Published in final edited form as:

J Land Use Sci. 2019 ; 14(4-6): 347–361. doi:10.1080/1747423X.2020.1719225.

Agricultural Technology Adoption among Migrant Settlers and Indigenous Populations of the Northern Ecuadorian Amazon: Are Differences Narrowing?

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Abstract

We consider trends in the use of modern agricultural inputs of migrant settlers and indigenous populations in the Northern Ecuadorian Amazon and the demographic, socioeconomic, and land use-related factors affecting input use. It is widely believed that the different livelihood strategies and therefore different relationships to the land of indigenous populations and migrant settlers result in different uses of chemical inputs in agriculture. We analyze data from two panel surveys, one of migrant settler households and a separate panel of indigenous households. We find low input use among both types of households, particularly among two of the five main ethnicities of indigenous households in the study region, the Cofán and Waorani. Multivariate statistical models were run separately for each panel, with significant relationships found between several predictors and the use of pesticides and herbicides. Our results highlight continuing differences in land use patterns between households in the NEA.

Keywords

inputs; agricultural intensification; fertilizer; pesticide; herbicide; chainsaw

Introduction

Improving the productivity of agriculture is a key component of fostering sustainable livelihood strategies and reducing poverty among rural populations (Irz et al., 2001). One way to do this is through the adoption of technologies to increase yields and therefore farm incomes, such as fertilizers and pesticides. Another means to increase farm household incomes is by expanding the area in agricultural use, by using capital equipment such as chainsaws to clear additional land for agriculture and/or to cut down trees for timber sales.

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Data Availability Statement

The datasets generated during and/or analyzed during the current study are not publicly available due to the collection of personally identifiable information but are available from the corresponding author on reasonable request.

Conflict of Interest: The authors declare that they have no conflict of interest.

However, to date little research has been conducted on the factors—demographic, social, and land use—that may be affecting agricultural technology adoption among rural households in frontier settings, particularly in Latin America. Exceptions include Godoy et al. (1998), finding that among Bolivian indigenous households, education and income were strong predictors of technology adoption in less market-oriented communities; Perz (2003), noting that Brazilian settler households with higher levels of labor and capital were more likely to adopt various agricultural technologies; Carr (2008) finding low levels of fertilizer and pesticide use in a Guatemalan frontier region, particularly among poor or newly established households; and Radel et al. (2010) showing that in Mexico input use was more common among farms with a greater variety of agricultural activities.

We explore technology adoption in the context of the Northern Ecuadorian Amazon (NEA), a region characterized as a developing forest frontier, steadily growing in population and economic importance within Ecuador. Our focus is on determinants of modern agricultural inputs, namely, pesticides (including fungicides), herbicides, and fertilizers, as well as chainsaw ownership. First, we describe overall trends in input use during the past three decades in the NEA, comparing and contrasting patterns of adoption among settler and indigenous households and trends over time. Second, we explore the determinants of input adoption and changes over time, seeking to better understand processes of land use intensification (through higher use of inputs) as a possible alternative to the long-term process of extensification (growth of agricultural area via deforestation) linked to population pressure, changing livelihood patterns, and urban expansion.

Theoretical Background

Forest frontiers represent important sites for testing theories of land use change processes. Broadly speaking, growth in human populations along with increasing incomes and access to modern technologies can stimulate two distinct types of responses to growing per capita scarcity of farmland. Following Malthus, farmers may respond to demographic or economic pressures by expanding the area in agricultural use, called agricultural *extensification*, often achieved through clearing land via deforestation. This is viewed by so-called Neo-Malthusians as having a negative impact on the environment (Bilsborrow, 1987). Particularly in the NEA, extensification is often associated with the expansion of small farms by cutting primary forest (Barbieri et al., 2005; Brondízio et al., 2009). On the other hand, farmers may be induced by pressures on the land to intensify land use. *Intensification* occurs by increasing labor and other associated inputs per unit of land (Boserup, 1965). While this can involve greater labor inputs (such as more intensive or frequent weeding) or shorter fallow periods for the land to regenerate after periods of use, it may additionally involve the use of technologies designed to increase agricultural yields. Such technologies include pesticides (commonly understood in our study region to include fungicides), herbicides, and fertilizers. Among tropical farmers, fungicides are used to control the very common problem of *la raya* or coffee rust (Avelino et al., 2015). Additionally pests such as the coffee berry borer also attack coffee trees, eliciting the use of pesticides (Damon, 2000). Other forms of intensification also exist, including shortening fallow cycles, increasing irrigation, multiple cropping, and changing crops to higher value, more labor-intensive crops (Bilsborrow, 1987).

Whether intensification or extensification processes predominate depends on a variety of socioeconomic, environmental, and demographic factors, as well as on the scale of analysis. For example, household life cycle approaches argue that intensification and extensification processes can be influenced by the availability of household labor relative to consumption needs (Barbieri et al., 2005; Chayanov, 1986; Perz, 2001). When household labor is abundant, generally when children are available in the household and old enough to assist with farm labor tasks, households are likely to adopt more labor-intensive approaches to agriculture, which generally emphasize crops. By contrast, when labor is less abundant, such as after children have grown up and left the home, households are more likely to adopt more extensive land use practices, such as cattle ranching. Changes in household size and age structure also tend to correlate closely with the length of time a household has lived on the farm, making it difficult for researchers to disentangle the significance of duration on farm from household labor supply in affecting land use (VanWey et al., 2007).

