017 and was not statistically different from zero. Diagnostic tests indicated heteroskedasticity, supporting the use of robust standard errors, with no evidence of multicollinearity or functional-form misspecification according to the RESET test. The results were robust to influential observations and to restricting the analysis geographically to the Andean region. The unexplained component cannot be interpreted as a causal effect of fertilizer type, as it may capture unobserved heterogeneity, omitted variables, and other productive differences not available in the survey.

Keywords: agricultural productivity, Ecuador, fertilizers, maize, Oaxaca-Blinder decomposition.

Resumen

Este estudio analiza la brecha de productividad del maíz suave entre productores que utilizan fertilizantes químicos y orgánicos en Ecuador y su relación con características productivas de la Encuesta de Superficie y Producción Agropecuaria Continua [ESPAC]. Se analizaron 895 productores de 13 provincias. Las estimaciones se realizaron sin factores de expansión, por lo que los resultados corresponden a la muestra analizada y no deben interpretarse como estimaciones poblacionales. La estrategia empírica combina Mínimos Cuadrados Ordinarios [MCO] con errores

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robustos HC1 y descomposición Oaxaca-Blinder threefold con bootstrap. La productividad promedio fue de 1,81 TM ha-1 con fertilizantes químicos y de 1,30 TM ha-1 con fertilizantes orgánicos, una diferencia descriptiva cercana al 38 %. En el modelo ampliado, el uso de fertilizante químico se asocia con una productividad 35,8 % mayor que la del grupo orgánico, mientras que el riego se asocia con una diferencia del 24,1 %; ambas asociaciones son estadísticamente significativas. La descomposición Oaxaca-Blinder identificó una brecha total de −0,281 log puntos en la orientación Orgánico − Químico, equivalente a −24,5 %. El componente explicado fue de 0,041 log puntos y su intervalo de confianza al 95 % incluye cero; el componente no explicado fue de −0,305 log puntos y difirió de cero, mientras que la interacción fue de −0,017 y no difirió estadísticamente de cero. Los diagnósticos muestran heterocedasticidad, lo que justifica el uso de errores robustos, sin problemas de multicolinealidad ni de especificación funcional según RESET. Los resultados son estables ante observaciones influyentes y la restricción geográfica a la Sierra. El componente no explicado no puede interpretarse como un efecto causal del tipo de fertilizante, pues puede recoger heterogeneidad no observada, variables omitidas y otras diferencias productivas no disponibles en la encuesta.

Palabras clave: descomposición Oaxaca-Blinder, Ecuador, fertilizantes, maíz, productividad agrícola.

1. Introduction

Maize is a crop of great importance for Ecuador's economy and food security, in addition to representing a relevant source of income for small and medium-sized producers. However, the yield of soft maize declined from 2.14 TM ha^{-1} in 2019 to 1.72 TM ha^{-1} in 2023 (Ministerio de Desarrollo Económico y Productivo [MDEP], 2024). Differences between provinces persist: in 2023, Tungurahua reached 4.45 TM ha^{-1}, compared with 1.49 TM ha^{-1} in Cotopaxi, 1.40 TM ha^{-1} in Imbabura, and 1.02 TM ha^{-1} in other provinces. These figures correspond to the combined yield of soft maize harvested as fresh corn (choclo) and dried grain. This heterogeneity evidences differences in productivity and raises the need to identify the factors associated with them.

Among the factors associated with productivity is the type of fertilization, although productive, technological, and socioeconomic characteristics also play a role. Integrated Nutrient Management proposes that productivity depends on the interaction between fertilization, soil quality, and agroecological conditions, rather than on the isolated use of a single input (Chen, 2006). From this perspective, the combination of organic and inorganic sources can favor nutrient availability, fertility, and yield, although their results depend on management and the production system (Hernandez et al., 2021; Sahu et al., 2024; Timsina, 2018). In addition, fertilization strategies have implications for sustainability and soil properties (Boru, 2025; Sharma & Chetani, 2017; Yang et al., 2025).

International experimental evidence shows that the response to fertilization sources is heterogeneous. The combination of organic and inorganic fertilizers has shown improvements in yield and nutrient use efficiency across different crops and production systems (Blanchet et al., 2016; Han et al., 2022). In maize–wheat systems in China, mineral fertilization combined with manure showed favorable results for sustainability and yield (Wang et al., 2025). In rice, the incorporation of manure together with inorganic fertilization, and the combination of chicken manure with chemical fertilizer, also improved yield and nitrogen efficiency (Iqbal et al., 2019; Satyanarayana et al., 2002). Likewise, the partial substitution of chemical fertilizers with organic ones has shown favorable results in different crops, although with variable magnitudes (Dutta, 2026; Khadka et al., 2008).

In maize, several Asian experiments have found positive effects of partial substitutions of chemical fertilizer with organic fertilizer on yield, biomass, water efficiency, and grain quality (Chen et al., 2025; Lin et al., 2022; Wang et al., 2026). Other studies have identified favorable responses to different substitution levels, but also differences depending on the crop and production conditions (Shi et al., 2026; Wen et al., 2025). In other systems, the partial substitution of chemical nitrogen with organic sources improved yield and some soil quality indicators in maize, while favorable effects were also observed in *Camellia oleifera*, tobacco, and rice (Ma et al., 2022; Wen et al., 2025; Yang et al., 2026; Zhang et al., 2023; Zhao et al., 2026). This evidence supports the importance of considering fertilization within the management system rather than as an isolated factor.

However, the evidence does not allow for establishing a general superiority of organic or inorganic fertilization. In France, mineral fertilization showed yields similar to the conventional system and higher than the organic system in wheat and barley, although with lower stability; in the Philippines, inorganic fertilization and the combination of sources outperformed exclusively organic fertilization in rice (Latapie et al., 2026; Quimbo et al., 2014). In Indonesia, a combination of compost and urea achieved the highest soybean yield, although without consistent differences compared with chemical fertilizer (Sandrakirana & Arifin, 2021). A systematic review confirms that the effects of fertilizers on soil properties depend on the

type and amount applied and on the conditions of use (Cisneros Jayo & Nonones Vásquez, 2024). Because of this, productivity differences between fertilization systems must be analyzed considering the characteristics of the crop, agroecological conditions, and management practices.

