Weather Shocks and Agricultural Production: Evidence on Perennial and Non-perennial Crops in Colombia

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Abstract

Using data from Colombia, I address the effects of extreme weather events---such as precipitation shocks---on agricultural production, for the period 2008--2019. Combining official records on precipitation from more than 2,000 weather stations in the country with municipality-level information on sown area, production, and yields for more than 200 different crops, I estimate whether episodes of excessive or lack of precipitation induce farmers to change their decisions on production in the short run. Fixed-effect estimates reveal an increase in sown area for non-perennial crops (i.e., those that need replanting after harvest) after the occurrence of episodes of excessive precipitation. On the other hand, events of lack of rainfall are related with a fall in the area devoted to those crops, favoring the increase in sown area for perennial crops, especially in greater municipalities. The estimates do not provide evidence on short-term changes on crop concentration and yields.

Keywords: Climate change, precipitation shocks, agriculture, crops, Colombia

JEL: O13, O54, Q10, Q54

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1 Introduction

Nowadays, rural households and producers are much more exposed to the effects of climate change. More precisely, they must face longer and more severe episodes of droughts, excessive precipitation, and drastic changes in temperatures as well (Dell and Olken, 2012; Cai et al., 2014), affecting agricultural production. If these events act like negative productivity shocks, the production of food products may become more expensive, with their corresponding consequences on prices and food insecurity (Wheeler and Von Braun, 2013).

In this paper, I study the short-term effects of climate change on agricultural production in Colombia, a country located by the Equator, which makes it much more exposed to events like la Niña and el Niño, experiencing longer and more extreme episodes of excessive and lack of precipitation, respectively. Agriculture is no longer the most relevant economic sector (in 2020, its share on total GDP was only 7 percent), but is still important in the labor market since it absorbs 20 percent of the total labor force in the country (Otero-Cortés, 2019). Many families in rural areas rely on agriculture as their main source of income, by producing on their own land or working in other farms. Most farmers in rural Colombia lack enough technology (i.e., machinery or work skills) and infrastructure (e.g., adequate road networks to transport their production) that can help them to boost their productivity and, also, to combat the effects of climate change (e.g., irrigation systems when water supply is insufficient, or drainage when it comes in excess) (Hamann et al., 2019; Gafaro et al., 2019). Likewise, its geographical position of the country allows growing a wide variety of crops, all year long. According to the Colombian Ministry of Agriculture, more than 200 types of crops grow in the territory.

The main contribution of this paper is to understand how events of excessive or lack of precipitation affect the use of land for agricultural production, distinguishing by crops that differ due to the length of the growth cycle and intensity of use of water resources. More precisely, I address the differences between perennial and non-perennial crops. Perennial crops (e.g., fruit trees, coffee, African palm trees, plantains, and some tubers as well) characterize for having a longer lifetime, providing more than one harvest (i.e., no need of immediate replanting after the first one), although they require a longer growing cycle. Additionally, the planting process of perennial crops is more efficient, since they are less water-dependant and generate less erosion due to their longer lifespan. All these factors combined allow perennial crops to provide a higher value of production. On the other hand, non-perennial crops (e.g., vegetables, grains, leguminous, potatoes) have a shorter growing cycle (i.e., 6 months, approximately), but require replanting after the first or second harvest. These crops need more water to grow adequately and are more prone to generate land erosion. Additionally, their value of production is lower compared to perennial crops.

Based on the nature of extreme precipitation events caused by climate change and the characteristics of crops, producers may decide to change their use of land, taking into consideration the availability of production technologies and easiness to sell their products. For example, persistent events of excessive precipitation may induce farmers with low levels of technology (i.e., no irrigation systems) to increase the area devoted to crops that rely more on water to grow, since this resource becomes more available. Additionally, since non-perennial crops have a shorter growing period, farmers can sell them with ease, especially if they are easily connected to a wholesale central (i.e., adequate road infrastructure or proximity to larger cities). On the other hand, events of lack of precipitation can motivate farmers to increase the sown area for those crops that are more resilient to water scarcity.

For this paper, I rely on a panel of 729 Colombian municipalities (out of 1,109) that includes information on annual sown area (total, perennial, non-perennial), production, and yields for 222 crops, during the period 2008–2019. I merge these data with official records on precipitation from more than 2,000 meteorological stations in the country, in order to create a series of variables that account for the number of extreme precipitation events (i.e., excess of lack or rainfall) at each municipality per year. This data set allows me to estimate fixed-effect models that address the impact of such those events on agricultural production in Colombia.

The most recent literature regarding climate change and agricultural production addresses the effects on the short term (i.e., response after the occurrence of a weather shock) and the long term (i.e., adaptation to extreme weather events across time) as well (Burke et al., 2015, regarding global trends on climate change. Burke and Emerick, 2016; Lobell et al., 2020; Malikov et al., 2020, for studies in the United States. Rayamajhee et al., 2021; Chen and Gong, 2021, for Asian countries). As stated by Burke and Emerick (2016), and recently by Chen and Gong (2021), traditional fixed-effect models of agricultural output on precipitation and temperature changes (brought by Schlenker and Roberts, 2009) are optimal to identify the short-term effects of climate change. Unlike the primal cross-sectional approach of Mendelsohn et al. (1994), the estimation of regression models with panel data helps to control for time-invariant unobserved heterogeneity (i.e., omitted variables that are correlated with average climate).

The panel data approach, however, do not address the long-term effects of adaptation to climate change. Burke and Emerick (2016) point out that assuming short-run responses on climate change as representative of adaptation in the long run is erroneous because it could underestimate the time needed by farmers to adjust their behavior to new weather conditions (i.e., shifting to new technologies that help to cope with climate change). To identify adaptation effects, these authors suggest using data for very long periods of time (e.g., more than 30 years) in order to estimate first-difference models over two points of time that are sufficiently separated from each other. Given the nature of the data used in this paper, I provide estimates of the short-term response of Colombian farmers due to precipitation shocks.

The main results of this paper show that episodes of excessive precipitation increase sown area for non-perennial crops and, at the same time, decrease the area devoted to perennial crops. These effects mostly take place in municipalities with a population greater than 25,000, in towns that are located between 50 to 100 kilometers of distance from their nearest wholesale central, and municipalities that are between 1,000 and 2,000 meters above sea level. Additionally, I find that substitution into non-perennial crops after events of excessive precipitation favors sowing crops like cereals and grains. These staples are part of the basic basket of food products in Colombia.

The structure of this document is the following: Section 2 describes the data and reports the main trends on precipitation shocks and agricultural production in Colombia for the period 2008–2019. In Section 3, I present the empirical framework and identification strategy. Section 4 reports the regression estimates of the effects of precipitation shocks on sown area in Colombia. Likewise, I address whether farmers increase sown area of basic food products and, additionally, explain the role of trading networks as a mechanism to understand how extreme precipitation events affect agricultural production. Section 5 explores if precipitation shocks affect yields of some relevant crops and whether producers diversify the set of crops due to these events. Section 6 concludes.

2 Trends in Precipitation Shocks and Agricultural Production in Colombia

I merge official records on precipitation from all meteorological stations in Colombia with data collected by the Minister of Agriculture regarding annual agricultural production. The final data set comprises 729 municipalities—474 rural and 255 non-rural—out of 1,109 for the period 2008–2019, as displayed by Figure 1.[1] This data set covers 73.8 percent of total sown area in Colombia. I exclude the 23 main cities and metropolitan areas of the country, since their economic dynamics are not focused on agricultural production.

