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Agricultural Technology adoption and Adaptation Strategies Under Climate Change: Micro-evidence from Niger

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Abstract: Many regions of Sub-Saharan Africa (SSA) are experiencing fast increases in human population pressure and urbanization. By 2050, feeding a planet of 9 billion people will require an estimated 50 percent increase in agricultural production. Farmers in in the Sahel are exposed to a highly variable weather over time, and to their limited adaptive capacity, therefore often use livestock as income generator, export earnings, and as insurance against weather risk. There is an increasing demand for livestock products, which increase pressure on crop residues use on the land. In this study, I use panel socio-economic data combined with village rainfall level from Niger to investigate how different types of weather shocks including drought and wet conditions influence farmer's inputs adaption. Using cluster and year fixed effects estimations, I find that exposure to drought results in a strong and deep decrease in use of crop residues on the soil, which is particularly concerning because crop residue is crucial for soil protection, and fertility. I also find that one of the reasons poor Nigerien farmers remove crop residues on their land, is for livestock feeding purposes. This results in a bad synergy because removing crop residues could decrease long-term food production, and might keep households in poverty trap. Other determinants affecting inputs adoption on the land including temperature increase, income, farm size, and rainfall level of the previous year. I discuss policy recommendations.

Key words: Weather variability; Agricultural technology adoption; Adaptation; Risk; Fixed effects; Niger.

Introduction

By 2050, feeding a planet of 9 billion people will need an estimated 50 percent increase in agricultural production (World Bank). Climate change threatens agriculture and livestock assets in complex ways. Food security is becoming a problem worldwide, affecting the world's poorest. At the regional level, the biggest losses in cropland due to climate change are likely to be in Africa. The change in climate may consist of worsening weather conditions in some regions and improved weather in other regions and in a world without transaction costs, there may be migration from regions with deteriorating climate to regions with improving climate (Zilberman et al., 2012). Climate change also has a direct and indirect effects on livestock assets, and other assets. Direct effects occur on reproduction, animal growth, and its products; while indirect effects occur on availability, and quality of animal feeds such as pasture and forage (Seo and Mendelsohn, 2006a).

In poor countries for example, over the 1950–2003 period, a 1-degree Celsius increase in temperature in each year reduced economic growth in that year by 1.1 percentage points (Dell et al. 2008). Adapting to climate change could raise the expected agricultural payoffs (Kelly et al., 2005). Using a survey conducted in Ethiopia, Di Falco et al. (2011) find that there were significant differences in food productivity between farm households that adapted and those that did not adapt. The speed of adjustment to changing climate is an important question in economics, and is far-reaching for policy design across many domains (Hornbeck, 2012). Changes in the climate involve the long run period, and the key empirical challenge is in anticipating how economic agents will adapt in the light of these long run changes. In case of a large and rapid adjustment, the resulting economic damages related to climate change could be minimal. If the adjustment is slow or impossible, the global damages from climate change could be much larger. A strategy used by farmers to adapt to changes in climate is adoption of different inputs. The problem is that poor countries are most adversely affected by the negative effects, lack adaptation capacities, and are constrained to implement short-term survival strategies. For example, poor farmers in the Sahel are exposed to a highly variable weather over time and space, and farmers tend to use livestock as source of income, and as insurance against weather risk (Fafchamps and Gavian, 1996). This leads to an increase in use of land crop residues, especially in dry periods, to feed the animals, and keep them alive and healthy (Duncan et al, 2016).

Moreover, livestock is one of the fastest growing agricultural subsectors in developing countries (33 % of GDP) and is quickly increasing. The total meat production in the developing world tripled between 1980 and 2002, from 45 to 134 million tons (World Bank 2009). The demand for animal products is expected to increase in Sub-Saharan Africa, especially West Africa, by more than 250% by 2020 (Club du Sahel/OECD, 1998), driven by population growth, urbanization and increasing incomes (Delgado 2005). The country of focus in this study is Niger, which has the highest fertility rate in the world, is among the poorest countries in the world, and highly food insecure. For poverty alleviation and hunger eradication, it becomes important to look at how possession of livestock might influence strategies adopted by Nigerien farmers in the field, which has been done by few studies.

The closest paper to this study is Solomon et al (2016). The authors use the 2011 World Bank Niger cross-sectional data on farming households to investigate the determinants of technology adoption under climate change. In this study, I use long-term historical data on temperature and rainfall across Niger from 1983-2014 that I combine with household's socio-economic data, and data on farm practices adopted in 2011 and 2014, to investigate how farmers adapt to weather shocks. Particularly, I look at whether or not farmers' adaptive responses to different weather outcomes including drought and wet conditions differ with the possession of livestock.

Many studies have used a cross-sectional approach to investigate adoption. One of the greatest empirical challenges is the identification of adaptation responses to changing climatic conditions. There is an active literature using cross-sectional approaches to the problem, which are prone to suffering from the omitted variable issues (Aufhammer and Schlemker, 2014). To avoid this issue, other studies use panel data to identify the effects of exogenous climate outcomes (Schlenker and Roberts (2009), Dell, Jones, and Olken (2012)). The idea behind is that while average climate could be correlated with other time-invariant factors unobserved to the econometrician, short-run variation in climate or weather variation within a given area is plausibly random, and thus better identifies the effects of changes in climate variables on economic outcomes. The challenge with the use of panel data is that strategies adopted for a long run adjustment might not be feasible in the short run, and a quick response to weather change in the short run such as irrigation in a dry year, could not necessarily be implemented in the long run (Burke and Emerick, 2015).

To construct the exposure to weather shocks, I create a normal distribution of the rainfall across all clusters; I then create an exposure to drought dummy variable that takes the value 1 if the Standard Precipitation Index (SPI) for the reference year was 1 standard deviation below the long-term average (1983-2014). The same process was applied to construct exposure to wet conditions if the SPI was 1 standard deviation above the long-term average. I look at how farmers will adjust the use of three major inputs on their land including crop residues, organic fertilizers, and modern inputs. Crop residues are a conservative agricultural technique that creates a drought resistant soil by covering the soil, improving soil moisture, and water infiltration; organic fertilizers come mainly from living organisms, and improve the natural fertility of the soil; modern inputs which comprise chemical fertilizers and hybrid seeds provide high level of nutrients to the soil, but could potentially decrease long-term soil fertility. I find that drought results in a strong and deep decrease in the use of crop residues on the soil, which is particularly concerning because of the importance of crop residues on long-term land sustainability. One of the most important findings from my study is that, this negative adaptive response is partly connected to the possession of livestock. In fact, farmers remove crop residues on land to keep the animals alive and healthy, since livestock is an important asset. One explanation could be the effect of an increasing demand for livestock products such as meat from urban areas in Niger. I also find that farmers successfully adapt when exposed to wet conditions by using more crop residues on their land. This helps protecting the soil against wind and water erosions. Moreover, household's characteristics including farm size, household size, land ownership, income status, and previous year rainfall distribution affect inputs adoption as well.

