



RESEARCH ARTICLE

Evidence for the impact of malaria on agricultural household income in sub-Saharan Africa [version 1; peer review: 1 approved with reservations]

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Abstract

Background: Progress in suppressing malaria over the next two decades may have a significant impact on poverty among agricultural households in sub-Saharan Africa. A recent study found that if malaria were eradicated by 2040, poverty rates among such households would fall by 4 to 26 percentage points more from 2018 to 2040 than if the burden of malaria remained at its current level. The relatively wide range of these estimates is due to a lack of evidence regarding the long-term impact of suppressing malaria on the incomes of agricultural households. The objective of this study is to describe a research framework that would generate the necessary evidence for developing more precise estimates.

Methods: First, we developed a conceptual framework for understanding the potential long-term impact of suppressing malaria on the incomes of agricultural households. Next, we established a research framework for examining each component of the conceptual framework.

Results: Our proposed research framework enables a comprehensive examination of how malaria affects the decisions, productivity, harvest value and expenditures due to morbidity and mortality within an agricultural household. This contrasts with the 27 existing relevant studies that we have identified, of which 23 focused only on household productivity and expenditures, two focused on decisions, and two focused on harvest values.

Conclusion: By implementing the research framework presented in this study, we will increase our knowledge of how suppressing malaria over the next two decades would affect the incomes of agricultural households in sub-Saharan Africa. Evidence generated from the framework will inform funding allocation decisions for malaria elimination initiatives.

Keywords

malaria, agricultural households, Africa, economic impact, Sustainable Development Goals

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Introduction

Ambitious goals have been established to eradicate malaria by 2040. The suppression of malaria over the next two decades would have a significant impact on the welfare of malarious communities. During the first Global Malaria Eradication Campaign from 1955 to 1969, bold claims were made about how eradication would affect the welfare of these communities (Packard, 2009). Many of these claims focused on how suppressing malaria would facilitate economic development by increasing the productivity of agricultural households. Packard notes that in 1958 the World Health Organization (WHO) initiated an effort to collect the necessary data to estimate the economic impact of eliminating malaria (Packard, 2009). However, by 1962 its Director-General had recognized the challenges to identifying and collecting the necessary data, ex-post, to assess the impact of malaria on economic and social development:

“As you probably know, we have been interested in the problem of the relationship between malaria eradication and its tangible economic benefits. On several occasions we have attempted to produce solid proof of the relationship and express it either in £.s.d or Dollars. Again and again we have noticed that this is a much more difficult subject than we had anticipated and all our preliminary documents were considered unfit for publication” (cited in Packard, 2009).

A research framework is needed today to ensure that the current malaria eradication campaign can generate evidence regarding the long-term impact of suppressing malaria on the incomes of agricultural households. Developing credible evidence regarding how progress towards eradicating malaria would affect poverty rates among agricultural households for the next two decades could affect the amount of funding allocated to anti-malaria initiatives. A lack of continuous funding for these programs was one of the main reasons that previous anti-malaria initiatives failed to achieve elimination or prevent resurgence (Cohen *et al.* 2012).

A previous study found that eliminating malaria in sub-Saharan Africa by 2040 would lead to a reduction in poverty rates among agricultural households by 4 to 26 percentage points (Willis & Hamon, 2018). This implies that between 13 million and 83 million individuals in agricultural households would escape poverty by 2040 due to the eradication of malaria as compared to the counterfactual scenario in which the malaria burden remains at 2018 levels. One reason for the relatively wide range in these estimates is that the model that was used in the study relied on evidence that was primarily generated from studies conducted before the goal of eradicating malaria was established. A research framework tailored to generating evidence regarding the impact of eradicating malaria would facilitate more precise estimates of how the incomes of agricultural households would be affected.

The objective of this study is to present a research framework for examining the long-term impact of suppressing malaria on the incomes of agricultural households. This framework would help determine which longitudinal data should be collected from malarious communities.

Methods

Our methodology has two parts: building a conceptual framework for understanding the potential long-term impact of suppressing malaria on agricultural households and then developing a research framework for examining that relationship.

The first part of our methodology involved developing a conceptual framework for understanding the potential channels through which suppressing malaria may have a long-term impact on the income of an agricultural household.

Next, we established a research framework for examining this long-term impact comprising two components. The first is the research topics that inform how suppressing malaria will affect the incomes of agricultural households over the next two decades. We define a research topic as the difference between some aspect of a household's experience when there is malaria transmission within the community versus what it would have been if no malaria transmission had occurred over the same time period. The second component defines the characteristics of the data that need to be collected to examine each research topic.

We used several steps to develop our dataset (Willis, 2018). First, we identified studies that examined the impact of malaria on the welfare of agricultural households in sub-Saharan Africa. We included only sub-national studies that used primary or secondary data to analyze the impact of malaria on these households. Reviews of the literature of how malaria affects agricultural households were excluded.