In addition to fertilizer, productivity may be related to technology adoption and producer characteristics. In Bangladesh, the adoption of hybrid rice varieties was associated with higher levels of technical efficiency and yield (Salam & Sarker, 2023). In Africa, access to agronomic information, extension services, and technology adoption condition productivity and soil fertility management (Ayalew et al., 2022; Ayanwale et al., 2025; Buri et al., 2022). Institutional and social factors, such as rural extension and community support, can also influence productivity (Emmanuel et al., 2016; Mponela et al., 2023).

The choice of fertilizers, in turn, may be conditioned by economic, institutional, and technological factors. In Ghana, the use of organic fertilizers was associated with higher productivity and income and lower poverty, while in Kenya inorganic fertilizers increased sorghum yield and were related to better livelihood outcomes for producers (Martey, 2018; Musafiri et al., 2023). In China, internet use was associated with greater use of fertilizers and pesticides, while government incentives and digital technology can modify the willingness to substitute chemical fertilizers with organic ones (Liao et al., 2025; Na & Kang, 2023). This evidence reinforces the need to consider other factors when comparing productivity between producers.

Management conditions can also modify the response to fertilization. In China, irrigation of previous crops modified the response of millet to the replacement of chemical fertilizers with organic ones, while long-term experiments with maize have found productive and soil fertility improvements through partial substitutions (Liu et al., 2026; Zhang et al., 2026). Therefore, variables such as irrigation and soil management should be considered when analyzing productivity differences between producers.

Latin American evidence shows equally heterogeneous results. In Colombia, organic fertilizers favored the development and production of beans and maize, while in Mexico ecological fertilizers modified the physiological development and production of habanero pepper (García et al., 2020; Luna-Fletes et al., 2025). In Peru, productive differences associated with the application of organic fertilizers and chemical fertilizers were found, and producers' characteristics and perceptions also influence fertilizer use (Vicente-Solano & Calle-Arancibia, 2024; Zapana Pari et al., 2015). In Ecuador, evidence on fertilization and productivity remains limited and is concentrated mainly in agronomic, experimental, and case-specific studies. In banana, a study conducted in Machala found significant differences in variables associated with yield between organic and chemical fertilization, although not in all physiological variables (Burgo Bencomo et al., 2018). Other studies have evaluated crop response to fertilizers and combinations of sources, as well as access to inputs and technology through productive support programs (Buritica Casanova et al., 2026; Héctor-Ardisana et al., 2020; Luna Murillo et al., 2016). Likewise, agricultural support programs, conditions of access to fertilizers, and their use constitute relevant elements for understanding productive decisions in the country (Pino Peralta & Ortega Álvarez, 2024; Sánchez Arizo & Fernández Sastre, 2020; Saucedo Aguiar et al., 2024).

Despite this evidence, econometric research analyzing productivity differences between producers according to fertilization type remains limited in Ecuador. The available studies make it possible to identify agronomic or experimental responses to certain treatments, but they do not establish to what extent the differences observed between producers are related to their productive characteristics and how much remains unexplained. This distinction is relevant when groups using different types of fertilization may also differ in access to irrigation, drainage, improved seeds, education, and other characteristics.

An appropriate tool for studying these differences is the Oaxaca-Blinder decomposition, which makes it possible to identify the part of a gap associated with differences in observable characteristics and the part related to their returns. In Nigeria, it was used to analyze the productivity gap between rice producers by gender; in Cameroon, to study differences between maize producers who adopted improved seeds and those who did not; and in Bangladesh, to analyze the yield gap between rice producers who adopted hybrid varieties and those who did not (Ojo & Baiyegunhi, 2023; Salam & Sarker, 2023; Tchamou Meughoyi, 2018). These precedents show the usefulness of the methodology for distinguishing between differences in endowments and returns.

However, the agricultural applications identified have focused mainly on gender gaps and technology adoption. In the literature reviewed, no studies were found that use Oaxaca-Blinder to analyze the productivity gap between producers of the same crop according to fertilization type. This gap is particularly relevant in Ecuador, where experimental and agronomic evidence predominates. In this context, the present study contributes evidence on soft maize producers

who use chemical or organic fertilizers, decomposing the gap between the part associated with observable characteristics and the unexplained component. The contribution does not consist of establishing the superiority of one fertilizer, but rather of analyzing the productive differences between both groups. The results correspond to the selected sample and not to the entirety of maize producers in Ecuador.

Based on this gap, the study analyzes the productivity gap in soft maize between producers who use chemical fertilizers and those who use organic fertilizers in Ecuador. It is proposed that statistically significant differences exist and that these are not fully explained by observable characteristics. For this purpose, microdata from the 2024 Continuous Survey of Agricultural Area and Production [ESPAC] are used, corresponding to an analytical sample of 895 producers observed in 13 provinces. The estimates do not use expansion factors; therefore, the results are interpreted for the analyzed sample and not as population-level estimates. The strategy combines descriptive analysis, estimates using Ordinary Least Squares [OLS], and Oaxaca-Blinder decomposition to quantify the gap and distinguish the part associated with observable characteristics, the unexplained component, and the interaction.

2. Materials and Methods

2.1 Construction of main variables

Table 1 presents the description of the variables used in the econometric model to analyze the maize productivity gap between producers who use chemical fertilizers and those who use organic fertilizers in Ecuador, according to ESPAC 2024 data (Instituto Nacional de Estadística y Censos [INEC], 2025). The information came from the microdata of the Continuous Survey of Agricultural Area and Production, making it possible to identify the dependent variable (productivity), the variable of interest (fertilizer type), and the control factors (infrastructure and producer capacities) included in the estimation. Likewise, the name of each variable in the database, its conceptual definition, and the corresponding unit of measurement are specified. This classification facilitates understanding of the determinants of the productive gap and provides the framework needed to interpret the results obtained through the OLS models and the Oaxaca-Blinder decomposition.

