La Granja:
Revista de
Ciencias de la Vida

pISSN:1390-3799; eISSN:1390-8596

https://doi.org/10.17163/lgr.n43.2026.06

Artículo científico / Scientific paper

Agricultural Sciences

Quantitative analysis of crop richness and monoculture adoption in Ecuador

Análisis cuantitativo de la riqueza de cultivos y la adopción de monocultivos en el Ecuador

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Article received on December 19th, 2021. Accepted, after review, on June 22nd, 2022. Published on March 1st, 2026.

Abstract

In tropical countries, traditional production systems have proved to be fairly productive whereas having a lower environmental impact than conventional agriculture. Nevertheless, factors such as the penetration of the market economy and the disruption of commercial agriculture are reported to have negative effects on agrodiversity of traditional systems. This paper analyzes the socioeconomic determinants of crop richness and monocropping among Ecuadorian farmers. Using data from the Living Standards Measurement Survey-2014, multivariate techniques were used to assess the factors influencing decisions on how many crops to grow and on the likelihood of adopting monocropping. The results show that the number of crops a household grows is larger for poor large indigenous households. In contrast, crop richness is smaller for more educated households receiving off-farm income and residing near a road. In terms of which kind of household is the most likely to engage in monocropping, this is a household that has off-farm work, uses pesticides, and is located next to a road. On the other hand, poor indigenous households have less odds to adopt monoculture. These results demonstrate the importance of diversified agrosystems for rural people in Ecuador and reflect that policy makers should focus on the rescue and promotion of traditional agrosystems as a way to reach food security while promoting sustainable agriculture.

Keywords: Crop richness, monoculture, socioeconomic determinants, multivariate analysis, Ecuador.

Resumen

Los sistemas tradicionales de producción en países tropicales han demostrado ser relativamente productivos, al tiempo que tienen un menor impacto ambiental en comparación con la agricultura convencional. Sin embargo, la penetración de la economía de mercado y la irrupción de la agricultura comercial se reportan como factores que tienen un efecto negativo en la agrodiversidad de los sistemas tradicionales. Este artículo analiza los determinantes socioeconómicos de la riqueza de cultivos y adopción del monocultivo entre los agricultores ecuatorianos. Los datos corresponden a la Encuesta de Condiciones de Vida-2014, y se usaron técnicas multivariadas para evaluar los factores que influyen en las decisiones de cuántos cultivos producir y la probabilidad de adopción del monocultivo. Los resultados muestran que el número de cultivos que produce un hogar es mayor para los hogares pobres y numerosos que son liderados por indígenas. Por otra parte, la riqueza de cultivos es menor para los hogares con mayor educación, que tienen empleo fuera de la finca y residen cerca de una carretera. En términos de qué tipo de hogar tiene mayores probabilidades de incursionar en el monocultivo, este es un hogar que tiene empleo fuera de finca, usa pesticidas y se localiza cerca de una carretera. También, los hogares pobres con jefes indígenas tienen menores probabilidades de adoptar el monocultivo. Estos resultados demuestran la importancia que tienen los agrosistemas diversos para los habitantes de áreas rurales en Ecuador, y reflejan que los legisladores deberían enfocarse en la promoción y el rescate de los agrosistemas tradicionales como una estrategia para alcanzar la seguridad alimentaria y promover la agricultura sostenible.

Palabras clave: Riqueza de cultivos, monocultivo, determinantes socioeconómicos, análisis multivariado, Ecuador.

Suggested citation: Vasco, C. and Caisaguano, L. (2026). Quantitative analysis of crop richness and monoculture adoption in Ecuador. La Granja: Revista de Ciencias de la Vida. Vol. 43(1):114-127. https://doi.org/10.17163/lgr.n43.2026.06.

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1 Introduction

The expansion of conventional agriculture is reported to have negative environmental impacts (Ongley et al., 2010; Comoretto et al., 2008; Lambin et al., 2001). Therefore, many call for more sustainable production schemes (Holt-Giménez and Altieri, 2013). In many tropical countries, traditional production systems are essential to maintain food security and the livelihoods of rural people, as they have proved to be reasonably productive while being more environmentally friendly (Coq-Huelva et al., 2018; Torres et al., 2015). One of the key features of diversified systems is their high level of plant diversity in the form of polycultures and agroforestry systems.