Results

Conceptual framework

Figure 1 provides a concise summary of our conceptual framework for how the suppression of malaria over a sustained period could have a long-term impact on the income of an agricultural household. It illustrates a continual process in which an increase in household income both depends on the health of household members and affects their health.

The figure begins by showing how anti-malaria programs could improve the health of an agricultural household in two ways. First, they may have a direct impact on reducing malaria morbidity and mortality. Second, the suppression of malaria may increase the income of the household, which in turn may affect its nutrition security.

Next, the figure illustrates that the decisions of an agricultural household affecting its income depend on the health of its members, its income from the previous growing season and its expectations regarding productivity in the next growing season. The productivity of adults in the household during the next growing season will depend on the number of malaria cases experienced by members of the household.

The impact of suppressing malaria on the harvest value of the household will depend on the decisions the household makes and the productivity of its members. Therefore, the suppression of malaria can impact the income of an agricultural household by affecting harvest values and household expenditures related

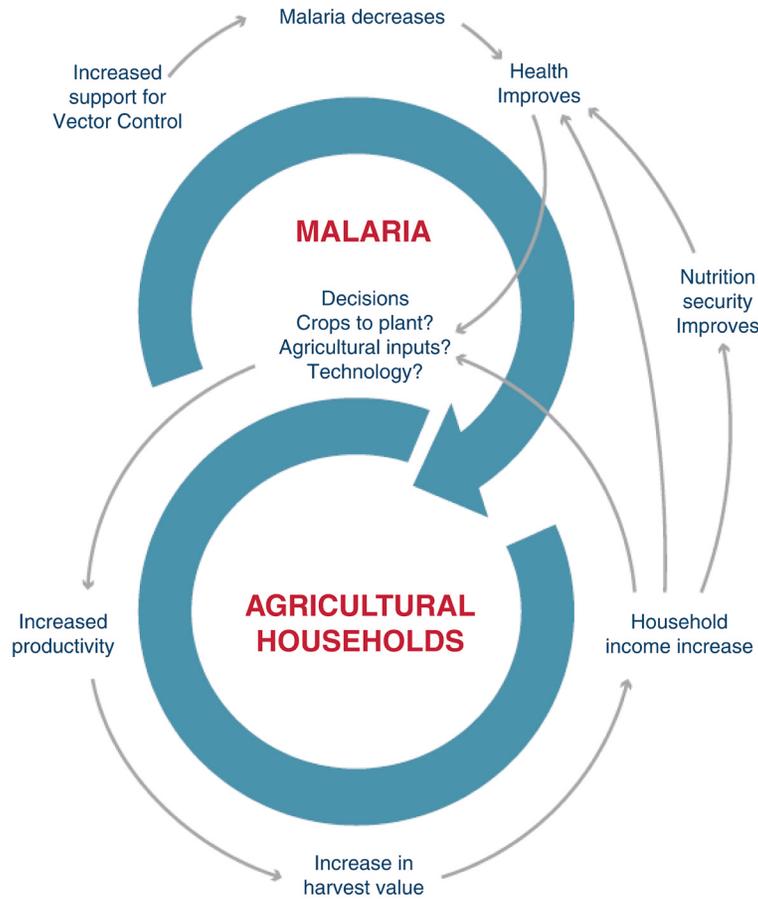


Figure 1. Conceptual framework for the long-term impact of malaria on the income of an agricultural household.

to malaria morbidity and mortality. Finally, to close the loop, the impact of suppressing malaria on nutrition security depends on changes in household income from the suppression of malaria.

Research framework

In the previous section, we described a conceptual framework for understanding the potential long-term impact of suppressing malaria on the incomes of agricultural households. In this section, we describe a research framework for examining each component of that conceptual framework.

Research topic: Decisions of an agricultural household

We focus on four types of decisions made by agricultural households. The first two are which crops to plant and how much land to cultivate. The third is how much investment should be made in agricultural inputs, defined as fertilizer and any technology that could increase crop yield. The fourth is the decision made regarding the level of resources to devote to purchasing anti-malaria interventions.

Our framework assumes that the choices made regarding these four key decisions depend on the resources available to the household and its expectations regarding the productivity of household

members. The resources available depend on the value of the harvest during the previous growing season and on expenditures during that growing season.

Few studies have examined the impact of malaria on these four decisions within agricultural households. A study conducted in Paraguay in the early 1970s did examine the relationship between malaria and the decisions made by farmers regarding which crops to plant. It found that an expectation of loss of labor due to malaria led farmers to plant less labor-intensive crops, even though those crops would provide lower revenues than more labor-intensive crops (Conly, 1975). A study in southern Africa in the 1950s suggested that, after malaria was suppressed, farmers began farming lands that had previously been considered too malarious (Annecke, 1950).

