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# Climate-induced crop failure and crop abandonment: What do we know and not know?

Nixon S. Chekenya
Texas Tech University, Lubbock, Texas. E-mail: nixon.chekenya@ttu.edu; chekenyan@gmail.com

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**Abstract**

*Our understanding of climate-induced crop failure and crop abandonment is limited at present. This study surveyed theoretical and empirical literature on climate-induced crop failure and crop abandonment. We reviewed widely used models of crop abandonment decisions and emerging evidence of determinants of crop failure and crop abandonment. While most of the studies reviewed focus on crop failure, a very limited body of work examines crop abandonment decisions, with climate variables emerging as the key determinant. The review also highlights both theoretical and empirical models popular in the literature. We link crop failure and crop abandonment to weather variables and the resultant agricultural productivity loss and possible risk management strategies, highlighting policy implications and areas for future research.*

**Key words**: crop failure, crop abandonment, climate change, moral hazard, fractional probit

## 1. Introduction

Our climate is now 1°C warmer than in the preindustrial era (Ortiz-Bobea, 2021:31).[1] Agriculture is one of the most climate-sensitive fields, with climate changes affecting total productivity. One of the direct effects of weather shocks on crop production is farmers' post-planting decisions to harvest or abandon a crop in each farming season.[2] Crop abandonment happens after an adverse shock lowers the yield below the point where the value of production equals the cost of harvesting (Obembe *et al*. 2021:2).

Despite extensive literature on participation in insurance programmes (crop, yield and revenue protection insurance) as adaptive strategies to cope with crop failure, there are surprisingly few studies on climate-driven crop failure and crop abandonment (Ortiz-Bobea 2021:37).

[1] Due to the lack of a convincing definition for preindustrial, IPCC AR5 chose the period 1850 to 1900 when referring to changes in global temperatures (Hawkins *et al*. 2017:1842; Kirtman *et al*. 2013).
[2] Regions with significant crop abandonment include India (Caparas *et al*. 2021:10), cotton in the United States (Caparas *et al*. 2021:10; Cui 2020:902; Mendelsohn 2007:61; Schillerberg & Tian 2020:1), wheat in China (Caparas *et al*. 2021:10; Challinor *et al*. 2010:6), Zambia (Shipekesa & Jayne 2011:1), Tanzania (Afifi *et al*. 2014:53), Madagascar (Hänke & Barkmann 2017:264) and Europe (Webber *et al*. 2016:1).

Notwithstanding the dearth of theoretical and empirical work on the subject, research interest in this vein is not new, as it dates back to Mendelsohn *et al*. (2007:67).

Mendelsohn *et al*. (2007:67) predicted rates of crop failure in the United States using a Ricardian style cross-sectional model. The authors used data for the sample period 1978 to 1997 from the US Census of Agriculture, which reports five-year county-level recorded rates of crop failure, and found that about 39% of cross-sectional variation in crop failure can be attributed to soil features and climate shocks. In a recent study, Cui (2020:901) employed panel data to examine the effect of climatic shocks on both historical corn and soybean yields and the harvested area (in acres). The study argues that participation in a federal crop insurance programme, as well as market conditions (mostly market price) at the time of harvesting, determine the proportion of harvested acreage.

Our current understanding of the difference between crop failure and crop abandonment, and the heterogenous nature of decisions to abandon crops, is still limited. What is the difference between crop failure and crop abandonment, and does the difference matter? What are the key determinants of decisions to abandon crops? This paper's objective is to sort out the available literature and attempt to answer these basic questions.

In section 2, we present the background to the study by distinguishing between crop failure and crop abandonment. Section 3 contains the methodology, The theory and empirical design behind crop failure and the measurement of crop abandonment are discussed briefly in section 4. We examine drivers of crop failure and crop abandonment in section 5. Section 6 presents risk management and coping strategies. We conclude in section 7 with policy implications and some directions for future research.