The rest of the study is organized as follows: Section 2 of my paper presents the literature review, which combines different strands of literature. Section 3 presents a background of Niger. Section 4 examines the methods used in this study. In Section 5, I present the results and provide possible explanations. Section 6 concludes and provides some policy recommendations.

2. Literature Review

I attempt to link different strands of literature that have developed separately but that are key in discussing adaptation in agricultural systems; namely that on risk and adoption of agricultural technologies based in the economic tradition, and that on vulnerability and adaptive capacity as presented from different disciplinary perspectives in the climate change literature.

Both the literature on adoption and that on adaptation were developed in other disciplines and were adopted and later adopted by economists. The research on adoption originated in sociology, and its introduction to economics filled a gap and explained behavioral patterns that were overlooked by neoclassical microeconomic models. Adaptation is an essential concept in biology, and although there were several earlier attempts to integrate this idea into economics, now it has become an important element in the economics of climate change (Zilbermann et al, 2012).

2.1 Adoption

Starting with the determinants of practice selection, much of the literature on adoption and diffusion comes from the adoption in agriculture. This literature indicates that there are several barriers to technology adoption including risk associated with the technology, information, farmer's attitude toward risk, limited access to credit, education, extension services, access to the technology. Adoption is an individual decision on the technology in the sense of whether to adopt (discrete) or not, and can also be associated with continuous variables (quantity used). Rogers (2003) defines technology adoption as a decision of "full use of an innovation as the best course of action available". Some people adopt ideas when they are first introduced, others wait a long time, while some never adopt (Beal & Bohlen, 1957). The idea that differential adoption of new technology can explain productivity differences across regions had gained acceptance in the economics literature. Income differences have been directly related to differences across countries in technology adoption (Comin and Hobjin, 2004), and small differences across countries in barriers to technology adoption could explain much of the difference in income levels and growth across countries.

Economists and sociologists have extensively contributed to the literature on the adoption and diffusion of technological innovations in agriculture. The pioneer work on adoption of an innovation was done by economist Griliches (1957). His work was done after Ryan and Gross (1943) had reported that a complicated range of objective and subjective considerations has shaped the reception of hybrid corn cultivation, as a substitute for the traditional farming regime based on open-pollinated corn-seed within Iowa farming communities. Griliches specifically studied the introduction and acceptance (diffusion) of hybrid corn among U.S. farmers in the Midwestern United States. His conclusion emphasized the role of economic factors such as expected profits, economic incentives, and scale in determining the varying rates of hybrid corn diffusion across the Midwestern states. In other terms, differentials in economic incentives and profitability of hybrid corn is the principal systemic factor affecting the speed of its diffusion. The model, however, assumes homogeneity across farmers. The literature eventually moved beyond his initial contribution, both in the theoretical analysis of technology adoption and in the specific econometric tools that have been employed.

Critical responses to Griliches (1957) that appeared in Rural Sociology from sociologists Babcock (1960), and Havens and Rogers (1962), emphasized on personal and social characteristics of the individual decision-maker, the structure of the networks, and interactions among decision makers are main determinants of the adoption and diffusion processes. Rogers (1962) modeled adoption as a multistage process with five stages including the knowledge about the technology, the decision to adopt, and the implementation. The main idea behind his imitation model is the presence of heterogeneity among farmers such as personality characteristics, ability or risk preferences that can influence adoption. Griliches (1960, 1962) acknowledged the critics and pointed out that the considerations the critics raised would affect both the reality and the perception of the innovation's profitability.

There can be heterogeneity across farmers in their perception of returns using a specific technology. This means that if one agent that used more fertilizer has higher yields than the lower user, it does not imply that all farmers should use more fertilizer. Two farmers can use the exact same amount of inputs but end with different yields, because of the potential difference in their land quality as well. Therefore, a farmer might decide not to adopt a lower yields variety because the higher yield variety might not be suitable for his soil. And in that case, it doesn't mean that rejecting the innovation is inconsistent with maximization behavior.

At this point, the literature on the microeconomics of adoption and diffusion began to move in the same direction. This development turned upon a more formalized acknowledgment of the implications of heterogeneities in the adopter population.

Considering, the implications of population heterogeneities and combined with fixed costs of adoption, David (1969) and Feder et al (1985) developed the "threshold model". It allowed for the possibility that expected scale of operations might enter investment decisions involving choices between new and old techniques, such, that given the relative prices of the fixed and variable inputs, there would be a "threshold" output scale below which adoption would not occur, if the decision agents were myopic cost-minimizers. Feder, Just and Zilbermann (1985) was the first major empirical study on agricultural technology adoption using new type of data (plot-level panel data) and techniques, with the idea that adoption is a dynamic process. This has contributed to a big advancement in the topic of adoption. In their model, farmers have their land used either with traditional inputs, or modern inputs such as new seed variety, inorganic fertilizers. In either case, the adoption behavior is an investment decision and, as any investment decision, is constrained and the farmer faces uncertainties associated with it. He forms expectations of the profitability of modern inputs relative to the traditional input on plot j in period t, and considers the farm characteristics, such as farm size, plot characteristics such as soil type or topography, and individual characteristics such as risk preferences.

An important variable that largely affects technology adoption is farm size. The latter contains the element of risk in the sense that small farms holders are more risk averse than large farms holders (Feder et al., 1982). Foster and Rosenweig (2010) also argue that size is a large barrier for adoption of technologies in developing countries, and a major contributor to low productivity. Another important variable in adoption of new technology is learning. Since adoption is a process, learning plays a key role, because it reduces uncertainty (Chatterjee & Eliashberg, 1990). Learning can happen through own experience of profit differentials using that technology, it can be augmented through network externalities (Katz and Shapiro, 1986), or through exposure to agricultural extension services. Education is often linked with learning, in the sense that more educated agents are better able to learn, to decode new information faster and more efficiently (Foster and Rosenweig, 2010a). Cameron (1999) studied the impact of learning from own experience on adoption of High Yielding Variety (HYV) cotton seed using ICRISAT panel data on 31 households in Kanzara, India. He proposes a simple model of learning where households are assumed to maximize their utility, subject to constraints, and adopt a given technology if and only if the technology is available and affordable, and if at the same time the selection decision is expected to be beneficial (in terms of profits or otherwise) (de Janvery et al., 2010). The household is uncertain of the profitability of the modern inputs relative to the traditional ones, and the household learns about this from agricultural extension services or from own experience. Cameron (1999) also suggests that one can think of the farmers supplementing their learning from sources at the village level learning (such as weather shocks) with learning from own experience or extension services. The study concludes that learning plays an important in adoption, as well as unobserved household heterogeneity factors.