Research topic: Productivity of individuals in an agricultural household

Suppressing malaria may increase the income of an agricultural household by increasing productivity. Our research framework focuses on two ways that suppressing malaria could increase productivity. First, the suppression of malaria would reduce the number of work days that are lost by adults due to adult

malaria cases or to the need for adults to provide care for other household members with malaria. Second, suppressing malaria may increase gender equality between men and women in the household by reducing the number of caregiving days provided by women to household members.

Work days lost during the time labor is most needed for cultivation activities would have a higher value than work days lost during other times. Very few studies have attempted to quantify the value of work days lost based on the time of year the cases occurred, although an extensive number of studies have examined the number of work days lost due directly to malaria morbidity among adults or for caregiving (Asenso-Okyere & Dzator, 1997; Alaba & Alaba, 2009; Audibert, 1986; Asante & Asenso-Okyere, 2003; Akazili *et al.*, 2007; Akazili, 2000; Badiane & Ulimwengu, 2013; Cropper *et al.*, 2000; Ettling *et al.*, 1994; Nur, 1993; Ettling & Shepard, 1991; Guiguemdé *et al.*, 1997; Girardin *et al.*, 2004; Hailu *et al.*, 2017; Leighton & Foster, 1993; Miller, 1958; Mohamed, 2012; Nur & Mahran, 1988; Oluyole *et al.*, 2011; Omotayo & Oyekale, 2013; Sauerborn *et al.*, 1991; Sauerborn *et al.*, 1996a; Sauerborn *et al.*, 1996b).

A wide range of methodologies have been used to estimate the number of work days lost and caregiving days provided for each case of malaria. As a result, it is difficult to determine the extent to which differences in estimates are due to methodological differences or other factors. Most estimates of work days lost by adults due to a malaria case range from 1 to 9 days, while work days thought to be lost due to caregiving range from 1 to 7 days. Table 1 summarizes the figures arrived at by 12 studies.

One of the first studies to examine the impact of malaria on the productivity of farmers analyzed the natural history of malaria among men aged 20 to 30 in Liberia (Miller, 1958). Using data from 1957, the study found that the clinical duration of a malaria case was 6.5 days and that the average number of work days lost per case was 3 (Miller, 1958). An analysis of the economic impact of malaria in Kenya arrived at estimates that two to four work days were lost by adults due to adult malaria cases and caregiving on the basis of focus group interviews conducted in 1992 (Leighton & Foster, 1993). In Nigeria, focus groups in rural areas estimated that one to three work days were lost (Leighton & Foster, 1993).

Table 1. Studies of malaria's impact on work days lost and caregiving days.

Author, publication year; study location	Work days lost per malaria case in adult	Caregiving days per case
Miller, 1958; Liberia	3 days per case	-
Nur & Mahran, 1988; Sudan	6.1 days (1,576 days for 256 cases)	4.6 days (55.5 days for 256 cases)
Sauerborn <i>et al.</i> , 1991; Burkina Faso	1 day for mild illness; 5 days for severe illness (assumptions)	1/3 of one day for mild illness; 5/3 of one day for severe illness (assumptions)
Nur, 1993; Sudan	6.1 days (1,576 days for 256 cases)	4.6 days (55.5 days for 256 cases)
Leighton & Foster, 1993; Kenya & Nigeria	2 to 4 (Kenya: focus group); 1 to 3 (Nigeria: focus group)	2 to 4 (Kenya: focus group); 1 to 3 (Nigeria: focus group)
Sauerborn <i>et al.</i> , 1996a; Burkina Faso	1.4 days (mild illness in dry season); 1.3 days (mild illness in rainy season); 7 days (severe illness in dry season); 5.8 days (severe illness in rainy season)	0.9 days (mild illness in dry season); 0.4 days (mild illness in rainy season); 5.6 days (severe illness in dry season); 1.9 days (severe illness in rainy season)
Guiguemdé <i>et al.</i> , 1997; Burkina Faso	4 days	-
Cropper <i>et al.</i> , 2000; Ethiopia	18 days	11 days
Akazili, 2000; Ghana	2.6 days (mild illness) 5.3 days (severe illness)	-
Asante & Asenso-Okyere, 2003; Ghana	9.4 days (men); 8.9 days (women)	6 days
Deressa <i>et al.</i> , 2007; Ethiopia	6.8 days	6.7 days
Tawiah <i>et al.</i> , 2016; Ghana	6.4 days	-

Three studies examined the impact of malaria on the productivity of agricultural households in Ghana (Akazili, 2000; Asante & Asenso-Okyere, 2003; Tawiah *et al.*, 2016). A study in the Kassena-Nankana District of northern Ghana used a cross-sectional survey of 423 households to estimate 5.3 work days lost for a case of severe malaria and 2.6 work days lost for a mild case (Akazili, 2000). Another study in Ghana, published in 2003, provides one of the few detailed analyses of differences in the number of lost work and caregiving days between men and women (Asante & Asenso-Okyere, 2003):

“The economically active male patients who could not perform their normal activities lost 9.35 workdays during the period of illness, while 8.87 workdays were lost by the female patients... Adults constituted 96% of the caretakers. Almost 83% of the caretakers were females. More than five workdays on the average were sacrificed by caretakers to take care of the sick who were mostly children. Male caretakers lost between 3.20 and 5.87 workdays in the districts. On the average, approximately six workdays were lost by female caretakers” (Asante & Asenso-Okyere, 2003).

