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# Use of chemical fertilizers and pesticides in frontier areas: A case study in the Northern Ecuadorian Amazon

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ABSTRACT

The excessive use of chemical fertilizers and pesticides in agriculture is one of the main sources of pollution globally. While a significant body of research has focused on analyzing the socioeconomic drivers of deforestation in the Amazon basin, far less attention has been paid to explaining why Amazonian people use chemicals in agricultural production. Using data from a household survey, this paper aims at analyzing the drivers of expenditure on chemical fertilizers and pesticides among *Kichwa* and mestizo colonist populations in the Northern Ecuadorian Amazon. The results show that most households in the research area use chemicals, which seems to be related to most households engaged in the production of *naranjilla*, a citrus fruit that requires high amounts of pesticides to prosper in the Amazon. Expenditure on chemicals is principally driven by wealth, access to credit and land use patterns, with households with more land in crops spending more on fertilizers and pesticides. An important finding is that households receiving money from government social programs spend more on both chemical fertilizers and pesticides than non-recipient households. Ethnicity does not play any role in shaping expenditures on both chemical fertilizers and pesticides. Our results reflect that clear, consistent and coordinated policies are necessary to reconcile conservation and rural development in the Amazon, since, at present, ambiguous and even contradictory policies are not effective in achieving that goal.

## 1. Introduction

Pollution resulting from agricultural activities has become a serious problem worldwide, especially in less developed countries. Nonpoint source pollution from agricultural activities is responsible for the contamination of soils, surface water, groundwater and farm products, among other undesirable environmental and social effects (Ongley et al., 2010; Sun et al., 2012). Among the principal contaminants from agricultural activities are the excessive use of chemical fertilizers (Chen et al., 2017; Jabbar and Grote, 2019), and synthetic pesticides and herbicides (Comoretto et al., 2008; Cruzeiro et al., 2015). Therefore, it is not surprising that many scholars call for cleaner and more sustainable agricultural production, which can reach the goal of producing enough food while reducing the risks for humans and the environment (Altieri, 2011; Altieri and Nicholls, 2001; Francis et al., 2003; Gliessman, 2016; Holt-Giménez and Altieri, 2013). In less developed countries, traditional production systems are key in achieving that goal, as they have proved to be reasonably productive while demanding low amounts of external inputs, preserving local biodiversity and having low environmental impacts (Altieri, 1999). Nevertheless, such traditional and more environmentally friendly production systems tend to disappear in favor of conventional farming as a result of the expansion of commercial agriculture and monocropping (Marini et al., 2011; Robson and Berkes, 2011).

The Amazon basin is considered one of the world's biodiversity hotspots (Myers et al., 2000). This region has gained considerable attention by researchers and practitioners due to high deforestation rates and increasing pressure on natural resources, which threaten its

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rich biodiversity and contribute to climate change. In this sense, several works have addressed the causes of deforestation and the advance of the agricultural frontier (Caviglia-Harris and Sills, 2005; Gray et al., 2008; Perz, 2002; Pichón, 1997; Sellers et al., 2017; Steininger et al., 2001). Far less attention, however, has been paid to the environmental contamination and the risks to human health that the (excessive) use of chemical fertilizers and synthetic pesticides generate in the Amazon. For instance, in a study conducted in the Northern Ecuadorian Amazon, Hurtig et al. (2003) reported that half of the farmers in their sample had experienced negative health effects associated with the use of pesticides. In terms of environmental effects, Sirén (2011) and Ramírez Hita (2020) reported a decrease in the amount of fish in Amazonian rivers of Ecuador and Peru, respectively, due to pollution resulting from the use of chemical fertilizers and pesticides.

The Ecuadorian Amazon is inhabited by two main groups. On one side, migrant colonists who migrated from other regions of the country. Such populations mostly obtain their livelihood from cattle ranching and commercial agriculture (Bilsborrow et al., 2004; Pichón, 1997), with many engaging in unsustainable practices including monocropping and the excessive use of chemical fertilizers and pesticides (Hurtig et al., 2003). On the other side, several indigenous peoples have long lived in the Amazon. These are reported to rely on subsistence agriculture and traditional agroforestry systems with low environmental impact (Coq-Huelva et al., 2017; Vera et al., 2019). Nevertheless, when in contact with the market, indigenous peoples are reported to also engage in unsustainable practices i.e., cash-crop production and monocropping (Vasco et al., 2018). Few quantitative studies have studied the drivers of agricultural input use among indigenous peoples in the Amazon. For instance, Godoy et al. (1998) found that the use of pesticides among indigenous peoples in the Bolivian Amazon is mainly determined by education and income. In the Ecuadorian Amazon, Sellers and Bilsborrow (2019) determined that the use pesticides and chemical fertilizers among indigenous peoples is positively correlated with cultivated area, the share of land in perennial crops and the use of credit. The authors also found that indigenous households are less likely to use herbicides and chemical fertilizers than their migrant-colonist counterparts. Nevertheless, the question of why indigenous peoples switch from traditional production systems to conventional agriculture remains unanswered. This paper contributes to fill this gap of research by examining the socioeconomic factors associated with the use of chemicals in the Amazon.