If intensification processes predominate, this may allow greater yields to be produced while sparing otherwise vulnerable tropical forest ecosystems, resulting in win-win outcomes for humans and natural systems. However, recent empirical findings question this conclusion, finding that intensification is often followed by additional land clearing (Ceddia et al., 2014; Rasmussen et al., 2018; Rudel et al., 2009). In particular, whether intensification results in forest conservation is in part a function of high-quality governance; areas where there are strong environmental governance institutions are more likely to preserve forests following intensification than areas with weaker institutions (Ceddia et al., 2014). Moreover, there are important scale effects associated with changes in agricultural technology. While technological adoption that increases yields through intensification is likely to result in land sparing effects globally, the effect in particular forest frontiers is indeterminate, depending on local market, ecological, and governance conditions, with the potential for forest loss to increase in some vulnerable geographies (Byerlee et al., 2014).

The type of landholder can also affect how intensification and extensification processes proceed. In general, indigenous communities use land less intensively than settlers, resulting in greater protection for natural systems. Empirical findings in Latin America outside of the Ecuadorian context suggest that indigenous groups often manage land for multiple uses and rely heavily on forest ecosystems for their sustenance, often through a mix of cultivated areas and subsistence hunting and gathering activities (Posey, 1985; Toledo et al., 2003). As a result, indigenous management of land often limits deforestation even as intensification processes elsewhere accelerate it (Ceddia et al., 2015; Vergara-Asenjo and Potvin, 2014). Other reforms, such as providing secure land titles, can further support indigenous communities in their efforts to preserve forest cover (Blackman et al., 2017). Collectively, these findings suggest that intensification processes have the potential to promote forest conservation in carefully circumscribed contexts, but are more often associated with furthering extensification.

Settlement and Land Use Practices in the Northern Ecuadorian Amazon

Our study region, the NEA, consists of the provinces of Napo, Orellana, and Sucumbios, and contains roughly 416,000 residents, as of the most recent Ecuadorian Census (INEC, 2011).

The NEA is comprised largely of dense rainforest, and is widely recognized for its extremely high levels of biodiversity (Bass et al., 2010). However, forest cover has greatly decreased in recent decades due to the growth of settler farms as well as the expansion of urban centers, including Lago Agrio and Coca (Holland et al., 2014). Deforestation rates have slowed in recent years, but are still substantial, with 0.26% of primary forest cover being lost annually in the provinces of Orellana and Sucumbios as of 2014 (Ministerio del Ambiente, 2015). Following the discovery of large oil deposits near Lago Agrio in 1967, infrastructure development (especially roads associated with oil exploration and production) opened up the NEA which facilitated large-scale in-migration of settlers from other parts of Ecuador, mainly the Sierra or Highlands regions. Most of these individuals settled in rural areas to establish farms and pursued crop and livestock agriculture (Bilsborrow et al., 2004).

Well before the arrival of migrant settlers, indigenous populations had populated the region for hundreds if not several thousand years, generally having little contact with outsiders until the mid-20th century (Lu et al., 2012; Lu and Bilsborrow, 2011). There are five main indigenous ethnic groups that inhabit the region: Kichwa, Shuar, Secoya, Cofán, and Waorani. Population sizes of the ethnic groups vary substantially, with Kichwa populations predominating. Based on self-reported identification in Ecuador's most recent census (2010), approximately 104,000 Kichwa lived in the study region, compared to approximately 4,000 Shuar, 1,000 (each) Cofán and Waorani, and 500 Secoya (INEC, 2011). Additionally, the indigenous surveys recorded a small number of individuals reporting mestizo ethnicity, which is the dominant ethnic group in the country of Ecuador (mixed Caucasian and indigenous). Mestizos encountered in the indigenous study communities are mainly male settlers marrying indigenous women and moving to live with them in their communities. Almost all of these indigenous populations now live in mostly permanent settlements with household land use (usufruct) rights are allocated by the community governing body or assembly. The communities vary greatly in population size, ethnicity, and market orientation, with many Shuar and Kichwa individuals spending considerable time working off their farms (Lu, 2007). The Shuar in particular have a unique history in the region, arriving more recently to the NEA and engaging in an interesting mix of agricultural practices which are more market-oriented than those of other indigenous groups while still being less market oriented than those of settlers (Lu, 2007; Rudel et al., 2002). The Cofán and Waorani are, in contrast, only slowly integrating into the formal market economy, and still rely heavily on subsistence agriculture, hunting and fishing (Gray et al., 2015; Lu and Bilsborrow, 2011). These indigenous populations are growing rapidly (at about 3% per year in recent decades) as a result of continuing high fertility (mean total fertility rate of 7 births per woman in 2012; Davis et al., 2015) and declines in mortality due to widespread programs of vaccination, sedentarization with communal land entitlements, provision of primary schools, as well as reductions in warfare (Lu et al., 2012).

