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Coping with drought: Lessons learned from robusta coffee growers in Vietnam

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ABSTRACT

An improved understanding of the benefits and uptake of drought mitigation strategies under a changing climate is critical to ensure effective strategies are developed. Here, using 10 years (2008–2017) of farm data from 558 farmers distributed across the major robusta coffee-producing provinces in Vietnam, we analysed coffee farmers' perceptions on drought and its impacts; we then quantified the impacts of drought on yield and farm profit, and finally, assessed the effectiveness of mitigation strategies. While drought reduced robusta coffee yield by 6.5% on average across all provinces, the impacts on gross margins were noticeable, with an average 22% decline from levels achieved in average-rainfall-condition years. Yield reductions from drought were consistent with farmers' perceptions, being on average − 9.6%. With irrigation being typical in coffee farming in Vietnam, the majority of surveyed farmers (58%) adopted mulching in drought years and had a 10.2% increase in economic benefits compared to their counterparts who did not. Furthermore, the chances of adopting mulching as an adaptation strategy decreased generally for every one unit increase in perceived drought impact or when shifting from surface water to groundwater in drought years. Although coffee farming remained profitable in drought years, our findings have potential relevance for the design of policies to address drought risks and encourage more resilient adaptation strategies for Vietnam and other coffee-producing countries experiencing similar climatic conditions.

Practical implications

Seasonal climatic variations coupled with climate change increasingly pose a major challenge to agricultural production and the livelihoods of smallholder farmers. While coffee farmers in Vietnam, and globally, continue to adapt, the effectiveness of drought mitigation strategies is largely unknown. Improved understanding of the effectiveness and uptake of drought mitigation strategies is critical to ensure effective strategies are developed and utilized. Here, we assess the impacts of drought on yield and farm profit, as well as the effectiveness of irrigation and mulching as drought mitigation strategies across four major robusta coffee-producing provinces in Vietnam. Our analysis reveals that surveyed farmers rely only on mulching and irrigation to cope with drought. Mulching is a practice consisting of spreading a layer of organic materials (i.e. pruned branches and leaves from coffee trees or other trees) on top of the soil around the plant stumps to conserve soil moisture and improve soil conditions. Irrigation and mulching have allowed coffee producers to alleviate the impacts of drought across the study provinces, with the majority achieving positive returns in drought years, mostly because of the availability and affordability of water for irrigation.

Several practical implications stem from this work. First, with the benefit of adopting mulching in addition to irrigation to cope with drought, at least in provinces such as Dak Nong, Gia Lai and Lam Dong, farmers should make it an integral part of their management practices, and even be able to improve it. Secondly, there is a need to improved climate information, and associated climate services, and yield information for robusta coffee farmers and trading companies to increase their awareness about the impacts of more extreme climate events such as drought and how to best manage them. More importantly, this will help to improve and/or diversify the current irrigation-based mitigation strategies. Currently, the availability and reliability of climate services are limited for farmers and the value chain industry in Vietnam. Better climate information would help all stakeholders in the coffee industry to develop targeted mitigation strategies to increase their climate resilience.

With the projected changes in rainfall patterns across the study area (IPCC 2014a), there is an increased risk of water scarcity

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conditions during critical irrigation periods. Lower groundwater tables subsequent to drought events have been recorded across the study provinces (CCAFS-SEA 2016), implying that irrigation costs (i.e. electricity charges) may also increase. Moreover, if the government decides to put a price on water, the negative impacts of drought may be even greater and detrimental to the financial viability of robusta coffee farming systems in Vietnam. It is critical to implement policies that optimize the use of water for irrigation in coffee areas in Vietnam since there are opportunities to reduce water for irrigation while achieving satisfactory yield levels (Amarasinghe et al., 2015; Byrareddy et al., 2020). Reliable seasonal climate forecasts are expected to play a key role in developing optimum irrigation strategies across Vietnamese coffee-producing provinces. Because incremental adaptation strategies adopted by coffee farmers in the study provinces may not be sustainable under a changing climate, transformational responses, which may include relocation to suitable environmental conditions, may be worth considering for the future expansion of coffee areas.

1. Introduction

Drought can cause considerable damage to the livelihoods and assets of a large number of people, national economies, and ecosystems (Kogan, 1997; Redmond, 2002). With the projected changes in spatio-temporal patterns of extreme weather events during this twenty-first century, coupled with increasing vulnerability of terrestrial ecosystems (IPCC, 2013, 2014b; Schwalm et al., 2017; Slette et al., 2019), the sustainability of agricultural production in several countries, worldwide, faces major challenges. Furthermore, any adverse impacts on agriculture would be detrimental to the economy of countries in which the agricultural sector constitutes an important pillar.

Vietnam is the world's second largest coffee-producing and exporting country (FAO, 2019; ICO, 2019b, 2019a). Ninety-seven percent of Vietnam's coffee beans are produced in the Central Highlands region; a region listed among the most drought-prone in the country (Nguyen, 2005; Vu et al., 2015; GSOV, 2017; ICO, 2019a). Considerable crop losses due to drought events have been reported during the past decades. For example, in 2015–2016 all the provinces in Central Highlands (Dak Lak, Dak Nong, Gia Lai, Kon Tum, and Lam Dong) were affected severely by drought, resulting in ca. 152,000 ha of agricultural land areas impacted and direct economic losses of VND 6,004 billion (about US$ 269 million) (Grosjean et al., 2016; MARD, 2016; World Bank, 2017). Reductions up to 25% of the total production of green coffee beans (relative to that in average-rainfall-condition years) were observed in Central Highlands during the 1997–1998 or 2010–2011 droughts (Nguyen, 2005; MARD, 2016). Droughts also affect river discharges and water reservoirs. For instance, water reservoirs across the Central Highlands declined by up to 50% of their average levels in 2016 after the 2015 drought, resulting in lower groundwater tables across the region (CCAFS-SEA 2016).

In vulnerable coffee-growing regions, several drought mitigation and adaptation strategies are being implemented to build longer-term resilience and to ensure sustainable and profitable production. At farm scale, these strategies typically include irrigation, water-saving technologies, conservation of soil water through mulching, shade management (e.g. shading systems with tree species, agroforestry, etc.), and diversification of farm activities (DaMatta, 2004a; Dias et al., 2007; Silva et al., 2008; Worku and Astatkie, 2010; Haggar and Schepp, 2012; Jassogne et al., 2013; Assis et al., 2014; Bisang et al., 2016; Boreux et al., 2016). Mulching is a practice consisting of spreading a layer of materials (i.e. pruned branches and leaves from coffee trees or other trees) on top of the soil around the plant stumps to conserve soil moisture and improve soil conditions. It is critical to improve our understanding of current drought mitigation and adaptation strategies to more effectively manage future drought risks.