Using data from a household survey conducted among colonists and Kichwa people of the Ecuadorian Amazon, this paper aims at analyzing the socioeconomic factors shaping expenditure on chemical fertilizers and pesticides among indigenous and colonist populations in the Ecuadorian Amazon. As for the rest of this paper, it is structured as follows: Section 2 presents the theoretical framework of the motivations for rural people to use modern agricultural technologies, in Section 3 the research area is introduced, and the sampling and statistical methods are described. Section 4 presents and discusses the results, while Section 5 concludes and describes key policy recommendations.

## 2. Theoretical background

A significant body of research has focused on studying the motivations for farmers to adopt new technologies. In an influential work, Boserup (1965) stated that, in rural populations, agricultural intensification (i.e., shorter fallow periods and adoption of new techniques and tools) occurs when a relatively high level of population density is reached. In absence of population pressure, however, farmers may still prefer using long fallows and basic tools even if aware of the existence of more sophisticated methods. Precisely, high population densities and famines in rural areas were the factors that prompted the "Green revolution" and triggered the use of modern agricultural technologies, including high-yielding varieties, irrigation, chemical fertilizers and pesticides among rural people in the developing world (Chakravarti, 1973; Morales, 2007). Broadly speaking, agricultural intensification may be technologically-driven or market driven (Byerlee et al., 2014). In the first case, technological change makes it possible to increase the amount of output per unit of input as a result of the use of new varieties, better crop and resource management as well as better crop protection. In the case of market-driven intensification, it occurs as a response to market opportunities, that is, for instance, the shift to more profitable crops or the use of fertilizers to obtain better yields in response to high land prices.

In frontier areas, where both population densities and the level of integration into the market economy are relatively low, there are opposing views concerning the relationship of agricultural intensification and deforestation. Some authors (Arima and Uhl, 1997; Laurance et al., 2001; Mattos and Uhl, 1994; Tachibana et al., 2001) support the argument that agricultural intensification may reduce pressure on natural resources, since it allows farmers to improve yields and therefore to reduce the need of expanding agricultural areas by clearing forest and encroaching protected areas. Others contradict such a statement by arguing that if agricultural intensification leads to higher returns to land, farmers may be encouraged to expand the area devoted to agriculture in order to improve their income (Angelsen and Kaimowitz, 2001; Byerlee et al., 2014; Kaimowitz and Angelsen, 2008; Nepstad and Stickler, 2008). Besides deforestation, concerns have been raised in over the pollution caused by the excessive use of pesticides and chemical fertilizers in frontier areas (Sawyer, 2008).

Angelsen and Kaimowitz (2001) propose that adoption of agricultural technologies in frontier areas is shaped by a number of socioeconomic and environmental factors among them: the *type of technology* (labor and capital intensity and the availability of modern technologies for recently cleared areas); *farmer's characteristics* (wealth, possession of assets and resource constraints); *output markets* (access as well as demand and functioning of markets), *labor markets* (wage rates, availability of labor in the area, in- and out-migration), *credit markets* (availability and conditions of credit), *property rights* (security of land rights and how farmers obtain right to forest); and *agroecological conditions* (quality of land and accessibility).

Adopting agricultural technologies may also be driven by household-level characteristics including education, farm size, type of land use and availability of alternative income sources i.e., participation in off-farm activities and remittances (Godoy et al., 1998; Perz, 2002; Zhang et al., 2020). In the context of the Amazon, ethnicity may play an important role in influencing adoption of agricultural technologies (Sellers and Bilsborrow, 2019). Indigenous populations practice subsistence agriculture and tend to use land less intensively than migrant-colonist populations. Historically, they principally rely on traditional agroforestry systems characterized by high levels of biodiversity, low use of external inputs and low environmental impact (Vera et al., 2019). In contrast, migrant-colonist populations are reported to engage in less sustainable agricultural practices including monoculture and cattle ranching (Bilsborrow et al., 2004; Pichón, 1997), and so to use more chemical fertilizers and pesticides than their indigenous peers (Sellers and Bilsborrow, 2019). With this broad theoretical framework, we analyze the effect of a set of household and community variables on the expenditures on chemical fertilizers and pesticides among indigenous and migrant-colonist populations in the Ecuadorian Amazon.