Maintaining crop biodiversity is a deliberate strategy used by farmers to reduce risks, stabilize crop yields, promote diet diversity, and maximize returns even with low access to modern technologies and resources (Altieri, 2009, 2002). Diversity of crops and trees in traditional agroecosystems promote the recycling of nutrients; improves the use of water, nutrients, and sunlight; reduces the incidence of pests and weeds; and allows farmers to produce in a variety of agroecosystems with different soils and agroclimatic conditions (Holt-Giménez and Altieri, 2013; Abebe, 2013; Altieri et al., 2012).

While traditional systems have proved to be resilient and have stood the test of time (Altieri et al., 2012), a number of factors, including market penetration, migration, population growth, land fragmentation, political changes, agricultural modernization, among others, may have a negative effect on crop diversity. Relatively few case studies have focused on analyzing the socioeconomic factors affecting crop diversity in tropical countries. For instance, in Ethiopia, Abebe (2013) found that proximity to markets exerts a negative effect on crop diversity, as farmers residing near markets prefer to specialize in the production of cash crops that can be easily marketed, and to purchase other products they need for household consumption from the market. In the Ecuadorian Amazon, Torres et al. (2018) found that households that obtain their livelihood principally from livestock production and off-farm employment grow fewer crops than those for whom agriculture is their main livelihood activity. In addition, the authors reported that households accessible by road tend to exhibit low levels of crop diversification.

In Malawi, Fatch et al. (2020) determined that households receiving off-farm income are less diversified than those obtaining their income only from agricultural activities. The authors argue that this is because households engaged in off-farm work lack the labor force required to maintain a diversified farm. In their study in Indonesia, Abdoellah et al. (2006) reported that crop diversification has decreased as many households engage in monoculture, switching from subsistence to commercial agriculture. Prior research also reveals that indigenous peoples tend to keep highly diversified impact (Perrault-Archambault and Coomes, 2008; Torres et al., 2018; Abril Saltos et al., 2016) home gardens and to use agricultural practices with low environmental; nevertheless, recent evidence (Vasco, Torres, et al., 2021) reflects that indigenous peoples also engage in unsustainable agricultural practices (i.e., forest clearing, monocropping, cattle ranching, use of chemicals) when in contact with the market economy.

Using data from the Living Standards Measurement Survey 2013-2014, this paper adds up to the existing literature by examining the socioeconomic determinants of crop diversity -proxied by the number of crops a household has produced- and the likelihood of monocropping adoption in rural Ecuador. As for the rest of this paper, it is structured as follows: Section 2 describes Ecuador in terms of its geographic regions and its agricultural patterns, Section 3 describes the survey and explains the statistical methods, Section 4 presents and discusses the results, while Section 5 concludes.

2 The context: Agriculture in Ecuador

The agricultural sector is important for the Ecuadorian economy. It accounts for 8 % of the country's GDP and for around 42 % of non-oil exports, with bananas, cocoa, coffee, fresh flowers and fruits being the principal exportable products (BCE, 2019). Agriculture is the main economic activity for around 48 % of the rural population, with earnings from agriculture accounting, on average, for around 40 % of rural households' income (Vasco

and Tamayo, 2017; INEC, 2010). Despite these figures, conventional agriculture has also been reported to have negative environmental effects, including the advance of the agricultural frontier and non-point source pollution (Wunder, 2001). Land concentration is an issue, with a Gini coefficient of 0.8 and 63.5 % of the farms smaller than 5 ha (Brassel et al., 2010). Many of those farms exhibit a high degree of biological diversity in the form of polycultures and agroforestry systems, and, while small, support peasant families and provide 64 % of the country's agricultural production (FAO, 2021).

Continental Ecuador is subdivided in three geographical regions: the coastal region (*la Costa*), the highlands (*la Sierra*) and the Amazon (*la Amazonía*). The marked differences in terms of landscape, ecosystems and sociocultural background determine agricultural patterns specific for each region (Intriago et al., 2017). To illustrate, the coastal region encompasses all the plains along the Pacific Ocean and the foothills of the Andes. It is characterized by lush vegetation combining dry and, to a lesser extent, evergreen forests, although an important part of the native vegetation has disappeared in favor of agricultural uses (MAE, 2013).