Field experiments have recently started being used in the development world to overcome certain issues in analyzing constraints to technology adoption. The technique is useful because it creates variation in inputs use that is orthogonal to land, farmer quality as well as time-varying profit shocks. Rousu et al. (2007) using experimental auctions in three US locations and two European locations, examines the value of information on consumer's willingness to pay; they find that information about environment, characteristics of the product, prior belief, and the source of information about the new product affect WTP of consumer to pay for Genetically Modified food. Duflo et al. (2008) conducted an experiment on the impact of fertilizer subsidy on fertilizer use in Kenya to understand the constraints of adoption. They find no impact of education on technology adoption.

Although the studies presented highlight a set of determinants of technology adoption, they do not investigate the impact of climate risk on adoption, or how farmers adjust their choices of inputs when facing climate shocks. Climate variability is likely to have a predominant direct effect through the psychological effects of risk and uncertainty (Porcelli and Delgado, 2009).

2.2 Adaptation to climate change

Turning to the literature on adaptation or adaptive capacity, the concepts of exposure and sensitivity, as well as the scale of adaptive capacity are key. Adaptation can be defined in different ways. Mendelsohn et al. (1994) using a Ricardian approach, defined it as adopting the best technology available given the new weather. Adaptation is sometimes modeled as a transition from one equilibrium to another in response to a shock, as in studies on the impacts of climate change, (Schlenker et al., 2005; and Deschenes & Greenstone, 2007). A successful adaptation is any adjustment that reduces the risks associated with climate change, or vulnerability to climate change impacts, to a predetermined level, without compromising economic, social, and environmental sustainability (de Franc Doria et al. 2009). Adaptive capacity expresses the ability of a system to prepare for stresses and changes in advance or adjust and respond to the effects caused by the stresses, thereby modulating the sensitivity to decrease vulnerability (Smit et al. 1999). A more recent definition of adaptation is provided by the National Research Council (2010a, p. 19), and is considered as an adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects. Although the adjustment can be a proactive or reactive behavior, historically, most adaptation activities have been reactive (Orlove 2005), meaning, in response to a shock. Climate change however, offers an opportunity for proactive adaptation: adaptation in anticipation of the major changes predicted by scientists. An example of proactive adaptation is integrating the use of climate forecasts into cropping decisions (Howden et al. 2007).

There are many adaptation strategies including adoption of certain inputs, risk management products, or migration. The logic behind adaptation is that once a decision maker realizes that a change occurs, they modify their objective functions. At the farm level, there are a wide range of strategies that may contribute to adaptation including: modifying planting times and changing to varieties resistant to heat and drought (Phiri and Saka, 2008); development and adoption of new cultivars (Eckhardt et al. 2009); changing the farm portfolio of crops and livestock (Howden et al., 2007); improved soil and water management (Kurukulasuriya and Rosenthal, 2003), adoption of crop insurance (Mendelsohn, 2006), and migration (Warner et al., 2009). Asfaw et al. (2016) using cross-sectional data of Niger find that the probability of using modern inputs and organic fertilizer is negatively and strongly correlated with variability in rainfall and temperature.

2.3 Literature on Importance of Crop residues and demand for livestock products

The core element in this literature is the trade-off between the use of crop residues on the land and for livestock feeding. To maintain soil fertility, in particular soil organic carbon, biomass needs to be returned to the soil on a regular basis and in adequate amounts. The use of crop residues in a conservation agriculture technique that allows to create a drought-resistant soil. Hudson (1994) find that 1-percent increase in soil organic matter increases the available water holding capacity in the soil by 3.7 percent. Moreover, Increased soil cover can result in reduced soil erosion rates close to the regeneration rate of the soil or even lower (Debarba and Amado,1997). However, farmers also need to sustain their livestock, and there is pressure to remove residual biomass in the form of straws, and feed them to livestock (Giller et al., 2009). Grazed feed resources used to form the major component of livestock diets in Ethiopia (Mekasha et al., 2014). This trend of crop residues removal could be due to increasing urban demand for livestock products, especially meat, and using livestock to smooth income during bad weather shocks as well. Over the period 1968-1988, large quantities of livestock were exported from Niger to Nigeria to satisfy the exploding demand for meat following the oil boom. Livestock prices influence demand for livestock, and farmers respond by feeding more crop residues to livestock. (Fafchamps and Gavian, 1996).

This study builds on previous work, a cross-sectional analysis that used the 2011 data from the same country to identify determinants of technology adoption (Asfaw et al., 2016). I expand the analysis by using both the 2011 and 2014 rounds of data (panel) to understand adaptation, and specifically how adaptation interacts with possession of livestock. I hypothesize that exposure to different weather outcomes including drought and wet conditions will not change farmers' decisions to use inputs on their land.

3. Country Background

Niger is a large landlocked country of 1.27 million square kilometers in Western Africa, bordered by Algeria, Benin, Burkina Faso, Chad, Libya, Mali and Nigeria. The northern part is covered by the Sahara desert that occupies about 75% of the country. Niger is among the poorest countries in the world. About 14% of Niger's GDP is generated by livestock production, including camels, goats, sheep and cattle (Asfaw et al, 2016). The high level of poverty is associated with high level of food insecurity, with only 56 kilocalories per person per day (World Bank). In addition, Niger has the highest total fertility rate of any country in the world, averaging close to 7 children per woman in 2016. Agriculture remains essential for rural households with 87% of the population relying on crop production and livestock growth for their livelihoods (Smith, 2011), and 99% of the cultivable land is rely on rainfall. The weather is highly variable in the Sahel, in general, causing frequent droughts and floods, degrading the land quality and preventing food production from keeping up with population growth. This makes the need of adaptation strategies very critical (IPCC, 2011).

Farmers in Niger often use livestock as source of income, and as insurance against weather shocks (Fafchamps and Gavian, 1996). In recent years, Niger has suffered droughts on average once every 2 years, and in 2009 the population was affected by both droughts and floods (Smith, 2011). The 2009 drought is reported to be among the most severe experienced by the Nigerien population. Although the main cultivated crops are well adapted to the tough climate conditions of the country, insufficient rains caused national crop production to drop by 31% compared to 2008 (IRIN, 2010). Given all those details, Niger is an interesting setting to understand how farmers react to dramatic changes in weather, and it is especially important for the new 17 Sustainable Development Goals, which include poverty reduction and hunger eradication.

4. Methods

4.1 Data Description

I use two main sources of data in my analysis. The first set is recently released socio-economic data from the Niger National Survey of Household Living Conditions and Agriculture (ECVMA). The second set of data is historical data on surface rainfall and temperature from the National Oceanic and Atmospheric Administration (NOAA) and the European Centre for Medium Range Weather Forecasts (ECMWF), respectively.

The socio-economic panel data is the Niger ECVMA survey collected in 2011 and 2014. The program was implemented by the Niger Institut National de la Statistique (INS) in collaboration with the World Bank. The ECVMA is designed to have national coverage, including both urban and rural areas. The target population is drawn from households in all eight (8) regions of the country. The sample was chosen through a random two-stage process. In the first stage, 270 enumeration areas (EAs) or communities were selected, with the probability proportional to size using the 2001 General Census of Population and Housing as the base for the sample and the number of households as a measure of size. In the second stage, 12 or 18 households were selected with equal probability in each urban or rural ZD, respectively.