## 3. Methods

### 3.1. Research area

The research was conducted in the *Hatun Sumaku* parish, province of Napo in the Central Ecuadorian Amazon. This area is considered one of the world's biodiversity hotspots (Bass et al., 2010) (Fig. 1). Mestizo colonists account for about 12% of the population in *Hatun Sumaku* (INEC, 2010). These populations migrated principally from El Chaco canton and the eastern part of the Pichincha province, after being

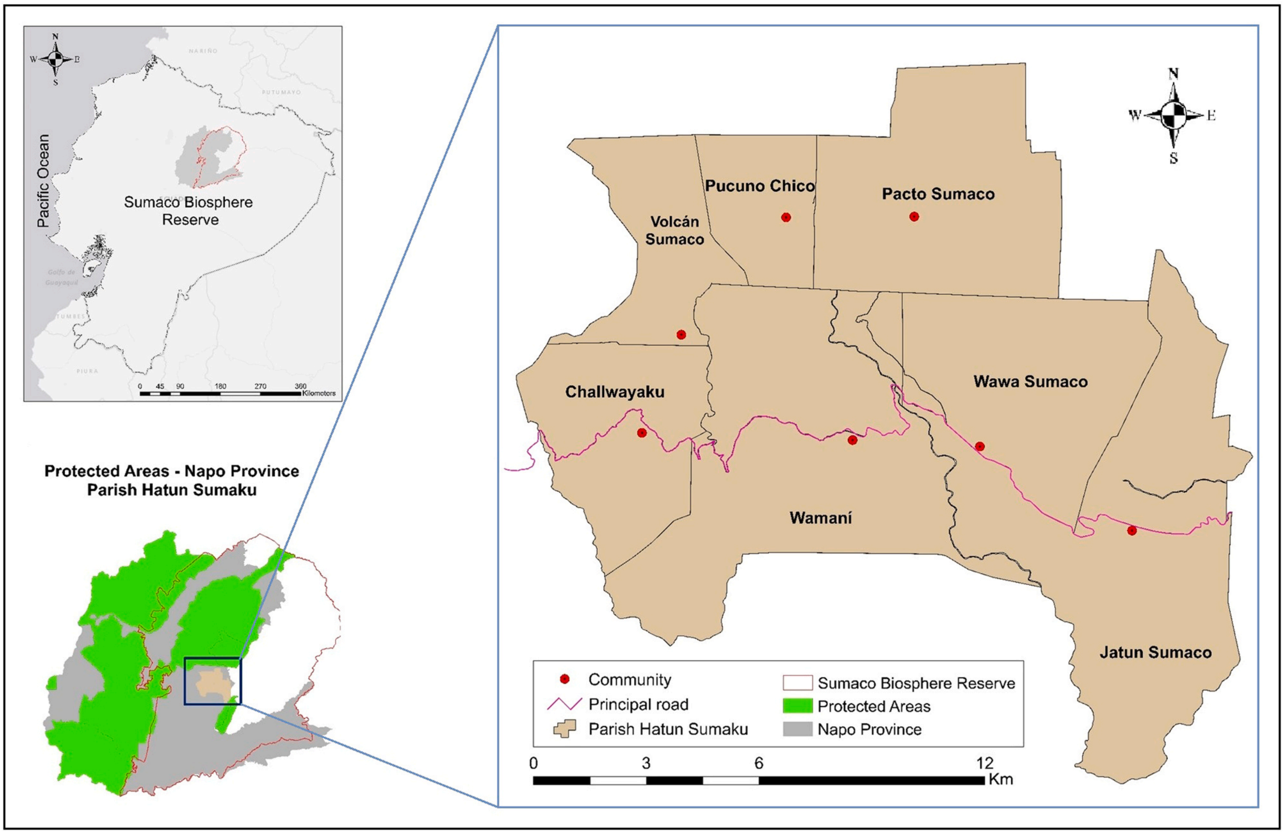


**Fig. 1.** The research area.

affected by an earthquake in 1987 (Izurieta et al., 2014). Colonists specialize in cattle ranching and cash crop production including *naranjilla* (*Solanum quitoense*)-a fruit bush of Andean origin, grown and consumed mainly in Ecuador, Colombia and Central America (Acosta et al., 2009)-, cacao and coffee (Vasco et al., 2018). As most soils in the Ecuadorian Amazon are poor (Mainville et al., 2006), colonists have a tendency to compensate for the low fertility of soils by both incorporating more land to agricultural production and using chemical fertilizers and pesticides (Pichón, 1997; Sellers and Bilsborrow, 2019).

The parish is mainly inhabited by indigenous peoples of the *Kichwa* ethnic group, who account for 88% of the total parish population (INEC, 2010). These peoples migrated from the neighboring *Rukullakta* parish. They settled and claimed possession of lands in *Hatun Sumaku* starting in the late 1960s, following the construction of the Hollin-Loreto-Coca road (Valarezo et al., 2002). Traditionally, the *Kichwa* or *Napo Runa* people are reported to obtain their livelihood mainly from subsistence agriculture and the collection of forest products, game and fish (Nuckolls, 2010). Most of the *Kichwa* households rely on the *chakra* system for both self-consumption (plantains, cassava, and peach palm, the principal staple crops) and market-oriented crops (e.g., cacao and coffee). This ancestral agroforestry system is characterized by high levels of biodiversity and low environmental impact as it, normally, does not use external inputs (Coq-Huelva et al., 2018; Vera et al., 2019). Nevertheless, in recent years, many *Kichwa* people are also reported to engage in less sustainable activities including monocropping (principally *naranjilla*) (see Fig. 2) (Torres-Navarrete et al., 2018), as well as forest clearing and illegal timber harvesting (Vasco et al., 2017). This is reported to be related to the (relatively) recent expansion of the road system, which facilitates the transport of timber and agricultural produce to markets (Sellers et al., 2017). In contrast, prior research (Vasco et al., 2018; Vasco et al., 2020) has revealed that households located farther from urban areas and those who have off-farm income tend both to devote less land to agricultural uses and to preserve forest.[1]