These estimates were based on a cross-sectional survey conducted in three districts from March to May of 2003 among households in which at least one member had experienced a case of malaria during the preceding month (Asante & Asenso-Okyere, 2003). A more recent cross-sectional study of 947 households in Kintampo, Ghana estimated that a malaria case resulted in 6.4 days of work being lost on the basis of data collected from October 2009 to July 2011 (Tawiah *et al.*, 2016).

The intensity of malaria transmission in Ethiopia is generally lower than in the equatorial regions of Africa. As a result, we would expect that adults in Ethiopia would have lower levels of acquired immunity and longer durations of symptomatic infections. These expectations are consistent with two studies of the impact of malaria on work days and caregiving days (Cropper *et al.*, 2000; Deressa *et al.*, 2007). Cropper *et al.* (2000) found that a malaria case resulted in 18 lost work days for an adult and the provision of 11 days of caregiving by a household member. These findings are based on a cross-sectional survey of 569 individuals in subsistence agricultural households conducted in the Tigray region of northern Ethiopia in January of 1997 (Cropper *et al.*, 2000). Another study that used cross-sectional data collected from 2,195 households in the Adami Tulu district from October to November of 2003 found that a malaria case resulted in 6.8 lost work days and 6.7 caregiving days (Deressa *et al.*, 2007).

A study of agricultural households in a district in Burkina Faso assumed that a malaria case in an adult led to a loss of 1–5 work days and that cases among children resulted in one-third of a day to one and two-thirds days being lost to caregiving activities (Sauerborn *et al.*, 1991). Those assumptions are consistent with a study using cross-sectional data collected from 3,065 patients from three villages in the Bobo-Dioulasso region of Burkina Faso, which found that a malaria case resulted in an average of 4 lost work days (Guiguemdé *et al.*, 1997). A third

study in Burkina Faso collected longitudinal data from 566 households at six time points in 1992, carrying out two surveys during the dry season and four in the rainy season (Sauerborn *et al.*, 1996b). By collecting data from the same households at different time points, the study could examine seasonal differences in the impact of malaria. Household revenue was lower during the rainy season than during the dry season, but the opportunity cost of time during the rainy season was higher, as that this was the peak production period for the household. The lower revenues and higher opportunity costs during the rainy season led to a reduction in work days missed and caregiving days provided per case (Sauerborn *et al.*, 1996b).

While studies of the impact of malaria on work days provide a range for days missed per case, the coping mechanisms used by households when work days are lost are less well understood. Two studies of farmers in Gezira, Sudan provide the most detailed evidence in this regard (Nur, 1993; Nur & Mahran, 1988). The first study concluded that the malaria burden was highest during the months in which labor was most needed for agricultural activities (Nur & Mahran, 1988). When men were not able to work due to malaria, women and children compensated for the loss of labor, which affected school attendance (Nur & Mahran, 1988). The same Sudanese community was studied again later (Nur, 1993), and it was confirmed that although the malaria burden was primarily on men, other members of the household felt an indirect impact:

“Thus, although the brunt of the infection fell upon men, it was clearly the women and children who had to compensate for this loss by providing a greater number of hours in physical labor in the fields. The result was that agricultural output was maintained, but at considerable cost to other persons and their activities (schooling, household activities) within the family” (Nur, 1993).

A growing body of research has shown how gender inequality, also described as the gender gap, affects the productivity of agricultural households in sub-Saharan Africa. A report developed by the United Nations and the World Bank found that reducing the gender gap in agricultural productivity could enable as many as 119,000 people to escape poverty in Uganda (Women & Others, 2015). A separate study by the World Bank found that women farmers produce significantly less per hectare than men (O’Sullivan *et al.*, 2014). For example, in Uganda the production of farm plots managed by women was 13% less per acre than the plots that men managed (O’Sullivan *et al.*, 2014). This study suggests that the provision of community-based childcare centers could reduce the gender gap (O’Sullivan *et al.*, 2014), positing that childcare duties are, in part, responsible for the gender gap. A study in Ghana found that 83% of caregiving activities for malaria cases in agricultural households were provided by women (Asante & Asenso-Okyere, 2003). Although the importance of addressing gender inequality to increase agricultural productivity has been recognized, only two studies have rigorously examined differences in malaria-related caregiving provided by women versus men within a household (Asante & Asenso-Okyere, 2003; Leighton & Foster, 1993).