## 2. Background

### 2.1 Crop failure vs crop abandonment

In this subsection, we differentiate crop failure from crop abandonment. Crop failure can be thought of in terms of the total loss of crops on a farm (Mulungu & Tembo 2015:2859). It happens mainly when disastrous weather shocks lead to the destruction of crops by pests, floods or droughts (Haque & Khan 2017:91). Crop failure is part of crop abandonment in terms of measurement, because a failed crop can still be captured as an unharvested area (Mulungu & Tembo 2015:2859). However, crop abandonment does not really imply crop failure. In periods of good rains, ceteris paribus, the unharvested area can be attributed to crop abandonment and not crop failure.[3]

Crop abandonment, on the other hand, is a situation in which farmers choose not to harvest their previously planted crop (Ortiz-Bobea 2021:37). This definition is contextualised to climate change by Obembe *et al*. (2021:2), who describe crop abandonment as occurring when adverse weather shocks negatively affect yields to a point where it does not make economic sense to harvest.[4] Cui (2020:910) argues that crop abandonment happens when extremely high temperatures cause yield loss to the extent that harvesting can no longer justify the opportunity cost. In this sense, crop abandonment is a decision at the margin made by a farmer not to harvest a field even after committing inputs such as labour and capital, which traditionally are expressed in an augmented neoclassical

[3] It may be instructive to note this difference when doing empirical work.

[4] Among the crops that have recorded a significant share of abandonment over the years are cotton (Cui 2020:902; Rippey 2015:59), corn (Cui, 2020:902), soybean (Caparas *et al.* 2021:10; Cui, 2020:902), maize (Caparas *et al*. 2021:10), rice (Caparas *et al*. 2021:10) and wheat (Obembe *et al*. 2021:3, 11; Travis & McCurdy 2015:12).

production function that expresses output as a function of labour and capital in a simple relationship, expressed as:

$$Y = f(K, L), \tag{1}$$

which can be expressed in a multiplicative form as:

$$Y = K^{\alpha}, L^{\beta}, \tag{2}$$

with $\alpha$ and $\beta$ being elasticities of output with respect to capital and labour respectively.

Taking the log of (2) gives:

$$lnY = \alpha lnK + \beta lnL + \varepsilon, \tag{3}$$

where $\varepsilon$ is a well-behaved disturbance term.

The difference between these two concepts matters and comes in handy when doing empirical work.

**2.2 Crop failure or crop abandonment: Chicken or egg?**

To inform the reader, we disentangle the relationship between crop failure and crop abandonment. Crop failure, in principle, is a pre-condition for crop abandonment if we consider how the latter is statistically measured. A failed crop is one component in the measurement of crop abandonment ratios (Mulungu & Tembo 2015:2859). On the other hand, crop abandonment does not really imply crop failure, because once good rains are received at a particular location in a given period, the unharvested crop is due to crop abandonment and not crop failure. If one wants to argue in terms of causality, the nature of the relationship between the two concepts is unidirectional, running from crop failure to crop abandonment (Thurman & Fisher 1988:237). By explaining the differences and similarities between crop failure and abandonment, we seek to provide basic guidance in empirical exercises for climate change impacts in agriculture.

The literature builds on the estimation of standard panel fixed effects combined with location fixed effects to model the link between weather variables and crop abandonment (Cui 2020). Mathematically:

$$\left(\frac{Acres^H}{Acres^P}\right) = g\left(\{T_{it,d}\}_{d=1}^{D}\right) + \gamma_1 Prec_{it} + \gamma_2 Prec_{it}^2 + h_s(t) + \omega_t + \alpha_i + \varepsilon_{it} \tag{4}$$

The harvested ratio of a particular crop in location $i$ in crop year $t$ is the dependent variable. $Acres^H$ and $Acres^P$ show harvested and planted acres respectively. By design, the ratio is bound between zero and one.

Cui (2020:909) extends this crop abandonment model to include a 3°C bin specification so as to "flexibly characterise the effects of growing-season temperature on crop abandonment". The resulting equation is expressed as follows:

$$\left(\frac{Acres^H}{Acres^P}\right) = \sum_j \emptyset_j \, TBin_{it}^j + \gamma_1 Prec_{it}^2 + h_s(t) + \omega_t + \alpha_i + \varepsilon_{it} \tag{5}$$

$TBin_{it}^{j}$ controls for temperature distribution in location $i$ at time $t$, with each $TBin_{it}^{j}$ variable counting the days in each growing season and temperature variations falling into the $j^{th}$ bin.