*Naranjilla* production is the main economic activity among both indigenous and colonist populations (Torres-Navarrete et al., 2018), with about 75% of the households in the parish engaging in such an activity (Criollo Rojas, 2014). This poses a serious environmental problem since *naranjilla* is highly susceptible to pests (principally to *Fusarium oxysporum*), so that its management is complex and not possible with conventional methods (Ochoa et al., 2016). Traditionally, *naranjilla* producers try to obtain good yields in two ways, either by clearing primary/secondary forest to establish new plots, where infestation levels are low, or by using more chemicals (see Fig. 3) in already established plots (GAD Hatun Sumaku, 2016). In fact, some years ago, the community of *Wamani* gained visibility for having the highest suicide rate in the world, which is probably associated with neurological

[1] While local regulations control the amount of timber a household can harvest, prior research in the Napo province showed that an important share of households (39%) engage in informal timber operations (Vasco et al., 2017). Income from timber sales may account up to 16% of households' total income (Mejía, Pacheco, Muzo, & Torres, 2015). In terms of the contribution of non-timber forest products (NTFPs) to household income, previous research reflects that it is low (1.3%) (Torres-Navarrete et al., 2018; Torres, Günter, Acevedo-Cabra, & Knoke, 2018).

**Fig. 2.** Land use change from rainforest to naranjilla fields in the *Hatun Sumaku* parish.


**Fig. 3.** Use and management of chemicals in the *Hatun Sumaku* parish.

damage caused by excessive use of pesticides in *naranjilla* production (Morales Pozo and Torres Tobar, 2010; Sowell and Shively, 2012). Similarly, the high amount of pesticides used in *naranjilla* production is linked to several health problems including impaired vision and birth defects in children (Ehlers, 2009).

Some households engage in cattle ranching, with the average household devoting of 6–8 ha to pastures.[2] In recent years, several households are involved in the production of *guayusa* (*Ilex guayusa*) -a tree leaf that is traditionally consumed in form of tea by indigenous groups in the Ecuadorian Amazon region (Dueñas et al., 2016)- and oyster mushrooms (*Pleurotus ostreatus*) as alternative income sources more sustainable than *naranjilla* production and cattle ranching. While some households have access to off-farm income -mainly government jobs-, the availability of such positions is rather low (GAD Hatun Sumaku, 2016).

### *3.2. Data and sampling*

Data came from a household survey conducted from November 2013 to April 2014 in the *Hatun Sumaku* parish, Napo province (Fig. 1). A template household questionnaire from the Poverty and Environment Network (CIFOR, 2007) was modified to gather information about household characteristics including age, gender, education and ethnicity; farm size and land use; household assets, off-farm work and income as well as distance to markets. Additionally, the questionnaire included questions on use and expenditure of chemical fertilizers and pesticides, which made the survey useful for the purposes of this paper. More specifically, the survey inquired about the amounts, units, and prices of agricultural inputs a household used during the 12 months preceding the survey. This information allowed us to estimate the yearly expenditure on chemical fertilizers and pesticides. A survey team

[2] Around 19% of the households in our sample have land in pastures, with an average area of 7.4 ha.

approached and administered the survey to the household head, with support of spouse if available. A total of 180 surveys were collected.

Data were collected in seven out of the eight communities of the *Hatun Sumaku* parish, including *Pacto Sumaco, Jatun Sumaco, Wawa Sumaco, Wamani, Challwayaku, Volcán Sumaco, Pukuno Chico* (see Table 1). The sample size was estimated using probabilistic sampling at 5% probability. Within each community, we used random sampling to select the households to take part in the study. Households were selected from a list provided by community leaders. A total of 180 households were surveyed, 85% of wich were *Kichwa*, while the remaining 15% were mestizo colonists who were principally concentrated in the community of *Pacto Sumaco*. These figures are consistent with official data showing that 88% of the parish population defined themselves as indigenous people of the *Kichwa* ethnic group (INEC, 2010). So, the data are expected to reliably reflect the parish population as well as livelihood strategies, land use and use of external inputs in the research area.

