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The Linkages Between Agriculture and Malaria

Issues for Policy, Research, and Capacity Strengthening

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ABSTRACT

Malaria afflicts many people in the developing world, and due to its direct and indirect costs it has widespread impacts on growth and development. The global impact of malaria on human health, productivity, and general well-being is profound. Human activity, including agriculture, has been recognized as one of the reasons for the increased intensity of malaria around the world, because it supports the breeding of mosquitoes that carry the malaria parasite. Malaria can cause illness (morbidity), disability, or death; and all three effects have direct and indirect costs that can affect productivity. Since agriculture is the main activity of rural people in many endemic areas, it has been suggested that effective malaria control measures can be devised if attention was paid to the two-way effects of agriculture and malaria. There is the need to compute the direct costs of malaria treatment and control and the impacts of those costs on the ability of farm households to adopt new agricultural technology and improved practices, and keep farm and household assets. It is equally important to know the indirect costs of seeking health care and taking care of children and others who are afflicted by malaria and the relationship of the indirect costs to the farm labor supply and productivity. On the other hand, many agricultural activities like irrigation projects, water-harvesting and storage, land and soil management techniques, and farm work sequencing can lead to increase in mosquito populations and therefore increase the incidence of malaria in agricultural regions. This paper has raised issues on the two-way effects of agriculture and malaria and recommended areas that require policy actions and further research. The research findings can then be used in devising effective policies for controlling malaria in endemic areas of the world and assist in preparing a tool kit for capacity development on agriculture and malaria.

Keywords: malaria, agriculture, development, technology, impact, research, policy, capacity strengthening

1. INTRODUCTION

Background

Poor health has significant negative impacts on the growth of developing countries. The U.S. Government Accountability Office (2008) cites impact of poor health on the agricultural workforce as one of the major causes of chronic malnourishment (food insecurity) in sub-Saharan Africa. In the developing world, especially Africa, malaria is the disease that has the most widespread impacts on growth and development.1 Malaria costs Africa more than US$12 billion annually, and it may have slowed down economic growth in African countries by as much as 1.3 percent per year (Roll Back Malaria 2003). Drug and insecticide resistance, the general worsening of primary health-care services, and human activities are the main reasons for the increased intensity of malaria around the world.

There are 300 to 500 million cases of malaria every year, and between 1 and 3 million deaths, mostly of children, attributed to the disease. Every 40 seconds a child dies of malaria, resulting in a daily loss of more than 2,000 young lives worldwide (World Health Report 2002). Malaria kills over a million people each year, mostly in Africa, according to the World Health Organization (WHO). More than 90 percent of deaths from malaria in 2006 occurred in Africa, where 45 of the 53 countries are endemic for the disease (WHO 2008). These estimates render malaria the preeminent tropical parasitic disease and one of the top three killers among communicable diseases (Sachs and Malaney 2002). Malaria also can cause morbidity through fever, weakness, malnutrition, anemia, spleen diseases, and vulnerability to other diseases. According to Breman (2001), malarious patients experience asymptomatic parasitemia, acute febrile condition, chronic debilitation, and complications of pregnancy.

Since the inception of the Roll Back Malaria Initiative of the World Health Organization in 1998, and particularly since the Abuja Malaria Summit in 2000, malaria prevention and control have once again received the attention of the international community. International spending for malaria has increased at least two-fold since 1998, especially with the establishment of the Global Fund to Fight AIDS, Tuberculosis and Malaria. The global target of Roll Back Malaria is to halve malaria-associated morbidity and mortality by 2010 from the levels in year 2000.

Given the severe impacts of malaria in developing countries, a key development challenge is to examine the linkages between malaria and agriculture. Agriculture has for many centuries played a pivotal role in economic growth worldwide. Three-quarters of the world's extremely poor—800 million out of 1.16 billion—live in rural areas. They depend on agriculture and other rural jobs for their livelihood (Global Donor Platform for Rural Development 2007). Presently, there is widespread recognition among African leaders, international organizations, and the donor community that improving the productivity and income-generating capacity of agriculture is essential in poverty reduction and economic growth. The potential for increased food production and the development of vibrant agro-processing and agribusinesses necessary to kick-start the growth process is evident in all parts of Africa. The induced dynamics would indeed constitute a significant source of economic growth in Africa (UNECA 2001).

To foster progress toward agriculture-led food security and economic growth, developing countries need to pay closer attention to the development of human capital through investments in education and training, health and sanitation, and food and nutrition. Pursuing a vision that "promotes human development is key to sustaining social and economic progress in all countries" (World Bank 2004). Addressing the linkages between health and agriculture is one step in this direction. In particular, developing countries need to formulate policies to address malaria and its linkages with agricultural

[1] Malaria is a disease that can be transmitted to people of all ages. It is caused by parasites of the species *Plasmodium* that are spread from person to person through the bites of infected mosquitoes. There are four types of human malaria: *Plasmodium falciparum, P. vivax, P. malariae,* and *P. ovale. P. falciparum* and *P. vivax* are the most common. *P. falciparum* is by far the most deadly type of malaria infection. Drug and insecticide resistance, the general worsening of primary health-care services, and human activities are the main reasons for the increased intensity of malaria around the world.

development, given the significance of the disease in the developing world and the importance of agriculture in the livelihood of rural people.

The Shared Links between Health and Agriculture

The interactions between health and agriculture are bidirectional: health affects agriculture and agriculture affects health. In both cases there are negative or positive effects that contribute to good or bad outcomes. Agriculture is essential for good health through the production of food and other raw materials for shelter and medicines (Hawkes and Ruel 2006). However, agriculture also contributes to major health problems such as malaria, food-borne diseases, diet-related chronic diseases, and occupational health hazards.

Health plays a key role in agricultural production in two main ways. Poor health limits the capacity of the labor force to work, leading to a decrease in productivity and its spillover effects on agrarian economies. Illness and death from HIV/AIDS, malaria, and other diseases also reduce innovations in agriculture through loss of knowledge of productive adults working in the sector and the loss of assets used to carry out innovations. Indeed the two-way linkages between agriculture and health offer the chance for policymakers and practitioners to collaborate to ensure an increase in positive feedback between these two entities.

Good health and productive agriculture work hand in hand in the fight against poverty. Since the majority of the world's poor work in agriculture and the poor suffer disproportionately from related illness and disease, an integrated view of agriculture and health is necessary to promote agricultural growth and development and reduce pervasive rural poverty.

Even though the linkage between agriculture and health was first recognized long ago, health considerations still play little part in the decisions of governments about agricultural policy. The health sector also has not reached out to agriculture as a key partner in addressing global ill health. There have been reasons for this disjuncture—some borne out of unawareness, others out of distinct policy conflicts. Whatever the reasons, the divisions are slowing down efforts to overcome ill health among poor rural communities (Lipton and De Kadt 1988). Taking advantage of the positive policy synergies between agriculture and health sectors has the possibility to yield great welfare benefits for the poor in developing countries.

In the first instance, the energy and time devoted by agricultural producers to their work conflicts with their time devoted to child care, food preparation, and nutrient-related activities (Goodman 2000). On the other hand the labor processes also expose producers to occupational hazards such as accidents and waterborne vector diseases such as malaria.

Agricultural systems affect health in a number of ways and also in interaction between agricultural producers and outputs. A notable intermediary process in this regard is environmental changes in water, soil, and air. A good example is the link between irrigated agricultural systems and malaria. Irrigation creates a suitable environment for parasitic vectors that spread the diseases to producers and its subsequent negative effects on productivity. Conversely, irrigation can also boost the income of producers, enabling access to both preventive and curative health-related services (Mutero, McCartney, and Boelee 2006).