This region concentrates export-oriented agriculture, with large plantations of banana, cacao, and oil palm accounting for around 67 % of the area planted with perennial crops. This region also has important areas devoted to pastures and temporary crops, including rice, maize, and soybean (INEC, 2021). Despite the expansion of monoculture to produce agricultural commodities, many small-scale farmers still practice traditional agriculture and maintain farms with high levels of biodiversity, principally for self-consumption (Intriago et al., 2017).

La Sierra comprises the Andean territories. The region is highly heterogeneous in terms of altitude, topography, temperature, and soils (Hofstede et al., 1998). Agriculture is principally focused on the production of staples, including potatoes, maize, beans, and tuber crops, among others, although there are important areas -usually the plain and most fertile lands- devoted to the production of fresh flowers and broccoli for export (INEC, 2021). Agricultural income is the main income source for rural households accounting, on average, for 45 % households' total income in this region (Vasco and Tamayo, 2017).

Land concentration is more marked in the highlands than in the rest of Ecuador's geographical regions, with a Gini coefficient of 0.81. Unequal distribution of resources (i.e., land and irrigation water) threatens the livelihoods of many small-scale farmers, principally the indigenous population, who account for 20 % of the total rural population in the highlands (INEC, 2010). The *chakra andina* is the most common traditional system in the highlands. Widely used by indigenous populations, it is an agrosystem characterized by high levels of biodiversity, and a complex system of seed conservation and varietal adaptation at different altitudinal levels (2,400-3,500 m) (Intriago et al., 2017). Small-scale farmers practicing the *chakra andina* have been able to develop ingenious methods for the ecological management of soils, water, and genetic resources. Nevertheless, limited access to land and water, together with land fragmentation is reported to threaten the *chakra andina* (Gortaire, 2016), as, in some areas, farm sizes are too small to support and nourish rural families.

The Ecuadorian Amazon is one of the world's biodiversity hotspots. It is home to several indigenous peoples, who have long lived in the area and account for 47 % of the rural population, while the rest are principally mestizo-colonists who migrated from the coastal region and the highlands, starting in the 1960s (INEC, 2010). Agriculture is still an incipient activity due to the low fertility of soils, a poor road network and remoteness from the main agricultural markets (Vasco Pérez et al., 2015). Mestizo-colonists have usually engaged in unsustainable activities, including forest clearing, cattle ranching, and monocropping, as a consequence, deforestation rates in the territories controlled by colonists ranked as the highest among the Amazonian countries (Bilsborrow et al., 2004).

In contrast, indigenous peoples are reported to obtain their livelihood from subsistence agriculture and to use agricultural practices with low environmental impact (Nuckolls, 2010). Most indigenous peoples in the Amazon practice the *chakra amazónica*. This is a traditional agroforestry system featured by high levels of biodiversity that combines subsistence crops (e.g., plantains and cassava) with

cash crops (e.g., cacao and coffee) and has proved to be successful in providing food and income to indigenous peoples while having a low environmental impact, as it normally does not require the use of external inputs (i.e., chemical fertilizers and pesticides) (Coq-Huelva et al., 2017). Although it is deeply rooted in the culture of Amazonian peoples, factors like the penetration of the market economy and the adoption of monocropping may be detrimental for the continuity of the *chakra amazónica* (Vasco, Torres, et al., 2021).

3 Methods

3.1 Data and variables

Data came from the Living Standards Measurement Survey 2013-2014 (LSMS 2013-2014) conducted by the National Institute of Statistics (INEC). This is a cross-sectional data set that has national representation and includes a full section about housing, household composition, health, education, household assets and economic activities for a total of 28,970 households (INEC, 2014). The survey also incorporates a section about agricultural activities, which includes information on landholding size, crop and animal production, yields, farm equipment and investments, which makes this survey useful for the objectives of this study. For the analysis, we selected the households that reported having produced at least one crop during the twelve months preceding the data collection. This resulted in a sample of 9,819 households distributed as follows: 5,619 households in the highlands, 1,942 in the coastal region and 2,258 in the Amazon[1].