### 3.3. Statistical methods and specification

Multivariate analysis was used to establish the socioeconomic drivers of expenditure on both chemical fertilizers and pesticides. A methodological issue must be addressed before proceeding. There is the possibility that characteristics inherent to the community where a household is located have an influence on the dependent variables of interest. In absence of control, such contextual variables may have an effect on the expenditure on fertilizers and pesticides and so lead to draw wrong conclusions and misleading interpretations of the predictors included in the model. In order to control for the hierarchical nature of the data, we use a semilogarithmic random-effect regression model of the following form:

$$Y_{ij} = \alpha + \mathbf{X}_{ij}\beta + \varepsilon_{ij} + v_j \quad (1)$$

where $Y_{ij}$ is the natural logarithm of the expenditure on either chemical fertilizers or pesticides by household $i$ in community $j$, $\mathbf{X}$ is a vector of predictors to be described later on, $\beta$ is a vector of coefficients the direction and size of which we are interested to find, $\varepsilon$ is the household-level disturbance term and $v$ stands for the community-level error term. This kind of model aims at measuring a relative (percent) change in $Y$ for a given absolute change in $X$. Additionally, logging the dependent variable also simplifies issues of censoring, reduces the effect of outliers and is useful to improve the model fit (Gujarati et al., 2012). It is worth mentioning that an important share of households reported no expenditure neither on fertilizers nor on pesticides (31% and 35%, respectively). While the use of limited dependent variable models (e.g., Tobit model) is an alternative to cope with dependent variables taking the value of zero for a large number of cases, we still prefer using linear regression models as most observations have values different from zero.

The list of dependent and independent variables as well as descriptive statistics are presented in Table 2. As mentioned above, the dependent variables of interest are the natural logarithms of the annual expenditure on chemical fertilizers and pesticides, in each case. The predictors described below are expected to have an effect on household decisions concerning expenditure on agricultural inputs. We divided explanatory variables into household head, household, and community-level characteristics. The first, household head characteristics, included age, sex, and the number of years of formal education of the household head. Additionally, we included the squared age of the household head in order to control for possible non-linearities in the model. As mentioned earlier in the text, the use of agricultural inputs may be influenced by ethnicity (Sellers and Bilsborrow, 2019). Thus, to control for the role of ethnicity, a dichotomous variable taking the value of 1 has the household head defined himself/herself as *Kichwa* was included in the list of predictors.

Household-level predictors included household's economic conditions and land use patterns. In this sense, wealth may influence decisions of using agricultural inputs (Godoy et al., 1998), as wealthier households are in a better position to afford buying fertilizers and pesticides. To control for this effect, we included a wealth index in the specification.

**Table 1**
Communities included in the sample.

| Community | Year of establishment | Predominant ethnic group | Total population | Number of surveyed households |
|---|---|---|---|---|
| *Pacto Sumaco* | 1987 | Mestizo colonist | 222 | 33 |
| *Jatun Sumaco* | 1980 | Kichwa | 335 | 40 |
| *Wawa Sumaco* | 1972 | Kichwa | 628 | 32 |
| *Wamani* | 1969 | Kichwa | 572 | 33 |
| *Challwayaku* | 1978 | Kichwa | 285 | 20 |
| *Volcán Sumaco* | 1987 | Kichwa | 121 | 12 |
| *Pukuno Chico* | 1988 | Kichwa | 136 | 10 |

**Table 2**
Descriptive statistics and definitions.

| | Description | Overall | Kichwa | Colonist |
|---|---|---|---|---|
| *Dependent variables* | | | | |
| Chemical fertilizers | Annual expenditure on chemical fertilizers (US $) (natural logarithm) | 28.015 (39.771) | 28.010 (38.642) | 28.018 (46.479) |
| Pesticides | Annual expenditure on pesticides (US $) (natural logarithm) | 26.472 (39.898) | 26.500 (38.192) | 26.314 (46.313) |
| *Household-head predictors* | | | | |
| Age | Age of household head (years) | 49.211 (12.394) | 49.019 (12.647) | 50.298 (11.009) |
| Education | Completed years of formal education of head (years) | 6.944 (3.605) | 7.000 (3.600) | 6.596 (3.682) |
| Sex | Household head is male (0/1) | 0.811 | 0.816 | 0.777 |
| Ethnicity | Household head is Kichwa (0/1) | 0.850 | – | – |
| *Household-level predictors* | | | | |
| Wealth | Wealth index | 0.000 (1.349) | -0.070 (1.275) | 0.396 (1.683) |
| Credit | Household has received credit (0/1) | 0.383 | 0.392 | 0.333 |
| Off-farm income | Annual earnings from off-farm work (US $) | 392.383 (1062.861) | 342.882 (834.149) | 672.888 (1900.910) |
| Bono de Desarrollo Humano | Household benefits from governmental social transfers (0/1) | 0.777 | 0.823 | 0.518 |
| Farm size | Total farm size (ha) | 26.311 (13.094) | 26.026 (13.036) | 27.925 (13.555) |
| Crops | Land in crops (ha) | 1.944 (2.491) | 2.078 (2.629) | 1.185 (1.272) |
| Agroforestry | Land in agroforestry (ha) | 1.361 (2.731) | 1.529 (2.821) | 0.407 (1.926) |
| Pastures | Land in pastures (ha) | 1.166 (3.816) | 1.209 (3.953) | 0.925 (2.973) |
| Forest | Land in forest (ha) | 20.411 (13.289) | 20.000 (13.064) | 22.740 (14.543) |
| *Community-level predictors* | | | | |
| Road | Household is located near a road (0/1) | 0.877 | 0.856 | 1 |
| Distance to Tena | Distance to reach Tena from household (km) | 81.704 (5.491) | 81.054 (5.578) | 85.390 (3.021) |

Note: (0/1) identifies dummy variables. Standard deviations in parentheses for continuous variables.