Agricultural outputs affect health mainly through the quantity and quality of food produced, level of variety, and price. All these affect nutrition and food-borne diseases that mainly arise in the microbiological and chemical hazards introduced in agricultural systems. However, there is also the potential to employ agricultural methods that can be adapted to prevent these food-borne diseases (Todd and Narrod 2006).

Objectives and Structure of the Paper

The objective of this paper is to bring out the issues that connect agriculture and malaria so that they can be addressed through policy, research, and programs. The paper highlights questions that require further research to support policy formulation and intervention and capacity strengthening.

The rest of the paper is structured as follows. In Section 2, the impacts of malaria on agricultural productivity are examined through a conceptual framework and a review of the literature. The third section focuses on awareness of malaria and current practices employed to address the disease, using a survey of the knowledge, attitudes, practices, and perceptions (KAP) of people regarding malaria. Section 4 examines the impacts of agricultural development, particularly water and land use practices, on the incidence of malaria; and Section 5 presents conclusions.

2. KNOWLEDGE, ATTITUDES, PERCEPTIONS, AND PRACTICES OF MALARIA

Effective disease control programs use information about the knowledge, attitude, perception, and practices (KAP) regarding malaria in formulating their strategies. Information about KAP has been found to be useful in minimizing the negative impacts of malaria on agriculture or reducing the effects of agriculture on malaria infection.

This section gives an overview of the general awareness of malaria (the causes, signs, and symptoms of malaria) and attitudes, perceptions, and practices regarding malaria. The information presented is a summary of a review of recent KAP studies on malaria.

Knowledge about Malaria

General awareness of malaria is high in most malaria-endemic areas of the world. A baseline survey in five districts of Uganda indicated 99 percent level of awareness among the people (Net Mark 2001). A study by Kilian (2002) on knowledge of and behavior toward malaria in three districts in Western Uganda also indicated significant level of knowledge about malaria. Also, results from an investigation of the knowledge and beliefs about malaria transmission and practices in Southern Mexico revealed that knowledge about malaria was poor among about half of the people sampled (Rodriguez et al. 2003).

A number of studies have shown that community members' knowledge about the cause of malaria has increased from the 1990s to the present. The Net Mark survey (2001) indicates that 92 percent of the respondents in the five districts knew that mosquitoes cause malaria, although only 21 percent knew that mosquitoes are the only cause of malaria, while 71 percent erroneously thought that there were several other causes of malaria, such as drinking dirty water, being in the rain, living in dirty surroundings, and contact with an infected person.

The Home Based Management (HBM) follow-up survey by the Ministry of Health to the World Health Organization program of The Basic Support for Institutionalizing Child Survival (BASICII)in nine districts of Uganda indicates that the majority of caretakers (91.1 percent) knew how malaria is transmitted (Fapohunda et al. 2004). A study conducted in Kassena-Nankana and Bulsa districts of the Upper Region of Ghana on the causes and symptoms of malaria showed that 79 percent of respondents attributed the cause of malaria to mosquitoes (Adongo, Kirkwood, and Kendell 2005). Most of the respondents made a link between water, mosquitoes, and malaria; however, the causal relationships were not well established. These results are quite similar to the findings from a study in Nepal on malaria-related KAP. The results revealed that about 86 percent of the total number sampled had heard about malaria, and about 73 percent associated mosquito bites with malaria transmission (Joshi and Banjara 2008).

Knowledge about signs and symptoms of malaria is relatively high across Africa, with most studies indicating that respondents were aware of key symptoms including elevated body temperature or hot body followed by other symptoms like vomiting, loss of appetite, and restlessness. A cross-sectional study carried out in the Ile-Ife community in southwestern Nigeria showed that most of the respondents (more than 60 percent) were familiar with at least three signs and symptoms associated with malaria; 68.3 percent of respondents reported fever as a common symptom of malaria, 67.4 percent reported headache, 61.8 percent reported body pains, 19.6 percent reported dizziness, 10.0 percent reported vomiting, and 4.3 percent reported diarrhea (Erhun et al. 2005). The study by Adongo et al. (2005) in Northern Ghana reported 97 percent of respondents recognized having a hot body as symptomatic of malaria, followed by vomiting (38 percent), chills (27 percent), headache (26 percent), and loss of appetite (8 percent). In Northern Thailand, a malaria-related KAP study showed that headache (89 percent), shivering (83 percent), and fever (79 percent) were the most frequently mentioned symptoms (van Benthem et al. 2006).

Although general knowledge of malaria symptoms is relatively high, the literature indicates that symptoms of severe malaria are not well known among community members. Studies in Ghana and other countries found that people do not often recognize the connection between fever, convulsions, and malaria (MacCormack and Snow 1986; Adongo and Hudelson 1995; Mwenesi, Harpham, and Snow 1995; Winch et al. 1996; Njama et al. 2003; Hill et al. 2003). The less common symptoms, which require medical diagnosis and close observation, like jaundice, anemia, and splenomegaly, were not well known. The DISH II (2002) qualitative study in Uganda also reported similar findings where convulsions, jaundice or anemia, and splenomegaly were not associated with malaria and were often believed to be spiritual illnesses requiring spiritual remedies**.** Nuwaha (2002), in a study about people's perceptions of malaria in Mbarara district of Uganda, reported that some community members felt that convulsions were due to supernatural causes and required traditional treatment. The study by Adongo et al. (2005) in Northern Ghana reported that 62 percent of respondents did not know the cause of convulsions. Most respondents did not want to talk about convulsions because of their spiritual undertones and the fact that people still have memories of children who died "through convulsion." The limited knowledge of signs of severe malaria, including convulsions, indicates an area that requires strengthening largely through health education and communication (Fapohunda et al. 2004).

Attitudes and Perceptions about Malaria

Attitude toward malaria as a disease is important in understanding health-seeking behavior and use of preventive methods. Some of the studies reviewed indicate that communities now regard malaria as a dangerous disease that can kill and affects more children under age 5 than adults. Studies also indicate that most community members strongly felt that malaria can be prevented. Such positive attitudes are essential opportunities for behavior change campaigns. In a study done in Mpigi district in Uganda (Riisa 2000), 87.5 percent of the community knew that malaria can be prevented, but others thought otherwise. Also the results show that 95.4 percent of respondents looked at malaria as a severe problem that could kill.

Some studies have indicated that communities generally observed that malaria was a seasonal problem in their areas. A study conducted in Gambia indicated that total expenditure on malaria prevention was 42 percent higher in the wet season than for the rest of the year (Wiseman et al. 2006). This result is not unexpected since mosquito populations are higher during the wet season when water is easily available for breeding than during the dry season. The Commercial Marketing Strategies (CMS) survey in Uganda (Okello 2001) noted a strong conviction among community members (75 percent) that children under age 5 were more vulnerable to malaria than older children or adults, and only 10 percent of the respondents felt that pregnant women were also more vulnerable to malaria. In a related survey by Net Mark (2001) in five districts of Uganda it was noted that 82.5 percent of the respondents perceived that pregnant women were more vulnerable to malaria, while 97 percent were of the opinion that children below age 5 were more vulnerable to malaria (these were prompted responses).