Although a number of studies have dealt with drought in the coffee farming system in Vietnam (Nguyen, 2005; Haggar and Schepp, 2012; CCAFS-SEA, 2016), they are generally focused on one province or were limited to two to 3-years of data. Using 10-years (2008–2017) of survey data from 558 farmers distributed across the major Vietnamese coffee-producing provinces, the objectives of this study were to: (1) investigate coffee farmers' perceptions and responses to drought; (2) assess the yield and financial impacts of drought, and estimate the economic impacts of drought mitigation strategies and (3) examine the drivers that influence the adoption of mitigation strategies. Coffee is one of the top-traded agricultural commodities in the world, generating substantial gross revenues annually and contributing critically to the gross domestic product of coffee-producing countries such as Vietnam (TCI, 2016; ICO, 2019a). The findings of this study, therefore, will have particular relevance for the design of policies to address drought risks and encourage the uptake of climate resilience increasing adaptation strategies for both Vietnam and other coffee-producing countries experiencing similar climatic conditions.

2. Material and methods

2.1. Study area and data

Farmers were randomly selected across four Vietnamese coffee-producing provinces in the Central Highlands - Dak Lak, Dak Nong, Gia Lai, and Lam Dong (Fig. 1) to represent districts dominated by coffee farmers dependent primarily upon coffee production for household income. A total of 558 farmers were selected across 18 districts in the study provinces: 180 farmers in Dak Lak (six districts), 120 in Dak Nong (four districts), 93 in Gia Lai (three districts), and 165 in Lam Dong (five districts). These four provinces accounted for>90% of national coffee production with about 581,000 ha harvested on average during 2014–2017 (GSOV 2017). The study area is characterized by a humid tropical climate: daily average maximum temperatures are normally above 24 °C; the average monthly solar radiation varies between 400 and 700 MJ m^{-2}; and total annual rainfalls range from 1800 to 3000 mm (NCHMF, 2018; Byrareddy et al., 2019). Coffee is typically grown as an unshaded and clean-weeded monocrop, with 95% of plantations dominated by *Coffea canephora* Pierre ex A. Froehner ('robusta coffee') (GSOV, 2017; ICO, 2019a). High rates of chemical fertilizers and intensive use of irrigation water are typical in robusta coffee farming in the study provinces (D'haeze et al., 2005; Marsh, 2007; Byrareddy et al., 2019, 2020).

Data collection combined farm surveys and archival research. Farm surveys were carried out in 2017 using structured questionnaires (see example in Table S1). These surveys included questions about demography, farming system, perception of drought frequency and drought impact on coffee plants, responses to drought events, and access to climate information and agricultural extension services. For each farmer, we also had access to archival materials for the 2008–2017 period relevant to the study, such as coffee production, irrigation and fertilizer data, costs of production, and household incomes. Farm data over the 2008–2017 period were made possible thanks to the Sustainable Management Services program implemented by ECOM Agro-industrial Corporation in Vietnam, within which>5000 coffee farmers are enrolled (as of 2018). See Byrareddy et al. (2019) for details.

2.2. Classifying drought periods

In this study, we considered meteorological droughts, which are usually related to precipitation deficiencies over a specific region (Wilhite and Glantz, 1985; American Meteorological Society, 1997; Redmond, 2002). Gridded annual rainfall data (0.25° × 0.25° spatial resolution) for a 30-year period (1985–2014) were used to classify each year of the 2008–2017 period. All rainfall data were sourced from the US National Oceanic and Atmospheric Administration website

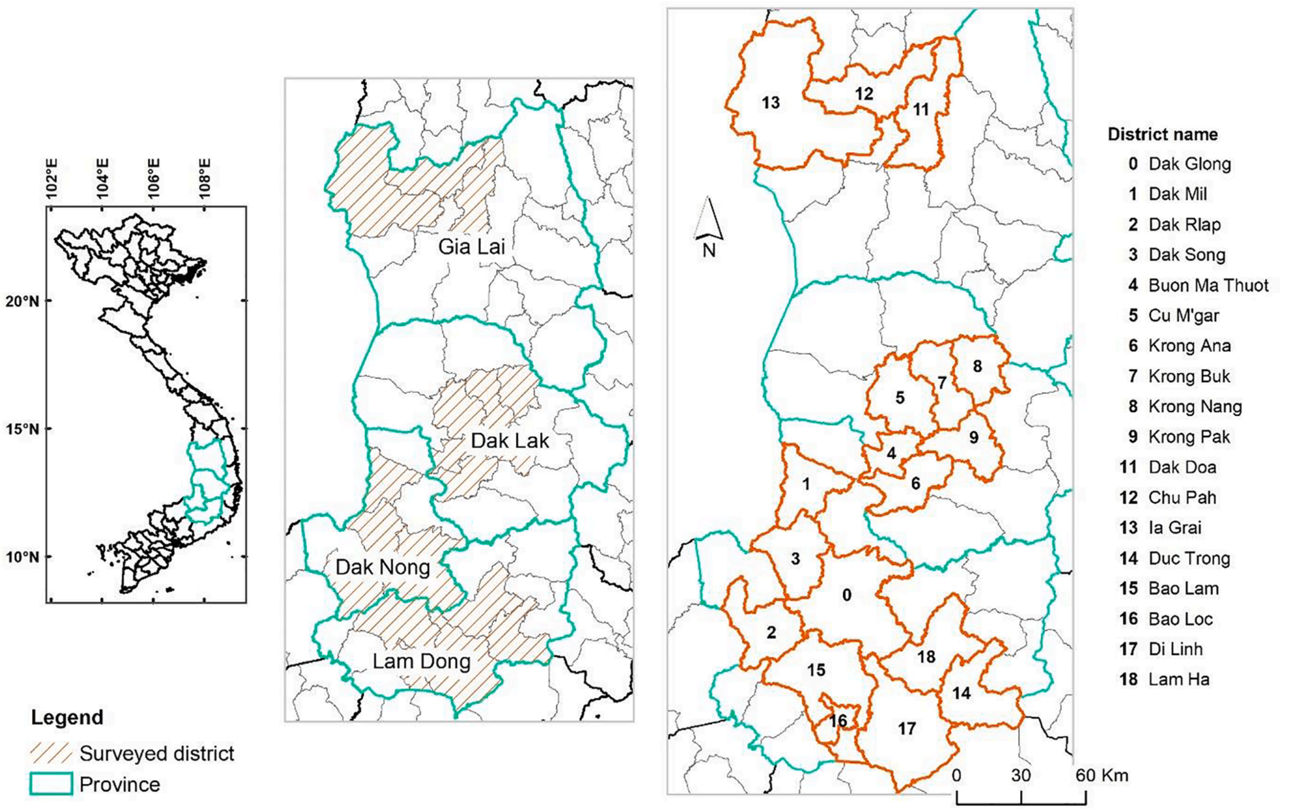

Fig. 1. Location of study areas across Vietnamese robusta coffee-producing provinces. ().
Source: https://gadm.org/

(https://www.ncdc.noaa.gov/cdr). For each district in a given province, the 30 annual rainfall amounts were first ranked. Years with an annual rainfall below the 20th percentile were classified as 'drought years'; 'average-rainfall-condition years' were years with annual rainfall between the 30th and 70th percentiles; and 'above-average-rainfall-condition years' indicated years with an annual rainfall greater than the 70th percentile. Although the standardized precipitation index (SPI), which rely only on precipitation and has been used in several studies on drought in Vietnam (e.g. (Vu-Thanh et al., 2014; Vu et al., 2015, 2018)), it might not be suitable for characterizing drought conditions in various areas in Vietnam, given the lack of socioeconomic and agronomic drought records and the sparseness of climate stations having long-term data records (Vu-Thanh et al. 2014). Hence the choice of the percentile ranking method in this study. This method is currently used for monitoring drought conditions in Indian agricultural regions (MAFW 2016). It is also similar to that adopted by the Australian Bureau of Meteorology to classify annual rainfall (www.bom.gov.au).