Precipitation Data

Precipitation data come from official records of daily rainfall from all weather stations in Colombia, collected by the Colombian Institute of Hydrology, Meteorology and Environmental Studies (IDEAM for its acronym in Spanish). IDEAM collects the data from more than 2,000 stations in the country. The main measure of precipitation I use in this document comes from averaging monthly rainfall from all the meteorological stations at each municipality. Then, for any given month from the period of interest, I compare the observed value of precipitation with its historical distribution from the same month during the last 30 years (1988–2007). Then, I define a event of excessive (lack of) precipitation as an indicator variable equal to one if the observed value of monthly precipitation at a given municipality is at or above (at or below) 2 standard deviations (-2 sd.) from the historical mean, zero otherwise. Finally, I count the number of both events of excessive or lack of precipitation by year at each municipality.

[1] Rural municipalities refer to those with a population equal or smaller than 25,000.

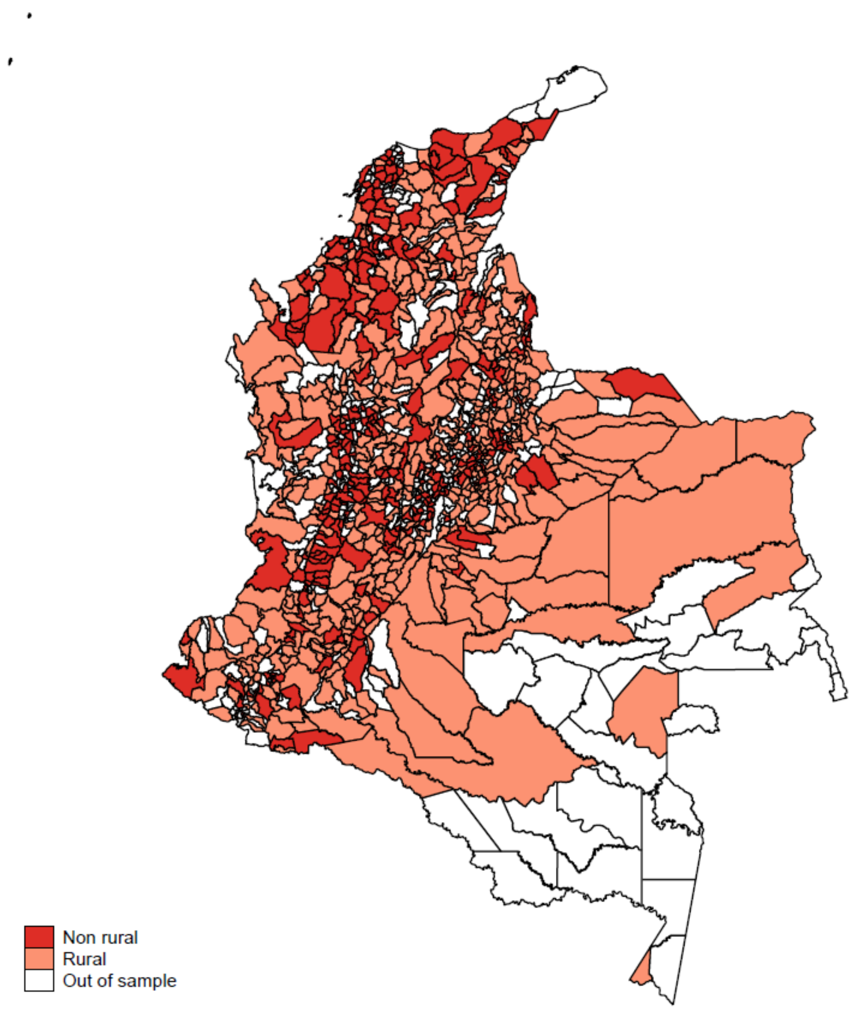
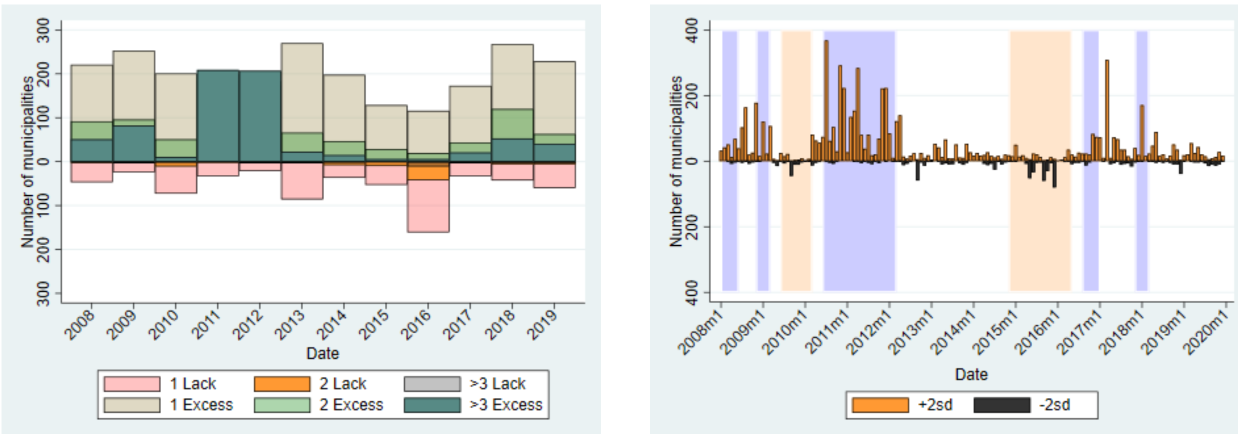


Figure 1: Map of municipalities included in the sample

Figure 2a displays the number of municipalities that experienced precipitation shocks at any year of the period of interest. This figure reflects heterogeneity in the incidence of extreme precipitation events: episodes of excessive rainfall above two standard deviations are more likely to happen than episodes of lack of rainfall below two standard deviations. Additionally, it is important to notice the incidence of municipalities experiencing three or more episodes of excessive precipitation during 2011 and 2012, while in 2016 it is possible to identify municipalities experiencing more than one episode of lack of rainfall. Figure 2b, which displays the number of these events on a monthly frequency, reveals the influence of el

Niño (light red areas) and la Niña (light blue areas) phenomena on precipitation patterns in Colombia.[2] As expected, the number of positive shocks is relatively higher during la Niña, while negative shocks are more likely to occur during el Niño.



(a) Number of shocks/year

(b) Monthly shocks

Figure 2: Distribution of episodes of precipitation shocks, 2008–2019

How likely are these measures of rainfall shocks, compared with other thresholds? Figures A1 and A2 from the Annex compare these events with different standard deviations and distribution percentiles, respectively. These figures reveal that precipitation episodes above (below) two (-2) standard deviations are less likely to happen, indicating they represent extreme weather events.

Production Data

Production data come from the Municipal Agricultural Evaluations (EVA, by its acronym in Spanish), collected and processed by the Colombian Ministry of Agriculture. The EVA include information on total sown area, total harvested area, production and yields for 222 crops—144 perennial and 78 non-perennial. These data are collected by local authorities

[2] I take the begin and end dates of each episode of el Niño and la Niña from IDEAM.

from municipalities and officials from the Rural Agricultural Planning Units (UPRA, by its acronym in Spanish) on a yearly basis.[3] EVA are not an agricultural census because data come after reaching a "consensus" between officials, producers, merchants, agronomists, and extensionists regarding municipal agricultural production.

Figure 3 displays the evolution of sown area in Colombia for the period 2008–2019. During this time, the area devoted to perennial crops has steadily increased, excepting for the years 2017 and 2018. On the other hand, sown area for non-perennial crops displays an irregular behavior, although it is possible to observe relevant jumps in 2013, just one year after the longest episode of la Niña phenomenon during the period of study, and 2016. Likewise, Figure 4 shows the evolution of the five most important—perennial and non-perennial—crops in terms of total sown area. This figure reveals a positive trend of the area devoted to African palm trees, whereas sown area on coffee started to decline after 2013. Regarding non-perennial crops, it is important to highlight the increase of rice fields during the period of study.