Research topic: Incomes of agricultural households

Agricultural households face three primary types of expenditures related to malaria morbidity and mortality: for interventions to prevent malaria, for interventions to treat malaria cases, and related to a death due to malaria. These expenditures depend on the number of malaria cases a household expects to experience and the number of malaria cases and deaths the household actually experiences. Our framework assumes that the impact of suppressing malaria on the harvest value of a household depends on the impact of malaria suppression on its decisions and productivity.

Many of the studies listed above that examined the number of work days lost due to malaria also quantified the expenditures by households on interventions to prevent or treat malaria infections (Asenso-Okyere & Dzator, 1997; Asante & Asenso-Okyere, 2003; Akazili, 2000; Asante *et al.*, 2005; Akazili *et al.*, 2007; Alaba & Alaba, 2009; Ettling & Shepard, 1991; Ettling *et al.*, 1994; Guiguemdé *et al.*, 1997; Hailu *et al.*, 2017; McElroy *et al.*, 2009; Omotayo & Oyekale, 2013; Sauerborn *et al.*, 1991; Shepard *et al.*, 1991; Sauerborn *et al.*, 1996a; Tawiah *et al.*, 2016). An additional set of studies focused exclusively on such expenditures (Guiguemde *et al.*, 1994; Sauerborn *et al.*, 1996b). For example, a study conducted in agricultural households in Burkina Faso found that expenditures on malaria prevention and treatment interventions were, on average, about 4.5% of family income over a 6-month period (Guiguemde *et al.*, 1994). While a significant number of studies have examined these expenditures over a short period of time, often less than 1 year, we are not aware of any studies that have analyzed how suppressing malaria transmission leads to a long-term change in household expenditures on anti-malaria interventions.

Studies of the cost of treatment for a malaria case often include expenditures for antimalarial drugs, transport and care for the patient, and the time spent seeking care. Expenditures by households to treat malaria cases often fluctuate throughout the year. Sauerborn *et al.* (1996b) found that expenditures during the rainy season were significantly less than during the dry season, due, in part, to differences in the opportunity costs of time. In some settings, the opportunity cost of the time for a patient to seek care may be higher than the cost of the treatment (Asenso-Okyere & Dzator, 1997).

Households are often unable to pay for treatment in cash and must use other coping mechanisms (Sauerborn *et al.*, 1996a) to generate sufficient resources to cover treatment costs. A study of agricultural households in Burkina Faso identified multiple strategies:

“Cash sources included agricultural and craft production and migrant remittances... The sale of assets was the second most common way to meet health care expenditures. For households who did not possess sufficient cash, the sale of assets in the form of livestock was a widespread response to crises of many kinds. Indeed, in this part of Africa, animals were perceived as ‘ambulatory savings-banks’. The sale of cereals, on the other hand, was considered a last resort” (Sauerborn *et al.*, 1996a).

Only two studies have examined the relationship between malaria and harvest values. The first examined the impact of malaria on the revenues of farmers from vegetable cultivation (Girardin *et al.*, 2004). The revenues from cabbage were 53% lower for farmers who missed more than two days of work due to malaria than the revenues of farmers who missed less than two days of work (Girardin *et al.*, 2004). The second study found that providing agricultural households with access to vector control interventions increased harvest values by 14.7%, likely due to the additional number of days worked (Fink & Masiye, 2015).

Table 2 summarizes our research framework for examining the long-term impact of suppressing malaria on the income of agricultural households.

Data necessary to examine research topics

The two types of data that could be used to examine the research topics described in the previous section involve the collection of either cross-sectional data or longitudinal data. Cross-sectional data are collected from different individuals in a study population over one or more surveys in order to examine some aspect of that population. Longitudinal data are data collected from the same study population over time in order to understand the effect of changing conditions in the community. Collecting cross-sectional data from a community is generally easier and requires fewer resources than collecting longitudinal data.

With the exception of two studies (Nur, 1993; Sauerborn *et al.*, 1996b), which used longitudinal data collected within 1 year, each study that examined the impact of malaria on the decisions, productivity, expenditures and harvest values of agricultural households used cross-sectional data. Almost all of these studies, 25 of the 28, used less than 2 years of cross-sectional data.

The objective of our research framework is to provide a means of enriching our understanding of the cumulative impact of suppressing malaria over time on the income of agricultural households with regards to all of these topics. Given this objective, long-term longitudinal data are needed. For example, with data collected from the same agricultural household over time, a researcher could examine how the suppression of malaria transmission affected its decisions, productivity, and income.

In Table 3 we display the results of our analysis of the number of studies that have examined each research topic and the type of data that each study used. None of the studies we examined used longitudinal data. Furthermore, only two studies examined the impact of malaria on the decisions of agricultural households, and both of these studies were published before 1980.