Practices Regarding Malaria

Families are pragmatic in seeking care as they attempt to blend traditional medicines with modern medicines (Adongo et al. 2005). Malaria is usually first treated at home with herbal teas and baths prepared with neem, pawpaw, guava, and eucalyptus leaves. Analysis of "what respondents will do first" during malaria attack showed that 35.5 percent of respondents will use synthetic antimalaria drugs, 0.9 percent will consult a herbalist, and 13.4 percent will use local herbs; while 27.3 percent will go to the hospital, 1.7 percent will take spiritual/ritual waters for cure, and 18.2 percent will just pray, with 3.0 percent of the respondents indicating that they will ignore the signs (Erhun et al. 2005). Reliance on herbs as the first treatment action for malaria was also noted in Zimbabwe (van Geldermalsen and Munochiveyi 1995). A study by Asenso-Okyere, Dzator, and Osei-Akoto (1997) confirmed that in Ghana, self-medication was a popular choice for the treatment of malaria/fever. Patients often turn to hospitals when their self-administration of drugs had failed. The study revealed that cost seemed to be the deterrent factor. The study by Rodriguez et al. (2003) also showed that 40 percent of respondents in southern Mexico are self-medicated, and about 51 percent attended a health facility. Joshi and Banjara (2008) indicate that in Nepal, even though public hospital treatment for malaria was free, about 50 percent of the respondents in the study were unaware of that and about 16 percent of them were found consulting traditional healers for treatment.

It is obvious from past studies that attention has not been paid to the knowledge, attitudes, and perceptions of farmers regarding malaria, although many of the respondents in rural areas where most of the studies were conducted were farmers. What is needed is the knowledge of farmers and extension workers about the linkages between malaria and agriculture in terms of causation and impacts, and the attitudes and perception of farmers in this relationship. With this information, capacity-strengthening activities can be planned for farmers to reduce the negative consequences of the relationship between agriculture and malaria.

3. IMPACT OF MALARIA ON AGRICULTURAL DEVELOPMENT

To examine the effects of malaria on agricultural development, this paper adopts the conceptual framework developed by the UN Secretariat (Population Division) to assess the impact of HIV/AIDS on agriculture (Figure 1). Malaria results in morbidity and sometimes mortality. Incapacitation of the economically active population also affects the quantity and quality of labor supply to the household because the sick abstain completely or partially from work during the period of illness. The potential effect of malaria therefore lies in the productive time (labor time) lost by the sick and the family members who divert productive time on the farm to care for the sick. Reduced farm labor may adversely affect adoption of labor-intensive technologies.

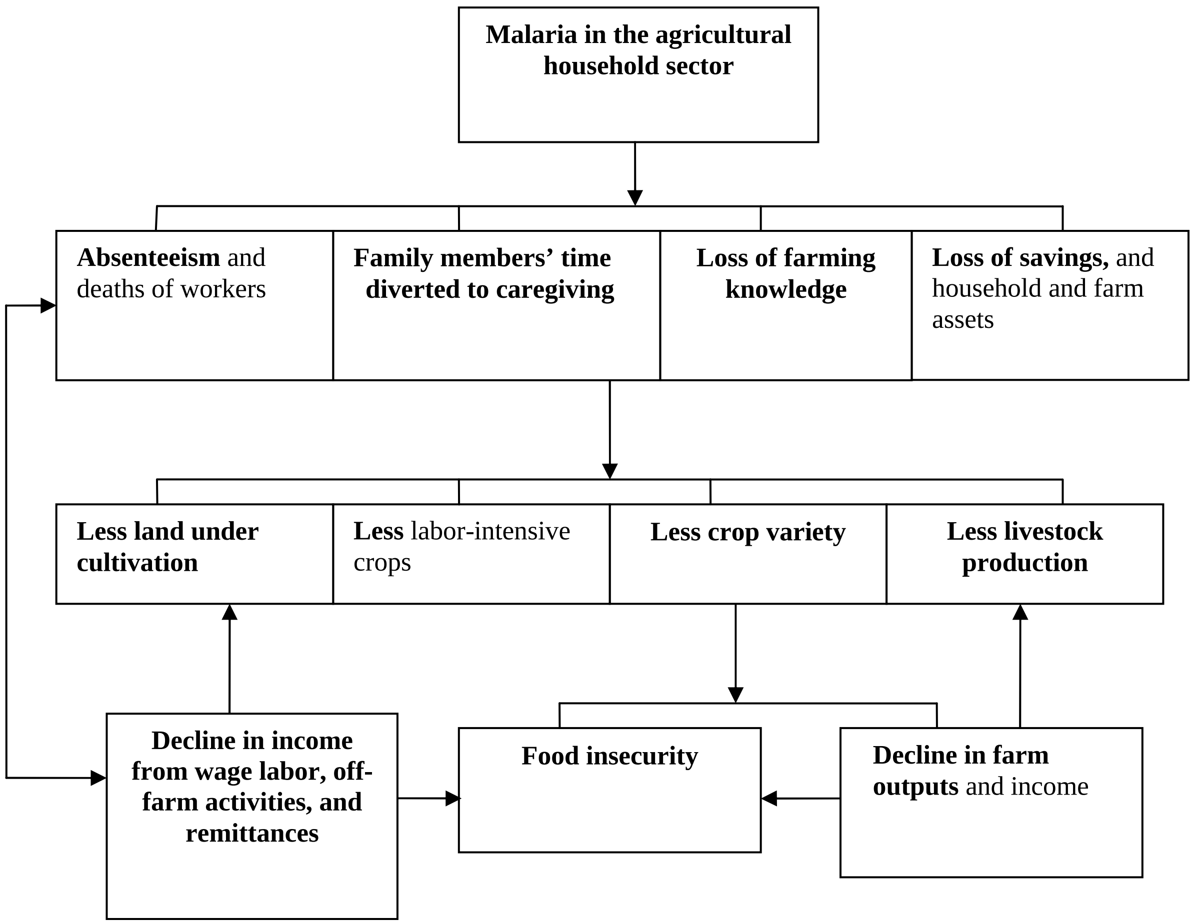
In the event of death of adults, the supply of farm labor is affected in addition to the loss of farming knowledge, which slows the acquisition and diffusion of agricultural innovations. Although new knowledge is needed for innovations in agriculture, knowledge that has been accumulated by farmers has been found to be useful in creating new technology and innovations. Knowledge that spills over from one farmer to another is an effective way of disseminating technology in rural areas. Such opportunities are lost when a farmer dies from malaria or other illness.

Another important potential effect is the reduction in investments in agriculture due to high expenditures on malaria treatment and prevention. Farm households may withdraw their savings, sell productive assets, or borrow money to pay for the cost of treating repeated bouts of malaria for household members. They may therefore not be able to make the necessary investments in their farms.

The direct cost of treating and preventing malaria could make households adopt several measures, depending on the circumstance. These could include reduction in area under cultivation, planting of less labor-intensive crops, changes in cropping patterns, adoption of labor-scarce innovations that may be less productive farming techniques, and reduction in the use of farm inputs. Though affected households could adopt coping mechanisms such as household labor reallocation and the hiring of labor, these strategies have cost implications. It is equally important to note that hired labor may not be a perfect substitute for family labor (Chima, Goodman, and Mills 2003; Larochelle and Dalton 2006).

It is anticipated that repeated bouts of malaria in agrarian households would cause a decline in farm output and farm income, and cause food insecurity and an increase in poverty (ESPD 2005). A recent report observed that smallholder farmers in Africa shoulder the heaviest burden of malaria because their margin of survival is small. According to the report, “a brief period of illness that delays planting or coincides with the harvest may result in catastrophic economic effects” (UN Millennium Project 2005). Egan (2001) also added that because malaria strikes during the rainy/harvest season, when worker productivity needs to be at its highest, the disease can harm agricultural production, food security, and household income.