3 Empirical Strategy

Following Schlenker and Roberts (2009), Burke and Emerick (2016), and Chen and Gong (2021), I implement a panel approach to estimate the effects of precipitation shocks on agricultural production in Colombia. As explained in Section 1, fixed-effect estimates capture short-term responses from farmers after extreme weather events. The regression model of interest is the following:

[3]The UPRA is in charge of planning and coordinating with authorities and farmers the local policies that aim to increase agricultural productivity throughout an efficient use of natural resources. https://www.upra.gov.co/web/guest/upra/funciones

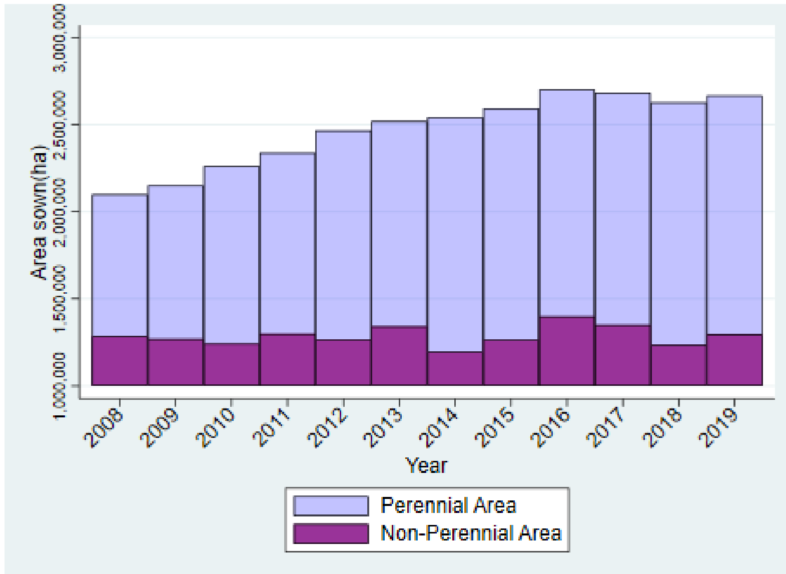
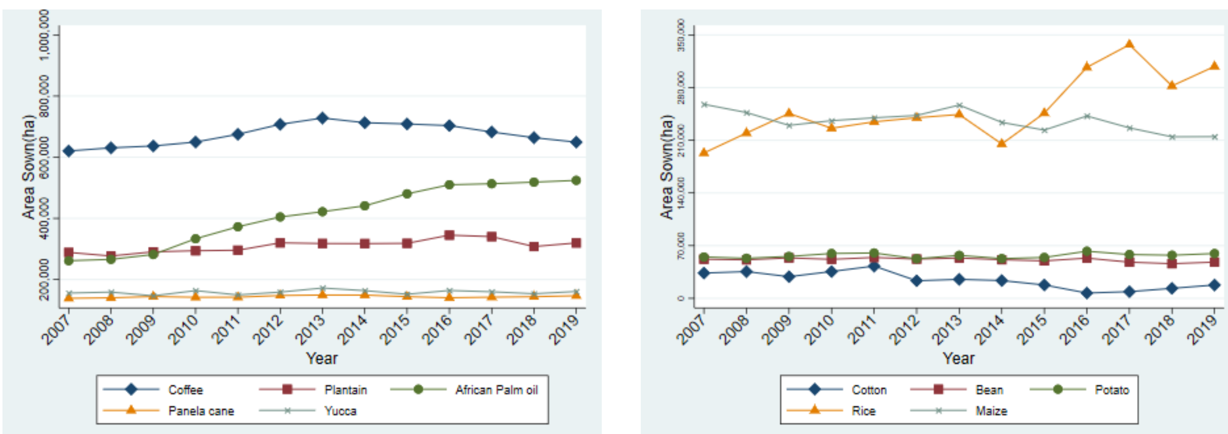


Figure 3: Sown Area in Colombia, 2008–2019

Figure 4: Sown Area of Relevant Crops in Colombia, 2008–2019



(a) Perennial Crops

(b) Non-perennial Crops

$$Y_{it} = \beta_1 P_{it}^{-} + \beta_2 P_{it-1}^{-} + \beta_3 P_{it}^{+} + \beta_4 P_{it-1}^{+} + a_i + b_t + u_{it} \tag{1}$$

where Y_{it} is sown area (total, perennial, or non-perennial) at municipality i in year t, P_{it} and P_{it-1} are contemporary and lagged number of episodes of lack of precipitation by municipality per year, respectively; P_{it}^{+} and P_{it-1}^{+} denote the current and lagged episodes of excessive rainfall shocks; a_i is a municipality fixed effect, and u_{it} is a zero-mean error. The inclusion of lagged precipitation shocks aims to capture the level of persistence of these episodes over time. Since I count with yearly-level data on agricultural production, it is not unlikely to consider situations in which weather episodes from the last months of the previous year can influence farmers at the moment of the next sowing period, especially for non-perennial crops.

To address causal effects from the estimation of Equation 1, the estimated parameters have to be plausibly exogenous (i.e., no unobserved heterogeneity, no measurement error, no reverse causality). The greatest concern comes from measurement error. The outcomes and explanatory variables of interest as well could have been measured with error. Regarding sown area, as explained in Section 2, that data come from subjective evaluations made by extensionists and agronomists at each municipality. Consequently, the presence of measurement error in the dependent variable would draw larger standard errors from the regression estimates. Assuming that measurement error is idiosyncratic at each municipality, I estimate clustered standard errors at that level.

With respect to precipitation data, it might come with error due to the quality of the weather stations (i.e., in smaller and remote municipalities is more complicated to provide adequate maintenance to the stations, and they are more difficult to replace as well). To minimize this problem, I average monthly precipitation across all stations for each municipality (on average, a municipality has two weather stations placed in its area). Additionally, I include fixed effects by municipality that accounts for time-invariant factors that might be correlated with the observed values of precipitation.

4 The Effects of Precipitation Shocks on Sown Area

Table 1 displays the regression estimates of Equation 1 for total sown area (columns 1–3), sown area on perennial crops only (columns 4–6), as well as for the area devoted to non-perennial crops only (columns 6–9). In addition to the complete sample, I address heterogeneous effects by type of municipality by estimating the regression model only for the sub-sample of rural municipalities as well as for non-rural municipalities only.

The estimated parameters reported in Table 1 reveal that only lagged episodes of lack of precipitation have an effect on the expansion of total sown area: an additional episode of this nature increases total sown area by 1.5 percent on average. More precisely, that increase comes from rural municipalities (1.9 percent), and can be attributed to the area devoted to perennial crops (2.5 percent). With respect to non-rural municipalities, the effect is positive, but not statistically significant.

Current episodes of excessive precipitation affect in opposite directions. Consequently, their effect on total area sown is close to zero. On one hand, an additional event decreases the area devoted to perennial crops by 2.6 percent. Such that fall is greater in non-rural municipalities (-3.4 percent) relative to rural municipalities (-2.1 percent). On the other hand, these episodes increase area sown for non-perennial crops by 2 percent on average. This change is driven by non-rural municipalities (3.3 percent). The effect on rural municipalities is positive but not statistically significant.

Table 1: The effects of precipitation shocks on total sown area (in logs)

	Total			Perennial			Non-Perennial		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	Rural	Non-Rural	All	Rural	Non-Rural	All	Rural	Non-Rural
Number of lack rain shocks 2 sd	0.002	0.002	0.000	0.003	-0.001	0.011	0.037*	0.031	0.048
	(0.009)	(0.012)	(0.011)	(0.011)	(0.015)	(0.017)	(0.021)	(0.026)	(0.038)
Lag number of lack rain shocks 2 sd	0.015*	0.019*	0.006	0.022**	0.025*	0.015	0.016	0.009	0.033
	(0.008)	(0.011)	(0.011)	(0.011)	(0.013)	(0.020)	(0.023)	(0.030)	(0.032)
Number of excess rain shocks 2 sd	-0.003	-0.006	0.001	-0.026***	-0.021***	-0.034***	0.020**	0.010	0.033***
	(0.003)	(0.005)	(0.005)	(0.005)	(0.007)	(0.009)	(0.009)	(0.012)	(0.013)
Lag number of excess rain shocks 2 sd	-0.002	-0.006	0.003	-0.009*	-0.011	-0.008	0.013	0.006	0.024**
	(0.004)	(0.006)	(0.005)	(0.006)	(0.007)	(0.009)	(0.010)	(0.015)	(0.011)
R-squared	0.927	0.917	0.941	0.947	0.939	0.957	0.824	0.806	0.856
Observations	8,748	5,688	3,060	8,748	5,688	3,060	8,748	5,688	3,060
Municipalities	729	474	255	729	474	255	729	474	255

All regressions estimates include municipality–level fixed effects. Significant at: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sources: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Agriculture of Colombia.