Over the 2008–2017 period, four to six years out of 10 were classified as drought years, depending on the district and province. The years 2011, 2012, 2014 and 2015 were drought years common to the majority of districts in all provinces (Table 1). 2008 was also classified as drought year for Dak Lak, Dak Nong and Gia Lai, with more drought years (6)

Table 1
Years when drought was experienced during the 2008–2017 period for each of the study robusta coffee-producing provinces in Vietnam. 'Drought years' (D) were defined as years when the total annual rainfall was below the 20th percentile; 'average-rainfall-condition years' (ARc) were years with annual rainfall within the 30th and 70th percentiles; and 'above-average-rainfall-condition years' (AARc) indicated years with annual rainfall greater than the 70th percentile.

Province	District	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total of drought years
Dak Lak	Buon Ma Thuot	D	ARc	ARc	D	D	ARc	D	D	ARc	ARc	5
	Cu Mugar	D	ARc	ARc	D	D	ARc	D	D	ARc	ARc	5
	Krong Ana	D	ARc	ARc	D	D	ARc	D	D	ARc	ARc	5
	Krong Buk	D	ARc	ARc	D	D	D	D	D	ARc	ARc	6
	Krong Nang	D	ARc	AARc	D	D	ARc	D	D	ARc	ARc	5
	Krong Pak	D	ARc	ARc	D	D	ARc	D	D	ARc	ARc	5
Dak Nong	Dak GLong	D	ARc	ARc	D	D	ARc	D	D	ARc	ARc	5
	Dak Mil	D	ARc	ARc	D	D	ARc	D	D	ARc	ARc	5
	Dak RLap	D	ARc	ARc	D	D	ARc	D	D	ARc	AARc	5
	Dak Song	D	ARc	ARc	D	D	ARc	D	D	ARc	ARc	5
Gia Lai	Chu Prong	D	ARc	ARc	D	D	ARc	D	D	D	ARc	6
	Dak Doa	D	D	ARc	D	D	ARc	D	D	ARc	ARc	6
	Ia Grai	D	ARc	ARc	ARc	D	D	D	D	D	ARc	6
Lam Dong	Bao Lam	ARc	ARc	ARc	D	D	ARc	D	D	ARc	ARc	4
	Bao Loc	ARc	ARc	ARc	D	D	ARc	D	D	AARc	AARc	4
	Di Linh	ARc	D	AARc	D	D	ARc	D	D	AARc	AARc	5
	Duc Trong	ARc	D	AARc	D	D	ARc	D	D	ARc	ARc	5
	Lam Ha	ARc	D	ARc	D	D	ARc	D	D	ARc	ARc	5

found for all districts in the latter province.

2.3. Data analysis

2.3.1. Drought mitigation strategies and their economics

For each drought mitigation strategy i in drought year j, the gross margin (GM) in a given surveyed farm was calculated as follows:

$$GM_{ij} = \left(Production_j \times \overline{Price}\right) - CP_{ij} \quad (1)$$

where $Production_j$ is the robusta green coffee production (beans yield × area harvested) in year j; $\overline{Price}$ is the 10-year (2008–2017) average coffee price; and CP_{ij} refers to the costs of production in year j for drought strategy i.

Prices for green coffee beans and costs of production were all expressed in real prices (US$) using the Consumer Price Indices for Vietnam during the 2008–2017 period (GSOV 2019). The 10-year average real price used in our study was US$ 1.29 kg^{-1}. The costs of production included costs related to electricity, fuel, labor, and inputs (e.g. fertilizers, agrochemicals). The price of irrigation per application in the surveyed farms was computed based on the cost of the fuel, electricity, and labour needed.

2.3.2. Factors influencing the adoption of drought mitigation strategies

We hypothesized that there is a statistical association between a set of farm-specific variables (socio-economic and environmental characteristics) and the drought mitigation strategy adopted. To investigate this relationship a logistic regression model was used following (Gelman and Hill 2007):

$$Pr(Y_i = 1) = Logit^{-1}(X_i\beta) \quad (2)$$

where Y_i refers to the outcome variable which is the mitigation strategy; β is a vector of coefficients of the covariates (explanatory variables) X_i. The outcome variable is a binary variable coded as 1 = strategy based on mulching (irrigation + mulching), and 0 = no mulching (irrigation alone). Covariates included the socioeconomic and environmental characteristics of surveyed farmers. They were X_1 = gender, X_2 = farm ownership, X_3 = farming experience, X_4 = farm size, X_5 = 10-year average farm income (from coffee and non-coffee), X_6 = 10-year average rainfall at the start of the cropping season, X_7 = water source, X_8 = irrigation method, and X_9 = drought impact level on yield as perceived by the farmer (Table 2). Continuous covariates (X_3, X_5, X_6, and X_9) were standardized [mean(x)/2 × sd(x)] to allow the direct comparison of effect sizes (Gelman and Hill 2007).

Furthermore, we hypothesized that the adoption of a drought coping strategy is positively associated to farm ownership, farming experience, farm income (used as a proxy of wealth in our study), rainfall at the start of the cropping season, and the perceived drought impact level. A variable effect across provinces was expected for variables related to gender, age of farmer, farm size, water source, and irrigation method. All surveyed farmers had access to agricultural extension and climate information services (e.g., weather forecasts, warnings for extreme events like typhoons). Consequently, this factor was not included in the model. All the statistical analyses were carried out in R (R Core Team 2019).

Table 2
Explanatory variables hypothesized in the logit model.

Variable	Variable specification	Hypothesis
X_1	Gender of respondent (i.e. farm's head): 1 for male, 0 for female	+/-
X_2	Farm ownership: 1 for tenant, 0 for owner	+
X_3	Farming experience (years)	+
X_4	Farm size: 1 for smallholder (area ≤ 1 ha), 0 for large-holder (area < 1 ha)	+/-
X_5	10-year (2008–2017) average farm income from coffee and non-coffee (US$)	+
X_6	10-year (2008–2017) average rainfall at the start of the cropping season, i.e. November-December total rain (mm)	+
X_7	Water source: 1 for groundwater, 0 surface water	+/-
X_8	Irrigation method: 1 for basin, 0 sprinkler	+/-
X_9	Drought impact level (i.e. farmer's perception of drought impact on yield) (%)	+

3. Results

3.1. Participant background information

Table 3 presents the socio-demographic and farm characteristics of the surveyed farmers. Male farmers predominantly managed robusta coffee farms in the selected provinces; with only 17% heads of farm being female out of the 558 farmers interviewed. The highest proportion of female farmers was found in Dak Lak. This province also had the relatively highest proportion of tenant farmers (39%) (Table 3). In Dak Nong and Lam Dong all the participants were, however, owners. Farming experience varied from 18 to 24 years on average depending on the province, with farmer's age ranging from 30 to 70 (as of 2017). Variable farm sizes were found, with average sizes ranging from 1.4 to 2.4 ha. Coffee trees were relatively young across the selected provinces, with more than half of them being < 20 years old. Coffee farming was the main source of income for the surveyed farmers (Table 3, Fig. S1). All farmers in Dak Lak, Dak Nong and Gia Lai (only 22 farmers in Lam Dong) had additional incomes from fruit trees or pepper (Fig. S1).