Such an index is the first principal component of availability of cellular phone, TV, chainsaw, motorcycle, stove and refrigerator, and accounts for 31% of the variation. As referred to above in the theoretical background, availability of credit may be an important determinant of the adoption of agricultural technologies (Angelsen and Kaimowitz, 2001). Here, we controlled for this potential effect by including a dummy variable taking the value of 1 if the household has received credit in the twelve months preceding the survey in the model. Prior research reported mixed effects concerning the role of off-farm work on the use of agricultural inputs. While, on one side, off-farm income may provide rural households with liquidity to apply chemicals (Zhang et al., 2020). On the other side, it may reduce expenses on fertilizers (Chang and Mishra, 2012), probably because households engaged in off-farm work are less dependent on agricultural income and so spend less on fertilizers. So, to test this hypothesis, we included the earnings a household has received from off-farm activities in the twelve months preceding the survey as a predictor. Additionally, we included a dichotomous variable taking the value of 1 has the household received the governmental transfer *Bono de Desarrollo Humano*[3] in the specification.

Land use patterns may also influence decisions regarding expenses on chemical fertilizers and pesticides, with cash crops requiring more agricultural inputs than subsistence crops and agroforestry systems (Pichón, 1997; Sellers and Bilsborrow, 2019). We controlled for this potential source of variance by including the total farm size, and the areas devoted to crops (principally *naranjilla*),[4] agroforestry (the *chakra* system where households obtain subsistence crops from), pastures and forest.

In terms of community-level predictors, we controlled for accessibility and distance to markets by including a dichotomous variable taking the value of 1 whether the community is accessible by road, and the distance from community to the nearest town with a population higher than 10,000, which in all cases was Tena, the provincial capital. Here, we expected that households in communities located closer to urban areas have more access to chemical fertilizers and pesticides. Similarly, roads may facilitate the transport of agricultural inputs (Vasco, 2011), so households in communities accessible by road are expected to spend more on chemicals.

Finally, it is worth noting that all colonist households in the sample have or claim property rights over their farms while all *Kichwa* households have rights over their farms by semi-private schemes. Under this system, land remains of communal property, but a plot is allocated to each household by a community's assembly or *asamblea* (Bremner and Lu, 2006). Hence, we did not control for the type of property rights over land here since it is totally defined by ethnicity, which is already controlled for.

## 4. Results and discussion

### 4.1. Descriptive analysis

Table 2 shows that the average amount spent on chemical fertilizers is the same for both *Kichwa* and colonist households. Similarly, there is little variation among ethnic groups in terms of the expenditure on pesticides. A likely explanation is that, as referred to earlier in Section 3, *Kichwa* people in the *Hatun Sumaku* parish are highly integrated in the market economy, with 90% of indigenous households in our sample devoting land to crop production. Concerning sociodemographic predictors, the results show that indigenous heads are slightly younger and better educated than their colonist counterparts. The share of female headed households is higher for colonist (23%) than for the *Kichwa* (19%). A possible explanation for this finding has to do with some migrant colonists either heading back to the provinces they originally migrated from or working off-farm elsewhere (Bilsborrow et al., 2004).

The negative sign of the wealth index for the *Kichwa* indicates that they are poorer than their colonist peers in terms of the assets used to construct the index[5] (Kuntashula et al., 2014). The share of *Kichwa* (39%) households that has received credit is higher than that of colonists (33%). This finding substantially differs from those of Vasco Pérez et al. (2015) who found that, comparatively, more colonist households (37%) accessed a loan than their *Kichwa* counterparts (21%) in Pastaza, in the central Ecuadorian Amazon. A likely explanation is that, as mentioned earlier in the text and in distinction from *Kichwa* populations in other Ecuadorian Amazon settings, many *Kichwa* households in the research area engage in the production of *naranjilla*, a crop that demands relatively high levels of investment (Criollo Rojas, 2014). The average off-farm wage of a colonist household is twice as high as that of their *Kichwa* counterparts. This may reflect that colonists are in a better position to access well paid non-agricultural jobs. More *Kichwa* households (82%) received the *Bono de Desarrollo Humano* than their colonist peers (51%). This finding is consistent with the figures obtained for the wealth index and with prior research in the Ecuadorian Amazon (Vasco Pérez et al., 2015), and reflects that, comparatively, *Kichwa* households are poorer than mestizo colonist ones.

Concerning land use variables, the average colonist farm (27.92 ha) is larger than that of a *Kichwa* household (26.02 ha). On average, indigenous households have larger areas devoted to crops, agroforestry and pastures. In contrast, colonist households have larger areas in forest than their *Kichwa* counterparts. This is a surprising finding that differs from prior research (Lu et al., 2010; Vasco et al., 2018) reporting that deforestation rates in colonist lands are higher than those in indigenous territories. Overall, these figures support the statement holding that, when in contact with the market economy, indigenous peoples may also engage in monocropping and deforestation (Henrich, 1997; Rudel et al., 2002). In terms of locational variables, all colonist households belong to a community accessible by road, while 85% of the *Kichwa* reside in communities next to a road. On average, colonist households are located farther away from the provincial capital than their *Kichwa* peers, although the difference is minor.[6] In the following section, we incorporate multivariate techniques to the analysis in order to disentangle the effect of each predictor on the dependent variables under study.