What is the interpretation of these results? First, the observed increase in total area sown due to precipitation shocks can be attributed to past episodes of lack of precipitation. More precisely, farmers increase the area devoted to perennial crops, while keeping constant the area for non-perennial crops. As explained earlier, perennial crops are more resilient to water scarcity. Therefore, agricultural producers prefer to extend the area devoted to these crops in order to increase benefits, based on the expectation of more episodes like these in the future.

On the other hand, current events of excessive precipitation induce farmers to increase the area sown for non-perennial crops, but, at the same time, to reduce the area devoted to non-perennial crops. In this case, water becomes relatively cheaper for sowing non-perennial crops, that more dependant on the use of water for growing. Additionally, harvesting takes place twice a year for most products, providing more selling opportunities relative to perennial crops. Furthermore, this crop substitution takes place in non-rural municipalities, in which is more likely to expect better trading networks that allow farmers to sell their products with ease.

Do Precipitation Shocks Increase Sown Area for Basic Food Products?

The Results from Table 1 show that episodes of excessive precipitation are related with an increase in the area sown for non-perennial crops in non-rural municipalities (those with a population larger then 25,000). At the same time, there is a decease in the area devoted to perennial crops, causing a zero effect on total area sown. Thus, farmers may shift to sow products that can be traded with ease. I test this hypothesis by estimating Equation 1 on non-rural municipalities, and dividing total sown area (of perennial and non perennial crops) into two categories: area devoted to basic food products and rest of crops.

According to the Colombian Department of Statistics (DANE)—which is in charge of estimating the Consumer Price Index, cereals, fruits leguminous, tubers, and vegetables are part of the basket of basic food products.[4] The first three categories consist of non-perennial crops. Leguminous and most fruits (with the exception of cantaloupe melon and watermelon) are perennial. Tubers like arracacha, plantain, yam, and yucca are perennial crops, whereas potato and ullucus are non-perennial.

Table 2 reports the regression estimates for non-rural municipalities on sown area devoted to perennial and non-perennial crops that are part of the basket of basic food products in Colombia. The estimated parameters show the observed increase in total sown area for non-perennial crops due to episodes of excessive precipitation comes in almost equal parts from basic food products and the rest of crops. With respect to the sown area for perennial crops, the observed decrease takes place on fruits (column 5), while there is no statistically significant change for the remaining crops. Likewise, Table A1 of the Annex disaggregates the effects of weather shocks by different categories of basic food products that are non-perennial crops. As this table displays, the increase in sown area for non-perennial crops in non-rural municipalities takes place on cereals and the rest of non-basic food products (column 5). This table also reveals that area devoted for vegetables decreases after lagged events of lack of precipitation and current episodes of excessive rainfall as well, indicating these crops can be much more sensitive to extreme precipitation events.

[4] `https://www.dane.gov.co/index.php/en/statistics-by-topic/prices-and-costs/consumer-price-index-cpi` consulted on June 27, 2021.

Table 2: The effects of precipitation shocks on sown area of basic food products

	Perennial			Non-Perennial		
	(1)	(2)	(3)	(4)	(5)	(6)
	Total	Basket	Rest	Total	Basket	Rest
Number of lack rain shocks 2 sd	0.011	0.006	0.058	0.048	0.051	-0.058
	(0.017)	(0.033)	(0.046)	(0.038)	(0.035)	(0.066)
Lag number of lack rain shocks 2 sd	0.015	0.015	0.063	0.033	0.035	0.028
	(0.020)	(0.034)	(0.050)	(0.032)	(0.030)	(0.045)
Number of excess rain shocks 2 sd	-0.034***	-0.035***	-0.027	0.033***	0.028**	0.033**
	(0.009)	(0.010)	(0.019)	(0.013)	(0.012)	(0.016)
Lag number of excess rain shocks 2 sd	-0.008	-0.027***	0.001	0.024**	0.024**	0.012
	(0.009)	(0.010)	(0.014)	(0.011)	(0.011)	(0.015)
R-squared	0.957	0.932	0.938	0.856	0.866	0.778
Observations	3,060	3,060	3,060	3,060	3,060	3,060
Municipalities	255	255	255	255	255	255

All regressions estimates include municipality–level fixed effects. Significant at: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sources: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Agriculture of Colombia.

The Role of Trading Networks: an Approximation

Trading networks could help to explain the mechanisms in which farmers decide to shift from perennial to non-perennial crops, especially those that belong to the basket of basic goods, when excessive precipitation takes place. If a given municipality is closer to a big capital city—and its corresponding wholesale central, producers can sell their products with ease. Using the road distance between centroids of municipalities and the centroid of their nearest town with a wholesale central (taken from Google Maps) as a proxy of better trading networks, I re-estimate Equation 1 for a series of sub-samples of municipalities, grouped into three categories according to that distance: 0–50 km, 50–100 km, and more than 100 km. Only four of the 729 municipalities that comprise the data set used in this paper have a wholesale central, (i.e., its distance is equal to zero). The majority of wholesale centrals in Colombia are located in the capital cities (that were excluded in the final data set).

Table 3 reports the regression estimates of Equation 1 for the three sub-samples of municipalities. According to the results, in municipalities located within 50 km or less to their nearest capital city, only events of excessive precipitation affect sown area. More precisely, current events decrease the area devoted to perennial crops. But, past episodes increase total area sown, presumably from the area for non-perennial crops (although the estimated parameters for this category of crops is not statistically significant, but is greater than the corresponding to perennial crops).

The regression estimates for the category of municipalities located between 50 and 100 km shows the substitution of perennial crops into non-perennial after current and lagged episodes of excessive precipitation. The effect on total sown area is close to zero. Nevertheless, present and past events of lack of precipitation also increase the land devoted to non-perennial crops, contrary from what I expected. Last, but not least, the estimated parameters for the sub-sample of municipalities that are more than 100 km away from their nearest city with wholesale central only shows the negative effect on the sown area for perennial crops after episodes of excessive precipitation.