In 2011, the first visit took place at the end of the planting season (July to September), and the second visit took place at the end of the harvest season (November to January). In 2014, the first visit was conducted post-planting season (September to November), and the second visit was conducted post-harvesting season (January to March). To ensure the panel nature of the dataset, the same households interviewed in 2011, were tracked in 2014. Households that did not move were interviewed in their existing location. Households that had moved to other locations in Niger were followed and interviewed in their new locations if they could be found in the new location. Households that moved outside of Niger were not followed.

The household, agriculture/livestock and community/price questionnaires were administered during the first visits. During the second visits, only household and agriculture/livestock questionnaires were administered. In 2011, the total sample size after both visits was 3,968 households drawn from 270 enumeration areas EAs, and 3,614 in 2014. However, for this study, I restricted the sample to households involved in farming activities during the rainy season. This results in an unbalanced panel of 2,338 households in 2011, and 2,105 households in 2014.

The household questionnaire was designed to provide information on various aspects of household welfare in Niger, such as household composition and characteristics, health, wage employment and income sources, as well as data on consumption, food security, non-farm enterprises, and durable and agricultural asset ownership. For households that were involved in agricultural activities, data were collected on access to land with information such as land tenure, labor and non-labor input use, and crop cultivation and production at the plot level. Data were also collected at the community level to capture determinants of system-level capacity in terms of enabling factors for adaptation, which include issues related to collective action, access to information and to infrastructure among other factors.

Rainfall data were extracted from the Africa Rainfall Climatology version 2 (ARC2) of the National Oceanic and Atmospheric Administration's Climate Prediction Center for each decade (i.e., 10-day intervals) covering the period of 1983–2014. ARC2 data are based on the latest estimation techniques daily, and have a spatial resolution of 0.1 degrees (10 km)[1]. Temperature data are surface temperature measurements at each decade for the period of 1989–2010 obtained from the ECMWF at a spatial resolution of 0.25 degrees (50 km)[2]. These data are then merged with the socio-economic data at the EA/community level (270 EAs in ECVMA) to create a set of exposure to weather variables to represent the short- and long-term variations both within and across years in rainfall and temperature.

4.2 Descriptive Statistics

Given the data set, I focus on three (3) different potentially climate-smart agricultural practices (crop residues and organic fertilizers) and consider two practices that are aimed primarily at improving average yields (improved seeds and use of inorganic fertilizers). Since there were few observations on use of improved seeds, I created a variable modern input that combines inorganic fertilizer and improved seed.

Crop residues and organic fertilizers use on the land is a conservation agriculture method

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[1] Average of a 10-km radius buffer of decadal sum of daily values per each EA centroid. For more details on ARC2 algorithms, see http://www.cpc.ncep.noaa.gov/products/fews/AFR_CLIM/AMS_ARC2a.pdf

[2] Point extraction per each EA centre point of values of an average of a 50-km radius buffer of decadal values.

consisting on leaving residue from past harvest such as leaves, stalks and pods of legume crops to provide natural nutrients to the soil. This technique has many benefits including improvement in soil fertility originating from organic matter, earthworms and other soil life. It provides healthy crops and good yields. Another benefit is that it covers the soil, reducing erosion, and preserving the soil for the future. Modern inputs, on the other hand, are chemical fertilizers and hybrid seeds that provide higher yields than using crop yields and organic fertilizers, but the risk is that it might reduce the long-term natural fertility of the soil.

The use of crop residues is more widespread in the rural areas of the country and particularly in the agricultural and agro-pastoral zones (Asfaw, 2016). Although Niger is among the world's largest producers of crop residues, 35% of the households use crop residues on their land during both years 2011 and 2014. In fact, crop residues (CR) have become a limited resource in mixed crop-livestock farms, which form the dominant farming system in the developing world (Herrero et al., 2009, 2010). The use of organic fertilizer is another major component of a sustainable agricultural system and a commonly suggested method of improving soil fertility while capturing economies of scope in crop–livestock systems. The data show that organic fertilizers (which is composed of animal manure, compost, and green manure) are used by 48% of the households in the sample in 2011, and by 54% in 2014. Despite the potential productivity benefit, the proportion of plots planted with improved varieties in Niger is only about 4%. I also consider the utilization of inorganic fertilizers, and the data show that about 18% of the sample used inorganic fertilizer on their land in 2011, and 24% in 2014. Mixed cropping, which involves planting different types of crops on the same parcel, is practiced by 80% of the households in the sample. It is important, however, to point out that for farmers in Niger, crop residues are highly valuable as they are used as feed for livestock, and as fuel for cooking.

In 2011, 21% of the households in the sample have reported being affected by erosion, and the number increased to 27% in 2014. This problem of environmental degradation is particularly acute in the pastoral areas, where 31% of the households report being affected by erosion, as opposed to 24% in agro-pastoral areas. Despite the high rate of erosion, the use of an anti-erosion measure is very low in all the land use types. Only 5% in 2011, reported using anti-erosion techniques aiming to offset the effects of soil degradation, and the number shrank to 2% in 2014.

The average age of household's head is 46 years with a standard deviation of 14. The average size of household is 7 with a standard deviation of 4. The average number of years of education within the household is about 4 years with a standard deviation of 5 (See Table 3).

4.3 Empirical strategy

Based on the extensive literature on the choice of farming practice (including input use), I model the farming practice selection decision as the outcome of a constrained optimization problem by rational agents (Feder et al., 1985; Foster and Rosenzweig, 2003). Most of the previous studies use cross-sectional data to model adoption, because panel data are difficult to come by, resulting in an omitted variable problem. The same issue of omitted variables bias is encountered when measuring the effects of climate change on different outcomes (Schlenker et al. 2014).

In the model of adoption, households are assumed to maximize their utility, subject to these constraints, and adopt a given technology if and only if the technology is available and affordable, and if at the same time the selection decision is expected to be beneficial (in terms of profits or otherwise) (de Janvery et al., 2010). The household is uncertain of the profitability of the modern inputs relative to the traditional ones, and the household learns about this from agricultural extension services. When forming expectations of the profitability of using modern inputs relative to traditional inputs, the farmer considers the household or farm characteristics such as farm size, plot characteristics such as soil type or topography, his or her knowledge about the inputs, and observes the weather.