Figure 1. Conceptual framework for the impact of malaria on agriculture



Source: Culled from Negin (2004) with modification by authors

Estimating the Economic Impact of Malaria

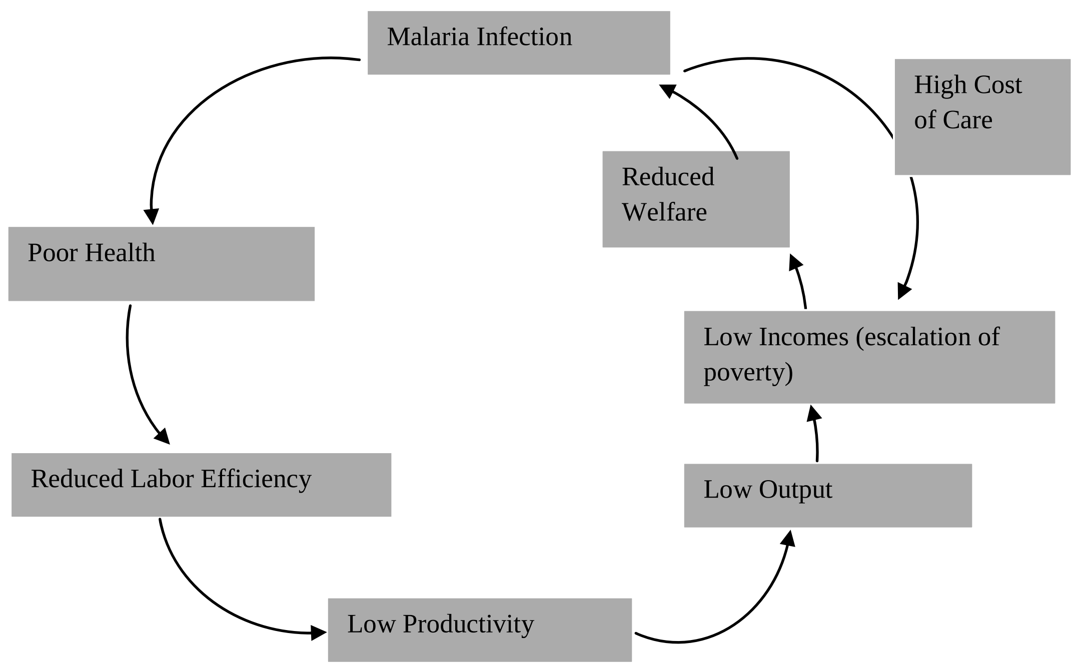
Economists have attempted to put an economic value on the burden of malaria by measuring the impacts on (a) households, (b) health systems, and (c) national economies. At the household level, malaria imposes both direct and indirect costs. Direct costs include time lost from work and medical treatment costs (including transportation and medical care). Indirect costs, which are typically harder to measure, include loss of work efficiency and time and work reallocation within the household. For children in particular, indirect costs also include nutritional deficiencies, cognitive and educational disabilities, and physical retardation. Pain and suffering are clearly substantial indirect costs but are perhaps most difficult to quantify. In general, long-term effects such as child development and resistance are unknown (Hutubessy, Bendib, and Evans 2001). The indirect costs of malaria are also widely felt as worker productivity lowers with increased sick leave, absenteeism, and premature mortality of the workforce. For many, the transmission period of malaria coincides with the planting season, which further lowers agricultural productivity.

The joint mortality and morbidity impacts of malaria were estimated to be 45 million DALYs (disability adjusted life years) in 2000, or nearly 11 percent of all infectious diseases (Guerin et al. 2002). Retrospective analysis of the burden of malaria in India showed that DALYs lost due to malaria was 1.86

million years (Kumar et al. 2007). India accounts for almost 80 percent of the total malaria in Southeast Asia.

Malaria has been called the epidemic of the poor. It is an aspect of ill health that negatively affects adult productivity and hampers the accumulation of human capital in younger generations. Quite recently, a number of studies have used malaria as an explanatory variable in economic growth models using cross-country regression analysis and have demonstrated a significant relationship between growth in gross domestic product (GDP) per capita and the burden of malaria (Gallup and Sachs 2001; McCarthy et al. 2000). The results suggest that countries with a substantial amount of malaria grew 1.3 percent per year less (controlling for other influences on growth), and that a 10 percent reduction in malaria was associated with 0.3 percent higher growth per year (Guerin et al. 2002; Gallup and Sachs 2001; Sachs and Malaney 2002; McCarthy et al. 2000). In its entirety, the economic impact of malaria has been estimated to cost Africa $12 billion every year. This includes costs of health care, working days lost due to sickness, days lost in education, decreased productivity, and loss of investment and tourism (Greenwood et al. 2005). In some countries with a heavy malaria burden, the disease may account for as much as 40 percent of the public health expenditure, 30–50 percent of inpatient admissions, and up to 50 percent of outpatient visits (WHO 1999). To the extent that slow economic growth limits funds for malaria control, there is a vicious circle of poverty and malaria that diminishes economic opportunities for a large number of the world's inhabitants (see Figure 2).

Figure 2. The vicious circle of malaria and household poverty



Indeed, the loss of human capital and lower productivity results in a lower economic growth rate. This in turn negatively affects the poor who are stuck in a vicious circle of poverty and malaria. The link of malaria to poverty is ultimately a link to lower economic growth since malaria exacerbates poverty, which is a contributing factor of lower economic growth. Ill health through malaria means lower income due to lower productivity, and this in turn results in lower economic growth and higher poverty. Furthermore, high prevalence rates of malaria among the most vulnerable groups have a double effect of limiting poverty-reduction strategies and seriously impeding the accumulation of human capital by these groups. The health consequences of malaria vary in terms of severity, but the global impact of malaria on human health, productivity, and general well-being is profound.

Review of Existing Studies

Social scientists, particularly economists, have studied the social and economic impacts of malaria at several scales, examining inside families and households, looking across communities, and comparing entire nations and continents. The studies all come to the conclusion that malaria imposes substantial social and economic costs and impedes economic development through several channels, including but certainly not limited to quality of life, fertility, population growth, savings and investments, worker productivity, premature mortality, and medical costs (Sachs and Malaney 2002).

Malaria morbidity and caretaking have serious consequences on agricultural productivity and production. Potential impact (direct and indirect) of malaria on agricultural productivity could be summarized as follows:

- Reduction of time for farming due to productive workdays lost by the sick person and the sick person's caregiver
- Reduction of effort in working
- Reduction/absence of investment in agriculture due to cost of prevention and treatment
- Loss of farm labor through the death of adults, keeping in mind that agriculture in Africa is very labor intensive, most of the time using family and hired labor
- Adoption of less productive farming techniques due to incapacitation
- Reduction in cultivated areas due to reduced labor and capital
- Changes in cropping patterns
- Migration from agricultural lands infested with mosquitoes

Most studies on the indirect cost of malaria have based their estimates on the amount of time lost by the sick person (or the caretaker in the case of child illness) multiplied by the value for a day's work. Key variables are thus the amount of time lost and the assumed value of that time. The cost of time is defined as the sum of the opportunity cost of wages forgone by the sick individual due to illness, and the opportunity costs of healthy household members' time spent on treating or attending to the sick person or accompanying them for treatment.