Most of the studies that we identified that examined the productivity of individuals in agricultural households addressed the number of work days lost due to malaria cases directly or from caregiving. No studies examined the impact of malaria on gender inequality in agricultural households.

Table 2. Research framework for examining the long-term impact of suppressing malaria on the income of agricultural households.

Research topics		Relevant factors
1. Household decisions	1.1 Which crops to plant	-Household resources -Household expectations regarding productivity of individuals during next growing season
	1.2 How much land to cultivate	
	1.3 How much to invest in agricultural inputs	
	1.4 How much to invest in anti-malaria interventions	
2. Productivity of individuals in an agricultural household	2.1 Work days lost due to adult malaria cases	-Malaria transmission intensity in the community -Effectiveness of anti-malaria interventions used by household
	2.2 Work days lost due to caregiving for household malaria cases	
	2.3 Impact on gender inequality due to caregiving provided by women for household malaria cases	-Cumulative number of malaria cases experienced by household members that required caregiving
3. Incomes of agricultural households	3.1 Expenditures on anti-malaria interventions (prevention)	-Expectations regarding malaria risk over next 1 to 3 years
	3.2 Expenditures on anti-malaria interventions (treatment)	-Number of malaria cases experienced by household members
	3.3 Expenditures related to malaria deaths	-Number of malaria deaths experienced by household members
	3.4 Impact on harvest values	-Household decisions -Productivity of household members

Table 3. Data used in previous studies on the impact of malaria on the welfare of agricultural households.

Research topics		Number of studies using each type of data	
		Cross-sectional	Longitudinal
1. Household decisions	1.1 Which crops to plant	1	0
	1.2 How much land to cultivate	1	0
	1.3 How much to invest in agricultural inputs	0	0
	1.4 How much to invest in anti-malaria interventions	0	0
2. Productivity of individuals in an agricultural household	2.1 Work days lost due to malaria cases experienced by adults	22	2
	2.2 Work days lost due to caregiving for malaria cases experienced by individuals in the household	18	2
	2.3 Malaria's impact on gender inequality due to caregiving provided by women for malaria cases among household members	1	0
3. Incomes of agricultural households	3.1 Expenditures on anti-malaria interventions (prevention)	7	0
	3.2 Expenditures on anti-malaria interventions (treatment)	17	0
	3.3 Expenditures related to malaria deaths	2	0
	3.4 Malaria's impact on harvest values	2	0

For topics related directly to the income of an agricultural household, most studies examined household expenditures on interventions to prevent or treat malaria infections. Only one studied the impact of malaria on harvest values.

In [Figure 2](#), we illustrate the number of years of cross-sectional data that were used in each of the 27 studies that examined one

or more of the topics in our research framework. Each line in [Figure 2](#) represents the number of years of data that were used in each study. For example, the line in the lower left section of the figure indicates that Annecke's findings that the suppression of malaria led to farming of areas that were previously considered too malarious were based on his observations from 1932 through 1935 ([Annecke, 1950](#)). The number on the vertical axis

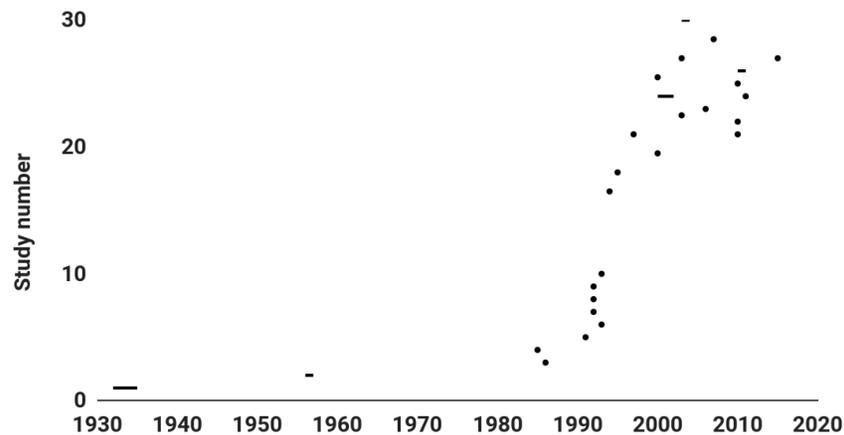


Figure 2. Number of years of data used in studies of malaria's impact on agricultural households in sub-Saharan Africa.

represents the number we assigned to each of the 28 studies. Most of the studies, 23 of 27, used cross-sectional data collected over a period of less than 1 year. There were two studies that used cross-sectional data from a period of more than 2 years (Annecke, 1950; Audibert, 1986; Girardin *et al.*, 2004) and two studies used longitudinal data (Nur, 1993; Sauerborn *et al.*, 1996b). Table 4 provides additional information about each study included in Figure 2.

Discussion

We have developed a research framework for understanding how suppressing malaria may affect long-term growth in agricultural household income. This framework was informed by the literature regarding the impact of malaria on the welfare of those households.