The model used in this study is a cluster and year fixed effects[3] estimation. The fixed effects model addresses the problem of unobserved heterogeneity and exogeneity. In other words, it controls for all time-invariant differences between households or clusters, and the estimated coefficients are unbiased. The complete model is:

$$\mathbf{Adoption_{it} = B_0 + B_1\,Rainfall\ shock_{ijt} + B_2\,Temperature_{ijt} + B_3\,Controls_{it} + C_i + e_{it}}$$

$$\mathbf{for\ each\ i=1\ldots,\ n,\ and\ j=\ 1\ldots,\ m}$$

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[3] Hausman test proposed by Hausman (1978) was done between fixed and random effects to test for the exogeneity of the unobserved household effects. P>chi2 =0.000, thus, fixed effect model yields consistent estimators.

where,

$Adoption_{it}$ represents adoption of a farming practice (1 if the household adopts, 0 otherwise) at year t, and the farmer can adopt either crop residues, organic fertilizers or modern inputs on his land, $Temperature_{ijt}$ is the total extra temperature above 29 degrees Celsius for the growing season in cluster j at year t, Rainfall $shock_{ijt}$ is a dummy representing whether or not, during rainy season, in cluster j, at year t the rainfall level is one (1) standard deviation above, and below the historical rainfall average (1983-2014). The variable $Controls_{it}$ represents a set of household control variables, including farm size, family size, income status, access to mobile phone, livestock size, whether the household's head is educated or not, the non-agricultural wealth index, land ownership, and the rainfall distribution of the previous year. Farm size is considered as an indicator for risk level of farmers, with small farmers being more risk averse. Family size is considered as a potential indicator of labor supply for production, and labor blockages can also be a significant constraint to the use of some farm management practices. The variable income status is a dummy indicating if a household annual per capita expenditures is below the national poverty line. I expect poor households to have constraints in adoption of modern inputs since it requires access to capital. Education has been found by some authors to be positively related to adaptation to climate shocks. The rainfall distribution of the previous year is included as a control variable because it serves as a proxy of the agricultural income level farmers had the previous year, and therefore might influence their current adaptation strategies. All time invariant factors such as types and topography of soil are absorbed by the fixed effects C_i. Thus, effects of temperature and rainfall shocks on input adoption are thus identified from deviations from specific means. The variable e_{it} represent the error term of the model.

For the rainfall shock dummy variable, I use long-term historical data on rainfall patterns (1983-2014), and for each cluster, I create a historical long-term average rainfall. Then, for each year (growing season), I create a score of rainfall that represents a deviation relative to the long-term average rainfall level from 1983-2014 in each cluster. This results in a standard normal distribution (zero mean and unit standard deviation), with the z value being the Standard Precipitation Index (SPI) (McKee et al., 1993). The SPI values correspond to a standardization of gamma-transformed total precipitation values, therefore a SPI equal to zero implies that there is no deviation from the mean rainfall value at the chosen time scale for the analyzed period.

Positive values of SPI indicate that precipitation is above the mean value and negative values of SPI indicate that precipitation is below the mean value. Thus, humid periods are characterized by positive values of SPI (Guerreiro et al., 2008).

A one standard deviation below negative rainfall shock refers to exposure to drought, whereas a positive rainfall shock refers to exposure to wet weather. There are different thresholds below which a shortfall in precipitation can be considered a negative rainfall shock, and previous papers using the cumulative precipitation anomaly index use a variety of measures, such as one or two standard deviations from the mean. Thomas et al (2010) emphasize that using this index is straightforward to calculate, and flexible.

I finally created a variable that characterizes temperature increase using a degree-month technique (Schlenker and Robert, 2009; Wetherly and Antilla-Hughues, 2005). I first created a dataset containing only temperatures above 29 degrees Celsius, with temperature below 29 considered as 0. I then summed the extra-temperature above 29 degrees Celsius for the growing season (May-September) of each year, and within each cluster. This allows controlling for the non-linearity effects of heat above a certain threshold. Temperature is included as a control variable because of its correlation with precipitations, but it will be interesting to see how farmers also react to temperature increase above 29 degrees Celsius threshold.

My identifying assumption is that rainfall outcomes are exogenous conditional on the fixed effects, meaning that there is randomness within a village or cluster. I hypothesize that there will be no effect of exposure to rainfall shocks on inputs adoption. In other words, farmers will not adjust their inputs use when exposed to drought to wet weather. The alternative hypothesis is that farmers will adapt by changing their inputs.

5. Results

5.1 Description of weather variability and reported adaptation strategies in Niger

I provide a description of the weather variables available (both objective and subjective) and a preliminary view of how they may influence their adaptation strategies.

The amount of precipitations in the country is increasing over time. In 2011, 99 clusters among the 270-sampled experienced a drought or negative rainfall shock, as opposed to none (0) in 2014. This means that the amount of precipitations has increased from 2011 to 2014. The increasing trend was found as well by forecasts from NECSD (2006), which predicted rainfalls to increase in the Sahel region due to weather change.

Although Nigerien farmers are specialized in the cultivation of crops that are particularly resistant to high temperatures (e.g., millet and sorghum), the increase in the temperature level will eventually change farming environments in the three land use types (Asfaw et al. 2016).

I also present subjective data capturing perceptions of weather change of farming household, as well as the strategies used to adapt to and mitigate the effect of weather changes. Most of the households interviewed reported changes in rainfall and temperature patterns in the 5 years preceding the interview (See Table 1).

In all land use types, the most relevant phenomena are the early end of the rainy season, the presence of more droughts, the reduction in the amount of rainfall (likely a consequence of the drought in 2009), and the change in the distribution of rain. The general tendency for the sample households was to report an early end of the rainy season (80%), more frequent droughts (75%), less rainfall (69%), and worse rain distribution (71%), which is particularly true in pastoral areas. Although agricultural areas share the same overall patterns, 38% of the households report more frequent floods compared to 19% for both agro-pastoral and pastoral areas. About 72% and 82% of the sample households report respectively more of a delayed start and an early finish of the rainy season in the 5 years before the interview. Changes in temperatures also affected 65% of Nigerien households, who report longer heat periods.

In Table 2, I describe the most common strategies farmers report using to adapt to the effects of weather change. The most commonly used strategies are diversifying the sources of revenues, changing seeds varieties, engaging in dry season agriculture, and use methods to protect against erosion. I should also note that only 24% of the sample report prioritizing increase crop production and raising less livestock.

5.2 Determinants of Technology Adoption and Adaptation to Climate Shocks

The primary objective of this study has been to investigate the link between exposure to different weather outcomes and farmers' inputs adoption decisions as adaptation responses. The results suggest that households adjust differently when exposed to negative, and positive rainfall shocks. Both Figure 1 and Table 3 in the appendix present the cluster and year fixed effects results. These results describe how farmers in Niger respond to drought and wet conditions by changing inputs use including crop residues, organic fertilizer, or modern inputs on the land. The findings show that exposure to negative rainfall shocks reduces the likelihood of adopting crop residues on the soil by about 32%.