The dependent variables of interest were crop richness, that is the number of crop species grown in a farm, and a binary variable taking the value of 1 if the household adopted monocropping and 0 otherwise (see Table 1 for definitions). Concerning independent variables, we included a number of household head and household predictors that are expected to have an effect on the dependent variables under study. The first group, household head predictors, include the age of the head and a binary variable taking the value of 1 if the household is a woman and 0 otherwise. Two binary variables taking the value of 1 whether the head defines himself/herself as indigenous or afro Ecuadorian, respectively, controls for the effect of ethnicity on the outcome variables under analysis. The group of people who define themselves as *mestizo* -the largest in the sample- is left as the comparison group. In addition, three binary variables taking the value of 1 if the household head is illiterate, had completed secondary education or held a university degree, respectively, are used to control for the role of education. Those who had completed only primary education are left as the baseline group. Prior research (Perrault-Archambault and Coomes, 2008; Torres et al., 2018; Abril Saltos et al., 2016) reported that these predictors exerted a significant effect on the number of crops in a farm.

At household-level, the household size and a binary variable taking the value of 1 has the household hired extra family labor control for labor force availability. Additionally, we include the number of internal and international migrants as these predictors may reduce the household labor for agricultural activities (Gray, 2009). Farm size and the area a household has rented during the twelve months preceding the survey controlled for land a household possesses or manages for farming. Overall, diversified agrosystems are reported to have a low environmental impact and to use low amounts of external inputs (Coq-Huelva et al., 2018). To test this hypothesis, a dummy variable was used, taking the value of 1 if the household has used pesticides during the twelve months prior data collection. Off-farm employment is expected to exert a negative effect on crop diversity as it takes household labor out of the farm, so that households engaged in off-farm work may lack the labor force to maintain a diversified farm (Fatch et al., 2020; Torres et al., 2018). To control this potential source of variance, our specification includes a binary variable taking the value of 1, which has the household receiving off-farm income.

[1]While the LSMS 2013-2014 includes households from the Galápagos islands (the insular region of Ecuador), we did not consider that region in the analysis here as the number of households involved in agricultural production (56) was too little to conduct multivariate analysis.

A wealth index[2], the number of heads of cattle a household possesses and a dummy taking the value of 1 whether or not the household is benefiting from the *Bono de Desarrollo Humano* social program[3], are used to proxy households' economic conditions. In a similar fashion, we also included a dummy indicating if the household has received a loan during the 12 months preceding the survey as a covariate. The role of road infrastructure on shaping decisions of how many species to grow is controlled by a dummy taking the value of 1 if the household is accessible by road. Finally, the model includes two binary variables indicating if the household is located in the *Costa* or the *Amazonia*, with the households located in the *Sierra* as the reference group.

3.2 Statistical Methods

We used multivariate regression to find the socioeconomic determinants of crop diversity and adoption of monoculture. It is worth noting, before proceeding, that there may be characteristics that are inherent to a specific area and are not considered in the model. Such contextual variables may shape households' decisions concerning how many crops to grow. Ignoring the hierarchical nature of the data may lead to wrong results and misleading interpretations. To control the hierarchical nature of the data, we used multilevel models. These kinds of models are commonly used in environmental sciences and are useful to control clustered sampling designs and to model contextual effects (Wikle, 2003). Hence, in the case of species richness, we relied on a multilevel linear model:

$$Y_{ij} = \alpha + X_{ij}\beta + \varepsilon_{ij} + u_j \quad (1)$$

Where Y is the number of crops that household i in canton j has grown in the twelve months preceding data collection, α is the intercept, X is a vector of covariates that were listed and described above, β is a vector of coefficients, the size and direction of which we are interested to know, ε stands for the household level error term and v is the error term at canton level.

As for the likelihood for a household to adopt monoculture, it was estimated using a multilevel logistic model:

$$Pr(Y_{ij} = 1|X_{ij}, u_j) = H(X_{ij}\beta + z_{ij}u_j) \quad (2)$$

Where Y is a binary variable taking the value of 1 if the household i in the canton j adopted monoculture, X is a vector of the covariates already described, u is a set of random effects at canton level, H is the logistic cumulative distribution function β is a vector of coefficients and z are the covariates of the random effects. Since the coefficients of a logit model are not directly interpreted, in the section of results we present and discuss the marginal effects of each predictor.