Among settlers in the NEA, land use practices have changed over time, involving both intensification and extensification (Pan and Bilsborrow, 2005; Sellers et al., 2017). Since the beginning of our study, the majority of the large farms of about 50 hectares owned by the initial settlers have been subdivided as the population of the region has grown. Subdividing land allowed the original owners to provide parcels for their children as they became adults and formed families as well as sell parcels to new in-migrants. Recent evidence suggests that

these smaller plots are largely planted in crops, with less pasture and little primary forest in contrast with intact, larger farms (Sellers et al., 2017). Settlers typically engage in multiple forms of land use on a single farm, including 1) annual crops (such as rice, maize, or bananas/plantains), largely for their own subsistence consumption; 2) perennial crops (such as coffee or cacao), which are for market sale and often require substantial chemical inputs; 3) livestock (primarily cattle); and 4) maintaining some area in primary or secondary forest.

In the NEA, indigenous land use practices differ substantially from those of settlers, as most indigenous households have access to larger areas of land but farm only small portions, traditionally in subsistence crops (mostly annual crops) although increasingly in cash crops (mostly perennial crops), while most of their land remains as primary forest to use for hunting and extraction of non-timber forest products. Some small-scale timber harvesting also occurs, although this harvesting is often conducted illegally due to challenges in regulatory compliance among smallholders (Mejía et al., 2015). While indigenous farmers are also much less likely to own cattle than settlers, this varies greatly by ethnicity, with cattle-raising being common among the Shuar in particular (Lu et al., 2010). Unlike settler land use, which is largely market-oriented, indigenous land use, although changing over time towards greater market orientation, is still primarily subsistence-driven (Gray et al., 2008). Recent research has documented similar contrasts in land use and cropping decisions in the central Ecuadorian Amazon (Pastaza Province), where settlers tend to engage in commercial agriculture and cattle ranching while indigenous communities (particularly Kichwa) tend to emphasize subsistence agriculture (Vasco et al., 2018).

Settler and indigenous farmers in the NEA also have different practices with regard to land tenure. Property in settler communities is privately owned, although some owners lease plots to/from other owners and others lack a title to their land (Bilsborrow et al., 2004; Sellers et al., 2017). While some indigenous communities are adopting private property rights, communal property is still dominant among all the ethnicities studied (Bremner and Lu, 2006).

Adopting intensive agricultural practices through the use of chemical inputs may increase crop yields, but also may pose dangers to environmental conditions and/or human health, creating a disincentive for their use. Improper or excessive use of chemical inputs may result in ecological harm, as has been documented in much of the Brazilian Amazon (Schiesari et al., 2013). Additionally, exposure to chemical inputs can result in serious health harms to farmworkers, as found in earlier research on Ecuador (Hurtig et al., 2003).

While at least one earlier study has explored chainsaw ownership in the Amazonian context (Perz 2003), there has been little investigation regarding the linkages between chainsaw ownership and specific land use patterns. We anticipate that chainsaw ownership is largely associated with both land clearing and more extensive forms of agricultural land use, including cattle ownership, particularly among settlers. We note that there is virtually no use of large, mechanized agricultural technologies in the region, such as tractors, in either settler or indigenous communities.

Methods

Two sets of household panel surveys were conducted in the NEA to understand land use and farming patterns as well as household livelihoods and demographics, one panel for settler households and another for indigenous households. We use all five waves of these two panel surveys in our analyses below. The settler surveys (three waves total) were longitudinal for property, that is, they sought to interview individuals inhabiting the same area of land over time, even if those individuals differed over time and/or the property was subdivided into smaller lots. Indigenous surveys (two waves total) were longitudinal for households. Figure 1 presents a map showing the location of the settler farm plots and indigenous communities studied. We describe the procedures used for sampling settler households first, followed by those for indigenous households.

Surveys of settler households were conducted in 1990, 1999, and 2014, with the lattermost survey covering only a subset of the earlier households due to funding limitations. The original sample of households was selected in 1990 through two-stage sampling and designed to be representative of the entire rural settler population of the region at the time. First, groups of geographically contiguous farms called *sectores* were selected from lists of settler farms provided by the Instituto Ecuatoriano de Reforma Agraria y Colonización (Ecuadorian Institute of Agrarian Reform and Settlement) using probabilities of selection in proportion to estimated size (PPES). Second, a cluster of 5–10 contiguous farm plots (*fincas madres*) of 40–50 hectares each was randomly selected from each chosen sector also using PPES. In 1990, 405 households on 362 *fincas madres* successfully completed male and female questionnaires, representing approximately 6% of the region's rural settler population (Bilsborrow et al., 2004). In 1999, due to the land subdivisions of the *fincas madres* described above, 652 households recorded complete questionnaires on 374 *fincas madres*.¹ A third survey round including roughly one quarter of the 1999 farm properties was conducted in 2014, with 185 households completing both male and female questionnaires. Thus, these surveys are longitudinal for *property*, but not necessarily for people, as some occupants moved out between survey waves (and were not followed), while new occupants arrived on the property and were surveyed in 1999 and/or 2014.