2.2 Methodology for descriptive analysis

For the first specific objective, a descriptive approach was used with the purpose of characterizing the territorial distribution of fertilizer use and its relationship with maize productivity in Ecuador, based on ESPAC 2024 data. The analysis combined thematic cartography techniques and descriptive statistics. A thematic map of chemical fertilizer use was constructed at the provincial level. For this purpose, the percentage of agricultural production units [UPA] using chemical fertilizers in each province was calculated, and this proportion was subsequently classified into quintiles, which made it possible to identify the provinces with the lowest and highest intensity of use of this input.

Table 1. Description of the econometric model variables.

Variable	Description	Measurement	Unit
Dependent variable			
Agricultural productivity	Yield obtained in maize production per unit of harvested area.	Total production / harvested area.	Tons per hectare (TM ha^{-1})
Logarithm of productivity	Transformation of agricultural productivity to reduce data skewness.	Natural logarithm of productivity.	Continuous variable
Main explanatory variable			
Fertilizer type	Type of fertilizer used by the producer during the agricultural cycle.	1 = Chemical; 0 = Organic	Binary variable
Control variables			
Access to irrigation	Availability of irrigation infrastructure in the production unit.	1 = Yes; 0 = No	Binary variable
Access to drainage	Existence of drainage systems on the plot.	1 = Yes; 0 = No	Binary variable
Improved seed	Use of improved varieties for planting.	1 = Yes; 0 = No	Binary variable
Secondary education or higher	Educational level attained by the producer.	1 = Secondary or higher; 0 = Primary or less	Binary variable

Likewise, a territorial classification map was prepared relating average maize productivity to chemical fertilizer use. For each province, the average crop productivity and the percentage of producers using chemical fertilizers were calculated. Subsequently, both variables were classified using their respective medians as cut-off points, generating four categories: high productivity and high chemical fertilizer use, high productivity and low chemical fertilizer use, low productivity and high chemical fertilizer use, and low productivity and low chemical fertilizer use. This classification made it possible to identify spatial patterns of maize production systems.

Additionally, descriptive statistics were calculated for the main variables included in the study, considering agricultural productivity and variables related to the technification of production units, such as access to irrigation, access to drainage, use of improved seeds, and the producer's educational level. These indicators made it possible to characterize the sample and provide the descriptive context for the econometric analysis developed in the second specific objective.

2.3 Methodology for econometric analysis

For the second specific objective, cross-sectional econometric methods were used with the purpose of estimating and decomposing the productivity gap in maize cultivation between producers who use chemical fertilizers and those who use organic fertilizers. The analysis was structured in two complementary stages: estimation using Ordinary Least Squares [OLS] and the Oaxaca-Blinder decomposition.

2.3.1. Ordinary Least Squares [OLS] Models

The dependent variable in all models corresponded to the natural logarithm of maize agricultural productivity, expressed as $\ln(Productivy)$, where productivity is measured in metric tons per hectare (TM ha^{-1}). The logarithmic transformation is directly applicable because all observations in the analytical sample present strictly positive productivity. This specification avoids adding an arbitrary constant to the dependent variable and allows $100(e^{\beta}-1)$ to be interpreted as the percentage difference associated with the coefficients of dichotomous variables.

The variable of interest was the type of fertilizer used by the producer, where 1 corresponds to chemical fertilizer and 0 to organic fertilizer. To analyze whether the relationship between fertilizer type and productivity changes when other producer characteristics are incorporated, three models were estimated progressively.

Because productivity is transformed, the models' results were not expressed directly in TM ha^{-1}. Therefore, the coefficients were converted to percentages using $(e^{\beta}-1) \times 100$, which facilitated their interpretation. These percentages show the difference associated with each characteristic between producers, holding constant the other variables included in the model. The results should be understood as statistical associations and not as causal effects.

- **Model 1: Simple OLS.** The first model, called simple OLS, relates the logarithm of transformed productivity solely to fertilizer type, without incorporating additional control variables. This model made it possible to identify the average difference in transformed productivity between producers who use chemical fertilizers and those who use organic fertilizers. The econometric specification is expressed in equation [1].

$$ln(Prod_i) = \beta_0 + \beta_1 chem_fert_i + \varepsilon_i \quad [1]$$

where $\ln(Prod_i)$ represents the natural logarithm of the agricultural productivity of producer i; β_o corresponds to the expected value of the transformed dependent variable for producers who use organic fertilizer; $chem_fert_i$ is a dichotomous variable that takes the value of one if the producer uses chemical fertilizer and zero if they use organic fertilizer; β_1 represents the average difference associated with the use of chemical fertilizer relative to the reference group; and ε_i represents the error term, which captures unobserved factors related to productivity.

- **Model 2: Productive OLS.** The second model, called productive OLS, incorporated variables associated with the producer's agricultural infrastructure conditions, specifically access to irrigation and drainage systems. The inclusion of these variables made it possible to consider observable differences in the productive conditions of the plots that could be related to productivity. The model specification is expressed in equation [2].

$$ln(Prod_i) = \beta_0 + \beta_1 chem_fert_i + \beta_2 irrigation_i + \beta_3 drainage_i + \varepsilon_i \quad [2]$$

where $irrigation_i$ represents access to irrigation systems and $drainage_i$ indicates the existence of drainage systems on the agricultural plot. The coefficients β_2 and β_3 represent the associations between these infrastructure characteristics and transformed productivity, holding constant the other variables included in the model.

- **Model 3: Extended OLS.** The third model, called extended OLS, incorporated variables related

to technology adoption and the producer's human capital characteristics, specifically the use of improved seed and educational level. The inclusion of these variables made it possible to analyze whether the observed differences in productivity are also associated with characteristics related to technification and producer capacities. The econometric specification is expressed in equation [3].

$$ln(Prod_i) = \beta_0 + \beta_1 chem_fert_i + \beta_2 irrigation_i + \beta_3 drainage_i + \beta_4 imp_seed_i + \beta_5 educ_level_i + \varepsilon_i \quad [3]$$

where imp_seed_i identifies the use of improved seeds and $educ_level_i$ represents the producer's educational level, taking the value of one when the producer has secondary education or higher and zero otherwise. The coefficients β_4 and β_5 represent the associations of these variables with transformed productivity, holding constant the other characteristics included in the model.