4 Results

4.1 Crop richness

Column I in Table 2 shows the results of an ordinary least squares (OLS) regression with species richness as the dependent variable. There is a quadratic behavior with respect to the age of the household head, with the number of species grown increasing with age to a threshold at 53 years and then decreasing. Having a woman as the head reduces the number of crop species in 0.192. As expected, households having a head that defines himself/herself as indigenous increases the species richness in 0.588. In contrast, our results show that households with afro Ecuadorian heads grow fewer species than their mestizo counterparts.

In terms of the education predictors, the dummy variable accounting for having a university degree has a negative effect on the number of species. Holding a university degree reduces by 0.325 the number of crops grown by a household. Each new household member increases the number of crops produced by a household by 0.10. On average, households that have off-farm employment grow fewer crops than their counterparts not engaged in off-farm activities.

Households benefiting from the *Bono de Desarrollo Humano* grow more crops than their non-recipient peers. Receiving the BDH increases by 0.23, on average, the number of crops grown by a household. Proximity to roads has a negative effect

[2]The index was the main component of possession of a radio, TV, cell phone, computer, gas stove, refrigerator, car, and motorcycle. The first principal component explained 31 % of the variance.

[3]The *Bono de Desarrollo Humano* is a governmental conditional transfer granting US $ 50 to households living under the poverty line on the condition that the money is spent on health and education.

on species richness, with households located next to a road having, on average, 0.33 fewer crop species than those not served by a road system. Finally, the results reveal that there are geographical differences in terms of species richness. Households located in the coastal region grow, on average, 0.51 fewer species than their counterparts in the highlands.

Table 1. Descriptive statistics and variable definitions.

Variable	Description	Mean	S.D.
Dependent variable			
Crop richness	Number of crops a household grows.	3.811	2.838
Monoculture	Household has adopted monoculture (0/1).	0.138	-
Independent variable			
Age	Age of household head (years).	51.798	16.424
Female	Household head is a woman (0/1).	0.190	-
Mestizo	Household head is mestizo (0/1).	0.583	-
Indigenous	Household head is indigenous (0/1).	0.307	-
Afro Ecuadorian	Household head is afro Ecuadorian (0/1).	0.024	-
Illiterate	Household head is illiterate (0/1).	0.153	-
Primary education	Household head has completed primary education (0/1).	0.623	-
Secondary education	Household head has completed secondary education (0/1).	0.179	-
University degree	Household head holds a university degree (0/1).	0.043	-
Household size	Household size.	4.122	2.243
Hired labor	Household has hired labor force (0/1).	0.223	-
Internal migrants	Number of internal migrants.	0.196	0.707
International migrants	Number of international migrants.	0.021	0.239
Landholding size	Farm size (ha).	10.836	212.641
Rented land	Amount of rented land (ha).	1.920	112.765
Pesticides	Household has used pesticides (0/1).	0.438	-
Off-farm employment	Household has off-farm employment (0/1).	0.377	-
Wealth index	Wealth index.	-0.012	1.710
Cattle	Number of cattle the household owns.	2.440	7.087
Bonus	Household received *Bono de Desarrollo Humano* (0/1).	0.589	-
Credit	Household has received credit (0/1).	0.127	-
Road	Household is located next to a road (0/1).	0.753	-
Sierra	Household is located in the *Sierra* (0/1).	0.572	-
Costa	Household is located in the *Costa* (0/1).	0.197	-
Amazonia	Household is located in the *Amazonia* (0/1).	0.229	-

Note: (0/1) identifies dummy variables. S.D.: Standard Deviation.

Columns II-IV present independent regressions for each region. While most of the coefficients remain unaltered, the landholding size becomes significant in the regression for *la Sierra*. In the case of the Coast, the dummy controlling for receiving the *Bono de Desarrollo Humano* is not significant anymore, while in the *Amazonia*, the effect of female headship is no longer significant.

4.2 Monoculture adoption

The results of a multilevel logit model are shown in Column I in Table 3. The likelihood of adopting monoculture grows with age to a threshold at 73 years and then declines. As expected, indigenous households are less likely to adopt monoculture. Having an indigenous head reduces the odds of adopting monoculture in 4 %. Household size has a negative effect on the likelihood of adopting monoculture. Each new member of a household increases the odds of monoculture in 0.7 %. Households using

pesticides are 2.7 % more likely to practice monoculture.