One explanation for this result is that when exposed to droughts, farmers use less crop residues on their field for livestock feeding purposes. To test this idea, I interact the exposure to drought to the variable logarithm of livestock size expressed in Tropical Livestock Units (TLUs), and I find that farmers with larger livestock size are 67% less likely to use crop residues on their land (see Figure 2 and Table 4). It means that farmers in drought conditions, favor the animals' nutrition and health over land sustainability, because livestock is an important asset. Livestock is a very important asset for many farmers because they provide meat, milk, hides, and manure, and they pull farm implements and carts. Thus, farmers often allow their animals to graze on crop residues in fields to keep them alive. For example, Valbuena et al (2014) using a multi-country comparative analysis including Niger to identify determinants of crop residues use find that pressures and trade-offs of residues use are common particularly in the dry season. The authors also find that crop residues became an essential resource for household activities, especially for livestock keeping; a major livelihood element of smallholder farmers in the developing world. Duncan et al (2016) also find that livestock pressure per hectare expressed as Tropical Livestock Units over land size also show consistent effects, with higher livestock density leading to more feeding and other uses, and less retention on land. Another interesting is that where livestock product marketing was important, households fed more residues to livestock.

Another possible explanation of this results is the influence of demand for meat. Economic wealth in Western Africa as elsewhere tends to be concentrated in cities, and the aggregate demand for meat is thus largely urban (Eddy, 1979). Over the period 1968-1988, large quantities of livestock were exported from Niger to Nigeria, in part to satisfy the exploding demand for meat following the oil boom. For example, Fafchamps and Gavian (1996) find that in Niger, rainfall exerts a major influence on crop output, and thus on the production of crop residues that are normally fed to livestock. Rational herd management dictates that animals should be sold when pasture and fodder are unavailable and productivity is low. Poor rains should incite farmers to sell part of their livestock assets to finance grain purchases. In other words, Sahelian livestock producers are expected to liquidate some of their animals when rains are low and to purchase animals or sell fewer of them when rains are good.

This negative adaptation is a problem in conservation agriculture because of the need to keep the soil covered. In other words, the strategy is not sustainable because if the animals eat all the cover crops or stalks from the previous harvest, the soil surface will be bare, and exposed either to rain and/or wind erosion. There will be little organic matter left to enrich and protect the soil (FAO).

Another important result is that farmers successfully adapt when exposed to wet conditions. The results show that farmers are 15% more likely to use crop residues on their land if it is too rainy. This strategy helps to protect the land against water erosion, as the soil fertility will decrease with erosion. The difference in adaptation responses between drought and wet conditions implies that the problem does not lie in whether farmers know how to adapt or not. The problem lies in the fact that poor farmers are constrained to make short-term survival decisions when the weather is dry, at the cost of long-term food production.

Due to the endogeneity between precipitations, we included temperature in Table 5 as a control variable. We find that a unit temperature increase in the yearly extra temperature above 29 degrees Celsius for the growing season reduces farmers' likelihood to adopt modern inputs and crop residues on the land. The first result seems plausible because using modern inputs need initial investment in capital, and high temperature will dry out the chemical fertilizers resulting in a waste of investment. The fact that farmers remove crop residues at high temperature is consistent with the negative effects of drought on crop adoption on land. This is a maladaptive response as well because crop residues protect the soil from high temperatures by regulating it at the surface.

Other results suggest that household's characteristics also play a role in adoption decision of inputs. Poor farmers, for example, are 5% less likely to use organic fertilizers and modern inputs on their land. This seems to be plausible, since modern inputs such as hybrid seeds or chemical fertilizers require high level of capital investment, and cannot be afforded by those poor households. Non-agricultural household wealth index is positively associated with the use of modern inputs, which is reasonable because the wealthy households have more adoption choices, and can afford modern technologies. Households that have access to a mobile phone seems also more likely to use modern inputs. Owning land increases the probability that the household will use crop residues by 8.4%. This result suggests the importance of land property rights on farmers' willingness to take care of their land. Having a mobile phone might facilitate access to information about the use of modern technology, and therefore increases the likelihood to adopt those inputs. Households with larger family size appear more likely to adopt all input practices. As mentioned before, labor availability constraints input use. Table 7 (in the appendix) summarizes the variables that could potentially affect the different input choices. I also investigate if poor and rich farmers differ in their adaptation strategies when exposed to shocks. I do not find any evidence of a difference in adaptive responses to drought between poor and rich farmers. I observe that larger farms are more likely to adopt more of all inputs in general. Farm size is a proxy for risk aversion, small farmers being more risk averse; it is also a proxy for income and access to credit (Feder et al, 19882). Therefore, the results make sense because larger farmers are not constrained to make short-term survival decisions as smallholders.

I conduct a robustness check by running a Hausman test between random effects and fixed effects, the null hypothesis being that there is no systematic difference in coefficients between both estimations. In case I fail to reject the null hypothesis, it would imply I should use random effects. The results of the test show that I reject the null at 99% level of confidence across all estimations, therefore the use of fixed effects is proper. Table 8 also presents another robustness check where I did a comparison of my main coefficients across two different specifications including household and year fixed effects versus cluster and year fixed effects. The coefficients of the variables from the table are very close to each other, meaning that my use of cluster and year fixed effects is appropriate.

6. Discussion and Conclusion

Farmers in Niger were aware of climate change but not all of them responded by adapting to the change in climate to reduce the negative impact and increases resilience on cropping systems. Socioeconomic factors of the households influenced farmer's adaptation choices, where some hinder, while others promote adoption of adaptation strategies.

Although conservation agriculture or the use of crop residues as soil cover has strong benefits, the realities of smallholder farming in mixed systems in Sub-Saharan Africa do not allow such an approach (Giller et al., 2009). Many households in poor countries are food insecure, and the pressure not to return crop residues to soil remains strong. Because they rely on livestock to survive at the expense of long-term agriculture, feeding residues to livestock is a rational choice for farmers as a mean of stabilizing nutrients, and making them more available for crop use or using them for other means. This results in a bad synergy because removing crop residues decreases long-term food production and might keep households in poverty trap. Another concern is that increasing demand for livestock products in Sub-Saharan Africa because of urbanization, and increase in income is a sign of future high pressure on crop residues use on land to feed livestock. The problem seems to be complex, and we need to be cautious before implementing policies that intensify livestock production in the developing world because of negative impacts on the return of biomass to soils (Duncan et al., 2016). To design inclusive policies and programs that can help farmers adapt to climate change, it is critical to understand what kind of choices people make when faced with climate shocks (CGIAR, 2016). In Niger, for example, farmers without livestock pay herders to graze the crop residues in their fields. In exchange, the livestock manure improves the soil nutrient status, enhancing crop yields (Powell et al., 2004). Another alternative involves the diversification of farming practices by promoting multipurpose crops or/and trees that provide food, feed, and fuel offering additional biomass resources and reducing biomass demand. When synergies are not used, pressures can contribute to increase trade-offs. The removal of residue from the soil combined with the low use inorganic fertilizer and minimal return of manure increases the potential erosion and nutrient depletion of already fragile and poor soils (Breman et al., 2001; Haileslassie et al., 2005).