## 3. Methodology

To shed more light on crop failure and crop abandonment, we employed a systematic literature review approach and identified papers that seek to analyse climate-induced crop failure and abandonment in developed and developing countries, both theoretically and empirically. The studies are generally focused on failed crops such as soybean, and abandoned crops which include cotton (in Texas), and corn, soybean, rice and wheat in Kansas. A systematic literature review is more fitting for this study as a way to highlight what we know and what remains to be known about climate-induced crop failure and abandonment. The commonly used data across the studies reviewed dates back to the 1970s and includes agricultural censuses, climate data, temperature and rainfall, and fertiliser data at both the national and subnational level.

We extensively reviewed an estimated 29 studies out of the 34 references on crop failure and abandonment. We selected studies appearing in peer-reviewed agricultural economics, development economics, soil science and environmental economics journals. There are potential problems with our selection method. First, our search was conducted in English, which means that we likely excluded potentially quality and relevant papers on the topic that were not published in English. Second, the literature review is focused on studies published in academic journals. As such, this explicitly excludes extensive grey literature on crop failure and abandonment that may be in the form of working papers, master's and doctoral theses, and policy briefs and reports. Despite these drawbacks, our review attempts to cover the existing literature on crop failure and abandonment published or forthcoming in peer-reviewed journals to date.[5]

The review focuses on studies on crop failure and abandonment and discusses the implications for policy and future research. In doing so, we highlight what is known and what remains to be known about climate-induced crop abandonment and failure. We also highlight the crops and geographical areas covered in the literature, and the theoretical and empirical models frequently used.

## 4. Models

### 4.1 Theoretical models

#### 4.1.1 Static model

The static model builds on existing literature on moral hazard in crop insurance. The main argument in this model is that the analyses build on static models, which overlook the fact that crop abandonment decisions naturally happen after variations in harvest-time price and yield expectations during a given growing season (Chambers & Quiggin 2002:320; Chen & Miranda 2007:5)

#### 4.1.2 Intra-seasonal dynamic optimisation model

Borrowed from utility theory, the intra-seasonal dynamic optimisation model is a theoretical dynamic model of crop abandonment that can explicitly account for a producer's crop abandonment decisions

[5] In this section, we follow an approach presented in Bellemare and Bloem (2018).

(Chen & Miranda 2007:4, 5).[6] The basic assumption of the model is that the main objective of a typical farmer is to maximise expected net profit at harvest. As such, the model enables farmers to re-evaluate their expectations about price and yields at a given intermediate point in time between planting and harvesting and, based on their revised expectations, decide whether to abandon the crop or not (Chen 2007:27).

#### 4.1.3 Pareto optimal approach

In the Pareto optimal approach, an average farmer's prime objective in terms of the model is profit maximisation given different fields, thus making labour allocation decisions to achieve a pareto optimality condition subject to different fields and crops. The decision to abandon one field and allocate labour to the most deserving field is arrived at after considering where the potential higher returns lie. As such, a typical farmer's objective is to maximise profit subject to a labour constraint that needs to be allocated efficiently among competing fields (Mulungu & Tembo 2015:2860).

### 4.2 Empirical models

Two popular empirical models ae used to study crop abandonment at the national and sub-national level. These are ordinary least squares (OLS) and the fractional probit, with the latter being favoured by most model test statistics.

#### 4.2.1 OLS model

The OLS approach is useful in studies making estimations at the national level. Compared to the generalised linear model (GLM), the OLS model, in general, tends to produce slightly lower estimates in absolute terms. Specifically, OLS coefficients tend to be lower than estimates from the fractional probit approach, as argued by Papke and Wooldridge (1996:619). OLS fails to capture the fractional nature of the response variables in most empirical setups, as it is measured as the proportion of failed crops. In studies using a dependent variable that is fractional (fraction), OLS is both biased and inconsistent. To control for this, Papke and Wooldridge (2008:122) designed a fractional logit model that employs a quasi-maximum likelihood estimation (QMLE) approach to generate robust estimates of the conditional mean parameters with satisfactory efficiency properties to control for problems originating from using OLS when we have fractional dependent variables (Mulungu & Tembo 2015:2864).