Having off-farm income increases the likelihood of adopting monoculture in 2.8 %. Each head of cattle a household possesses reduces the likelihood of monoculture in 0.1 %. Contrary to the results for crop richness, receiving the *Bono de Desarrollo Humano* reduces the likelihood of practicing monoculture in 2.2 %. Households located next to a road are 4.4 % more likely to adopt monoculture. Consistent with the results for crop richness, households residing in the coastal region are 5.7 % more likely to engage in monoculture than their peers from the highlands. In contrast, Amazonian households are less likely to engage in monoculture. Residing in the Amazon reduces the likelihood of adopting monoculture in 5.5 %.

Whereas most of the coefficients remain unchanged when running independent regressions for each region (Columns II-IV), the dummy accounting for indigenous household head and the number of cattle is not significant anymore in the *Sierra*. The effect of age is no longer significant in the regressions for the Coast and the *Amazonia*.

Table 2. Socioeconomic determinants of crop richness (OLS).

	Richness of crops			
Variable	**Overall (I)**	**Sierra (II)**	**Costa (III)**	**Amazonia (IV)**
Age	0.070***	0.067***	0.083***	0.068***
Age squared	-0.000***	-0.000***	-0.000***	-0.000***
Female (0/1)	-0.192***	-0.146*	-0.413***	-0.157
Indigenous (0/1)	0.588***	0.456***	-0.518	0.762***
Afroecuadorian (0/1)	-0.401**	-0.307	-0.444**	-0.608
Illiterate (0/1)	-0.042	-0.012	0.014	-0.066
Secondary education (0/1)	-0.102	-0.203	0.018	0.035
University degree (0/1)	-0.325***	-0.637***	0.065	0.097
Household size	0.102***	0.129***	0.052*	0.078***
Hired labor (0/1)	0.486***	0.573***	0.363***	0.435***
Internal migrants	-0.049	-0.070	0.018	-0.054
International migrants	-0.003	-0.073	-0.105	0.217
Landholding size	-0.000	0.005***	-0.000	0.000
Rented land	-0.000	-0.008	-0.000	-0.004
Pesticides (0/1)	0.799	0.934	0.645	0.574
Off-farm employment (0/1)	-0.566***	-0.601***	-0.369***	-0.601***
Wealth index	0.017	0.020	0.059	-0.040
Cattle	0.003	0.000	-0.002	0.014*
Bonus (0/1)	0.232***	0.283***	0.093	0.280***
Credit (0/1)	0.081	0.155*	-0.094	-0.070
Road (0/1)	-0.339***	-0.232***	-0.674***	-0.341***
Costa (0/1)	-0.524***	-	-	-
Amazonia (0/1)	0.199	-	-	-
Intra-class correlation	4.792***	3.187***	2.447***	3.125***
Number of cantons	659	348	187	124
Number of observations	9,819	5,619	1,942	2,258
Wald test	880***	586***	180***	204***

Note: *, ** and *** stand for significance at 10, 5 and 1 %, respectively. (0/1) identifies dummy variables.

Table 3. Socioeconomic determinants of monoculture adoption (logit).