3.2. Farmers' perception on drought

Our survey was structured so that farmers could state whether drought events occur every year, or biennially, or once in three years. They were also asked to indicate when the impact was felt on their coffee plantations, and to subjectively assess the impact level on coffee production. Overall, farmers associated drought with a deficit of rainfall, relative to average conditions, during the cropping season. The majority of respondents in Dak Lak (57%), Gia Lai (54%) and Lam Dong (64%) reported an occurrence of drought once in three years (Table 4). In Dak Nong, 57% of the interviewees reported the occurrence to be biennial. Virtually none of the participants experienced drought every year.

When asked to provide a level of drought impact on coffee production, the average yield reduction indicated by the surveyed farmers ranged from 7.6% (Lam Dong) to 12.2% (Dak Lak); across all provinces the overall average reduction was −9.6%. The majority of surveyed farmers in Dak Nong (70%), Gia Lai (70%) and Lam Dong (82%) indicated 5 to 10% of their coffee production decreased due to drought. In Dak Lak there was no clear indication, with 70 farmers (39%) reporting a decrease in coffee production up to 10%, and 86 (48%) reporting 10–15% decrease (Table 4).

3.3. Drought impact on robusta coffee

Prior to analysing the economics of the drought coping strategies, the differences in yields and gross margins between drought and average-rainfall-condition years were quantified for each province using data from 2008 to 2017 historical data. Overall, robusta coffee yield reduction due to drought was on average 6.5% (all provinces considered; Fig. 2a), compared to that in average-rainfall-condition years. Gross margins declined by 22% in drought years compared to those in average-rainfall-condition years: from US$ 1144 ha^{-1} to US$ 892 ha^{-1} (all provinces considered; Fig. 2b).

More specifically, in Dak Lak and Gia Lai yield reduction due to drought was 9% and 14%, respectively, with the difference in yields between drought and average-rainfall-condition years being statistically significant ($P < 2e^{-16}$). The corresponding decreases in gross margins were on average from US$ 1097 ha^{-1} to US$ 748 ha^{-1}, and US$ 1189

Table 3
Distribution of participants' sociodemographic and farm characteristics. The total number of surveyed farms was 558.

	Dak Lak(N = 180)		**Dak Nong**(N = 120)		**Gia Lai**(N = 93)		**Lam Dong**(N = 165)		**All provinces**(N = 558)	
	Mean ± standard deviation									
Farmer's age (year)	50 ± 7		46 ± 9		55 ± 9		52 ± 8		51 ± 8	
Farming experience (year)	23 ± 6		18 ± 6		21 ± 7		24 ± 5		22 ± 6	
Farm size (ha)	1.4 ± 1.0		1.8 ± 1.5		1.5 ± 1.3		2.2 ± 1.6		1.7 ± 1.4	
Age of tree (year)	24 ± 5		19 ± 4		21 ± 4		23 ± 4		22 ± 5	
Proportion of farmers[1] (%) according to:										
Gender	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
	22	78	17	83	17	83	12	88	17	83
Ownership	Owner	Tenant	Owner	Tenant	Owner	Tenant	Owner	Tenant	Owner	Tenant
	61	39	100	0	78	22	100	0	84	16
Income (US$ 1000)										
< 5	42		32		31		34		34	
5–10	37		36		43		38		38	
> 10	22		33		26		28		28	

[1] : Head of the farm.

Table 4
Distribution of the surveyed farmers according to their perception on drought frequency and drought impact on robusta coffee production in Dak Lak, Dak Nong, Gia Lai and Lam Dong.

	Dak Lak (N = 180)	**Dak Nong** (N = 120)	**Gia Lai**(N = 93)	**Lam Dong** (N = 165)	**All province**(N = 558)
	Proportion of farmers (%)				
Drought frequency					
Every year	0	1	0	0	0.2
Once in 2 years	43	76	46	36	50.3
Once in 3 years	57	23	54	64	49.5
Year when drought impact is felt on crop					
Same year	57	58	54	42	53
Following year	43	42	46	58	47
Impact level on coffee yield (%)					
Less (0–5)	0	6	2	8	4
High (5–10)	39	70	70	82	65
Very high (10–15)	48	19	28	9	26
Severe (>15)	13	5	0	0	4

ha^{-1} to US$ 616 ha^{-1}, respectively (Fig. 2b). In Dak Nong and Lam Dong, coffee yields in drought and average-rainfall-condition years were statistically similar on average ($P = 0.3$ and $P = 0.076$, respectively; Fig. 2a). However, in Dak Nong, gross margins in drought years were reduced by 20% on average compared to their levels in an average-rainfall-condition year (from US$ 913 ha^{-1} to US$ 730 ha^{-1}); whereas in Lam Dong gross margins did not statistically differ between average-rainfall-condition and drought years ($P = 0.7$; Fig. 2b). The relatively shorter data period (10 years) used to assess objectively coffee yield reduction due to drought could explain, partly, the differences found from farmers' assessments. Indeed, although 94% of the surveyed farmers had>10 years of coffee farming experience, no historical yield data spanning that farming experience were available. It is also worth mentioning that apart from drought yield reductions could be related to the biennial bearing effect of coffee yield, i.e. alternation of high and low coffee bean production years (DaMatta 2004b).

3.4. Drought coping strategies and their economics during 2008–2017

To cope with the adverse effects of drought, the survey revealed that farmers adopted mulching as a coping strategy, in addition to irrigation which was already included in their management practices. Farmers rely on irrigation to trigger synchronous robusta coffee blossoming, and for maintaining high yield levels in both drought and average-rainfall-condition years. Nevertheless, in drought years, this practice is implicitly used as a coping strategy. Shade trees, which can also be considered a drought coping strategy (Boreux et al. 2016), are not commonly used among the surveyed farmers in this study. In our analysis, mulching was the drought adaptation strategy investigated.

Irrigation was predominantly supplied through basins across the study provinces (60% of the 558 surveyed farmers; Table 5), with frequencies varying between two and four rounds per year in drought years. In drought years, the amounts and costs of irrigation increased compared to those in average-rainfall-condition years across all provinces, though with varying levels according to the province (Fig. 2c and 2d). The average increase in irrigation costs for all four provinces was 24% (US$ 139 ha^{-1} to US$ 173 ha^{-1}), with higher increases recorded in Dak Lak (27%) and Lam Dong (49%) (Fig. 2d).