In all three settler survey waves, separate questionnaires were administered to the male and female heads of household in order to increase the amount of information that could be collected without inducing respondent fatigue and increasing the likelihood of collecting better quality data. Questionnaire topics were determined based on the traditional gendered division of household activities which continues to be common in this study area. The men's questionnaire included questions on farming practices and land use, land tenure, household wage work off the farm, agricultural production, incomes, inputs, and technology adoption. The women's questionnaire included questions on household membership (completing a household roster), household assets, and health. In the event that a male head of household was not present, the spouse or female head was asked to complete both questionnaires. Male

¹A small number of farms surveyed in 1990 that had incomplete data were resurveyed in 1999 and complete data collected, while a small number of households near the Colombian border were not resurveyed in 1999 due to security concerns. As a result of improved completion rates in 1999, the number of *fincas madres* included in our analysis increased slightly between the two waves.

interviewers interviewed males and females interviewed females. Additional details on sampling and data collection are provided in earlier papers (Bilsborrow et al., 2004; Pichon, 1997).

Surveys of indigenous households were conducted in 2001 and 2012. Interviews were initially conducted with households in 36 indigenous communities (32 communities in 2012 due to logistical difficulties and the vacating of one community by all households), representing all five of the major indigenous ethnicities in the region (Gray et al., 2015). Up to 22 households were selected at random for interviews in each community, with all households sampled in communities with fewer than 22 households. As with settler surveys, separate questionnaires were administered to males and females, with the gendered distribution of topics similar to the settler survey. In 2001, 481 households completed both male and female questionnaires. In 2012, despite the loss of four communities, the inclusion of split-off households (usually where a 2001 child household member grew up to become the head of a new household in 2012), increased the total number of households where both questionnaires were successfully completed to 599.

Regarding our outcome variables, male heads in both panels were asked about the use of agricultural inputs on the farm. Specifically, they were queried about their use of pesticides, herbicides, and chemical or organic fertilizers. Questions were binary and asked about any use in the previous 12 months and not the amount of use (although in some years, respondents were also asked to provide cost estimates for their spending on inputs, and the name of the brand, but we opted not to analyze this information in detail here given considerable variability in data quality and missing data among respondents). Moreover, as question wording and response options differed slightly between survey rounds, some results on input use details are not fully comparable between years without combining categories, as described in the Results section below. Chainsaw ownership was asked about in the women's questionnaires as part of a group of questions about ownership of household assets. Information about the frequency of chainsaw use, purpose and timing of use, and the acquisition cost was not collected.

Below, we first provide a descriptive analysis of levels of input use and trends over time for both migrant settlers and indigenous households, followed by a statistical analysis of the factors predicting input use and chainsaw ownership, based on household-level demographic, socioeconomic, and land use characteristics. Table 1 displays these variables. Demographic variables include household size, characteristics of the household head (age, education, primary language spoken, and ethnicity (for indigenous households)). Household labor allocation variables include whether the household hired outside labor, whether someone in the household worked off the farm (broken down by oil- and non-oil employment in the indigenous surveys due to the high frequency of employment of indigenous populations by oil companies; Bozigar et al., 2016). Land use variables include perceived soil quality, livestock ownership, credit use, land title, plot size, share of land in perennial crops, and years living on the plot (settlers only). Additionally, a wealth index was generated by taking the first polychoric principal component of a series of dwelling characteristics (roof, floor, and wall type, as well as number of rooms and existence of a separate kitchen) and household ownership of certain non-agricultural assets. The index was

generated separately for each of the survey populations using the full panel of data (1990 and 1999 surveys for settlers, 2001 and 2012 for indigenous), and the outcome was standardized on a 0–10 scale for input into the regression models (Kolenikov and Angeles, 2009).

As the outcomes modeled are binary, logistic regression models were used, and run separately for settler and indigenous households, with the settler models including data from the 1990 and 1999 surveys (excluding the 2014 survey data due to its small sample size and lack of representation of the entire 1990/1999 sample), and the indigenous models based on the 2001 and 2012 survey data. While the 2014 settler data were excluded from the regression models, we include them as part of the descriptive statistics shown below to help illustrate how trends in household-level demographic, social and land use variables after 1999 relate to input use based on more recent data. Logistic regression model coefficients are presented below as odds ratios, which can be interpreted as the multiplicative effect of a one unit change in a predictor on the odds of adopting a particular technology. An odds ratio of 1 indicates a null effect of a predictor on the outcome.

Although the settler and indigenous models include most of the same variables, slight variations exist in the inclusion and wording of questions between surveys, as illustrated in Table 1. For instance, because the 1990 settler survey did not ask about pesticide and herbicide use separately, pesticide or herbicide use is modeled as a single outcome variable for settlers for comparability over time, whereas pesticide and herbicide use are modeled as separate outcomes for indigenous households because they were asked about separately in both indigenous surveys. A regression on a combined pesticide/herbicide use indicator for the indigenous population did not turn up significant differences from the separate pesticide use and herbicide use models, so these outcomes are presented separately. As organic fertilizer use was very low in all settler surveys (and not asked about in the indigenous surveys), this outcome is combined with chemical fertilizer use. Standard errors are clustered by farm sector in the settler models, and by community in the indigenous models to account for unobserved relationships between nearby households.