All studies assumed that the value of a day's work lost could be treated as the gain that would result if malaria was reduced or eliminated. The most common is to use an average wage rate (Asenso-Okyere and Dzator 1997; Asenso-Okyere et al. 1997; Cropper et al. 1999; Konradsen et al. 1997). Other studies have used average daily income (Ettling et al. 1994; Guiguemde 1994) or an average daily output per adult (Sauerborn et al. 1991; Shepherd et al. 1991). Attanayake, Fox-Rushby, and Mills (2000) conducted the only study to use an output-related approach that measured the actual loss of income attributable to malaria (lost harvest, lost wages) for each respondent in a study in Sri Lanka. They reported an average loss of four activity days per malaria episode with about 27 percent of the total sample completely incapacitated for three days per malaria episode.

The disease reduces labor input into agriculture. Studies have shown that attacks, depending on the severity, typically entail a loss of four working days, followed by additional days with reduced capacity (Brohult et al. 1981; Picard and Mills 1992; Hempel and Najera 1996). A study in the Oyo State of Nigeria recorded that the average number of workdays lost per malaria episode by productive adults in the agrarian households was 16 days (Alaba and Olumuyiwa 2006). A study of farmers engaged in intensive vegetable production in Côte d'Ivoire showed that those suffering from malaria produced about half the yields and received half the incomes of healthy farmers because they were absent from work for up to 26 days in a 10-month period (World Bank 2007; Girardin et al. 2004). Another survey in the rural

Bukoba district of Tanzania found that a woman with a sick husband spends 60 percent less time on agricultural activities than she would normally have done (ILO 2000). A 1993 study in Sudan showed that a total of 8,409 labor hours were lost to malaria during the farming season. Farmers caring for the sick lost 1,332 labor hours, and 1,307 labor hours were lost due to incapacitation (Bollinger, Stover, and Seyoum 1999).

The monetary value of days lost due to malaria is hard to compare across studies because of the different methodologies used to value lost time. There are two key problems with this assumption. First, the potential for substitution of labor crucially affects whether or not the loss of time is translated into a loss of output. Second, estimates of loss based on the average product or wage may also be an overestimate of the actual gains because the increase in labor supply would not be accompanied by changes in other factors of production.

Chima et al. (2003) provide a summary of different studies in Africa that have measured, firstly, patient and caregiver days lost per malaria episode. Nearly all studies from Africa found that sick adults lost one to five days per malaria episode, depending on severity. Aikins (1995) cautions that estimation of caregiver time for children is complicated by the need to differentiate time spent on general child care and extra time spent on caring for a sick child. Average figures for days lost per malaria episode conceal large variations across individuals, for example, in most studies only 50 percent or less of the sample lost economically productive time due to malaria but a minority lost a lot of time. In Malawi, 52 percent of adults reported that malaria had affected their work or study, but 32 percent of these cases could still work at a reduced rate (Ettling et al. 1994). In Sri Lanka, 39 percent of malaria patients were economically active (n=133/344), and of these only 59 patients (only 17 percent of the whole sample) were affected in terms of lost wages, business revenue, or agricultural production. The variations in number of productive days lost to malaria may be due to proximity to health facilities and ability to seek health care during malaria episode.

The economic impact of malaria extends beyond the direct impact on labor productivity. A high malaria burden is likely to increase labor turnover, resulting in increased hiring and training costs and reduced profitability for enterprises. Furthermore, a high malaria incidence within a particular area may reduce tourism, deter otherwise profitable foreign and domestic investment, and prevent the use of land or other natural resources (WHO 2001). Malaria may also limit the movement of workers due to the reluctance of both foreign and domestic labor to move to malaria-infested regions. The quality of skill matching may suffer as a result. With regard to the internal mobility of labor, Gallup and Sachs (1990) argue that the better educated workers who often move to the largely malaria-free communities are likely to lose their natural protection. As a result, they may be reluctant to return to rural areas or even to maintain contact with such areas.

It has been observed that the most significant loss associated with malaria is borne indirectly by the affected households through productivity losses (Alaba and Olumuyiwa 2006; Asante, Asenso-Okyere, and Kusi 2005; Russell 2003; Chima et al. 2003; Asenso-Okyere and Dzator 1997). Malaria is more common in rural farm communities, and transmission generally coincides with the planting and harvesting seasons and so may affect area cultivated and area harvested (Sauerborn et al. 1991; Endah and Ndambi 2006; Chuma, Thide, and Molyneux 2006). Invariably, malaria induces changes in planting patterns to minimize the overlap between malaria episodes and peak agricultural work. According to Chuma et al. (2006), “having high levels of malaria during the farming season has important negative implications for wellbeing over time.” Two studies in Sri Lanka also indicated that most of the days lost to malaria were concentrated in the rainy season when agricultural activities were at their peak (Konradsen et al. 1997; Attanayake et al. 2000).

Leighton and Foster (1993) also observed that the total value of production loss in Kenya was higher in the agricultural sector than the industrial and service sectors. In Kenya, the agricultural sector accounted for 57 percent of the total value of production loss, compared with 35 percent and 8 percent for the service and industrial sectors, respectively. In measuring the economic cost of malaria to households in a rural community in Sri Lanka, Konrandsen et al. (1997) estimated that the annual economic loss amounted to US$15.56 per household, a figure equivalent to 6 percent of the net annual household income. The implication for agricultural production was that the malaria cases were found to be concentrated in the agricultural season and that during this season 5.6 percent of working days were lost to malaria sickness.

The association between malaria and agriculture has also been observed in some Central and South American countries. In Brazil, the government's agrarian reform through the colonization process in the frontiers of the Amazon region has not achieved the expected results due to what has been termed "frontier malaria," especially in the states of Acre and Rondonia. According to Sawyer (1987, 1993), high malaria prevalence among the agricultural settlers in the colonies often interferes with the scope and stability of the permanent agricultural programs, which comes with huge economic and social costs. Because these settlers are migrant farmers, when they get sick, they do not have family members to take their place in the fields with adverse consequences (e.g., loss of harvest due to illness, abandonment of fields).

Studies examining socioeconomic status (SES) using assets, education, and occupation suggest an inverse relationship between the impact of malaria and SES. In Lao People's Democratic Republic, investigators found a difference in malaria prevalence between socioeconomic groups (Sychareun et al. 2000). In Zambia, households without a sick head of household planted on average 22 percent more area in 2002–2003 than in the previous year. There are differences by income quintiles. The well-off but ill household heads in Zambia cultivated only 1 percent less area in 2002–2003, relative to 2001–2002. However, in poor households the decline in cultivated area was nearly 70 percent less. Ill-health-affected poor households were more at risk of losing land, farm implements, and livestock, which would push them into deeper poverty.

It is worth noting that in Africa, children and women (particularly pregnant women) are more vulnerable to malaria attacks; infection during pregnancy often results in maternal anemia and low birth weight. Hence, malaria contributed to an estimated 400,000 cases of anemia among pregnant women in Africa in 1995 (Guyatt and Snow 2001; Gikandi et al. 2008).

The potential impact of malaria for women engaged in agriculture, especially food production, could be also substantial. This is because of the crucial role women play in African agricultural production. It has been well documented that nearly all the tasks associated with subsistence food production in Africa are performed by women. Women account for about 70 percent of agricultural workers and 60–80 percent of the food crop producers for household consumption and sale. They also raise and market livestock (Todaro 2000; FAO 1996). Taking substantial time off to care for sick adults and especially their children constitutes a threat to food production on the continent.