Table 3: The effects of precipitation shocks on total sown area (in logs) at non-rural municipalities by categories of distance to the nearest wholesale central

(a) 0–50 km

	(1) Total	(2) Perennial	(3) Non-Perennial
Number of lack rain shocks 2 sd	0.017	0.007	-0.018
	(0.015)	(0.019)	(0.048)
Lag number of lack rain shocks 2 sd	0.019	0.017	-0.017
	(0.017)	(0.022)	(0.035)
Number of excess rain shocks 2 sd	0.003	-0.028**	0.007
	(0.007)	(0.013)	(0.016)
Lag number of excess rain shocks 2 sd	0.013**	0.005	0.020
	(0.006)	(0.016)	(0.014)
R-squared	0.943	0.952	0.885
Observations	1,776	1,776	1,776
Municipalities	148	148	148

(b) 50–100 km

	(1) Total	(2) Perennial	(3) Non-Perennial
Number of lack rain shocks 2 sd	0.002	0.019	0.067**
	(0.012)	(0.019)	(0.029)
Lag number of lack rain shocks 2 sd	0.023*	0.036**	0.073**
	(0.012)	(0.018)	(0.035)
Number of excess rain shocks 2 sd	0.001	-0.029***	0.048***
	(0.006)	(0.008)	(0.014)
Lag number of excess rain shocks 2 sd	-0.009*	-0.016**	0.029**
	(0.006)	(0.007)	(0.014)
R-squared	0.938	0.959	0.852
Observations	3,108	3,108	3,108
Municipalities	259	259	259

(c) More than 100 km

	(1) Total	(2) Perennial	(3) Non-Perennial
Number of lack rain shocks 2 sd	-0.005	-0.013	0.040
	(0.016)	(0.019)	(0.037)
Lag number of lack rain shocks 2 sd	0.006	0.013	-0.012
	(0.014)	(0.018)	(0.042)
Number of excess rain shocks 2 sd	-0.011*	-0.023***	0.002
	(0.006)	(0.009)	(0.015)
Lag number of excess rain shocks 2 sd	-0.004	-0.011	-0.002
	(0.008)	(0.009)	(0.018)
R-squared	0.909	0.923	0.773
Observations	3,864	3,864	3,864
Municipalities	322	322	322

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Overall, the regression estimates reported in Table 3 show that the effect of precipitation shocks on sown area mostly takes place on those municipalities that are located between 50 and 100 km from cities with wholesale centrals. Farmers might consider is worth to sow more of those products that are highly demanded by households (e.g., non-perennial crops like cereals) when weather conditions propitiate it, and sell them in places with a bigger demand for food, like capital cities. On the other hand, farmers from towns that are much farther from wholesale centrals (i.e., more than 100 km of distance) might face more obstacles (e.g., more travel time or worse road conditions) to sell their products with ease. Thus, it should not be worth it to change their use of land for sowing crops after precipitation shocks. However, I do not find crop substitution on municipalities that are just within 50 km or less from cities with wholesale central. Better access to production technologies (since they are closer to capital cities) could be driving this result.

Sensitivity Analysis and Robustness Checks

As described in Section 2, precipitation episodes at or above (at or below) two standard deviations (-2 sd.) are less likely to happen. Since these events are more extreme than those under looser thresholds, it is important to test whether the results I observe in Table 1 also take place under precipitation events of smaller intensity, but with greater incidence. Tables A2 to A4 of the Annex report the regression estimates of Equation 1 using different pairs of thresholds: $+/-1$ sd, $+/-1.5$ sd, 20th and 80th percentiles, and 10th and 90th percentiles as well. With respect to total sown area (Table A2), current events of lack of precipitation under one standard deviation or below the 10th percentile of the historic distribution have an negative effect, principally in non-rural municipalities. As Table A4 confirms, this result is driven by a reduction in sown area for non-perennial crops. On the other hand, episodes of excessive precipitation, measured under different thresholds, have an impact on reducing the area for perennial crops, but the magnitudes are neglectable (Table A3). Overall, only extreme precipitation events—like those beyond two standard deviations in absolute terms—can have an effect on sown area.

The regression estimates reported in Table 1 capture the average effect of an additional extreme weather event on sown area (i.e., the intensive margin). I also explore the effects at the extensive margin by replacing the explanatory variables with a set of indicator variables equal to one whether at least one episode of such that event took place, zero otherwise:

$$Y_{it} = \alpha_1 I[P^-_{it} = 1] + \alpha_2 I[P^-_{it-1} = 1] + \alpha_3 I[P^+_{it} = 1] + \alpha_4 I[P^+_{it-1} = 1] + a_i + b_t + u_{it} \qquad (2)$$

The estimated parameters reported in Table A5 of the Annex tend to display the same signs as those from Table 1. However, only the associated parameters from the indicator variable that address at least one episode of excessive precipitation in year t are significant for perennial crops. From these results, I conclude that exposure to just one episode of lack of precipitation could trigger farmers to reduce the area devoted to perennial crops. But, in order to increase the sown area for non-perennial crops in the short term, they must face more than one month of excessive precipitation.

Altitude is another important determinant of precipitation in Colombia. Table A6 displays the regression estimates of Equation 1 after grouping the municipalities in the sample into three different categories, based on their altitude: 0–1000, 1000–2000, and more than 2000 meters above sea level. The estimated parameters show that increases in area sown for perennial crops due to lagged events of lack of precipitation mostly take place on municipalities at or below 1000 meters of altitude. Additionally, the decrease of tat sown area due to excessive precipitation occurs on low and high-altitude municipalities. On the other hand, the positive effect of the former shocks on the area devoted on non-perennial crops mostly takes place on municipalities between 1000 and 2000 meters above sea level.

5 Effects on Yields and Crop Concentration

So far, I find that episodes of lack of precipitation have an effect on increasing the sown area for perennial crops. As described earlier, they are more resilient to droughts. On the other hand, events of excessive precipitation are related with increases on the area devoted to non-perennial crops, which are more water-dependent. Literature shows that precipitation can act as a positive productivity shock (Jayachandran, 2006). Conversely, lack of precipitation—or droughts—can be related with negative productivity shocks (Aragón et al., 2021). For Colombia, Julio-Román et al. (2020) show that events of el Niño phenomenon are related with increases in food prices during the last 50 years. The question that arises is whether farmers react after gains or loses of yield by changing the sown area.

Using the EVA, I identify the five most relevant crops in terms of sown area in 2007. According to the data, African palm, coffee, and plantain—all three perennial crops, as well as maize and rice—both non-perennial crops, are the most sown in the country, accounting for 58 percent of total sown area for that year. Then, for each crop, I create a series of sub-samples that group municipalities that registered sown area on each product in 2007. The goal is to estimate the effect of precipitation shocks on yields.

Table 4 reports the regression estimates of yields—measured as log(production in tons / total area harvested)—on episodes of excessive and lack of precipitation. According to the results, only current and lagged episodes of excessive precipitation have an statistically significant effect on yields for the selected crops. However, these effects seem to be very small: between -0.9 percent for plantain to -2.1 percent on coffee. These weather events do not have impact on the yields of palm trees, a crop that counts with high levels of production technologies.

Do the former results mean that excessive precipitation events act as negative productivity shocks? The magnitude of the estimated effects are very small to consider that production per hectare is heavily affected by these episodes. Moreover, since I have found that episodes of excessive precipitation increases sown area for non-perennial crops, like rice or maize, the fall in yields can be interpreted as a short-term adjustment that comes after expanding the area devoted to those products. In the case of coffee, harvesting is mostly manual. Thus, when excessive rainfall occurs, coffee pickers may reduce the time devoted to this task.

In addition to the change of land use, precipitation shocks can also induce farmers to "diversify" their portfolio of crops to sow, as a mechanism to reduce risk. To test this

Table 4: The effects of precipitation shocks on yields (in logs) of most important crops

	(1) Rice	(2) Coffee	(3) Maize	(4) Palm	(5) Plantain
Number of lack rain shocks 2 sd	-0.003	0.006	0.011	0.035	0.015
	(0.013)	(0.007)	(0.009)	(0.022)	(0.010)
Lag number of lack rain shocks 2 sd	-0.028	0.008	-0.005	-0.012	0.011
	(0.018)	(0.008)	(0.009)	(0.021)	(0.012)
Number of excess rain shocks 2 sd	-0.006	-0.012***	-0.011***	0.008	0.001
	(0.006)	(0.003)	(0.003)	(0.006)	(0.005)
Lag number of excess rain shocks 2 sd	-0.014**	-0.021***	0.005	0.007	-0.009**
	(0.006)	(0.003)	(0.003)	(0.006)	(0.004)
R-squared	0.858	0.379	0.762	0.370	0.713
Observations	2,150	4,129	6,613	776	5,139
Municipalities	208	386	625	72	491

All regressions estimates include municipality–level fixed effects. Significant at: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sources: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Agriculture of Colombia.

hypothesis, I estimate the regression model of interest using the number of crops as the dependent variable. Additionally, I calculate a measure of crop concentration using the Herfindahl-Hirschman index on sown area for perennial and non-perennial crops:

$$1 - HHI_{it} = 1 - \sum_{j=1}^{J} s_{jit}^2 \tag{3}$$

where s_{jit} is the share of crop j on total sown area (for perennial or non-perennial crops) in municipality i at year t. This measure captures how concentrated is the sown area for each one of the categories of crops at a given municipality. Smaller values of $1 - HHI_{it}$ indicate greater concentration since the Herfindahl-Hirschman Index goes up as the share of one crop is bigger than the rest at each municipality.