Results

Table 1 presents summary results for input use and mean levels of socioeconomic, demographic, and land use variables from each of the settler and indigenous surveys. Earlier studies discuss differences between most of the household-level predictors over time, which are therefore not elaborated upon here (Sellers et al. 2017; Gray et al. 2008).

In settler communities, somewhat surprisingly, pesticide and herbicide use *decreased* over time. Nearly half of settler households used pesticides or herbicides in 1990, but this share declined to about 1 in 3 households by 1999 and 2014. Fertilizer use was very low in 1990 and 1999, rising sharply in 2014 to roughly 1 in 4 households, although we interpret this trend somewhat cautiously due to the smaller sample size of that survey. Chainsaw ownership was high in settler communities across the three surveys, but reached its highest levels in 2014, which may suggest both growing household wealth as well as greater use of chainsaws to clear forest.

Based on the regression models (Table 2), hiring outside labor as well as not having a household member working off the farm were associated with a greater likelihood of pesticide or herbicide use. Moreover, the share of land in perennial crops was also significantly associated with pesticide and/or herbicide adoption, reflecting the fact that such crops in the Amazon often require high levels of pesticides to facilitate satisfactory yields. Somewhat counterintuitively, having cattle on the farm was also significantly associated with pesticide or herbicide use. This may result from the need to use herbicides on grass pasture to cope with weed infestations in Amazonian conditions, and/or from farms adopting mixed crop and livestock farming operations. With respect to fertilizer, as its use was low among settler households, it is unsurprising that few variables in this regression were found to be significant, although the receipt of credit was significantly and positively associated with fertilizer use, which may reflect the use of credit to finance fertilizer purchases by some farmers.

Finally, chainsaw ownership was strongly correlated with variables expected to be associated with chainsaw use, including a larger household and larger plot size, greater household wealth, having cattle on the farm, and less engagement with off-farm employment. These results indicate that chainsaw ownership is disproportionately concentrated among larger farms engaged in livestock agriculture, where swaths of primary and secondary forest cover have been removed over time for pasture expansion.

In contrast to settler communities, input adoption was generally very low in indigenous communities, although there was a marked increase over time between survey rounds. In 2001, a small fraction of households (6%) used *any* input, tripling to just under one in five households by 2012. As with settlers, pesticides and herbicides are used much more than chemical fertilizers, with only five households (out of more than 400) reporting chemical fertilizer use in 2001, growing to 31 (out of roughly 600) in 2012. Meanwhile, use of pesticides or herbicides tripled during this period. Despite low levels of chemical input adoption, indigenous households were roughly as likely as settler households to own a chainsaw around 2012, at just over 2 in 5 households.

In the regression models for indigenous populations, low adoption levels contribute to high and unstable odds ratios (Table 3). Nevertheless, some key patterns can be detected. The share of land in perennial crops was significantly associated with pesticide, herbicide, and chemical fertilizer use. Larger cultivated areas were also significantly associated with pesticide use, while credit receipt and livestock ownership were both significantly associated with herbicide use, as expected and as also observed with settlers. As with settlers, larger, wealthier indigenous households with more cultivated area were more likely to own chainsaws, as were those with Spanish-speaking heads and households which employed outside workers.

Importantly, there are key differences in input adoption across indigenous households of different ethnicities (Table 4). Notably, input use remains virtually nonexistent among Waorani and Cofán communities, which are the two ethnicities generally living in the most remote areas and with the least market contact and integration. Thus no pesticide or herbicide use was recorded in any Waorani or Cofán survey households in 2012, and only a

single Cofán household reported using pesticides in 2001. Similarly, chemical fertilizers were used only by a single Cofán household in 2001 and a single household each in the Cofán and Waorani samples in 2012. Input use was also nearly nonexistent in Secoya communities in 2001, with only a single household reporting use of herbicides. But by 2012, nearly one-quarter of Secoya households used herbicides, with others adopting pesticides and chemical fertilizers. By contrast, in Kichwa, Shuar, and Mestizo households, input use was low in 2001, but grew by 2012.

In contrast to input use, chainsaw ownership is relatively high among all groups, although the directionality of trends in ownership differed between groups. Between 2001 and 2012, ownership increased substantially among Kichwa and Shuar communities, less among the Cofan and Mestizos, and fell slightly among the Secoya and Waorani. Notably, there is not a clear association between chainsaw ownership and livestock ownership, in contrast to settlers. Chainsaw ownership is high even among groups that have low rates of livestock ownership in the later survey wave in 2012, such as the Cofán and Secoya, in line with other evidence that chainsaws are commonly used in indigenous communities for small-scale timber harvesting, not for clearing forests for cattle ranching, in contrast to settler households (Gray et al., 2015).