#### 4.2.2 Fractional and linear approach

Also known as the fractional probit or generalised linear model (GLM), the fractional and linear model is normally estimated in crop abandonment studies, as it is thought of as being better than the OLS approach in capturing the fractional nature of crop abandonment at the subnational level (Mulungu & Tembo 2015:2858). The approach is most suited for examining differences in effects across various agroecological regions using disaggregated data. Another merit attributed to this model is that it allows for time non-variant unobserved effects to be correlated with independent variables in panel data (Mulungu & Tembo 2015:2861; Papke & Wooldridge 2008:122). Compared to the OLS model, the fractional probit approach has a better fit, as normally indicated by the Ramsey's regression specification-error test (RESET).

[6] The model presented here lacks an analytic solution. The numerical solution is beyond the scope of the present paper. For such a solution, see Chen and Miranda (2007:5) and Miranda and Fackler (2004).

## 5. Drivers of crop failure and abandonment

Here we focus on the determinants of crop failure and crop abandonment.

### 5.1 Determinants of crop failure

There are several reasons for crop failure. We summarise some of the influential factors leading to crop failure in Table 1.

**Table 1: Determinants of crop failure decisions**

| Determinant | Sources | Region(s) | Main argument/finding |
| --- | --- | --- | --- |
| Rainfall patterns | Hanisch (2015:6)<br>Hänke and Barkmann (2017:273)<br>Mendelsohn (2007:66)<br>Schillerberg and Tian (2020:1) | Madagascar, United States | Poorly distributed precipitation is positively related to crop failure rates. Considering seasonal effects, higher annual precipitation reduces crop failure. At some point, higher levels of rainfall also increase failure rates, obeying the law of diminishing marginal returns (Schillerberg & Tian 2020:1). |
| Rise in mean temperatures | Challinor *et al.* (2010:6, 7) | China | Heat and water stress negatively affect crop productivity. Crop failure rates (median and maximum) increase with temperature. |
| Multiple and combined anomalous meteorological drivers | Goulart *et al.* (2021:1503, 1515)<br>Mendelsohn (2007:61)<br>Schillerberg and Tian (2020:1) | United States | Crop failure largely results from the occurrence of multiple and combined anomalous meteorological drivers. The argument about causality is complex because the links connecting weather and crop yield can be multiple and non-linear. |
| Lack of fertiliser | Shipekesa and Jayne (2011:1) | Zambia | About 25.6% of crop failure in Zambia can be linked to a lack of fertilisers. |
| Soil variables | Mendelsohn (2007:61, 67)<br>Mulungu and Tembo (2015:2858, 2864)<br>Schillerberg and Tian (2020:1)<br>Shipekesa and Jayne (2011:4)<br>Wilhelmi (2002:1399) | United States, Zambia | Soil characteristics (soils that hold moisture well can reduce the probability of short-term dry spells – a month of little rain, while sandy soils may increase drought sensitivity). Other soil variables may contribute to the stresses that crops are under and exacerbate crop failures (by reducing crop productivity). For instance, soil erosion, wetlands and hilly terrain can be associated with lower cropland values (Mendelsohn *et al*. 1994:753). |
| Pests | Mendelsohn (2007:61, 63)<br>Reilly *et al*. (1996:427) | United States | One of the leading factors in crop failure rates is pest outbreaks. Sadly, there is not yet a direct measure of pestilence in the literature. However, weeds, insects and pathogen-mediated plant diseases are affected by climate (Reilly *et al*. 1996:427). Climate variables directly influence pests, which in turn cause crop failure (Mendelsohn 2007:61, 63) |

### 5.2 Determinants of crop abandonment

In Table 2, we summarise the literature showing the determinants of crop abandonment decisions among farmers.