Robust HC1 type standard errors were used in all three models. This decision was maintained because the Breusch-Pagan test rejected homoscedasticity in the extended model. As additional diagnostics, multicollinearity was assessed using the variance inflation factor [VIF], functional form using the RESET test, and influential observations using Cook's distance. The correlation matrix was used only for descriptive purposes and not as a test of OLS assumptions.

The main specification retained the original, editorially evaluated sample, comprising 895 producers who use exclusively organic fertilizer or exclusively chemical fertilizer and present valid productivity. The cases were observed in 13 provinces. The estimates do not use ESPAC expansion factors; therefore, the results were interpreted for the analytical sample and not as population-level estimates of maize producers in Ecuador. As a geographic sensitivity check, the estimates were repeated restricting the sample to the ten provinces of the continental Andean region (Sierra) (N = 887).

2.3.2. Oaxaca-Blinder Decomposition (Threefold)

With the purpose of further examining the composition of the productivity gap between producers who use chemical and organic fertilizers, the Oaxaca-Blinder decomposition was applied in its threefold version. The orientation used by the implementation employed was Organic − Chemical. The total difference was broken down into three components: explained or endowments, unexplained or coefficients, and interaction. To incorporate inferential uncertainty, the standard errors of the three components were obtained through 1,000 bootstrap replications. The standard error of the total gap was obtained through bootstrap stratified by group, preserving the organic/chemical composition. 95% confidence intervals are reported. The percentage transformation $100(e^{\theta} - 1)$ is presented to facilitate the interpretation of each individual component, but these percentages are not additive.

The interpretation of the decomposition must consider its methodological limitations. The unexplained component cannot be interpreted as a causal effect of fertilizer type, as it may incorporate differences in coefficients, omitted variables, unobserved heterogeneity, and specification problems. Furthermore, its magnitude depends on the characteristics included in the model, so factors not available in ESPAC 2024, such as soil characteristics, agroecological conditions, management practices, and input availability, may remain uncontrolled for. The cross-sectional nature of the data makes it impossible to control for producer-level fixed effects, and the choice of fertilizer type may be related to characteristics of the producer, the plot, or the production system, generating possible endogeneity problems. The results should be interpreted as conditional associations and not as evidence of causal relationships between fertilizer type and maize productivity.

The decomposition is formally expressed in equation [4].

$$\overline{\ln(Prod)}_O - \overline{\ln(Prod)}_Q = (\bar{X}_O - \bar{X}_Q)'\hat{\beta}_Q + \bar{X}_Q'(\hat{\beta}_O - \hat{\beta}_Q) + (\bar{X}_O - \bar{X}_Q)'(\hat{\beta}_O - \hat{\beta}_Q) \quad [4]$$

where the first term represents the explained or endowments component, the second corresponds to the unexplained or coefficients component, and the third represents the interaction component. In this expression, O identifies the group of producers who use organic fertilizer and Q the group who use chemical fertilizer, such that the gap is expressed as Organic − Chemical.

3. Results

3.1 Characterization of agricultural productivity and fertilizer use in maize cultivation in Ecuador

3.1.1 Descriptive statistics of the analyzed variables

Table 2 shows the main characteristics of the sample analyzed. Average maize productivity is 1.532 tons per hectare, although there is high dispersion, reflec-

Table 2. Descriptive statistics of the study variables.

Variable	Mean	Standard Deviation	Minimum	Maximum	N
Productivity (TM ha^{-1})	1.532	1.321	0.152	9.091	895
Log productivity	0.064	0.879	-1.887	2.207	895
Access to irrigation	0.184	0.388	0.000	1.000	895
Access to drainage	0.011	0.105	0.000	1.000	895
Improved seed	0.027	0.162	0.000	1.000	895
Secondary education or more	0.191	0.393	0.000	1.000	895

ted in a standard deviation of 1.321, which evidences heterogeneity among producers. Likewise, access to irrigation is relatively low, as only 18.4% of producers have this resource. Access to drainage and the use of improved seeds also present reduced percentages, at 1.1 and 2.7%, respectively, indicating limited adoption of these practices and technologies. On the other hand, only 19.1% of producers have secondary education or higher, a characteristic that may be related to the capacities to adopt certain management practices and agricultural technologies.

A relevant consideration for the interpretation of the subsequent econometric models is the limited variability of some technification variables. In particular, access to drainage represents 1.1% and the use of improved seeds reaches 2.7%, which evidences a low prevalence of these practices in the sample and may limit the statistical capacity to identify associations between these variables and productivity. Therefore, the absence of statistical significance of these variables in the subsequent models should be interpreted with caution and considering the characteristics of the sample.