A total of 324 robusta coffee farmers surveyed (58%) adopted mulching to cope with drought (Table 5). The breakdown by province shows that those in Dak Nong and Lam Dong predominantly relied on mulching, while the majority of their counterparts in Dak Lak (65%) and Gia Lai (57%) preferred to keep irrigation alone to cope with the adverse effects of drought (Table 5). In terms of yield difference (Fig. 3), for all the provinces, yields for farmers that mulched were on average 7.7% higher than those in absence of mulching (Fig. S2a). The highest average yields were observed in Lam Dong, regardless of the strategy: they ranged from 2285 to 3051 kg ha^{-1}, and 2277 to 3156 kg ha^{-1} for non-mulching and mulching farmers, respectively. In Dak Lak there was no statistical yield difference between farmers that used mulch and those that did not in drought years ($P > 0.05$; Fig. 3a): coffee yields ranged from 2206 to 2863 kg ha^{-1}, and 2203 to 2848 kg ha^{-1} for non-mulching and mulching farmers, respectively.

Farmers using mulching had gross margins US$ 10.2% ha^{-1} higher than farmers that did not use mulch (Fig. S2b). The gross margins for farmers applying mulch were US$ 974, 917, 1132, and 1369 ha^{-1} on average, for Dak Lak, Dak Nong, Gia Lai and Lam Dong, respectively (Fig. 4b-d). The respective differences in gross margins from their counterparts using no mulch were −6, −17, −11, and −9%, and were statistically significant in the majority of provinces ($P < 0.05$), except Dak Lak. When comparing farmers with unprofitable coffee farming in drought years, the highest proportions occurred in 2008 in Dak Lak, Dak Nong and Gia Lai (Table S2). The majority of them were among those applying no mulch: 66% and 64% in Dak Lak and Gia Lai, respectively. The opposite was found in the remaining provinces Dak Nong and Lam Dong, though in this case only 17 farms out of the 165 surveyed were concerned with such losses (Table S2). Irrespective of the province, these numbers noticeably decreased in subsequent drought years (up to five farms), suggesting, in part, improved resilience to drought.

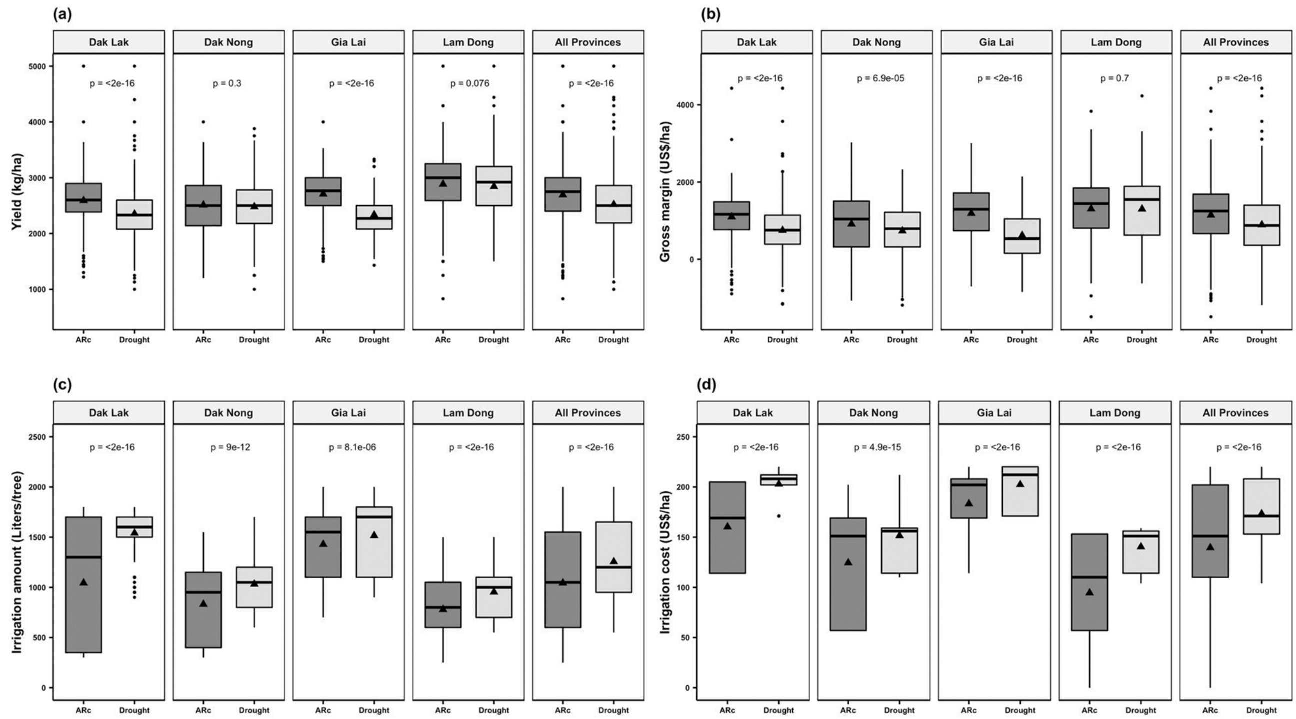

Fig. 2. Boxplots of (a) robusta coffee yields, (b) gross margins from coffee farming, (c) irrigation amount, and (d) irrigation cost according to rainfall pattern (drought and average-rainfall-condition, ARc) for each of the selected Vietnamese robusta coffee-producing provinces during 2008–2017. Upper and lower border of the boxes represent the 3rd and 1st quartiles, respectively. The line within the box represents the median value, and black triangle is the mean value. Bars extend to the minimum and maximum values. Black circles are the outliers. For each province, the P-values from the *t*-test comparing mean values are shown (significant difference at $P < 0.05$).

Table 5
Distribution of the surveyed farmers according to drought mitigation strategies (mulching and no mulching), irrigation frequency and methods in the study Vietnamese robusta coffee-producing provinces.

	Dak Lak (N = 180)	**Dak Nong** (N = 120)	**Gia Lai** (N = 93)	**Lam Dong** (N = 165)	**All provinces (N = 558)**
	Proportion of farmers (%)				
Mitigation strategy					
No mulching (irrigation alone)	65	36	57	13	42
Mulching (in addition to irrigation)	35	64	43	87	58
Irrigation frequency (rounds/ year)					
2	20	37	10	44	29
3	20	49	30	56	39
4	60	13	60	0	32
Irrigation method					
Basin	46	61	48	84	60
Sprinkler	54	39	52	16	40

3.5. *Factors influencing the adoption of the drought mitigation strategies*

A logistic regression model was used to examine the factors influencing the adoption of drought mitigation strategies. We applied this model to overall data (i.e. all provinces pooled) and as well as to each province separately. Considering all the provinces altogether, only rainfall at the start of the season had a positive and significant effect on adopting mulching as mitigation strategy ($P < 0.01$; Table 6). Farm size, irrigation method, farm ownership and perceived drought impact negatively influenced the adoption of mulching.