**Table 2: Determinants of crop abandonment decisions**

| Determinant | Source(s) | Region(s) | Main argument/finding |
|---|---|---|---|
| Labour inadequacy (for example due to changes in migration policy) | Mulungu and Tembo (2015:2860) | Zambia | Labor inadequacy on farms is a key rationing decision by households when they choose to concentrate on certain fields or crops to maximise profit from different fields by allocating the available labour in a pareto-efficient manner. |
| Postharvest decisions | Ortiz-Bobea (2021:17) | | Postharvest management considerations such as storage costs influence the decision whether or not to harvest. The expected benefits may be lower than the costs of harvesting due to changes in market prices (yield or output prices) at harvest time than what was anticipated at the time of planting. |
| Multiple and combined anomalous meteorological drivers | Goulart *et al.* (2021:1503, 1515) Mendelsohn (2007:61) Mulungu and Tembo (2015:2859, 2864) Schillerberg and Tian (2020:1) | United States, Zambia | Crop failure is largely a result of the occurrence of multiple and combined anomalous meteorological drivers. The argument about causality is complex because the links connecting weather and crop yield can be multiple and non-linear. |
| Lack of fertiliser | Mulungu and Tembro (2015:2859, 2860) Shipekesa and Jayne, (2011:4) | Zambia | In Zambia, a lack of fertiliser was forwarded as one of the major economic reasons behind unharvested area. The response is most prevalent among FISP non-recipients in provinces where the FISP programme is active. |
| Farmer perceptions | Shipekesa and Jayne (2011:3) | Zambia | There may be a perception that a failure to fertilise the field leads to such a low yield level that production is not worth the harvest labour time. Late delivery of fertiliser may be another disincentive to complete conversion of the area planted. |
| Weather-induced shocks | Cui (2020:902, 905) Goulart (2021:1503) Mendelsohn (2007:61) Mulungu *et al.* (2021:11863) Obembe *et al*. (2021:1) | United States, Zambia | Weather impacts (bad weather conditions and high temperatures, flooding and droughts) leading to yield reduction and crop abandonment). For instance, farmers in Texas abandoned 62% of their planted cotton acreage in 2011 under severe drought in the south-central United States. |
| Pests | Mendelsohn (2007:61, 63) Mulungu and Tembo (2015:2860) Obembe *et al*. (2021:9) Reilly *et al*. (1996:427) | United States, Zambia | One of the leading factors in crop failure rates is pest outbreaks. Sadly, there is not yet a direct measure of pestilence in the literature. However, weeds, insects and pathogen-mediated plant diseases are affected by climate. Climate variables directly influence pests, which in turn cause crop failure. Pest outbreaks are also often blamed for crop failure and abandonment. These are influenced by climate as well, and indirectly captured in the influence of weather variables. |

## 6. Risk management and coping strategies

There are potential risk management strategies that are gaining popularity. One such coping strategy is income diversification. This involves maintaining access to different income sources (Barrett *et al*. 2001:315; Ellis, 1998:12; Hanisch, 2015:8; Neudert *et al*. 2015:758–9). The strategy relies heavily on the role of non-farm income. One can also think of livestock insurance (Hänke & Barkmann 2017:265), federal crop insurance (Annan & Schlenker 2015:261), crop switching (Tessema *et al*. 2019:358) and crop and livestock diversification (Hänke & Barkmann 2017:264). Vegetable production can help diversify income sources and reduce risks due to crop failures in locations with ready markets. At the same time, for poor farmers in developing countries with little access to (mostly urban) markets, household vegetable production may be the only way to access vegetable produce for consumption (Hanisch 2015:58; Ruel *et al*. 2005).

## 7. Conclusions, policy implications and directions for future research

In this paper we have examined the theoretical and empirical literature on climate-induced crop failure and abandonment. This stems from the limited understanding of the nature of crop abandonment decisions at present. This paper highlights the state of research on the models used and emerging evidence of the key determinants of crop failure and abandonment.

Our main conclusions are as follows. First, crop failure is different from crop abandonment. The former relates to the total loss of crops on a farm, while the latter is a situation in which farmers choose not to harvest their previously planted crop. Second, it emerges from the literature that weather variables have a considerable effect on both crop failure and abandonment. Third, there are possible risk management and coping strategies, such as income diversification and insurance (crop and livestock), which are gaining popularity in the literature.

Providing a physical drought vulnerability index resulting only from intrinsic and, particularly, climatic variables can enable water resource managers and policymakers to develop adaptation strategies to alleviate the risk of crop failure in areas of high physical vulnerability (Obembe *et al*. 2021:2).

This review brings forth several open questions for research on (i) methodology, (ii) climate change impacts and adaptation, (iii) agricultural production and (iv) risk management. There is a need to develop econometric tools to analyse the fractional nature of the (dependent) variables. One can also use difference-in-difference techniques to control endogeneity. Further work on the heterogenous nature of crop abandonment decisions can improve our understanding of how these factors interact with risk factors such as yield prices, cost of storage post-harvest and risk management strategies like federal crop insurance and livestock insurance (Ortiz-Bobea 2021:17). Additional work is warranted to understand the risk factors shaping crop abandonment decisions, particularly in developing countries.

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