	Adoption of monoculture			
Variable	**Overall (I)**	**Sierra (II)**	**Costa (III)**	**Amazonia (IV)**
Age	0.003**	-0.004***	-0.000	-0.000
Age squared	-0.000**	0.000***	2.61	2.61
Female (0/1)	0.001	-0.012	0.002	0.002
Indigenous (0/1)	-0.039***	-0.014	-0.057***	-0.057***
Afroecuadorian (0/1)	0.008	0.097	0.017	0.017
Illiterate (0/1)	0.014	0.015	0.000	0.000
Secondary education (0/1)	-0.003	-0.006	0.007	0.007
University degree (0/1)	0.017	0.047*	-0.002	-0.002
Household size	-0.007***	-0.000***	-0.003*	-0.003*
Hired labor (0/1)	0.025	0.001	0.004	0.004
Internal migrants	-0.003	0.004	-0.002	-0.002
International migrants	0.012	0.017	-0.001	-0.001
Landholding size	0.000	-0.000	-0.000	-0.000
Rented land	-0.000	0.001	-0.004	-0.004
Pesticides (0/1)	0.027***	0.021***	0.016*	0.016*
Off-farm employment (0/1)	0.028***	0.020**	-0.001	-0.001
Wealth index	0.000	0.001	0.002	0.002
Cattle	-0.001**	-0.000	-0.003***	-0.003**
Bono (0/1)	-0.022***	-0.032***	-0.006	-0.006
Credit (0/1)	-0.006	0.002	-0.004	-0.004
Road (0/1)	0.044***	0.033***	0.027***	0.027***
Costa (0/1)	0.057***	-	-	-
Amazonia (0/1)	-0.055***	-	-	-
Intra-class correlation	1.56***	1.75***	2.45***	1.98***
Number of cantons	659	348	187	124
Number of observations	9,819	5,619	1,942	2,258
Wald test	193***			

Note: *, ** and *** stand for significance at 10, 5 and 1 %, respectively. (0/1) identifies dummy variables.

5 Discussion

The data suggest that decisions of whether to maintain diversified farms or engage in monoculture are principally shaped by ethnicity, education endowment, labor force availability and poverty. In the case of ethnicity, the results show that indigenous people have more diversified farms. This finding is not surprising, since, as referred to earlier in section 2, indigenous peoples are reported to maintain agrosystems featured by high levels of biodiversity (Gortaire, 2016). This pattern occurs in the *Sierra* and the *Amazonia*, but not in the *Costa*, probably because indigenous population in that region is low (INEC, 2010). Surprisingly, the results show that indigenous peoples in the *Sierra* are as likely as their mestizo counterparts to engage in monoculture. This should be a source of concern due to the importance that indigenous agriculture has for the preservation and promotion of sustainable agriculture (Parraguez-Vergara et al., 2018). Indigenous populations in the *Amazonia*, however, are less likely to engage in monoculture, probably because of the social, cultural and economic importance that the *chakra* system has among indigenous peoples in the Amazon (Coq-Huelva et al., 2018). Afro Ecuadorian populations in the Coastal have less diversified farms than their mestizo counter-

parts, which suggest that they are more engaged in commercial agriculture.

While in the *Costa* and the *Amazonia* education does not exert any significant effect on crop richness and monoculture adoption, in the *Sierra*, households with heads having a university degree have less diversified farms. This may signify that more educated households engage in cash crop production and, therefore, have less diversified farms. Whereas increasing education in rural areas is considered a development priority, this finding reflects a negative externality of education with regards to promotion of sustainable agriculture, so policy makers should focus on developing curricula that emphasizes the importance of sustainable agriculture and diversified agrosystems (Vasco, Tafur, et al., 2021).

The findings reflect the labor force as a key element for maintaining diversified farms. Overall, larger households have more diversified farms and are less likely to engage in monoculture. Prior research (Vasco, Tafur, et al., 2021) has already shown that larger households, with more labor force, are able to maintain more crops. This is also consistent with the Chayanovian postulate that peasant agriculture, like the one practiced in traditional agrosystems, has been able to survive and even compete with modern agriculture, mainly relying on family labor force (Chayanov, 1966). Also related to labor force availability, the results show that farms growing more crops need to hire extra-household labor, which confirms that labor force is a key element -perhaps a bottle neck- for the development of sustainable agriculture. In this sense, policy makers should address their efforts to develop labor-saving technologies for small-scale farmers.

Households having off-farm work have less diversified farms. Three possible arguments arise to explain this finding. First, it is possible that such households have less labor force available for agricultural production, so that they cannot grow many crops in their farms (Torres et al., 2018). Second, it is also possible that farming is not a priority for these kinds of households as earnings from off-farm employment tend to be significantly higher than those to be obtained from agricultural production (Vasco and Tamayo, 2017). Third, it is likely that earnings from off-farm work are invested in conventional agricultural production (Angelsen and Kaimowitz, 2001).