At the level of each province, varying patterns were found for the potential factors influencing the adoption of mulching (Tables 6, S2 and S3). For example, for one unit increase in household incomes (holding all other variables at a constant value) the odds of using mulching (as opposed to not mulching) in Dak Nong, Gia Lai and Lam Dong were 16%, 2% and 1%, respectively (Table S3). Rainfall at the start of the season positively and significantly ($P < 0.01$) affected the adoption of mulch in Dak Lak and Dak Nong: the odds of adopting mulch (as opposed to no mulch) were 3.4% and 6.1% higher, respectively, for a one unit increase of rainfall (Table S3). Whilst in Gia Lai and Lam Dong there was a 35% and 85% lower chances of adopting mulching for each one unit increase of rainfall at the start of the season.

4. Discussion

We illustrated through a comparative assessment that while the surveyed farmers in Dak Lak, Dak Nong, Gia Lai and Lam Dong shared certain climatic conditions, their perceptions and responses to drought varied. Drought was generally associated with a deficit in rainfall during the cropping season, compared to average-rainfall-condition years. The majority of respondents in Dak Lak, Gia Lai and Lam Dong reported an occurrence of drought once in three years, with varying adverse effects on their robusta coffee production. Although the yield reduction due to drought was<7% on average across all provinces, the impacts on gross margins were noticeable, with a 22% decline on average from levels achieved in average-rainfall-condition years. This can be explained by increasing production costs due to the increased number of irrigation applications and associated costs (labour, electricity) during dry years. To cope with these negative climate conditions, the surveyed farmers relied only on mulching and irrigation.

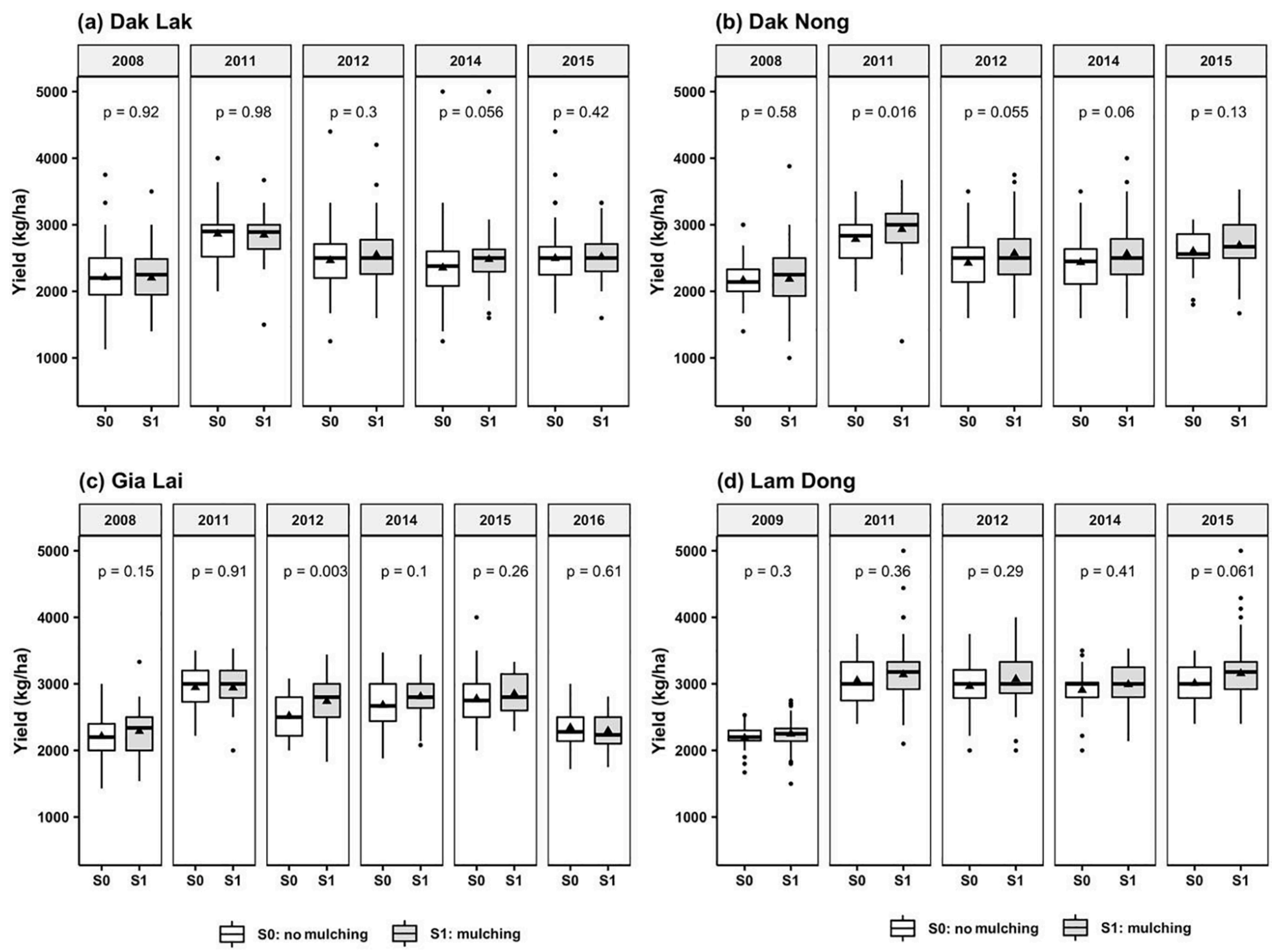

Fig. 3. Boxplots of robusta coffee yields according to drought mitigation strategy for (a) Dak Lak, (b) Dak Nong, (c) Gia Lai, and (d) Lam Dong in drought years during the 2008–2017 periods. Upper and lower border of the boxes represent the 3rd and 1st quartiles, respectively. The line within the box represents the median value, and black triangle is the mean value. Bars extend to the minimum and maximum values. Black circles are the outliers. For each province, the P-values from the *t*-test comparing mean values are shown (significant difference at $P < 0.05$).

The drought impacts observed in this study (both from farmers and based on our financial impact analysis) are consistent with other studies on drought and climate impacts in the study area (Kath et al., 2020, 2021; Kouadio et al., 2021), as well as in other important coffee producing areas e.g. Brazil, (Venancio et al. 2020). At the regional scale across the Vietnamese Central Highlands, drought stress, which acts by reducing daily biomass production, is a key component of process based models for predicting robusta coffee yields (Kouadio et al. 2021). While in a broader scale study across both Vietnam and Indonesia the impacts of drought and high temperatures have also been shown to be important factors in determining coffee farmer's yields (Kath et al. 2021).

To cope with drought, it was expected that the chances of adopting mulching across the study provinces would increase for one unit increase in the perceived drought impact level or for farmers with more experience. The opposite, however, was found among the surveyed farmers in three out of four study provinces (Table 6 and S2). Several factors can explain such results including the frequency of drought events as perceived by farmers and the resulting yield reductions, the availability and affordability of water for irrigation, as well as the affordability of agrochemicals compared to other coffee-producing countries. For example, the one-in-three-year drought occurrence reported by the majority of farmers and yield reduction predominantly estimated between 5 and 15% suggest that coffee trees, grown consistently under intensive fertilizer and irrigation use (D'haeze et al., 2005; Marsh, 2007; Byrareddy et al., 2019), were able to recover from any negative effects between each drought events. Our analysis indicated that regardless of whether farmers mulched or not the amounts of irrigation applied in drought years between the two strategies were statistically similar ($P > 0.05$; Fig. S3) in the majority of provinces (Dak Lak, Dak Nong and Gia Lai). Such an indifferent irrigation use could be explained by a "no-risk" attitude farmer can have while willing to achieve or sustain a high coffee yield regardless of the rainfall pattern.