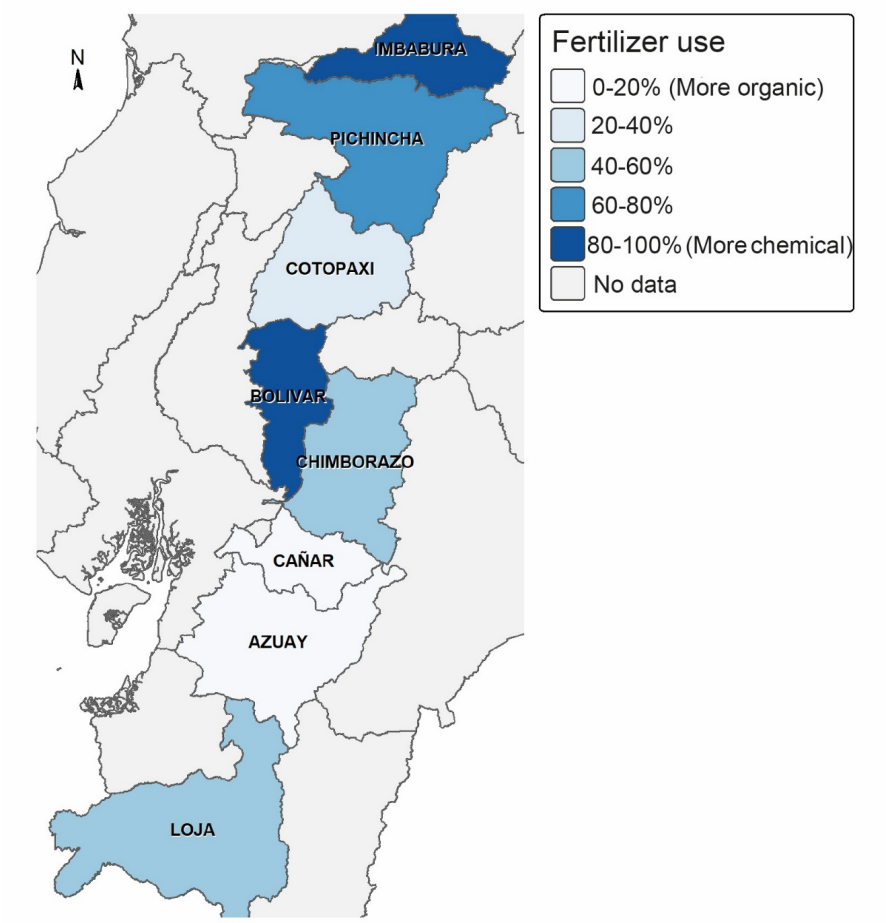

Figure 1. Spatial distribution of chemical fertilizer use.

3.1.2 Spatial distribution of productivity and fertilizer use

Figure 1 presents only the provinces with at least 10 observations in the analytical sample, a criterion applied for cartographic stability purposes and not as a filter for the econometric estimation. Under this rule, eight provinces are represented. Marked territorial heterogeneity is observed in the proportion of producers who use chemical fertilizers. This visualization is descriptive and does not imply provincial or national representativeness, given that the estimates do not use expansion factors. The coexistence of provinces with greater and lesser relative presence of chemical fertilization makes it possible to spatially contextualize the productivity gap analyzed later.

In Figure 2, the provinces with at least 10 observations are descriptively classified according to two relative dimensions within the represented set: average productivity and proportion of chemical fertilizer use, using their respective medians as cut-off points. The four resulting categories — high or low productivity combined with high or low chemical use — do not represent levels of efficiency, sustainability, or technification. Their function is solely to show that provinces with similar levels of productivity may present different fertilization compositions and vice versa.

The heterogeneity observed reinforces the idea that fertilization type, considered in isolation, does not by itself explain territorial differences in productivity. The figure should be interpreted as an exploratory description of the sample and not as a normative classification of production systems.

3.1.3 Correlation matrix between maize crop productivity and the explanatory variables

The correlation matrix presented in Figure 3 reveals that the associations between the analyzed variables are weak. Access to irrigation shows the highest correlation with productivity ($r = 0.11$), followed by the use of improved seed ($r = 0.06$), while access to drainage and educational level show practically null correlations ($r = 0.01$). These results indicate that no strong linear associations are observed between productivity and the variables considered. Likewise, the relatively low correlations among the regressors do not evidence high linear associations between them.

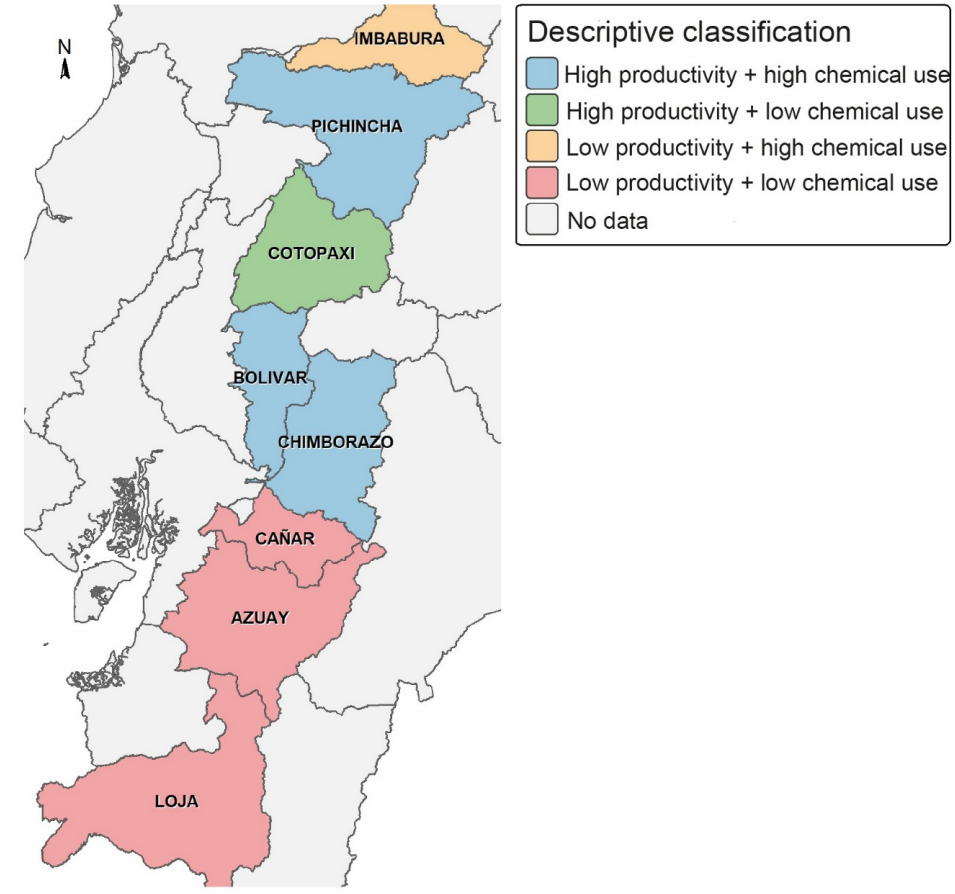

Figure 2. Provincial classification according to productivity and type of fertilization.