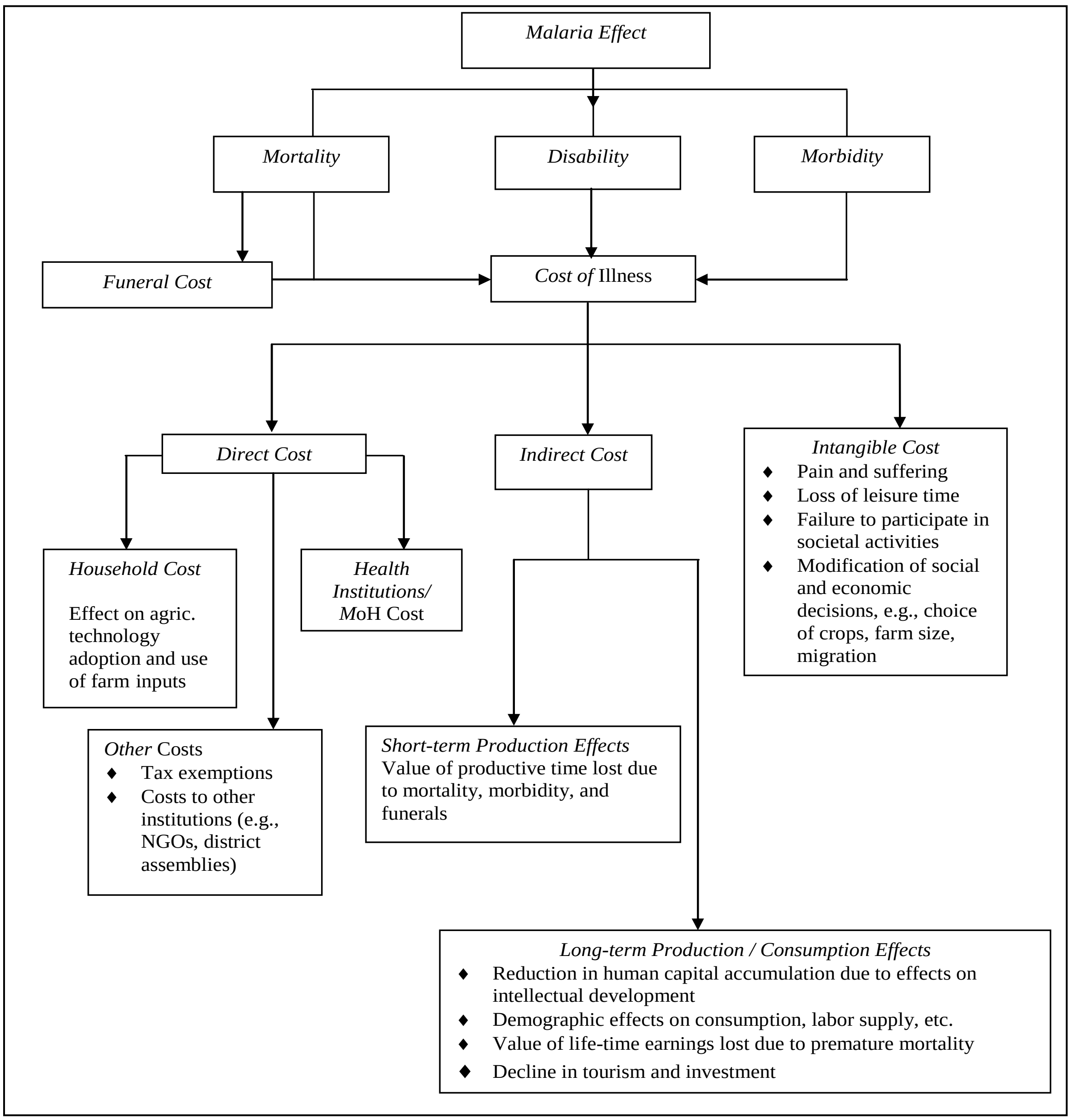
In a study on the impact of malaria on food production in Western Highlands of Cameroon, Endah and Ndambi (2006) concluded that malaria is a great hazard to food security because poor farmers in agricultural production zones are highly vulnerable. This is because "malaria causes weakness of patients thereby reducing labor output, causes interruption of the production cycle and also causes deviation of funds from farm inputs to treatment cost of malaria." Ersado, Amacher, and Alwang (2003) emphasized that poor health "has an adverse impact on household income and labor time", and sickness reduces the likelihood of agricultural adoption. All these give credence to the fact that malaria indeed could have negative consequences for agricultural development. It is, however, important to provide more concrete evidence of the listed potential impacts through more rigorous methodologies so that the impact can be quantified.

In addition to these direct effects, there are more indirect links between malaria and agriculture that impact negatively on productivity. For instance, frequent absenteeism caused by malaria reduces the efficiency of networks, requiring greater redundancy and reducing the scope for specialization.

Expenditures on Malaria

Figure 3 shows that malaria attack could result in morbidity, disability, and sometimes mortality. Whereas morbidity (illness) may be temporal, disability that results from morbidity is permanent and reduces the ability of a person to function normally. All these effects have direct and indirect cost implications to the household. For countries with a high malaria burden, the disease may account for as much as 40 percent of the public health expenditure, with malaria accounting for up to 50 percent of outpatient visits. In Tanzania, for example, malaria accounts for 30 percent of the national disease burden. Household expenditures on malaria control consist of two main components: expenditure on malaria (and mosquito nuisance) prevention, and expenditure on treatment. With respect to malaria prevention, measures such as mosquito coils, aerosol sprays, bed-nets, and mosquito repellents are used to very differing degrees in different areas and by different households. Household expenditure on malaria-related treatment includes out-of-pocket expenditures for treatment fees, drugs, transport, and the cost of subsistence at a distant health facility.

Figure 3. Framework linking malaria and agriculture: Cost-of-illness approach



Source: Culled from Shepard et al. (1991) with modifications by authors

The medical cost, as well as the treatment-seeking cost and the prevention cost, could be quite high especially among poor households. This could potentially result in reduced food consumption and investments in agricultural production by the household. It has been found that in sub-Saharan Africa, households could spend between US$2.00 and US$25.00 on malaria treatment and between US$0.20 and US$15.00 on prevention each month. In Kenya and Nigeria, treatment costs to small-scale farmers were estimated to be as high as 5 percent and 13 percent, respectively, of total household expenditure (WHO 1999). A study in Northern Ghana, the poorest part of the country, found that the cost of malaria care was 34 percent of the income of poor households (Akazili 2002). A study by Gatton and Cho-Min-Naing (2004) in Myanmar indicated that the total cost to patients per episode of malaria was equivalent to 4.2 days of per capita economic output on the average. In Malawi, total annual cost of malaria for an average household was calculated at $40 per year, 7 percent of total household income. Similar figures have been found in Kenya, with 9–18 percent of household income, and in Nigeria, with 7–13 percent of household income (Mills and Shillcutt 2004). In Santa Cruz in the Rio Naya region of Colombia and in the Perla de Sade in the Canton Quininde of Ecuador, an assessment of the socioeconomic impact of malaria in the regions revealed that the average cost per case of malaria was estimated at US$17.30 and US$10.40, respectively. These were equivalent to the value of 5.6 and 5.7 days of work in the two regions, respectively (Ruiz and Roeger 1994). According to the authors, the major economic impact lies in the reduction of labor force of families. This is considered more important because these rural families whose livelihood depends on economies at the subsistence level rely on the maintenance of their labor force.