Tables 5 and 6 report the regression estimates when using the Herfindahl-Hirchman Index-based measure of crop concentration, and the number of crops as well. According to the results, there is no clear evidence that farmers change the number of crops after the occurrence of precipitation shocks. Only current and lagged episodes of excessive precipitation decrease the number of crops and crop concentration, but the estimated parameters are very close to zero.

Table 5: The effects of precipitation shocks on crop concentration

	Perennial			Non-Perennial		
	(1)	(2)	(3)	(4)	(5)	(6)
	All	Rural	Non-Rural	All	Rural	Non-Rural
Number of lack rain shocks 2 sd	-0.001	-0.001	-0.002	-0.001	-0.000	-0.003
	(0.003)	(0.004)	(0.004)	(0.003)	(0.004)	(0.005)
Lag number of lack rain shocks 2 sd	-0.001	0.001	-0.004	0.000	0.001	-0.000
	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)	(0.005)
Number of excess rain shocks 2 sd	-0.003**	-0.003*	-0.002	-0.003**	-0.005***	-0.000
	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
Lag number of excess rain shocks 2 sd	-0.003**	-0.003**	-0.001	-0.003**	-0.003	-0.004*
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)
R-squared	0.801	0.783	0.826	0.676	0.670	0.681
Observations	8,498	5,556	2,942	8,608	5,589	3,019
Municipalities	721	469	252	729	474	255

All regressions estimates include municipality–level fixed effects. Significant at: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sources: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Agriculture of Colombia.

Table 6: The effects of precipitation shocks on the number of crops

	Total			Perennial crops			Non-Perennial		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	Rural	Non-Rural	All	Rural	Non-Rural	All	Rural	Non-Rural
Number of lack rain shocks 2 sd	0.009	0.012	0.003	0.012	0.013	0.009	0.005	0.011	-0.002
	(0.007)	(0.008)	(0.013)	(0.007)	(0.009)	(0.012)	(0.009)	(0.010)	(0.016)
Lag number of lack rain shocks 2 sd	0.011	0.014*	0.006	0.012	0.013	0.011	0.009	0.016	0.001
	(0.007)	(0.008)	(0.012)	(0.008)	(0.010)	(0.012)	(0.009)	(0.010)	(0.016)
Number of excess rain shocks 2 sd	-0.011***	-0.013***	-0.008**	-0.011***	-0.011***	-0.010***	-0.011***	-0.015***	-0.007
	(0.003)	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)	(0.006)	(0.006)
Lag number of excess rain shocks 2 sd	-0.012***	-0.015***	-0.007**	-0.013***	-0.017***	-0.007**	-0.011***	-0.013***	-0.008*
	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)	(0.004)	(0.005)
Pseudo R-squared	0.391	0.370	0.422	0.354	0.330	0.395	0.377	0.354	0.400
Observations	8,748	5,688	3,060	8,676	5,652	3,024	8,748	5,688	3,060
Municipalities	729	474	255	723	471	252	729	474	255

All regressions estimates include municipality–level fixed effects. Significant at: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sources: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Agriculture of Colombia.

6 Concluding Remarks

This paper addresses the short-term effects of climate change on agricultural production in Colombia, a country whose geographical location makes it more prone to experience the pounding of weather phenomena like la Niña and el Niño, causing longer and more severe periods of excessive and lack of precipitation, respectively. Additionally, its unique topography allows farmers to grow a wide variety of crops.

After merging data on agricultural production with official records on precipitation at the municipality level, I estimate the effects of yearly episodes of excessive and lack of precipitation on total sown area, as well as on the area devoted for perennial and non-perennial crops, for the period 2008–2019. Allowing the distinction between perennial (i.e., those that takes longer to grow but brings more than one harvest during their life cycle) and non-perennial (i.e., those that grow faster but only provide one or tow harvests before they lifetime comes to an end) crops, allows understanding whether farmers shift the use of land due to changes in precipitation conditions.

The regression estimates shows that episodes of excessive precipitation act as a trigger to increase sown area for non-perennial crops, with a reduction in the area devoted to perennial crops. As water becomes more available, and most farmers in Colombia lack of adequate irrigation systems, they take advantage of increasing the land devoted to crops that grow faster and, additionally, have a bigger demand in larger cities—like grains or cereals. Last, but not least, the results do not present clear evidence of loses in yields and crop diversification due to the occurrence of extreme precipitation events.

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Table A1: The effects of precipitation shocks on total sown area (in logs) at non-rural municipalities (disaggregated by type of products)

	(1) Total	(2) Cereals	(3) Vegetables	(4) Leguminous	(5) Tubers	(6) Rest
Number of lack rain shocks 2 sd	0.048	0.104**	-0.064	-0.031	0.018	-0.058
	(0.038)	(0.050)	(0.059)	(0.049)	(0.033)	(0.066)
Lag number of lack rain shocks 2 sd	0.033	0.084*	-0.121**	0.038	0.002	0.028
	(0.032)	(0.051)	(0.050)	(0.048)	(0.045)	(0.045)
Number of excess rain shocks 2 sd	0.033***	0.038**	-0.039*	0.004	0.012	0.033**
	(0.013)	(0.017)	(0.022)	(0.019)	(0.008)	(0.016)
Lag number of excess rain shocks 2 sd	0.024**	0.039**	-0.012	-0.010	0.016**	0.012
	(0.011)	(0.017)	(0.017)	(0.016)	(0.006)	(0.015)
R-squared	0.856	0.845	0.826	0.835	0.969	0.778
Observations	3,060	3,060	3,060	3,060	3,060	3,060
Municipalities	255	255	255	255	255	255

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipality–level fixed effects.

Sources: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Agriculture

Table A2: The effects of precipitation shocks on total sown area (in logs), using different thresholds

Variables	All	Rural	Non-Rural
Number of lack rain shocks p20	−0.003	−0.001	−0.007
	(0.003)	(0.003)	(0.004)
Lag number of lack rain shocks p20	0.003	0.003	0.002
	(0.002)	(0.003)	(0.004)
Number of excess rain shocks p80	−0.001	−0.001	−0.001
	(0.002)	(0.003)	(0.004)
Lag number of excess rain shocks p80	−0.003	−0.004	−0.001
	(0.002)	(0.003)	(0.003)
R-squared	0.927	0.917	0.941
Number of lack rain shocks p10	−0.006*	−0.002	−0.012**
	(0.003)	(0.004)	(0.005)
Lag number of lack rain shocks p10	−0.001	−0.002	0.001
	(0.003)	(0.004)	(0.005)
Number of excess rain shocks p90	−0.004	−0.005	−0.004
	(0.003)	(0.003)	(0.004)
Lag number of excess rain shocks p90	−0.006**	−0.008**	−0.002
	(0.003)	(0.004)	(0.004)
R-squared	0.927	0.917	0.941
Number of lack rain shocks 1 sd	−0.002	0.002	−0.012**
	(0.003)	(0.004)	(0.005)
Lag number of lack rain shocks 1 sd	0.005	0.006	0.001
	(0.003)	(0.004)	(0.004)
Number of excess rain shocks 1 sd	−0.002	−0.001	−0.003
	(0.002)	(0.003)	(0.004)
Lag number of excess rain shocks 1 sd	−0.002	−0.002	−0.002
	(0.003)	(0.004)	(0.003)
R-squared	0.927	0.917	0.941
Number of lack rain shocks 1.5 sd	−0.004	−0.000	−0.011
	(0.005)	(0.006)	(0.007)
Lag number of lack rain shocks 1.5 sd	0.006	0.008	0.004
	(0.005)	(0.006)	(0.007)
Number of excess rain shocks 1.5 sd	−0.002	−0.003	−0.001
	(0.003)	(0.004)	(0.004)
Lag number of excess rain shocks 1.5 sd	−0.004	−0.006	−0.001
	(0.003)	(0.004)	(0.004)
R-squared	0.927	0.917	0.941
Observations	8748	5688	3060
Municipalities	729	474	255

All regressions estimates include municipality–level fixed effects. Significant at: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sources: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Agriculture of Colombia.