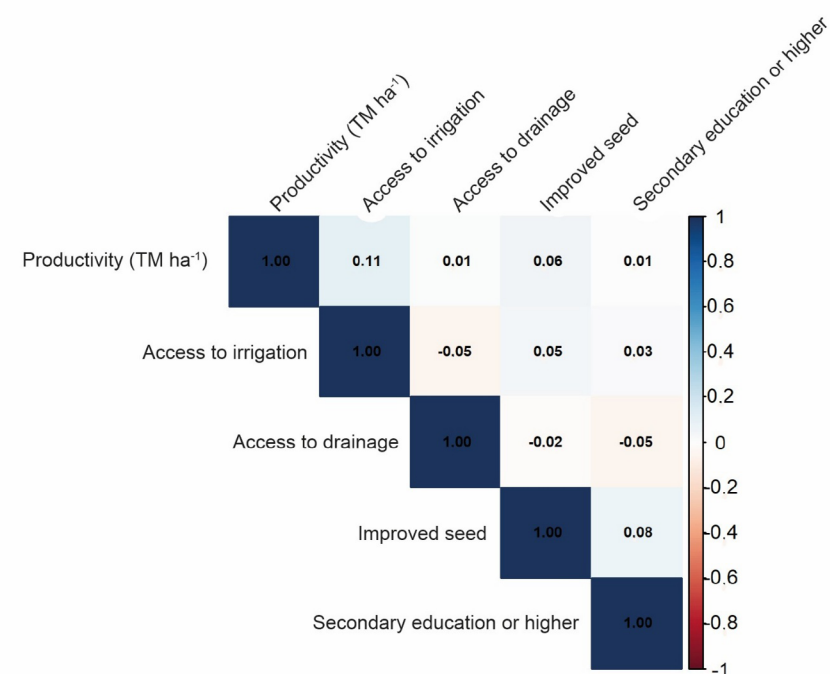

Figure 3. Correlation matrix of the study variables.

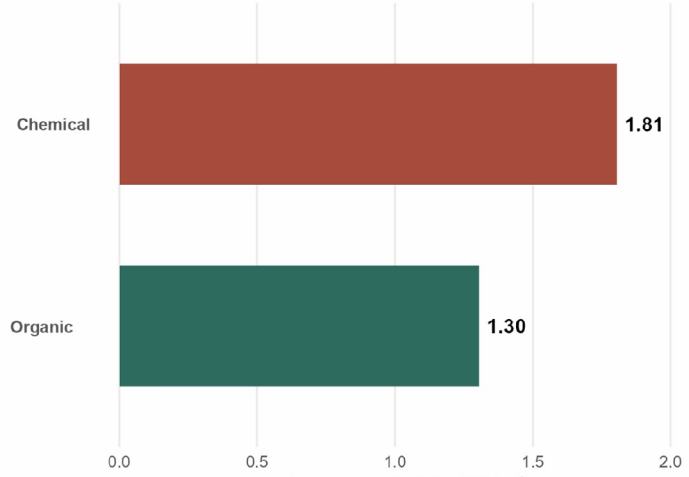

Figure 4. Productivity gap of maize cultivation according to the type of fertilization.

3.2 Productivity gap between producers who use chemical and organic fertilizers

Figure 4 shows that producers who use chemical fertilizers achieve an average productivity close to 1.81 TM ha^{-1}, while those who use organic fertilizers register approximately 1.30 TM ha^{-1}. The descriptive difference is close to 0.51 TM ha^{-1}, equivalent to around 38% relative to the average of the organic group. This difference constitutes a descriptive productivity gap between both groups and should not be interpreted as a causal effect of fertilizer type, since it may also be related to other observable and unobservable characteristics of producers and their plots. The composition of this difference is analyzed later through the OLS models and the Oaxaca-Blinder decomposition.

3.3 Association between chemical fertilizer use and maize crop productivity

3.3.1 Results of the OLS regression model

The results in Table 3 show a positive and statistically significant association between chemical fertilizer use and maize productivity across the three specifications. In the extended model, the chemical fertilizer coefficient is 0.306 log points, equivalent to an approximate difference of 35.8% relative to the group using organic fertilizer, holding constant the other variables included. Access to irrigation also shows a positive and statistically significant association: its coefficient of 0.216 is equivalent to approximately 24.1%. Access to drainage, use of improved seed, and educational

Table 3. Results of the ordinary least squares model.

	Model 1	Model 2	Model 3
Constant	-0.063*	-0.123***	-0.139***
	(0.038)	(0.040)	(0.042)
Chemical fertilizer	0.281***	0.313***	0.306***
	(0.059)	(0.059)	(0.059)
Access to irrigation		0.221***	0.216***
		(0.083)	(0.082)
Access to drainage		0.386*	0.403*
		(0.208)	(0.209)
Improved seed			0.074
			(0.197)
Secondary education or more			0.094
			(0.068)
N	895	895	895
R^2	0.025	0.036	0.038
Adjusted R^2	0.024	0.033	0.033

* p < 0.1, ** p < 0.05, *** p < 0.01

level do not reach statistical significance at 5% in the extended specification. These estimates describe conditional associations and not causal effects.

The explanatory power of the models is low. The adjusted R^2 of the extended model is 0.033, so a significant part of the heterogeneity in productivity remains associated with factors not observed or not available in ESPAC 2024.

3.3.2 Diagnostics of the OLS models

The Breusch-Pagan test rejects homoscedasticity ($p < 0.001$), which justifies maintaining robust HC1 standard errors. The variance inflation factors are low (maximum VIF = 1.045), with no evidence of problematic multicollinearity. The RESET test likewise detects no evidence of functional misspecification ($p = 0.860$). Cook's distance identifies 37 observations above the conventional threshold of 4/n; however, when these are excluded solely as a sensitivity check, the chemical fertilizer coefficient changes from 0.306 to 0.307, so the main association remains practically unchanged (Table 4).