One activity that costs money and takes household time from economic activities is funerals resulting from death from malaria illness. The premature death of a household member can pose significant costs such as transporting the body and funeral expenses (Asenso-Okyere and Dzator 1997). Members of the bereaved family and most people in the community and elsewhere miss productive activities for a number of days and attend burial and funeral rites.

It is obvious that even in health-care systems where medical services and treatment are free, malaria still has a significant impact on productivity. The depleted capital stock and lost savings due to expenditure on prevention and treatment of malaria, especially with the introduction of very expensive Artemisin-class Combination Therapy (ACT) in Africa, could reduce investment in agriculture by the affected households.

A holistic view of the effects of malaria on productivity should incorporate the implications of depleted capital stock and lost savings due to indebtedness or expenditures on prevention and treatment of malaria; the labor supply responses including limiting specialization of labor and maintaining labor reserves to reduce the risk of labor shortages at key times of the year; and the pervasive influence of risk of ill health on the incentive to invest (Over et al. 1992). At very low levels of income, the approach of households to prevention and treatment costs may be to sell arable land, economic trees, and livestock (Sauerborn, Adams, and Hien 1996). In Sri Lanka, poor urban households dependent on a daily wage were often pushed to pawn jewelry or borrow money when faced with additional expenses for health care (Russell 2001). This ultimately affects supply or production through low saving and investment. Furthermore, it means that the direction of causality of the economic impact of malaria may not necessarily be through uncultivated arable land and unavailable labor only, but also through lost capital and purchasing power.

However, the effect on demand has often been left out in the discussions. Malaria reduces labor productivity and also depletes household cash reserves. This reduces the demand for inputs for agricultural production and also the demand by households for other goods and services.

The cost-of-illness approach allows for the conceptualization of the potential loss of household income from malaria attacks. It also allows for the quantitative estimation of the impact of malaria on productivity (see Figure 3). Productivity loss can also be measured through production function approach at the macro level and the wage rate method at the micro level.

The impact of malaria on the agricultural sector is widely felt in Africa since about 70 percent of Africa's population is engaged in agriculture, producing food for consumption and the market. Ill health from malaria causes a decline in crop output, reduction in use of inputs, decrease in area planted, changes in cropping patterns, and loss of agricultural knowledge. The impact on agriculture is the loss of potential able-bodied adult labor as well as reduction in labor quality, time diverted from agricultural activities toward caring for the sick and attending funerals, and reduced funds to hire seasonal casual labor. In addition, households often sell their capital goods (farm equipment, cattle) to get funds to pay for health and funeral expenses. Information on the effects of malaria on agricultural productivity exists but is largely inadequate due to the nature of the disease and the coping mechanisms that families adopt to deal with the disease (Goodman 2000). More research is needed to shed light on the direct negative effects of malaria on farm households' food security, nutrition, and livelihood.

4. EFFECTS OF AGRICULTURAL DEVELOPMENT ON MALARIA

Agricultural systems vary across space, and therefore the types and severity of diseases associated with the systems also vary. As noted by Hawkes and Ruel (2006), “The influence of agricultural systems on health is particularly notable via the intermediary process of environmental change.” Agricultural production systems such as type of farming, farming practices, location of farms, and farming technologies could lead to environmental changes that create suitable ecological and climatic conditions for the breeding and survival of the anopheline mosquitoes, which transmit the disease.

According to Bradley (1992), African malaria is undergoing substantial and rapid changes in its basic epidemiology the last six decades (spanning the time period 1930–1991). The contribution of agriculture to these changes could be very significant. Agricultural water resource development in the arid (e.g., Sahel and Savanna) regions of the continent, deforestation in the tropical forest region due to agriculture logging and fuel wood, wetland cultivation, increase in urban agriculture, and land use changes for agricultural purposes in the highlands of East Africa and Cameroon are all expanding habitats for malaria-carrying mosquitoes (Brieger 2008; Patz et al. 2004; Yasuoka and Levins 2007; Keiser et al. 2005).

The general observation is that malaria transmission in a given area is proportional to the area’s mosquito density, and therefore, agricultural practices that increase the density of anopheline mosquitoes potentially increase the risk of malaria transmission among the inhabitants if effective preventive measures are not put in place.

Water for Agriculture

Expanded agricultural development in many parts of the world has increased the need for water for crop and animal production. Water for agricultural production has been sought from dams constructed and serviced from canals, sprinkler systems, boreholes, wells, dugouts, and bunds used as receptacles to collect water during the rainy season. Although water projects can lead to increased agricultural production, they have created suitable conditions for the breeding of mosquitoes (Diuk-Wasser et al. 2007). This is because the mosquito vectors are in constant contact with the population throughout the year because of the availability of water from the irrigation system or water pond, resulting in high anopheline density. Evidence abounds in the literature to link malaria transmission to agricultural water resources development in Africa. For instance, the construction of microdams for irrigation in the Tigray region of Ethiopia resulted in a seven-fold increase in malaria among children residing near the dams (Ghebreyesus et al. 1999; Keiser et al. 2005).

A global review of the effect of irrigation and large dams on the burden of malaria found that irrigation exposes non-immune populations in areas of unstable malaria transmission to high risk of acquiring the disease in Africa (Keiser et al. 2005). The report cites a study in Burundi, which found that irrigated villages in the Rusizi Valley had higher malaria prevalence and a 150-fold higher vector capacity of *An. arabiensis* compared with the situation in a neighboring village. This effect of irrigation—creating conditions for the transmission of malaria to nonimmune populations—may be one of the most severe negative consequences of these water projects. In the future, policies for agricultural water development need to take these likely consequences into account.

In Ghana’s Upper East Region, a study in the Kassena-Nankana district, which has one of the largest irrigation sites in the country, observed that malaria transmission was highly seasonal but the intensity of transmission was higher for people in the irrigated communities than in the non-irrigated ones. The results indicated that significant numbers of anophelines were captured from compounds in the irrigated areas (Appawu et al. 2004). In the same study site, a prevalent study carried out by Koram et al. (2003) also showed that prevalence of parasitemia was significantly higher among children living in irrigated areas than those residing outside the irrigated areas.

One area of intense research in Africa to assess the links between irrigation and malaria transmission has been in the area of rice cultivation. This is because rice fields are often flooded for long periods and therefore create puddles of water that allow a considerable multiplication of malaria vectors of the *An. gambiae* species. Yasuoka and Levins (2007) observed that "many irrigation schemes in Africa have resulted in increases in established malaria vectors such as *An. gambiae* and *An. arabensis* and thus increased the transmission of malaria." The construction of large-scale irrigation projects led to an increase in human malaria incidence (Service 1989; Robert et al. 1992). Another study conducted in the Northern Sudan region of Mali also reported that irrigation for rice cultivation increases the production of *An. gambiae*, which happens to be the main vector of malaria in Mali, and that mosquito abundance was linked to malaria transmission in the region (Diuk-Wasser et al. 2007)

More malaria outbreaks due to irrigation schemes have been reported elsewhere in South Asia. Lowland irrigated rice production in South Asia is reported to be associated with malaria transmission through the creation of conditions favorable for perennial malaria transmission (WHO 1996). Yasuoka and Levins (2007) further report that irrigation for rice cultivation in Java-Bali in Indonesia and in the Kunduz Valley in northern Afghanistan resulted in increased mosquito-breeding places and subsequently led to increase in malaria incidence in the regions. In Sri Lanka, the introduction of the Mahaweli Systems H and B is reported to have led to a five-fold increase in malaria in the region (IIMI 1996, cited in Keiser et al. 2005).