There are key similarities as well as differences in input use predictors between settler and indigenous households. Among both groups, there were not consistent patterns and few significant findings concerning the impact of individual demographic variables (age of male head, education level) on input use. A key difference exists in the role of hiring outside labor, which is much less common among indigenous communities and not significantly associated with input use, while it is significantly associated with an increased likelihood of using inputs among settlers. The household wealth index is not significantly associated with input use in either group, with the exception of chemical fertilizers among indigenous households. Thus, it appears that cost is not a key barrier to input adoption, at current (low) levels of use, although it should be remembered that the asset index does not directly measure household incomes.

In line with expectations, higher shares of perennial crops are associated with greater pesticide and herbicide use in both types of households. However, contrary to our expectations, larger cultivated areas are also associated with a *greater* likelihood of pesticide/herbicide use, suggesting that households facing land pressures from small plots are generally not the ones adopting chemical agricultural inputs. Despite falling plot sizes over time from subdivisions, this has not resulted in increased use of pesticides, whereas expanded crop agriculture among indigenous households has resulted in greater use, albeit still at low overall levels.

Concerning chainsaw adoption, in both populations, the household wealth index was strongly and positively correlated with chainsaw ownership, suggesting that chainsaw ownership is a luxury afforded by households as they grow wealthier over time. As expected based on observations from earlier literature, livestock ownership and property size were significantly and positively associated with chainsaw ownership (Carr, 2008; Perz, 2003). This is true even among indigenous households as a whole, despite the fact that, as noted

above, the relationship between cattle ownership and chainsaw ownership among particular ethnic groups is quite varied.

Discussion

Factors affecting input use provide a window into changing land use patterns in a dynamic forest frontier. Among settlers, plot sizes are declining, which may spur agricultural intensification. However, to the extent that such intensification is occurring, it appears to be largely without the use of external chemical inputs. While input use is correlated with some factors that we would expect from theory, including proxies of household wealth such as livestock ownership, use of these inputs has stabilized and in some cases fallen slightly. Many settler farmers have been finding either that they do not need or wish to use inputs on their smaller plots to achieve more satisfactory yields, or that off-farm employment provides better incomes for supporting families, making investment in farms less financially attractive.

Our results found several significant predictors of pesticide, herbicide, and fertilizer use in settler households, including hiring of outside labor, use of credit, area in perennial crops, and livestock ownership, but no statistically significant effects were observed for other variables hypothesized to correlate with usage, such as household size, farm size, or household wealth, in contrast to some earlier literature (e.g., Perz 2003; Carr 2008). This divergence may be explained by differences in agricultural activities and soil conditions, or the closeness of towns that increasingly provide other non-agricultural livelihood opportunities for members of farm households in the NEA—circumstances that differ from some other frontier settings in Latin America. As noted in other literature on the NEA, the relatively short distances between many of the surveyed communities in the region and major towns, along with improved infrastructure have facilitated migration among both settlers and indigenous populations, enabling households to maintain livelihoods through a combination of on- and off-farm activities (Barbieri et al., 2009; Davis et al., 2016). Market access can also influence the ability of households to acquire inputs on a regular basis. In the case of the Brazilian Amazon, distance to nearest market was negatively associated with pesticide or herbicide use, which is likely a result of easier access to inputs among farmers closer to market centers, as well as differences in land use patterns, where more commercially-oriented agriculture that tends to use such inputs often occurs closer to local markets than more subsistence forms (Perz, 2003).

Among indigenous communities, input use is still low overall, but growing. As of 2012, less than one in six indigenous households used pesticides or herbicides. This use varies substantially by ethnicity, with use being virtually nonexistent among the two ethnic groups (Cofán and Waorani) that are most isolated and least market-oriented compared to the other three indigenous groups in the NEA. Despite using agricultural practices that might benefit from input use, in particular, intensive cultivation on small plots largely for subsistence, most indigenous households have yet to adopt these technologies. As economic development in the NEA continues, with new infrastructure construction and greater market integration of indigenous groups, we anticipate that a survey conducted today would find higher levels of

input use among indigenous groups, though still at lower levels than among settlers, and varying significantly between ethnic groups.

Chainsaw ownership is considerably higher than chemical input use throughout the region, and as expected, among settlers is concentrated in households with cattle and large farms. Among indigenous households, by contrast, chainsaw ownership is widespread and linked to small-scale timber harvesting for household and community purposes, and is lowest among the most market-oriented indigenous population, the Shuar. This is particularly interesting given earlier research noting that Shuar households are not markedly less likely to sell timber than households from other ethnic groups (Gray et al., 2015).

Our results show that despite substantial land use change in the NEA during the past nearly half century going back to the beginning of migrant settler colonization in the early 1970s, adoption of ‘modern’ agricultural technologies is still in its relative infancy, particularly among settler households on smaller plots and among indigenous households. Our results suggest that there is a minority of land users, predominantly settlers, which have adopted chemical inputs and are also more likely to have large, market-oriented farming operations concentrated in cash crops and cattle. By contrast, most land users in our study region, including the vast majority of indigenous households, as well as many settlers with smaller plots and less capital-intensive farming operations, have not adopted such inputs. While this article does not explore the implications of chemical input adoption on deforestation specifically, we note that in this context, adoption appears to be linked with the types of more specialized farming operations that have been linked to deforestation in other settings (Rudel et al., 2009). While it is premature to draw firm conclusions, it is quite possible that intensification through technology adoption in this setting may be accompanied by extensification. Thus, there is a role for stronger environmental governance in the region to help reduce forest loss. Initiatives such as payments for ecosystem services schemes, more robust agricultural extension services, and greater legal protections for indigenous-managed land may enable land users in the NEA to realize the yield and labor-saving benefits associated with chemical input adoption while reducing incentives to extensify.