To recover soil conditions, some researchers, donors, and NGOs have promoted the use of crop residues for soil covering (Conservation Agriculture), trying to increase crop production while also improving the overall sustainability of farming (FAO, 2009; Kassam et al., 2010). This practice can yield substantial increases in crop production provided if it is accompanied by additional input use, and if agro-ecological conditions (Giller et al., 2009), the level of agricultural intensity (Valbuena et al., 2012), and specific household assets (Knowler and Bradshaw, 2007) are suitable. These more sustainable alternatives of crop and livestock intensification are receiving much attention to address both improvements in livelihoods as well as in the sustainability of farming systems through combining more and/or better resources and technologies to increase agricultural production while minimizing negative impacts on the environment (Pretty et al., 2011). Policy makers will need to improve farmers' socio-economic conditions, markets, infrastructure, and strengthen the linkages within the rural economy.

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APPENDIX

Table 1: Perception of Weather Changes Reported for the Last 5 Years by Land Use Types (in Proportion)

	Land use types			
	Agricultural (N=1,664)	Agro-pastoral (N=1,631)	Pastoral (N=559)	Total N=4,443
Less rainfall	0.68	0.70	0.69	0.69
	(0.01)	(0.01)	(0.01)	(0.01)
More rainfall	0.21	0.21	0.13	0.20
	(0.01)	(0.01)	(0.01)	(0.01)
Worst distribution rainfall	0.73	0.73	0.62	0.71
	(0.01)	(0.01)	(0.01)	(0.01)
Shorter heat period	0.18	0.17	0.12	0.17
	(0.01)	(0.01)	(0.01)	(0.01)
Longer heat period	0.60	0.58	0.54	0.59
	(0.01)	(0.01)	(0.01)	(0.01)
More frequent droughts	0.71	0.77	0.90	0.75
	(0.01)	(0.01)	(0.01)	(0.01)
More frequent floods	0.35	0.22	0.17	0.27
	(0.01)	(0.01)	(0.01)	(0.01)
Delay start of the rainy season	0.71	0.65	0.83	0.70
	(0.01)	(0.01)	(0.01)	(0.01)
Early end of the rainy season	0.75	0.83	0.89	0.80
	(0.01)	(0.01)	(0.01)	(0.01)

Table 2: Strategies to Adapt to and Mitigate Weather Change Effects by Land Use Types (in Proportion)

	Change in Rainfall				Change in Temperature			
	Agricultural (N=1,664)	Agro-pastoral (N=1,631)	Pastoral (N=559)	Total N=4,443	Agricultural (N=1,664)	Agro-pastoral (N=1,631)	Pastoral (N=559)	Total N=4,443
Change seed varieties	0.20	0.21	0.31	0.27	0.15	0.14	0.31	0.24
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Anti-erosion measures	0.15	0.14	0.27	0.23	0.14	0.14	0.26	0.23
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Engage in dry season agriculture	0.14	0.12	0.36	0.24	0.14	0.10	0.37	0.24
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Plant trees	0.13	0.08	0.24	0.19	0.14	0.08	0.24	0.20
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Irrigate more intensively	0.12	0.12	0.31	0.23	0.12	0.12	0.31	0.23
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Raise less livestock and increase crop production	0.20	0.21	0.21	0.24	0.19	0.18	0.20	0.23
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Raise fewer small ruminants and switch to cattle	0.12	0.12	0.13	0.19	0.12	0.12	0.13	0.19
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Raise fewer cattle and switch to camel	0.10	0.11	0.26	0.19	0.10	0.11	0.24	0.19
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Adopt techniques to regenerate grass cover favored by livestock	0.13	0.09	0.16	0.19	0.12	0.09	0.16	0.19
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Raise fewer sheep and switch to goats	0.12	0.16	0.26	0.22	0.12	0.15	0.23	0.21
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Migration	0.21	0.18	0.15	0.20	0.22	0.21	0.13	0.20
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Diversify sources of revenue	0.23	0.27	0.29	0.28	0.25	0.26	0.25	0.28
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)

Table 3: Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Household Size	7	3	1	27
Head of Household Age	46	14	17	95
Average household years of education	3.49	4.82	0	19
Livestock size (TLU)	1.10	2.21	0	34.55
Percentage use of crop residues on land	0.35	0.48	0	1
Percentage use of organic fertilizers on land	0.51	0.50	0	1
Percentage use of modern inputs (inorganic fert. and hybrid seeds)	0.24	0.42	0	1