Given this, farmers might not find it urgent to adopt water conservation strategies. As drought events are expected to be recurrent, and likely more severe (IPCC 2014b) there is a need to increase farmer's awareness of the availability of water for irrigation under the changing climate and help prepare for better drought management. The reliance on water resources (groundwater and river flows) to achieve high yields (Marsh, 2007; Haggar and Schepp, 2012) could be detrimental to the sustainability of the whole farming system during prolonged drought events in the study provinces. It also increases the vulnerability to climate change given its currently perceived and expected adverse impacts on agricultural water availability across the Vietnamese coffee-producing provinces (Haggar and Schepp, 2012; Parker et al., 2019; Pham et al., 2019).

Various benefits of mulching have been documented for several crops including coffee. In addition to reducing weed competition or improving soil moisture and texture, mulches also supply nutrients to soils, albeit at varying levels depending on the quality of the mulch materials, climatic conditions and soil types (Chalker-Scott, 2007; Kader et al., 2017; Nzeyimana et al., 2020; Qu et al. 2019). Relatively higher average coffee yields were found in the surveyed farms where mulching

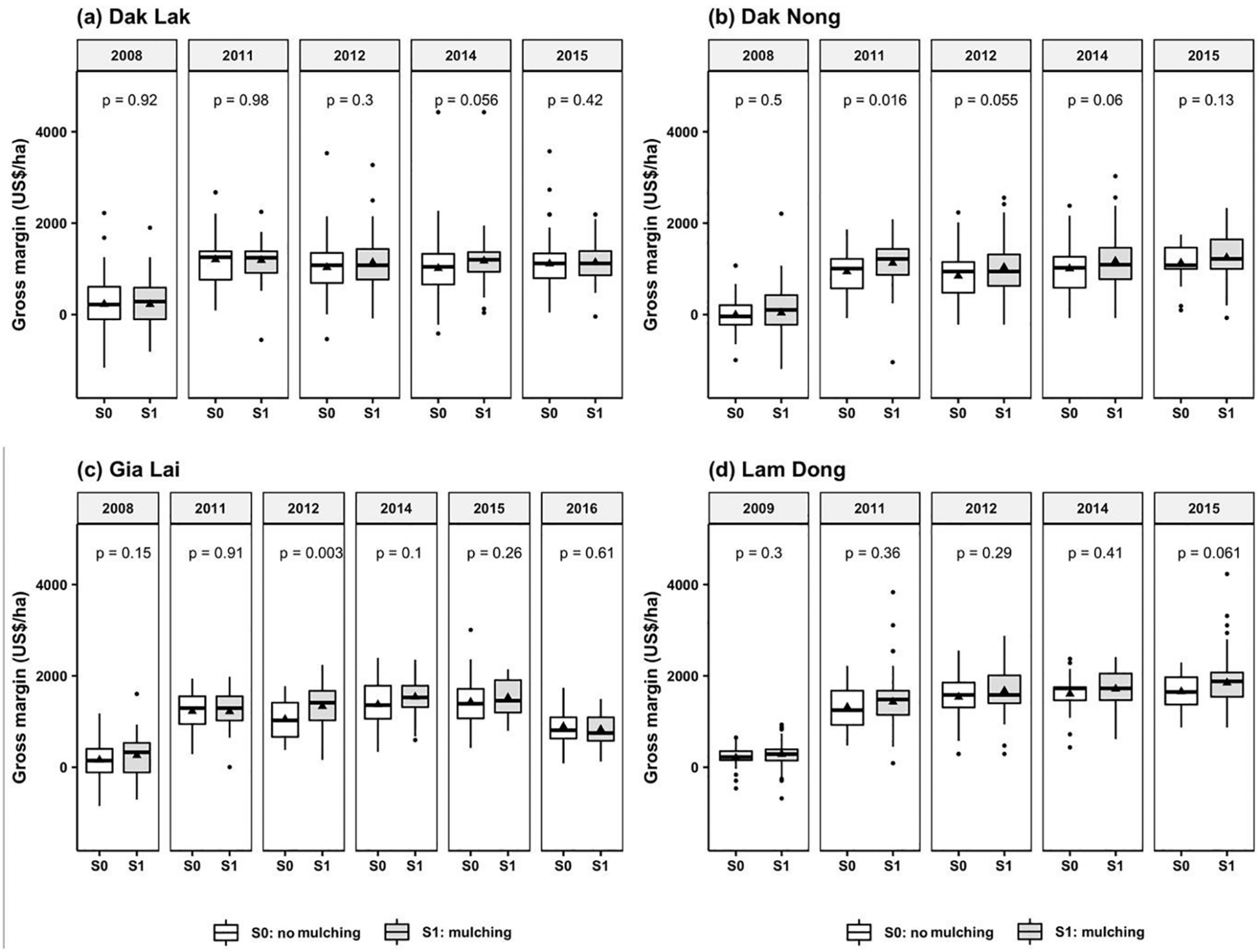

Fig. 4. Boxplots of gross margins according to drought mitigation strategy for (a) Dak Lak, (b) Dak Nong, (c) Gia Lai, and (d) Lam Dong in drought years during the 2008–2017 periods. Upper and lower border of the boxes represent the 3rd and 1st quartiles, respectively. The line within the box represents the median value, and black triangle is the mean value. Bars extend to the minimum and maximum values. Black circles are the outliers. For each province, the P-values from the *t*-test comparing mean values are shown (significant difference at $P < 0.05$).

Table 6
Coefficient estimates of factors influencing the adoption of mulching as drought coping strategy in the selected Vietnamese robusta coffee-producing provinces.