Acknowledgements and Funding Sources:

This research has received support from a variety of funding sources, most recently the National Institutes of Health (R00HD061752), USAID’s Higher Education for Development (A13-0670-002), the Land Use, Climate, and Infections in Western Amazonia project (CRNIII 3036) funded by the IAI—The Inter-American Institute for Global Change Research, and the Population Research Training (T32 HD007168) and the Population Research Infrastructure Program (P2C HD050924) grants awarded to the Carolina Population Center at the University of North Carolina at Chapel Hill by the Eunice Kennedy Shriver National Institute of Child Health and Human Development. We are grateful for all these sources of support as well as the excellent work of our field interviewers and collaboration of settler and indigenous household respondents.

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Figure 1.
Map of study region showing surveyed settler farms and indigenous communities

Table 1.
Summary statistics for settler and indigenous households (proportions of households)

Outcome Variables	Variable Type	Description	Settler Households				Indigenous Households			
			1990	1999	2014	2012	1990	1999	2014	2012
Chemical or Organic Fertilizer Use	Binary	Current or recent (within past 12 months) use of chemical or organic fertilizer.	Mean 0.04	Mean 0.05	Mean 0.26	Mean 0.22	Mean 0.01	Mean 0.10	Mean 0.05	Mean 0.05
Pesticide Use	Binary	Current or recent (within past 12 months) use of pesticides	SD 0.21	SD 0.23	SD 0.44	SD 0.22	SD 0.03	SD 0.18	SD 0.06	SD 0.24
Herbicide Use	Binary	Current or recent (within past 12 months) use of herbicides	0.12	0.32	0.15	0.36	0.02	0.14	0.11	0.31
Pesticide or Herbicide Use	Binary	Current or recent (within past 12 months) use of pesticides or herbicides	0.48	0.33	0.47	0.31	0.05	0.23	0.15	0.36
Chainsaw Ownership	Binary	Current ownership of chainsaw	0.31	0.46	0.42	0.41	0.29	0.45	0.42	0.49
Predictor Variables										
Household Size	Integer	Number of persons in household	6.74	5.84	3.03	4.50	6.35	2.89	7.81	3.87
Education: No Education	Binary	Male head of household has no formal education	0.08	0.27	0.08	0.26	0.18	0.39	0.09	0.29
Education: Some Primary	Binary	Male head of household has completed some primary school	0.45	0.50	0.36	0.48	0.23	0.42	0.16	0.37
Education: Primary Complete	Binary	Male head of household has completed primary school	0.41	0.49	0.44	0.47	0.36	0.48	0.40	0.49
Education: Some Secondary	Binary	Male head of household has completed some secondary school	0.04	0.20	0.08	0.27	0.17	0.38	0.20	0.40
Education: Secondary or Above	Binary	Male head of household has completed secondary school or higher	0.01	0.11	0.04	0.21	0.05	0.22	0.14	0.35
Male Head of Household Age	Integer	Male head of household age in years	43.50	43.91	50.76	50.76	38.99	13.69	41.39	14.39
Non-Spanish Speaking Head	Binary	Household head does not speak Spanish					0.09	0.29	0.04	0.20
Hired Labor	Binary	Household has hired outside labor within past 12 months to work on farm	0.62	0.49	0.43	0.50	0.22	0.41	0.19	0.39
Off-Farm Employment	Binary	At least one individual in household worked off-farm in past 12 months	0.37	0.48	0.57	0.49	0.59	0.49	0.51	0.50
Good Soil	Binary	Household plot contains black soil	0.68	0.47	0.57	0.50	0.42	0.58	0.49	0.49
Livestock Ownership	Binary	Household currently owns livestock	0.54	0.50	0.66	0.47	0.50	0.29	0.46	0.27
Land Title	Binary	Household has formal land title	0.53	0.50	0.38	0.48	0.70	0.46	0.27	0.45

			Settler Households			Indigenous Households		
			1990	1999	2014	2001	2012	
Plot Size	Continuous	Natural log of size of household farm plot in hectares (includes forest, crops, and pasture)	3.66	0.59	2.89	1.10	2.62	1.03
Cultivated Area	Continuous	Natural log of cultivated area in ha (crops or pasture)				1.31	0.70	1.32
Share Perennials	Continuous	Share of farm or cultivated area in perennial crops (coffee, cacao, etc.)	0.17	0.16	0.19	0.26	0.31	0.34
Years on Property	Integer	Years lived on current property	8.54	5.13	10.03	8.26	17.47	12.47
Credit	Binary	Utilized credit or loan (see notes for details)	0.21	0.41	0.25	0.44	0.33	0.47
Wealth Index	Continuous (0–10)	Index of household wealth	3.31	1.91	4.13	2.05	2.45	1.49
Ethnicities (Indigenous Survey Only)								
Kichwa	Binary	Reported ethnicity of male head is Quichua				0.48	0.50	0.56
Shuar	Binary	Reported ethnicity of male head is Shuar				0.20	0.40	0.14
Cofán	Binary	Reported ethnicity of male head is Cofan				0.09	0.28	0.08
Waoorani	Binary	Reported ethnicity of male head is Huaorani				0.13	0.34	0.09
Secoya	Binary	Reported ethnicity of male head is Secoya				0.07	0.25	0.06
Mestizo	Binary	Reported ethnicity of male head is Mestizo				0.04	0.19	0.07
Number of Households			405	655	185	481	599	