### 4.2. Multivariate results

Table 3 shows the results of multilevel regression models, with the natural logarithms of expenditures on chemical fertilizers and pesticides as dependent variables. The results reveal that there is a quadratic relationship between the age of the household head and the expenditure on chemical fertilizers, with the latter increasing with age to a turning point at 48 years. This may reflect that participation in agricultural production increases with age to a certain threshold and then decreases, probably as health and physical strength deteriorate (Vasco et al., 2018). The dichotomous variable controlling for ethnicity has the expected negative sign but is not significant neither for the expenditure on chemical fertilizers nor for the expenditure on pesticides. This may

[3] The *Bono de Desarrollo Humano* is a conditional transfer that grants US $ 50 a month to households living under the poverty line on the condition that the money is spent on food, education and health (Martínez et al., 2017).

[4] While our survey template did not control for the amount of land devoted to specific crops, *naranjilla* is the main crop in the *Hatun Sumaku* area, as mentioned earlier in the description of the research area (Criollo Rojas, 2014; GAD Hatun Sumaku, 2016).

[5] Although *Kichwa* people may fare better than colonists if other metrics are used, here we are interested in capturing the effect of financial capital on the decisions of how much to spend on chemicals.

[6] While, in the context of the Ecuadorian Amazon, mestizo colonist communities are generally located nearer towns and roads, this is somehow an unusual case, which is probably related to indigenous peoples arriving earlier in the area following the construction of a road as mentioned above in Section 3.

**Table 3**
Determinants of expenditure on chemical fertilizers and pesticides, multilevel linear regressions.

| | Expenditure on chemical fertilizers | Expenditure on pesticides |
|---|---|---|
| *Household-head predictors* | | |
| Age | 0.123** | 0.088 |
| Age squared | -0.001** | -0.001 |
| Education | 0.025 | 0.013 |
| Sex (0/1) | 0.183 | 0.307 |
| Ethnicity (0/1) | -0.100 | -0.304 |
| *Household-level predictors* | | |
| Wealth | 0.204** | 0.239** |
| Credit (0/1) | 0.076 | 0.751*** |
| Off-farm income | -0.000* | -0.000 |
| Bono de Desarrollo Humano (0/1) | 0.556** | 0.646** |
| Farm size | -0.002 | -0.008 |
| Crops | 0.136*** | 0.136*** |
| Agroforestry | 0.049 | -0.003 |
| Pastures | 0.073** | 0.056 |
| Forest | -0.023*** | -0.008 |
| *Community-level predictors* | | |
| Road (0/1) | -0.372 | -0.630 |
| Distance to Tena | -0.007 | 0.003 |
| Intra-class correlation | 0.208 | 0.801 |
| $\chi^2$ (Wald test) | 39*** | 37*** |
| Number of observations | 180 | 180 |

Notes: Asterisks *, **, and *** indicate significance at 10%, 5%, and 1%, respectively. (0/1) identifies dummy variables.

reflect that, in this area, indigenous peoples are as integrated into market-oriented agriculture as their colonist peers. Everything else held equal, wealthier households spend more on both chemical fertilizers and pesticides than their poorer peers. This finding is consistent with prior research in the Amazon (Godoy et al., 1998; Sellers and Bilsborrow, 2019) and likely indicates that agricultural inputs are not accessible for all households, with wealthier households in a better position to afford the use of chemicals.

Availability of credit has a positive effect on the amount spent on pesticides. Having received credit increases expenditure on pesticides by 110%.[7] A possible explanation is that, as referred to earlier in the text, *naranjilla* production is highly susceptible to diseases and therefore requires high amounts of pesticides to succeed. Hence, an important share of households needs to request loans in order to afford buying pesticides. The coefficient of off-farm income has a negative sign, suggesting that having off-farm income reduces participation in agricultural production and so investment in chemicals, nevertheless, this effect is marginally significant (at 90% probability). An interesting finding is that recipients of the *Bono de Desarrollo Humano* spend more on both chemical fertilizers and pesticides. Being a recipient increases expenditures on chemical fertilizers and pesticides by 74% and 90%, respectively. This result is, to some extent, surprising since the Ecuadorian Government emphasizes that the money granted to poor households in the framework of this social program must be invested in basic needs (food, education and health). A likely explanation for this finding is that either the money received relaxes household budgets allowing poor households to access chemical fertilizers and pesticides to improve their yields, or that the money granted in the framework of this social program is directly used to buy agricultural inputs.