	Dak Lak	Dak Nong	Gia Lai	Lam Dong	All Provinces
Variable	**Coefficient estimate (standard deviation)**				
Income[a]	−0.683 (0.525)	0.147 (0.567)	0.023 (0.823)	0.010 (0.543)	0.036(0.247)
Rain[b]	1.235** (0.360)	1.808*** (0.578)	−0.424 (0.641)	−1.910*** (0.540)	0.660*** (0.208)
Farming experience	0.481 (0.364)	−0.280 (0.445)	−0.034 (0.491)	−0.546 (0.514)	0.032 (0.190)
Farm size (1 for smallholder, 0 for large-holder) [c]	−1.274* (0.655)	0.087 (0.513)	0.949 (0.661)	−0.625 (0.548)	−0.518** (0.251)
Irrigation method (1 for basin, 0 for sprinkler)	−0.530 (0.576)	−0.171 (0.562)	0.016 (0.609)	0.081 (0.783)	−0.556** (0.241)
Water source (1 for groundwater, 0 for surface water)	0.758 (0.480)	0.324 (0.430)	0.251 (0.689)	0.495 (0.603)	−0.178 (0.205)
Gender (1 for male, 0 for female)	0.115 (0.430)	0.128 (0.570)	0.803 (0.724)	1.074* (0.647)	0.24 (0.258)
Farm ownership (1 for tenant, 0 for owner) [d]	−1.431*** (0.391)		−3.210*** (1.162)		−2.031*** (0.320)
Impact level	0.190 (0.352)	−0.321 (0.423)	−0.101 (0.508)	−0.724 (0.490)	−0.773*** (0.214)
Constant	−0.589 (0.649)	0.545 (0.593)	−0.738 (0.948)	1.198* (0.613)	0.775*** (0.277)
Observations	180	120	93	165	558
Log Likelihood	−99.946	−70.069	−51.172	−54.228	−319.751
Akaike Information Criterion	219.891	158.139	122.345	126.456	659.503

Statistical significance: *: $P < 0.1$; **: $P < 0.05$; ***: $P < 0.01$.
[a] 10-year (2008–2017) average income.
[b] 10-year (2008–2017) average of rainfall total at the start of each cropping season (November-December).
[c] Smallholder: farm size ≤ 1 ha; large-holder: farm size > 1 ha.
[d] All farmers in Dak Nong and Lam Dong were owners (no estimate provided for 'farm ownership').

was used in drought years (compared to those using irrigation alone) across three out of four selected robusta coffee-producing provinces in Vietnam (Fig. 3). Although mulching may have helped improve plant growth and increase yields, differences in yields between drought coping strategies could also be explained by such factors, such as fertiliser use. Fertilizer management (type, rate and frequency) and soil fertility differ between provinces or between farms within a specific province (Tiemann et al., 2018; Byrareddy et al., 2019). The impact of other crop management practices such as pruning, harvest methods, pesticides and herbicides applications are unlikely to have had a strong influence as they were generally similar across the surveyed farms (Byrareddy et al. 2019).

Mulching appears practicable in many coffee farms in Vietnam since the material (pruned branches and dead leaves from coffee trees or other trees) is readily available on-site and/or in surrounding areas, and the costs associated with pruning remain affordable and do not affect the economic viability of the farm. Although this practice might be adopted in all robusta coffee farms in Vietnam given the availability of mulch materials under normal weather conditions, such an adoption would be hampered if droughts become more frequent and severe in the future. Indeed, increased drought frequencies would limit the availability of organic mulch materials, forcing farmers to rely on other affordable soil moisture conservation techniques (e.g., contouring, spreading compost) to maintain their farm profitability. A better understanding of the potential benefits of alternative techniques for soil moisture conservation in robusta coffee farms in Vietnam is needed to improve farmers' preparedness to projected climate conditions.

More resilient coffee production systems are expected to sustain less damage and to recover more quickly when exposed to climate risk. It is critical to implement policies to ensure optimum use of water for irrigation in coffee areas in Vietnam since there are opportunities in the study provinces to reduce water for irrigation while achieving satisfactory yield levels (e.g., 3000–4000 kg ha^{-1}), (Amarasinghe et al., 2015; Byrareddy et al., 2020). Moreover, although there were examples of pepper planted as shade or windbreak trees in few farms (25 out of 558 farms), the farmers in question did not consider this as a drought mitigation/adaptation strategy. Rather, they were concerned about the competition for irrigation water from such trees and subsequent reduction of their coffee yield potential in drought conditions. Shade trees, when associated with good management practices, can benefit coffee farming systems by improving soil water infiltration and soil conservation, reducing water and heat stress, and in turn may increase production (Souza et al., 2012; Boreux et al., 2016; Meylan et al., 2017). However, the complex functioning and interactions between coffee and shade trees remain a challenge that has to be fully investigated to increase the chances of adopting this practice in robusta coffee farms in Vietnam.

Based on data spanning the 2008–2017 period, the majority of robusta coffee farms (>75%) achieved positive gross margins in drought years despite the adverse financial impacts of drought, mostly because of the availability and affordability of water for irrigation. Lower water tables subsequent to drought events can be observed across the study provinces (CCAFS-SEA 2016), implying that irrigation costs, namely electricity charges, would increase in water-scarce conditions. Moreover, if the government decides to put a price on water, the negative financial impacts of drought may be even greater and detrimental to robusta coffee farming systems in Vietnam. Our findings show that to date incremental adaptation strategies (irrigation + mulching) have allowed coffee producers to alleviate the impacts of drought. However, with an increase in drought frequency and severity, and considering sustainability, some incremental response may not be sufficient. For the future expansion of coffee areas, transformational responses, which may include relocation to suitable environmental conditions may be worth considering.

This study was restricted to intensely managed farms, which are heavily fertilised and irrigated (Byrareddy et al., 2019, 2020). Whether the positive effects of mulching we show here apply to less intensely rain-fed systems needs further investigation. Additional to this we only assess the financial benefits from increases in yield from mulching. However, it is possible that mulching also benefits aspects of coffee bean quality. Drought impacts have been shown to affect bean sizes, which can affect the price that farmers get for their coffee (Kath et al. 2021). The financial benefits of mulching may therefore be higher than we show here if reductions in gross margins from poor coffee bean characteristics resulting from drought were also considered. Future studies that consider less intensely managed systems which lack irrigation (e.g. Indonesia, (Kath et al. 2020)) and coffee bean characteristics are therefore important future research directions to better understand the benefits, or otherwise, that mulching has for coffee farmers.

5. Conclusion

We investigated farmers' perceptions and responses to drought, drought impacts on yield and gross margins in four major robusta coffee-producing provinces in Vietnam, and determined the economics of strategies adopted to cope with the adverse effects of drought. From the strategies adopted to cope with the adverse effects of drought on their coffee production, farmers adopting a combination of irrigation and mulching achieved greater gross margins compared to those relying on only irrigation. Although robusta coffee farming was generally profitable for all farmers in drought years, the current irrigation-based strategies need to be diversified or improved to increase climate resilience given the projected changes in rainfall patterns across the study provinces. Building the resilience of robusta coffee farmers in a changing climate also implies an incremental adaptation process to more variable climate conditions. With the benefit of adopting mulching in addition to irrigation to cope with drought, as demonstrated in this study (at least for provinces such as Dak Nong, Gia Lai and Lam Dong), farmers would make it an integral part of their management practices, and even be able to improve it. As such, this study could serve as a basis for the design of policies to address drought risks and encourage more resilient adaptive strategies Jassogne et al. (2013), Nzeyimana et al. (2020)

CRediT authorship contribution statement

Vivekananda Byrareddy: Conceptualization, Methodology, Investigation, Data curation, Software, Formal analysis, Writing - original draft. **Louis Kouadio:** Conceptualization, Methodology, Software, Validation, Writing - original draft. **Shahbaz Mushtaq:** Supervision, Project administration, Writing - review & editing. **Jarrod Kath:** Data curation, Validation, Visualization, Writing - review & editing. **Roger Stone:** Funding acquisition, Project administration, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cliser.2021.100229.

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