Note: Areas in gray are not applicable for a particular survey.

Table 2.

Results of settler input use logistic regression models (odds ratios)

Predictors	Pesticide or Herbicide	Chemical or Organic Fertilizers	Chainsaw Ownership
Household Size	1.023	0.986	1.075 ***
Male Head Age	0.993	0.997	0.992
Education: Some Primary	1.246	1.030	1.364
Education: Primary Complete	1.985 **	0.975	1.400
Education: Some Secondary	1.764	1.586	1.754
Education: Secondary and Above	1.269	3.211	1.250
Hired Outside Labor	1.612 ***	1.674 *	1.133
Off-Farm Employment	0.767 *	0.748	0.607 ***
Black Soil	1.175	1.661 *	1.094
Livestock on Farm	1.924 ***	0.749	1.642 **
Received Credit	1.153	2.143 **	1.037
Wealth Index	1.064	1.092	1.152 ***
Title	1.283	1.299	0.882
Years on Property	1.006	0.989	0.997
Plot Size	1.163	1.258	2.088 ***
Share Perennials	3.124 ***	1.126	0.485
1999 Year	0.559 ***	1.561	1.060
Number of Households	1017	1017	1017

* P <.10;

** <.05;

*** <.01

Note: No formal education and 1990 year are reference groups

Table 3.

Results of indigenous input logistic regression models (odds ratios)

Predictors	Pesticide	Herbicide	Chemical Fertilizers	Chainsaw Ownership
Household Size	1.018	0.921 **	1.076	1.093 ***
Male Head Age	1.018	1.009	0.983	0.995
Head Not Spanish-speaking	-	-	6.097	0.421 **
Education: Some Primary	1.060	0.504	8.723 *	1.598
Education: Primary Complete	1.227	1.291	2.660	1.456
Education: Some Secondary	3.004 **	0.859	2.641	1.230
Education: Secondary and Above	2.053	1.375	6.491	0.596
Hired Outside Labor	0.835	1.453	0.940	1.595 **
Oil-Related Off-Farm Employment	1.374	1.302	2.085	0.957
Non-Oil Off-Farm Employment	0.740	0.800	0.917	1.293
Black Soil	1.056	1.166	1.016	1.080
Livestock on Farm	1.309	2.580 ***	1.672	1.409
Own Plot	8.920 ***	1.164	1.060	1.181
Received Credit	0.993	2.127 **	1.645	0.574 ***
Wealth Index	0.941	1.035	1.301 ***	1.325 ***
Cultivated Area	2.184 **	1.609	1.420	1.427 **
Share Perennials	3.195 *	5.509 **	4.756 **	0.779
Secoya Ethnicity	0.672	1.826	2.185	1.395
Cofán Ethnicity	1.682	-	0.661	1.245
Shuar Ethnicity	1.208	0.987	0.132 **	0.367 ***
Worani Ethnicity	-	-	0.300	0.703
Mestizo Ethnicity	1.274	2.342 **	2.596 **	0.931
2012 Year	1.860	6.440 ***	2.663 *	1.214
Number of Households	885	815	1023	1023

*
P < .10;**
< .05;***
< .01

Note: Lack of pesticide and herbicide use among Worani households and herbicide use among Cofán results in these groups being excluded from the pesticide and herbicide models. No formal education, Kichwa ethnicity, and 2001 year are reference groups.

Table 4.

Ethnicity and input use among indigenous households (proportions)

Ethnic Group	Number of Households		Herbicide Use		Pesticide Use		Chemical Fertilizer Use		Chainsaw Ownership		Cattle Ownership	
	2001	2012	2001	2012	2001	2012	2001	2012	2001	2012	2001	2012
Kichwa	232	327	0.01	0.11	0.03	0.06	0.01	0.06	0.30	0.48	0.31	0.24
Shuar	93	84	0.05	0.13	0.06	0.13	0.00	0.01	0.18	0.31	0.37	0.70
Cofán	42	41	0.00	0.00	0.02	0.00	0.02	0.02	0.33	0.42	0.17	0.10
Waorani	64	53	0.00	0.00	0.00	0.00	0.00	0.02	0.22	0.19	0.02	0.00
Secoya	32	36	0.03	0.24	0.00	0.08	0.00	0.14	0.53	0.43	0.69	0.19
Mestizo	18	36	0.06	0.20	0.06	0.05	0.06	0.10	0.33	0.41	0.28	0.36