3.3.3 Oaxaca-Blinder decomposition of the productivity gap

The Oaxaca-Blinder decomposition is expressed in the Organic − Chemical orientation. The total gap is -0.281 log points, equivalent to -24.5%. The explained or endowments component reaches 0.041 log points, but its 95% confidence interval includes zero ($p = 0.054$), so it cannot be stated that it differs statistically from zero at the 5% level. The unexplained component is -0.305 log points and its confidence interval does not include zero, while the interaction, at -0.017 log points, likewise does not differ statistically from zero.

Table 4. Diagnostics of the extended OLS model.

Diagnostic	Result	Interpretation
Breusch-Pagan	BP = 31.779; p < 0.001	Heteroskedasticity; robust HC1 standard errors are maintained
Maximum VIF	1.045	No problematic multicollinearity
RESET	F = 0.151; p = 0.860	No evidence of functional misspecification
Observations with Cook's distance > 4/n	37 of 895	Sensitivity analysis excluding these cases maintains the main result

Table 5. Results of the Oaxaca-Blinder decomposition.

Component	Coef.	SE	95% CI	p	Effect (%)
Total gap (Organic - Chemical)	-0.2812	0.0558	[-0.3905; -0.1719]	< 0.0001	-24.51
Explained part (endowments)	0.0406	0.0210	[-0.0006; 0.0818]	0.0537	4.14
Unexplained part (coefficients)	-0.3050	0.0609	[-0.4244; -0.1856]	< 0.0001	-26.29
Interaction	-0.0168	0.0272	[-0.0701; 0.0365]	0.5370	-1.66

Note: percentage effects are obtained by individually transforming each coefficient using $100(e^{\theta} -1)$. This column is not additive and, therefore, its values should not be summed to reconstruct the total gap.

The predominance of the unexplained component indicates that the observable characteristics included do not capture most of the difference between groups. This component does not represent a causal effect of fertilizer type: it may incorporate differences in coefficients, omitted variables, unobserved heterogeneity, measurement errors, and other productive conditions not available in the survey (Table 5).

3.3.4 Geographic sensitivity

As a sensitivity check, the extended specification was repeated restricting the sample to the ten provinces of the continental Andean region (Sierra) (N = 887). The chemical fertilizer coefficient is 0.305, compared with 0.306 in the main sample of 895 observations. The magnitude and inference remain practically unchanged, so the eight cases observed outside the Sierra do not explain the main result.

4. Discussion

The results show marked heterogeneity in maize productivity among the producers analyzed, which suggests that the observed differences respond to the interaction of productive, technological, and environmental conditions and not exclusively to the type of fertilizer used. The limited presence of practices such as irrigation, drainage, and the use of improved seeds evidences differences in production conditions and may restrict the efficient use of available inputs. This interpretation is consistent with evidence that highlights the importance of infrastructure, access to information, and technology adoption for agricultural productive performance (Ayalew et al., 2022; Emmanuel et al., 2016).

The territorial distribution also shows that the relationship between fertilization and productivity varies according to the conditions of each province. In some provinces, the predominance of chemical fertilizers coincides with higher levels of productivity, while in others high levels of productivity are observed along with greater use of organic fertilizers. Likewise, the presence of chemical fertilization in territories with low productivity indicates that this input does not by itself constitute a sufficient condition for achieving higher yields. These patterns are consistent with studies indicating that the response to fertilization is conditioned by soil characteristics, agroecological conditions, and management practices (Cisneros Jayo & Nonones Vásquez, 2024; Hernandez et al., 2021).

The descriptive productivity difference in favor of producers who use chemical fertilizers and the positive association estimated through OLS are consistent with studies reporting higher yields associated with certain inorganic nutrient sources (Khadka et al., 2008; Sahu et al., 2024; Sharma & Chetani, 2017; Timsina, 2018). A possible explanation is the relatively rapid availability of nutrients from some chemical sources. However, given that the choice of fertilizer is not random and may be related to unobserved characteristics of the producer and the production unit, this association does not allow for establishing a causal effect. Access to irrigation constitutes, in turn, the main additional result of the OLS models, while the absence of significance for drainage, improved seeds, and education should be interpreted considering the low prevalence of some of these variables in the sample. This situation may help explain differences with studies that find associations between productivity and technology adoption or technical assistance (Ayalew et al., 2022; Emmanuel et al., 2016; Mponela et al., 2023).

The low adjusted R^2 values indicate that the variables incorporated explain only a fraction of the observed variability in productivity. This limitation does not invalidate the associations identified, but shows that a significant part of the productive differences remains outside the model. Among the unobserved factors are soil characteristics, agroclimatic conditions, fertilizer quantities and composition, management practices, input quality, technical assistance, and productive efficiency. These omissions are relevant because they can influence both the choice of fertilizer and the yield obtained.

This limitation also conditions the interpretation of the Oaxaca-Blinder decomposition. The explained or endowments component does not differ statistically from zero at the 5% level, while the unexplained component concentrates the greatest absolute magnitude and its confidence interval does not include zero. The latter does not represent a causal effect of fertilizer type, but rather the part of the difference that is not captured by the observable characteristics included in the model. It may incorporate differences in coefficients between groups, omitted variables, unobserved heterogeneity, and other sources of heterogeneity. The OLS diagnostics show no problematic multicollinearity nor evidence of functional misspecification through RESET, although they do detect heteroskedasticity, which is why inference relies on robust HC1 standard errors. Agronomic evidence supports this interpretation, showing that productivity depends on the interaction between nutrients, soil fertility, water availability, and management practices (Chen, 2006; Han et al., 2022; Iqbal et al., 2019; Ma et al., 2022). Likewise, physical, chemical, and biological soil processes can modify the response to fertilization over time (Chen et al., 2025; Liu et al., 2026; Shi et al., 2026; Zhao et al., 2026), while organic sources can influence soil conditions and nutrient use (Wen et al., 2025).