Figure 1: Effects of Rainfall Shocks and Temperature on Inputs adoption

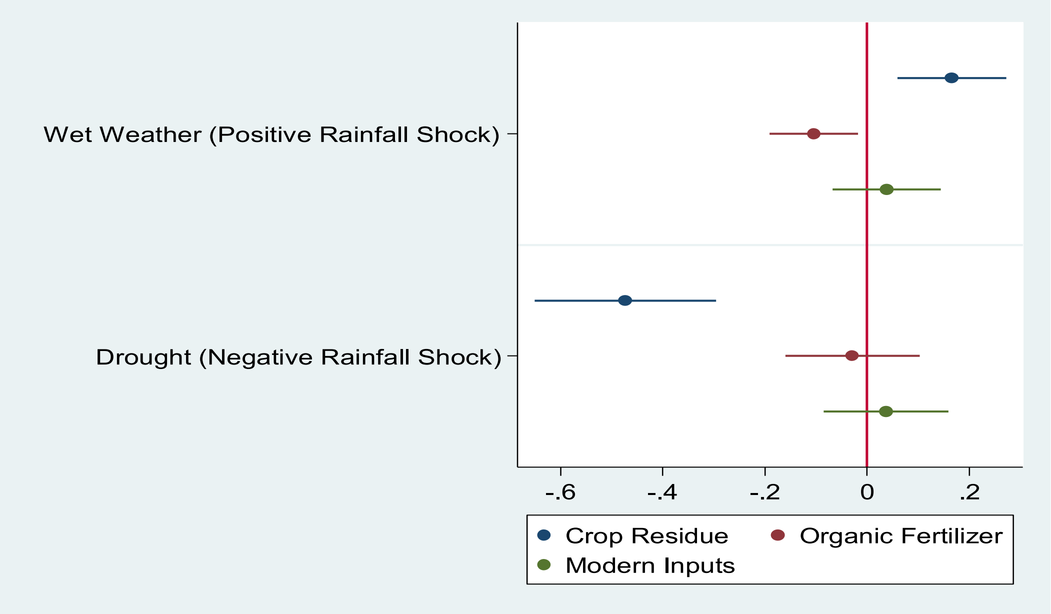

Figure 2: Effects of Livestock Possession on Adaptation to Drought

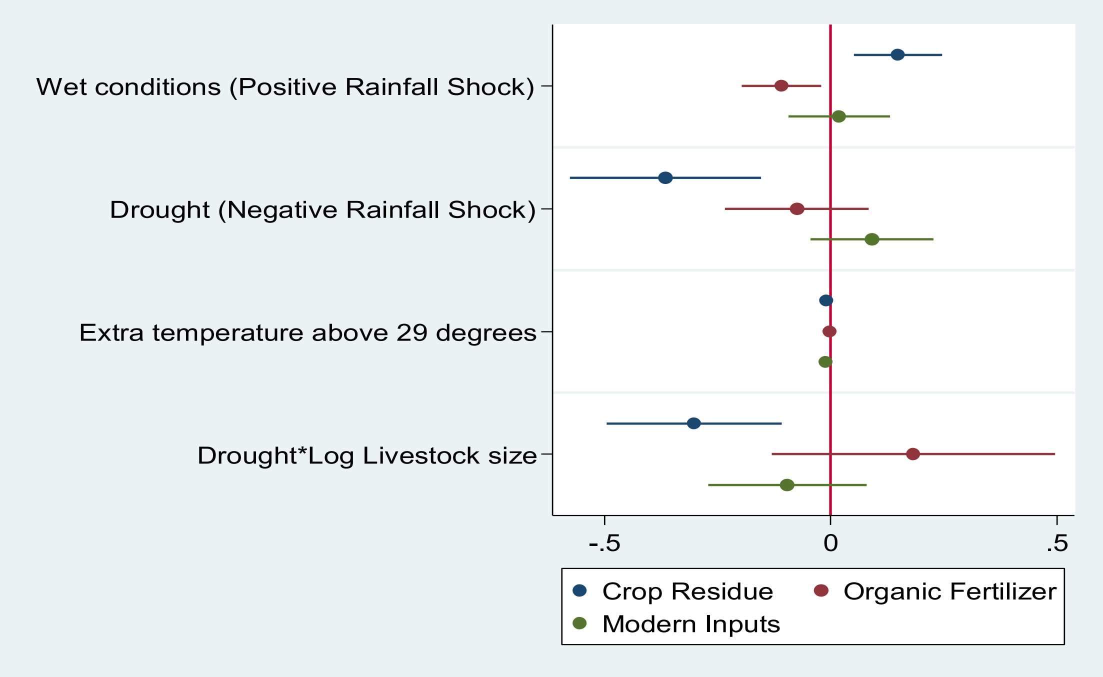

Table 4: Main effects of weather shocks on input use– Household Level Analysis

	PSU-Year FE	PSU-Year FE	PSU-Year FE
VARIABLES	Crop Residue	Organic Fertilizer	Modern Inputs
Wet Weather (Positive Rainfall Shock)	0.166***	-0.104**	0.038
	(0.002)	(0.019)	(0.478)
Drought (Negative Rainfall Shock)	-0.474***	-0.029	0.037
	(0.000)	(0.665)	(0.551)
Observations	4,433	4,433	4,433
R-squared	0.172	0.253	0.264

Clustered standard errors in parentheses

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

Cluster and Year Fixed Effects

Table 5: Effects of Rainfall Shocks and Temperature Increase

	PSU-Year FE	PSU-Year FE	PSU-Year FE
VARIABLES	Crop Residue	Organic Fertilizer	Modern Inputs
Wet Weather (Positive Rainfall Shock)	0.149***	-0.108**	0.019
	(0.003)	(0.016)	(0.740)
Drought (Negative Rainfall Shock)	-0.450***	-0.023	0.065
	(0.000)	(0.733)	(0.315)
Extra temperature above 29 degrees	-0.009***	-0.002	-0.010***
	(0.001)	(0.243)	(0.000)
Observations	4,433	4,433	4,433
R-squared	0.177	0.253	0.273

Clustered standard errors in parentheses

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

Cluster and Year Fixed Effects

Table 6: Effects of Livestock Size on Adaptation to Drought

	PSU-Year FE	PSU-Year FE	PSU-Year FE
VARIABLES	Crop Residue	Organic Fertilizer	Modern Inputs
Wet Weather (Positive Rainfall Shock)	0.149***	-0.108**	0.019
	(0.003)	(0.016)	(0.740)
Drought(Negative Rainfall Shock)	-0.365***	-0.074	0.092
	(0.001)	(0.356)	(0.185)
Extra temperature above 29 degrees	-0.009***	-0.002	-0.010***
	(0.001)	(0.243)	(0.000)
Drought*Log Livestock size	-0.301***	0.183	-0.095
	(0.002)	(0.249)	(0.283)
Observations	4,433	4,433	4,433
R-squared	0.178	0.253	0.273

Clustered standard errors in parentheses

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

Cluster and Year Fixed Effects

Table 7: Adaptation to Weather Shocks – Raw Effects and Control Variables

	PSU-Year FE	PSU-Year FE	PSU-Year FE
VARIABLES	Crop Residue	Organic Fertilizer	Modern Inputs
Wet Weather (Positive Rainfall Shock)	0.142***	-0.126***	0.019
	(0.051)	(0.043)	(0.057)
Drought (Negative Rainfall Shock)	-0.390***	0.041	0.039
	(0.095)	(0.062)	(0.060)
Extra temperature above 29 degrees	-0.008***	-0.002	-0.011***
	(0.002)	(0.002)	(0.002)
Dummy Head of household Educated	0.011	0.021	0.025

	(0.019)	(0.023)	(0.018)
Log of farm size	0.019**	0.052***	0.015*
	(0.008)	(0.010)	(0.009)
Household is poor	-0.013	-0.056***	-0.052***
	(0.018)	(0.016)	(0.015)
Household owns land	0.084***	0.022	-0.007
	(0.024)	(0.019)	(0.016)
Dummy if owns a mobile phone	-0.014	0.010	0.037**
	(0.017)	(0.016)	(0.014)
Non-agricultural wealth index	0.016	0.023	0.046***
	(0.017)	(0.014)	(0.013)
Log of household size	0.009	0.126***	0.072***
	(0.021)	(0.021)	(0.019)
Log of Tropical Livestock Units (TLU)	0.029*	0.072***	-0.003
	(0.016)	(0.016)	(0.013)
Rainfall distribution year before	0.072**	0.004	-0.126***
	(0.036)	(0.027)	(0.034)
Observations	4,433	4,433	4,433
R-squared	0.187	0.286	0.295

Clustered standard errors in parentheses

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

Cluster and Year Fixed Effects

Table 8: Robustness Check – Household and Year fixed effects vs Cluster and Year Fixed effects

	(1) HHID-Year FE	(2) HHID-Year FE	(3) HHID-Year FE	(4) PSU-Year FE	(5) PSU-Year FE	(6) PSU-Year FE
VARIABLES	Crop Residue	Organic Fertilizer	Modern Inputs	Crop Residue	Organic Fertilizer	Modern Inputs
Wet Weather (Positive Rainfall Shock)	0.169***	-0.103**	0.051	0.166***	-0.104**	0.038
	(0.001)	(0.027)	(0.342)	(0.002)	(0.019)	(0.478)
Drought (Negative Rainfall Shock)	-0.480***	-0.016	0.022	-0.474***	-0.029	0.037
	(0.000)	(0.825)	(0.691)	(0.000)	(0.665)	(0.551)
Observations	4,030	4,030	4,030	4,433	4,433	4,433
R-squared	0.550	0.683	0.654	0.172	0.253	0.264

Clustered standard errors in parentheses

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

Household and Year / Cluster and Year Fixed Effects