Table A3: The effects of precipitation shocks on total sown area for perennial crops (in logs), using different thresholds

Variables	All	Rural	Non-Rural
Number of lack rain shocks p20	−0.005	−0.002	−0.010
	(0.004)	(0.005)	(0.007)
Lag number of lack rain shocks p20	0.005	0.008*	−0.001
	(0.004)	(0.004)	(0.007)
Number of excess rain shocks p80	−0.010***	−0.005	−0.019***
	(0.004)	(0.004)	(0.007)
Lag number of excess rain shocks p80	−0.007*	−0.006	−0.008
	(0.003)	(0.004)	(0.006)
R-squared	0.947	0.939	0.957
Number of lack rain shocks p10	−0.003	−0.002	−0.007
	(0.004)	(0.005)	(0.009)
Lag number of lack rain shocks p10	0.003	0.003	0.002
	(0.004)	(0.005)	(0.009)
Number of excess rain shocks p90	−0.015***	−0.009*	−0.025***
	(0.004)	(0.005)	(0.007)
Lag number of excess rain shocks p90	−0.011***	−0.012**	−0.008
	(0.004)	(0.005)	(0.006)
R-squared	0.947	0.939	0.957
Number of lack rain shocks 1 sd	−0.003	0.001	−0.009
	(0.004)	(0.005)	(0.009)
Lag number of lack rain shocks 1 sd	0.009**	0.013**	0.001
	(0.004)	(0.005)	(0.008)
Number of excess rain shocks 1 sd	−0.011***	−0.003	−0.022***
	(0.004)	(0.004)	(0.006)
Lag number of excess rain shocks 1 sd	−0.006*	−0.006	−0.008
	(0.004)	(0.005)	(0.006)
R-squared	0.947	0.939	0.957
Number of lack rain shocks 1.5 sd	0.001	0.001	0.003
	(0.006)	(0.007)	(0.011)
Lag number of lack rain shocks 1.5 sd	0.020***	0.016**	0.028**
	(0.006)	(0.006)	(0.012)
Number of excess rain shocks 1.5 sd	−0.014***	−0.008	−0.024***
	(0.004)	(0.005)	(0.007)
Lag number of excess rain shocks 1.5 sd	−0.007	−0.007	−0.005**
	(0.004)	(0.005)	(0.007)
R-squared	0.947	0.939	0.957
Observations	8748	5688	3060
Municipalities	729	474	255

All regressions estimates include municipality–level fixed effects. Significant at: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sources: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Agriculture of Colombia.

Table A4: The effects of precipitation shocks on total sown area for non-perennial crops (in logs), using different thresholds

Variables	All	Rural	Non-Rural
Number of lack rain shocks p20	-0.005	0.004	-0.026^{**}
	(0.006)	(0.008)	(0.010)
Lag number of lack rain shocks p20	-0.001	-0.001	-0.002
	(0.005)	(0.007)	(0.009)
Number of excess rain shocks p80	0.005	0.008	-0.001
	(0.006)	(0.008)	(0.008)
Lag number of excess rain shocks p80	0.006	0.002	0.012
	(0.006)	(0.008)	(0.008)
R-squared	0.824	0.806	0.856
Number of lack rain shocks p10	-0.013^{*}	-0.009	-0.020
	(0.007)	(0.009)	(0.012)
Lag number of lack rain shocks p10	-0.004	-0.010	0.007
	(0.007)	(0.009)	(0.012)
Number of excess rain shocks p90	0.004	-0.002	0.011
	(0.007)	(0.010)	(0.010)
Lag number of excess rain shocks p90	0.008	-0.001	0.021
	(0.007)	(0.009)	(0.010)
R-squared	0.824	0.806	0.856
Number of lack rain shocks 1 sd	-0.011	-0.000	-0.032^{***}
	(0.007)	(0.009)	(0.011)
Lag number of lack rain shocks 1 sd	0.002	0.006	-0.007
	(0.006)	(0.008)	(0.010)
Number of excess rain shocks 1 sd	0.001	0.002	-0.001
	(0.006)	(0.009)	(0.008)
Lag number of excess rain shocks 1 sd	0.008	0.005	0.011
	(0.006)	(0.008)	(0.008)
R-squared	0.824	0.806	0.856
Number of lack rain shocks 1.5 sd	-0.026^{*}	-0.026	-0.026
	(0.013)	(0.017)	(0.020)
Lag number of lack rain shocks 1.5 sd	-0.006	-0.017	0.017
	(0.011)	(0.015)	(0.016)
Number of excess rain shocks 1.5 sd	0.007	0.002	0.014
	(0.007)	(0.009)	(0.010)
Lag number of excess rain shocks 1.5 sd	0.008	0.000	0.021
	(0.007)	(0.010)	(0.009)
R-squared	0.824	0.807	0.856
Observations	8748	5688	3060
Municipalities	729	474	255

All regressions estimates include municipality–level fixed effects. Significant at: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sources: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Agriculture of Colombia.

Table A5: The effects of precipitation shocks on total sown area (in logs) at the extensive margin

	Total			Perennial			Non-Perennial		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	Rural	Non-Rural	All	Rural	Non-Rural	All	Rural	Non-Rural
= 1 if at least one lack rain shock s2	-0.006	-0.010	0.004	0.003	-0.012	0.034	0.020	0.001	0.060
	(0.014)	(0.019)	(0.015)	(0.018)	(0.022)	(0.029)	(0.031)	(0.038)	(0.052)
Lag = 1 if at least one lack rain shock s2	0.010	0.015	0.001	0.025	0.025	0.027	-0.031	-0.049	0.010
	(0.013)	(0.017)	(0.016)	(0.019)	(0.023)	(0.032)	(0.036)	(0.048)	(0.048)
= 1 if at least one excess rain shock s2	-0.006	-0.013	0.008	-0.036***	-0.038**	-0.032*	0.025	0.016	0.043
	(0.008)	(0.010)	(0.012)	(0.012)	(0.016)	(0.019)	(0.019)	(0.025)	(0.026)
Lag = 1 if at least one excess rain shock s2	-0.001	-0.013	0.019	-0.008	-0.014	0.004	0.020	0.001	0.054*
	(0.010)	(0.012)	(0.014)	(0.013)	(0.017)	(0.019)	(0.021)	(0.028)	(0.030)
R-squared	0.927	0.917	0.941	0.947	0.939	0.956	0.824	0.806	0.856
Observations	8,748	5,688	3,060	8,748	5,688	3,060	8,748	5,688	3,060
Municipalities	729	474	255	729	474	255	729	474	255

All regressions estimates include municipality–level fixed effects. Significant at: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sources: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Agriculture of Colombia.