In terms of agricultural policy, the association between irrigation and productivity suggests that interventions could jointly consider access to water, technical assistance, and nutrient management, rather than focusing exclusively on fertilizers. Technical assistance adapted to soil characteristics and agroecological conditions could favor more efficient use of available inputs, in line with Ecuadorian evidence on the role of access to agricultural inputs and technologies (Pino Peralta & Ortega Álvarez, 2024; Sánchez Arizo & Fernández Sastre, 2020; Saucedo Aguiar et al., 2024). Evidence from Colombia and Peru also shows that the response to organic and chemical fertilizers depends on production conditions (García et al., 2020; Vicente-Solano & Calle-Arancibia, 2024; Zapana Pari et al., 2015). Nonetheless, due to the observational nature of the study, these implications should be understood as policy guidance and not as evidence of causal effects.

Finally, the main analysis comprises 895 producers observed in 13 provinces and is estimated without expansion factors. Consequently, the results correspond to the analytical sample and should not be generalized as population-level estimates of maize producers in Ecuador. The sensitivity restriction to the ten provinces of the continental Andean region (Sierra) (N = 887) produces practically identical results, indicating that the eight cases outside the Sierra do not explain the main association. The limited variability of some variables and the absence of relevant information also restrict the explanatory capacity and causal interpretation of the results. Future research could incorporate information on soil, agronomic management, fertilization, technical assistance, and agroecological conditions, as well as use longitudinal data or causal identification strategies to more precisely evaluate the relationships between fertilization, irrigation, and productivity.

5. Conclusions

The evidence obtained shows that productivity differences between maize producers who use chemical fertilizers and those who use organic fertilizers cannot be explained solely by the type of fertilization. Although producers who use chemical fertilizers present higher average productivity and the use of this type of fertilizer maintains a positive and statistically significant association with productivity in the Ordinary Least Squares (OLS) estimates, this relationship cannot be interpreted as a causal effect. The choice of fertilizer type may be related to observable and unobservable characteristics of the producer and the production unit that also influence productivity.

Access to irrigation was, in addition to fertilizer type, the only observable characteristic included in the models that showed a statistically significant association with productivity. This result suggests that water availability constitutes a relevant element within the productive conditions analyzed. However, the low explanatory capacity of the models, reflected in adjusted R^2 values below 5%, indicates that the variables incorporated capture only a small proportion of the observed variability in productivity.

The Oaxaca-Blinder decomposition complements these results. The explained or endowments component does not differ statistically from zero at the 5% level, while the unexplained component concentrates the greatest absolute magnitude and does show evidence of a difference distinct from zero. However, this component does not constitute a causal effect of fertilizer type, nor can it be directly attributed to structural factors associated with fertilization. Its magnitude may reflect differences in coefficients between groups, omitted variables, unobserved heterogeneity, and possible specification problems. The main contribution of the study is to show that the observed productivity gap is not sufficiently explained by the characteristics available in ESPAC 2024, and that its analysis requires considering a broader set of productive conditions.

The results should be interpreted considering the

characteristics and limitations of the information used. The study uses cross-sectional data from 895 producers observed in 13 provinces, and the estimates do not use ESPAC expansion factors. For this reason, the results describe associations within the analytical sample and should not be interpreted as population-level estimates for all maize producers in Ecuador. As a sensitivity analysis, restricting the sample to the ten provinces of the continental Andean region (Sierra) (N = 887) leaves the main association practically unchanged. Likewise, ESPAC 2024 does not contain detailed information on some factors potentially relevant for explaining productivity differences, such as soil quality and fertility, fertilizer dosage and timing of application, specific agronomic management practices, technical assistance, and certain agroecological conditions.

Additionally, the low variability observed in some control variables, particularly access to drainage and the use of improved seeds, limits the ability to identify statistical associations related to these characteristics. Therefore, the absence of statistical significance of these variables does not necessarily imply that they lack productive relevance, but rather should be interpreted in light of the limited variation available in the sample. These conditions, together with the possible presence of omitted variables and the cross-sectional nature of the data, restrict the study's ability to establish causal mechanisms.

Based on these findings, it is recommended that interventions directed at the producers analyzed be oriented toward a comprehensive approach to productive conditions, avoiding treating fertilizer type as an isolated determinant of productivity. In particular, access to irrigation constitutes a relevant aspect for sector support policies, given that it was the only productive characteristic in addition to fertilizer type that showed a statistically significant association with productivity. It is also pertinent to strengthen technical assistance related to nutrient management, considering soil characteristics, agroecological conditions, and the management practices of each production unit. These recommendations should be understood as guidance for policy targeting and not as evidence of causal effects derived from expanding irrigation or changing fertilization type.

Finally, it is recommended that the information collected in future rounds of ESPAC and complementary research be strengthened by incorporating variables related to soil quality, fertilizer dosage and timing of application, agronomic management practices, technical assistance, agroclimatic conditions, and other characteristics of production units. The availability of this information would make it possible to reduce the proportion of factors that remain unexplained in the decomposition and improve the identification of factors associated with productivity differences. Likewise, future research could use longitudinal information or causal-identification econometric strategies to more precisely evaluate the relationship between fertilization, irrigation, and maize productivity.

Contributor roles

- Daniela Alexandra García Chamba: conceptualization, investigation, methodology, resources.
- Alexandra Maribel Ordoñez Valdiviezo: investigation, software, writing – original draft.
- José Vicente Ordóñez Yaguache: validation, writing – review and editing.

Data Availability

The research used microdata from the Continuous Survey of Agricultural Area and Production (ESPAC 2024), prepared by Ecuador's National Institute of Statistics and Censuses (INEC). The data are publicly accessible and can be obtained through the official INEC portal. The corresponding link is cited in the manuscript and in the survey's official documentation.

Use of Artificial Intelligence

During the preparation of this manuscript the authors used ChatGPT 5.2 to improve the writing by 15%. After using this tool/ser-vice/software, the authors reviewed and edited the content as needed, to avoid bias, errors, or fabrication of references, and take full responsibility for the content of the published article.

Ethical implications

The authors declare that there are no ethical implications.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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