As the global malaria community has shifted from *controlling* malaria to *eradicating* malaria, a concurrent shift is needed in the methodologies used to examine its impact on agricultural households. Malaria policy-makers and researchers should not assume that the methodologies that were used to examine the impact of malaria on agricultural households during the period in which the goal was to control malaria will be equally appropriate now that the goal has shifted to eradicating malaria by 2040.

Summary of research framework recommendations

Our research framework for examining the long-term impact of malaria on the incomes of agricultural households uses longitudinal data to examine the impact on household decisions, productivity, expenditures and harvest values. By using longitudinal data, researchers will be able to examine how the decisions, productivity, expenditures and harvest values of households change over time and their relationships with changes in the intensity of malaria transmission. Our framework focuses on the impact of malaria on four decisions within an agricultural household: which crops to plant, how much land to cultivate, how much to invest in agricultural inputs, and how much to invest in interventions to reduce the risk of malaria infection. The available research evidence suggests that these decisions will

depend on the household's resources and expectations regarding the productivity of its members during the next growing season. Second, our research framework includes three means by which malaria can have a long-term effect on a household through its impact on the productivity of individuals: work days lost due to adult malaria cases, work days lost due to caregiving, and the impact on gender inequality. Finally, the framework defines the impact of malaria on the income of an agricultural household as being dependent on its expenditures related to malaria morbidity and mortality, and the value of the harvest. The harvest value will depend on the decisions made and productivity of individuals in the household. Existing systems for collecting longitudinal data from households in malarious communities should begin to collect the data necessary to address the topics described in this research framework.

Focus of this research framework on agricultural households

In many malarious regions, a significant number of households are engaged in agricultural activities. We focus on agricultural households because of the unique relationship between these households and malaria as compared to non-agricultural households. The malaria burden creates a unique challenge for these households given the labor-intensive nature of agriculture. Labor is particularly critical for these households during certain periods of the year, namely the planting and cultivation seasons. Given that rural agricultural households are often poorer than non-agricultural rural households, the additional burden that malaria imposes on agricultural households could be a significant challenge to their efforts to escape poverty.

Historically, improvements in agricultural productivity have played an important role in enabling developing countries to increase their economic growth and escape poverty (Awokuse & Xie, 2014; Datta, 2013; Gallup & Sachs, 2001; Mccarthy *et al.*, 2000; Thirtle *et al.*, 2003; Valdés & Foster, 2010). Four times the level of poverty reduction can be achieved by increasing growth in the agricultural sector than by increasing growth in other sectors of an economy (as outlined by the Gates Foundation).

Table 4. Studies on the impact of malaria on agricultural households.

Study number	Author, publication year	Number of years of data	Study name
1	Annecke, 1950	4	'The economic importance of malaria'
2	Miller, 1958	1	'Observations on the natural history of malaria in the semi-resistant West African'
3	Nur & Mahran, 1988	1	'The effect of health on agricultural labour supply: a theoretical and empirical investigation'
4	Sauerborn <i>et al.</i> , 1991	1	'Estimating the direct and indirect economic costs of malaria in a rural district of Burkina Faso'
5	Nur, 1993	1	'The impact of malaria on labour use and efficiency in the Sudan'
6	Leighton & Foster, 1993	1	'Economic impacts of malaria in Kenya and Nigeria'
7	Ettling <i>et al.</i> , 1994	1	'Economic impact of malaria in Malawian households'
8	Guiguemde <i>et al.</i> , 1994	1	'Household expenditure on malaria prevention and treatment for families in the town of Bobo-Dioulasso, Burkina Faso'
9	Sauerborn <i>et al.</i> , 1996a	1	'Household strategies to cope with the economic costs of illness'
10	Sauerborn <i>et al.</i> , 1996a	1	'Seasonal variations of household cost of illness in Burkina Faso'
11	Asenso-Okyere & Dzator, 1997	1	'Household cost of seeking malaria care'
12	Guiguemdé <i>et al.</i> , 1997	1	'Esquisse d'une methode destination du cout economique chiffre des acces palustres - application a une zone rurale au Burkina Faso - Afrique de Ouest'
13	Akazili, 2000	1	'Economic costs of seeking malaria care to households in the Kassena-Nankana District of Northern Ghana'
14	Cropper <i>et al.</i> , 2000	1	'The value of preventing malaria in Tembien, Ethiopia'
15	Asante & Asenso-Okyere, 2003	1	'Economic burden of malaria in Ghana'
16	Girardin <i>et al.</i> , 2004	3	'Opportunities and limiting factors of intensive vegetable farming in malaria endemic Cote d'Ivoire'
17	Akazili <i>et al.</i> , 2007	1	'Malaria treatment in Northern Ghana: What is the treatment cost per case to households?'
18	Deressa <i>et al.</i> , 2007		
19	Alaba & Alaba, 2009	1	'Malaria in Rural Nigeria; Implications for the Millennium Development Goals'
20	McElroy <i>et al.</i> , 2009	2	'Malaria prevention in north-eastern Tanzania: patterns of expenditure and determinants of demand at the household level'
21	Oluyole <i>et al.</i> , 2011	1	'Socio-economic burden of malaria disease on farm income among cocoa farming households in Nigeria'
22	Mohamed, 2012	1	'The Impacts of Water Borne Diseases on Rural Development in Sudan'
23	Badiane & Ulimwengu, 2013	1	'Malaria incidence and agricultural efficiency in Uganda'
24	Omotayo & Oyekale, 2013	1	'Effect of malaria on farming households' welfare in Ido Local Government Area of Oyo State, Nigeria'
25	Fink & Masiye, 2015	1	'Health and agricultural productivity: Evidence from Zambia'
26	Tawiah <i>et al.</i> , 2016	2	'Economic costs of fever to households in the middle belt of Ghana'
27	Hailu <i>et al.</i> , 2017	1	'Economic burden of malaria and predictors of cost variability to rural households in south-central Ethiopia'