In terms of land use predictors, as expected, households engaged in crop production spend more on agricultural inputs. Each hectare on crops increases the expenditure on chemical fertilizers and pesticides by 13% in both cases. Similarly, each hectare in pastures increases the amount spent on fertilizers by 7%. Amazon soils are normally poor, so that pastures require continuous fertilization to maintain yields. On the contrary, the use of pesticides in pastures is quite rare (León et al., 2018). The area in forest is negatively correlated with expenses on fertilizers. Each hectare preserved in forest reduces the expenditure on chemical fertilizers by 2.3%. This finding may reflect that households with more forest are less dependent on agriculture for their livelihoods, hence, they do not need to invest in chemicals.

## 5. Conclusions and policy implications

This paper has analyzed the socioeconomic drivers of the expenditure on chemical fertilizers and pesticides among *Kichwa* and mestizo colonist populations in the Northern Ecuadorian Amazon. The results show that expenditure on chemicals is determined by wealth, availability of credit, governmental social transfers and land use patterns. Ethnicity seems to play no role in shaping expenses on chemical inputs. Below, we offer some policy recommendations based on these findings.

Overall, the findings presented here leave four cautionary messages for policy makers. Firstly, clear, consistent and coordinated policies are necessary in order to reconcile conservation and rural development in the Amazon. Now, ambiguous and even contradictory policies are not effective in reaching that goal. To illustrate, while the Ecuadorian Government promotes sustainable agriculture and the rescue of traditional production systems as tools to reach food security, poverty alleviation and environmental conservation (SENPLADES, 2017), the Ministry of Agriculture not only promotes *naranjilla* as a promising crop for the Amazon but assists farmers on how to apply for governmental loans to plant *naranjilla* (MAGAP, 2018). In fact, 62% of the loans in the sample were granted by governmental organizations, which reflects that *naranjilla* production is, to a large extent, supported and promoted by the government. This is a source of concern given the environmental and health problems associated with *naranjilla* production. Whereas the use of hybrid and grafted varieties has been proposed as an alternative to reduce the environmental and health problems that *naranjilla* production entails (Ochoa et al., 2016; Sowell and Shively, 2012), our results reflect that the use of pesticides is still widespread among farmers in the *Hatun Sumaku* parish, affecting the health of farmers and the environment.

Secondly, our results are in line with prior research concluding that, when in contact with the market economy, indigenous peoples engage in unsustainable activities as much as colonists do (Henrich, 1997; Rudel et al., 2002). While this is not a surprising result in the Amazon, the findings presented here reveal that, at least in this case, indigenous people have larger areas devoted to agricultural uses and less forest than colonists. Probably because of this, indigenous people spend as much money as colonists on chemical fertilizers and pesticides. This is also a matter of concern given the importance that indigenous lands have for conservation (Nepstad et al., 2006), and that these patterns may also occur in other settings in the Amazon. Given the importance that territories under the control of indigenous peoples have for conservation, effective policies aiming at the preservation and promotion of traditional agroforestry systems (i.e., the *chakra*) are needed in order to reconcile rural development and conservation in the Amazon. In this sense, while previous research has revealed the positive outcomes of the *chakra* system for environmental conservation (i.e., biodiversity conservation and carbon sequestration) (Torres et al., 2015; Vera et al., 2019), relatively little formal research has been conducted on its economic performance and on how to improve its profitability. Such research is needed to promote the (re-)adoption of the *chakra* system among indigenous peoples in the Amazon.

Thirdly, while the *Bono de Desarrollo Humano* has improved the living conditions of an important share of poor Ecuadorians, principally in terms of children's educational attainment (Ponce and Bedi, 2010) and health indicators (Fernald and Hidrobo, 2011), our results reveal that it may have negative externalities, as recipient households spend more on chemical fertilizers and pesticides. While the US $ 50 that poor

[7] The percent change of a coefficient c multiplying a dummy variable in a log-linear model is given by the expression $100[\exp(c) - 1]$.

households receive are supposed to be spent on food, education and health, it is likely that either the money relaxes households' budgets and allows poor households to buy chemicals or that it is directly used to finance agricultural production. This is not the first time that such behavior is reported in the literature. Ojeda Luna et al. (2020) found that households receiving the *Bono de Desarrollo Humano* harvest more forest resources than those not benefiting from any social program. Given that 77% of the households in the survey are recipients, our results reflect that policy makers need to be careful in identifying and selecting the households to be granted with social aid, and in monitoring and controlling that recipient households do not spend the money on unsustainable agricultural practices. As mentioned above, all such policies should be coordinated and compatible in order to succeed.

As a closing statement, there is a need to improve the control and supervision of pesticide use in rural areas. Nowadays, farmers in the Amazon regions use pesticides and fertilizers with no supervision and technical assistance. Therefore, to promote more sustainable agricultural practices, it is necessary to review current policies, addressing the issue of chemical fertilizers and pesticides use, soil health, and the development of programs for the sustainable use of nutrients. Furthermore, it is important to foster extension and training programs about soil health, appropriate use of fertilizers, development of bio-fertilizers and participation in organic-agroecological markets as alternatives for the development of sustainable agriculture in the Amazon. These initiatives should be accompanied by educational campaigns aiming at making farmers aware of the health risks that the use of pesticides entails.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2021.105490.

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