Receiving the *Bono de Desarrollo Humano* is positively correlated with crop richness and negatively correlated with the likelihood of monoculture adoption. In the first case, a likely explanation is that poor households -like those benefiting from social aid- lack the resources to buy food in the market so they must rely on what they produce on their farms. As these kinds of households rely on subsistence agriculture, they must maintain diversified farms to meet their dietary requirements. In the case of monoculture adoption, the negative correlation may reflect that poor farmers lack the resources to engage in commercial agriculture. Similarly, it may indicate that poor farmers need to produce many crops as they are not able to buy food in the markets (Vasco, Tafur, et al., 2021). Beyond these arguments, these findings confirm the importance of diversified agrosystems for food security, food sovereignty and poverty alleviation of rural people in the developing world (Altieri et al., 2012).

Accessibility is another factor that shapes crop richness and monoculture adoption. Households located next to a road have less diverse farms and are more likely to adopt unsustainable production systems. Roads facilitate the transport of agricultural produce to urban markets; therefore, households located next to a road may be encouraged to abandon traditional agriculture in favor of more profitable commercial agriculture (i.e., monoculture). As it is the case of education, the construction of roads in rural areas is seen as a development priority to improve the livelihoods of rural people as it may facilitate the transport of goods and services (Vasco, Tamayo, and Griess, 2017). Nevertheless, such a policy may have negative externalities like increasing deforestation rates (Vasco, Torres, et al., 2017), and -as shown here- encouraging rural people to adopt unsustainable practices.

There are regional differences that are worth noting. Crop richness is smaller in the coast than in the Highlands. A possible explanation for this finding is that, as mentioned earlier in section 2, most of Ecuador's exportable commodities are produced in the coast; therefore, households in that region may exhibit a strong drive for cash crop production (Vasco and Tamayo, 2017) and have, to a great extent, abandoned traditional production systems.

The likelihood of monoculture adoption is higher in the *Sierra* than in the *Amazonia*, which may be associated with still incipient agricultural sector in the Amazon (Sellers et al., 2017) and many native Amazonian people practicing the *chakra* traditional system (Coq-Huelva et al., 2017).

6 Conclusions and policy implications

This paper has analyzed the determinants of crop richness and monoculture adoption in Ecuador. Results show that large indigenous households that receive the *Bono de Desarrollo Humano* have higher crop richness in their farms. In contrast, households headed by individuals who have completed university, have off-farm income and are located next to a road, grow fewer crops. In terms of monoculture, the likelihood of adopting such a system is higher for households using pesticides, having off-farm work and residing next to a road. On the other hand, numerous indigenous households receiving the *Bono de Desarrollo Humano* are the least likely to engage in monoculture. Beyond these conclusions, this paper also offers some policy recommendations.

First, our results are in line with prior literature (Altieri et al., 2012; Altieri, 2009; Astier et al., 2017) highlighting the importance of indigenous agriculture for preserving and promoting sustainable agricultural systems. While our findings show that indigenous households do have more diversity of crops in their farms and are more averse to engage in unsustainable practices (i.e., monoculture), previous research addresses that, when in contact with the market economy, indigenous populations also engage in unsustainable practices including monoculture and the use of pesticides (Vasco, Torres, et al., 2021). In this sense, policy makers should focus on rescuing and promoting the (re)adoption of traditional production systems among indigenous peoples.

Second, maintaining a diversified farm seems to demand high amounts of both family and extra-family labor. This is consistent with critics of peasant agriculture holding that it depends on the (over)exploitation of family labor, rather than in farmers' capacity to adapt to changing environments and farmers' technical knowledge (Heynig, 1982). In any case, if the adoption of sustainable systems is a rural development priority, research efforts should be oriented to develop labor saving technologies for traditional production systems.

Third, the results presented here suggest that crop diversity is higher in households receiving social aid from the government. While this suggests that deprived households do not have the resources to buy food on the market and so must produce most of the food they consume, it also reflects that diversified agrosystems are key for food security of poor rural households. In this sense, policies oriented to reduce poverty and hunger in rural areas should focus on promoting traditional and sustainable food systems as a tool to improve food security in rural areas.

Author's contribution

C.L.V.P.: Conceptualization, Formal analysis, Investigation, Methodology, Software, Writing – Original Draft, Writing – Review & Editing. **L.J.C.L.:** Data Curation, Validation, Software, Writing – Review & Editing.

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