Potential weaknesses in this study

One of the challenges in developing the research framework presented in this study is that malaria elimination has never been achieved and sustained in an agricultural region in sub-Saharan Africa. As a consequence, the identification of the research top-

ics in this study has been informed by studies conducted in communities in which elimination was never achieved. Therefore, there may be other channels through which suppressing malaria may have a significant long-term impact on the income of an agricultural household that were not identified in this

study. If malaria elimination were to be achieved in southern Africa over the next decade, evidence generated from that region may result in modifications to this framework as applied to equatorial regions of Africa where there are higher levels of malaria transmission.

Future research

We recommend that researchers examine how the suppression of malaria transmission over the next two decades may affect the duration of symptoms from a case of malaria. The suppression of malaria may lead to a reduction in acquired immunity levels among individuals in agricultural households, which may affect the probability of a malaria inoculation leading to a symptomatic case of malaria as well as the duration of the symptoms. Researchers should also examine how suppressing malaria transmission affects the seasonality of the impact of malaria on agricultural households and how the coping mechanisms used by households change over time.

We also recommend an analysis of the factors that contribute to heterogeneities across communities and over time in the long-term impact of suppressing malaria on the incomes of agricultural households. Given that the cost of illness methodology has been used more than any other methodology to examine the economic impact of malaria on agricultural households, we recommend a critique of this methodology to determine if it should continue to be used. Future research should also develop

models that can utilize the longitudinal data that would be collected with this framework in order to develop prospective estimates of the impact of suppressing malaria on the welfare of agricultural households

Data availability

The dataset for this research, detailing each of the studies used in this framework, has been deposited in CSV format with Harvard Dataverse. DOI: <https://doi.org/10.7910/DVN/RQGNLX> (Willis, 2018).

Data are available under the terms of the [Creative Commons Zero “No rights reserved” data waiver](#) (CC0 1.0 Public domain dedication).

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This is an important work in the area of malaria elimination. Thanks for the effort. Below are some comments that you may find useful to improve the paper:

Abstract: ...developing more precise estimates (of?)

Methods: Please clarify if possible whether the frameworks are author's own creation or particular method/resource was used e.g. literature review.

Introduction: Should include some statistics regarding the economic loss due to malaria at individual/national level.

Figure 1:

- Most of the items are too broad, breaking them down to sub-components could help the readers better.
- The term 'nutrition security' sounds too ambitious within this framework, may be increased food availability/security, or please describe clearly in the text the pathway you are proposing.
- You might also want to consider the component 'reduced health expenditure', 'higher disposable income'.

How does your framework help adjust the estimates for potential confounders?

Is there any estimate on how much investment will be required for how long till eradication?

Eradicating malaria will certainly boost economic productivity and lower poverty levels but the question is to what extent, as the issue is generally embroiled with various others e.g. HIV, which means that malaria eradication will require investment in addressing the risk factors as well. The scenario is certainly complex and hence it is necessary to provide a broader picture of the problems to facilitate effective interventions.

The impact of malaria on decision making among farming households on cropping/area of cultivation is a remote one or not readily understood. This can be explained by citing relevant papers.

Malaria is prevalent not only among farming communities, so focusing on farming communities alone will not help.

Table 4: Study name for #18 is missing.

The comment 'Evidence generated from the framework will inform funding allocation decisions for malaria elimination initiatives' needs a better justification.

Overall, the topic is too broad and hard to make sense of the frameworks in the fast changing health and agricultural landscapes. Despite the limitations, the present study is a good contribution to the literature. It is recommended that authors explain the frameworks by taking into account the proximate/distal factors that impact malaria and household income/well-being.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Not applicable

Are all the source data underlying the results available to ensure full reproducibility?

No source data required

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