Table A6: The effects of precipitation shocks on total sown area (in logs) by categories of altitude

(a) 0–1000 meters above sea level

	Total			Perennial			Non-Perennial		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	Rural	Non-Rural	All	Rural	Non-Rural	All	Rural	Non-Rural
Number of lack rain shocks 2 sd	0.004	0.010	-0.009	-0.001	0.002	-0.008	0.052*	0.052*	0.047
	(0.011)	(0.014)	(0.017)	(0.015)	(0.021)	(0.018)	(0.027)	(0.031)	(0.055)
Lag number of lack rain shocks 2 sd	0.028***	0.039***	0.002	0.031**	0.036*	0.017	0.025	0.048	-0.032
	(0.011)	(0.012)	(0.020)	(0.015)	(0.019)	(0.023)	(0.027)	(0.032)	(0.047)
Number of excess rain shocks 2 sd	-0.007	-0.008	-0.007	-0.020***	-0.015	-0.028**	0.018	0.024	0.011
	(0.005)	(0.007)	(0.007)	(0.007)	(0.009)	(0.012)	(0.012)	(0.016)	(0.016)
Lag number of excess rain shocks 2 sd	-0.005	-0.007	-0.002	-0.008	-0.004	-0.014	-0.002	-0.020	0.020
	(0.007)	(0.010)	(0.009)	(0.006)	(0.009)	(0.009)	(0.015)	(0.023)	(0.013)
R-squared	0.907	0.895	0.923	0.907	0.883	0.937	0.829	0.823	0.841
Observations	4,380	2,784	1,596	4,380	2,784	1,596	4,380	2,784	1,596
Municipalities	365	232	133	365	232	133	365	232	133

(b) 1000–2000 meters above sea level

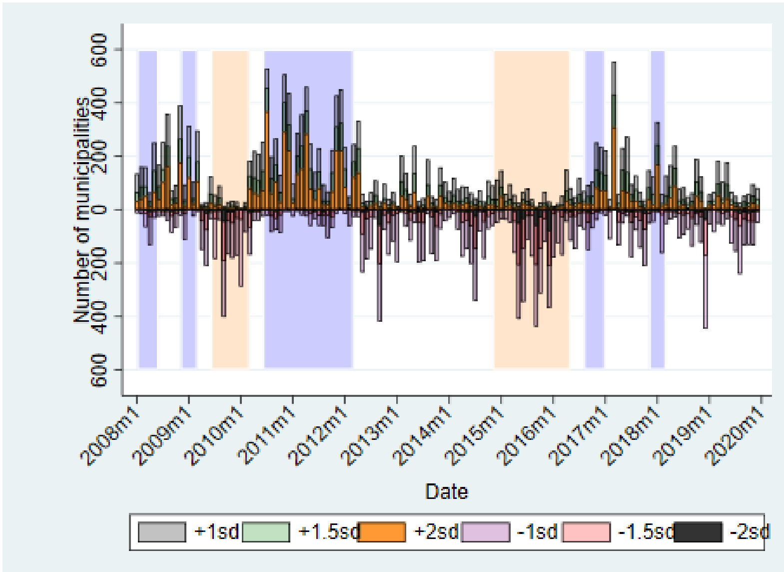
	Total			Perennial			Non-Perennial		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	Rural	Non-Rural	All	Rural	Non-Rural	All	Rural	Non-Rural
Number of lack rain shocks 2 sd	-0.011	-0.017	0.005	0.009	0.011	0.002	0.002	-0.023	0.065
	(0.014)	(0.019)	(0.013)	(0.017)	(0.023)	(0.015)	(0.045)	(0.055)	(0.081)
Lag number of lack rain shocks 2 sd	-0.006	-0.010	0.002	0.012	0.021	-0.009	-0.004	-0.064	0.112*
	(0.014)	(0.020)	(0.013)	(0.016)	(0.022)	(0.018)	(0.051)	(0.069)	(0.064)
Number of excess rain shocks 2 sd	0.003	0.002	0.006	-0.001	-0.005	0.007	0.028	-0.002	0.078**
	(0.004)	(0.006)	(0.005)	(0.005)	(0.007)	(0.007)	(0.020)	(0.025)	(0.031)
Lag number of excess rain shocks 2 sd	0.006	0.006	0.006	0.007	0.005	0.010	0.040**	0.046*	0.029
	(0.004)	(0.006)	(0.006)	(0.005)	(0.006)	(0.006)	(0.019)	(0.024)	(0.032)
R-squared	0.958	0.945	0.976	0.961	0.945	0.981	0.733	0.704	0.781
Observations	2,628	1,812	816	2,628	1,812	816	2,628	1,812	816
Municipalities	219	151	68	219	151	68	219	151	68

(c) More than 2000 meters above sea level

	Total			Perennial			Non-Perennial		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	Rural	Non-Rural	All	Rural	Non-Rural	All	Rural	Non-Rural
Number of lack rain shocks 2 sd	0.020	0.021	0.014	0.018	-0.033	0.103	0.067	0.087	0.025
	(0.033)	(0.048)	(0.032)	(0.043)	(0.047)	(0.087)	(0.044)	(0.062)	(0.041)
Lag number of lack rain shocks 2 sd	0.021	0.024	0.023	0.035	0.016	0.054	0.037	0.033	0.051
	(0.029)	(0.047)	(0.026)	(0.043)	(0.040)	(0.084)	(0.052)	(0.083)	(0.040)
Number of excess rain shocks 2 sd	-0.003	-0.016	0.009	-0.076***	-0.066***	-0.086***	0.012	-0.008	0.031
	(0.010)	(0.015)	(0.012)	(0.016)	(0.024)	(0.023)	(0.017)	(0.023)	(0.024)
Lag number of excess rain shocks 2 sd	-0.008	-0.027*	0.011	-0.037*	-0.059**	-0.016	0.013	0.003	0.023*
	(0.008)	(0.014)	(0.010)	(0.022)	(0.027)	(0.034)	(0.011)	(0.020)	(0.013)
R-squared	0.894	0.880	0.914	0.920	0.929	0.903	0.812	0.764	0.867
Observations	1,740	1,092	648	1,740	1,092	648	1,740	1,092	648
Municipalities	145	91	54	145	91	54	145	91	54

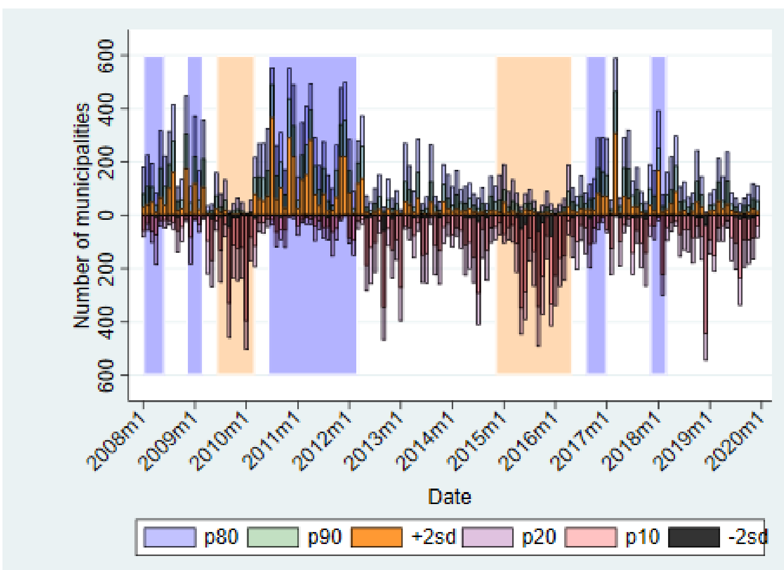
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Figure A1: Distribution of Rainfall Shocks (comparing with different standard deviations), 2008–2019



Light blue areas corresponds to La Niña episodes, whereas light red areas refers to El Niño episodes.
Source: Colombian Institute of Hydrology, Meteorology and Environmental Studies

Figure A2: Distribution of Rainfall Shocks (comparing with different percentiles), 2008–2019



Light blue areas corresponds to La Niña episodes, whereas light red areas refers to El Niño episodes.
Source: Colombian Institute of Hydrology, Meteorology and Environmental Studies