In India, evidence of the impact of irrigation on malaria transmission has been observed in several studies. For example, the annual parasite index increased from 0.01 in 1961 to 37.9 in 1976, following the construction of the Mahi-Kadana irrigation project. Malaria incidence in the canal-irrigated villages increased up to 9-fold in Meerut and Gurgaon. Again, a 2.4-fold increase in malaria cases and a more than 4-fold increase in the annual parasite incidence among children were recorded in villages closer to the Bargi Dam compared with the more distant villages (Keiser et al. 2005). Malaria has also become a major public health problem in the Thar Desert in Rajasthan state of India, with several reported epidemic outbreaks following the massive irrigation developments since the 1980s. The 8,000-km canal system in the Thar Desert region has transformed the desert physiography, vector preponderance, distribution, and vectorial capacity with *An. stephensis*, *An. culicifacies*, and the parasite *Plasmodium falciparum* invading the region (Tyagi 2004; Keiser et al. 2005; Joshi et al. 2005; Tyagi and Chaudhary 1997; Shiva and Shiva n.d.). Also in the Punjab region of India, irrigation schemes have made the region endemic for malaria, though it was only known for epidemic outbreaks (WHO/SEARO 2008).

The review by Keiser et al. (2005) also showed that in Peru, houses in villages located closer to fields and irrigation canals in the dry coastal areas recorded a five-fold increase in malaria incidence compared with those further away from fields and irrigation in the dry areas. Though higher malaria incidence has been reported at three large dam sites in Brazil (Balbina power plant, the Itaipu Dam, and the Tucurui hydropower dam), the review by Keiser et al. (2005) did not link it to irrigation activities. In general, we can conclude that irrigation and water harvesting and storage projects provide habitats for mosquitoes and increased malaria infection.

It is, however, important to understand that though irrigation areas are known to have high densities of mosquitoes, in exceptional cases, this may not automatically lead to higher malaria incidence among the inhabitants. In many areas of sub-Saharan Africa where malaria transmission is stable, the introduction of irrigated agriculture has little impact on the disease. In fact, several studies have documented that there is less malaria in communities living in close proximity to irrigation schemes when compared with populations living further away, which is partially explained by enhanced incomes that facilitate better protective measures to be taken (Boudin et al. 1992; Carnevale et al. 1999; Ijumba et al. 2002). This is the so-called paddies paradox, where agricultural development resulting in increased income for the community is likely to improve access to malaria treatment and may support an increased use of malaria preventive devices. For instance, the Mwea District in Kenya, where rice is cultivated and irrigation is used, was found to have a 30–300 times higher prevalence of the local malaria vector compared with those districts and villages without irrigation, but the irrigated areas had lower prevalence of malaria (Mutero et al. 2004). Similar observations have been made in studies in Burkina Faso, Senegal, Mali, and Tanzania, among others (Keiser et al. 2005; Diuk-Wasser et al. 2005; McCartney et al. 2005; Mutero et al. 2006). Several factors have accounted for this but include, most importantly, effective vector control programs, effective water management, and prevention interventions in the irrigated communities.

Land Use Practices

Agricultural development in Africa has contributed immensely to land use changes and has resulted in the upsurge of malaria transmission in several places, especially in unstable malaria transmission areas. Significant agricultural practices such as urban agriculture, wetland cultivation, clearing of tropical forest lands and its associated deforestation, and agricultural encroachment on highlands have been the primary drivers of malaria transmission in the affected areas (Patz et al. 2004). Specific land use–related activities are reviewed below.

Urban Agriculture and Malaria

In Africa, urban agriculture is aimed at improving food security and reducing poverty among the surging urban poor population across the continent. This is an increasing phenomenon in major cities in Africa (Lee-Smith and Prain 2006). It is generally held that malaria in Africa is predominantly a rural disease and it has been observed that *Anopheles* mosquito–breeding decreases with urbanization (Klinkenberg et al. 2005; Robert et al. 2003). However, this view holds less truth in the various cities in Africa where poor environmental management and peri-urban agriculture including fish ponds are providing favorable aquatic habitats for mosquitoes (Robert et al. 2003). Mosquitoes breed in temporary water pools that are clean and sunlit, and in shallow, standing water in places where wet crops (e.g., cabbage, tomatoes, lettuce) are cultivated in the cities (Lock and de Zeeuw 2001).

A study in Kumasi, Ghana, to assess the impact of irrigated urban agriculture on malaria transmission revealed higher adult anopheline densities in peri-urban and urban agricultural locations with more reported malaria episodes than in the non-agricultural locations in the city (Afrane 2003). The study found high levels of parasitemia among children living in communities closer to the agricultural sites and concluded that urban irrigated agriculture may increase the malaria risk in those communities (Klinkenberg et al. 2005). High malaria transmissions in urban agricultural communities have been observed in the central town of Bouake and the Western District town of Man in Cote d'ivoire (Matthys et al. 2006).

According to Lock (2000), malaria-carrying mosquitoes have adapted to urban environments in India, and to a lesser extent in the Middle East and Brazil. Malaria risk resulting from urban agriculture seems more pronounced in African cities because they have relatively more open space, abandoned lands, and cultivation compared with cities in the other regions (Lines, Leake, and Schofield 1994; Lock 2000). Though urban malaria is widespread in India and has been an increasing problem since the 1950s, it is largely related to changing urban ecology with construction activities. The urban malaria vector in India (e.g., *An. stephensi*) breeds in domestic water storage facilities, wells, garden water collection facilities, and garden ponds. For example, it is evident that more than 50 percent of the malaria cases in the Tamil state of India were due to urban malaria, of which 58 percent of the cases were from urban slums with poor sanitary conditions (WHO/SEARO 2008; Lock 2000).

Generally, as explained by Lock and de Zeeuw (2001), "although insight into the potential health risks of urban and peri-urban agriculture is growing, detailed information on the actual health impacts of urban agriculture is scanty." This calls for more research and assessments of the situation.

Deforestation

According to FAO survey, Africa lost over 9 percent of its trees between 1990 and 2005, mainly due to logging for lumber and fuel wood, and clearing for new farms. This represents over half of global forest loss, despite the fact that the continent accounts for just 16 percent of global forests (CTA 2007). Agricultural development is a major contributory factor to deforestation in tropical regions of the world. The clearing of the forest and the subsequent deforestation alter the local ecosystem (temperature, sunlight, humidity, water condition, soil condition, and vegetation). As explained by Yasuoka and Levins (2007), mosquitoes are very sensitive to environmental changes. Deforestation and land transformations have influence on vector anophelines, especially larval survivorship, adult survivorship, reproduction, and vector capacity. While deforestation can reduce the breeding habitats for anopheline species that breed in shaded water bodies in the forest, changes in environmental and climatic conditions in the deforested region can also promote the survival of other anopheline species that can lead to a prolonged seasonal malaria transmission (Kondrashin, Jung, and Akiyama 1991).

In a global review of closed forests, deforestation, and malaria risk, Guerra, Snow, and Hay (2006) observed that "the effects of deforestation on malaria transmission were spatially variable and highly dependent on vector distribution." This is because the vector species could adapt to different types of land cover and therefore could make the effect on malaria transmission regionally distinctive and even locally specific. To provide evidence of this, Guerra et al. (2006) cites from Kondrashin et al. (1991), Forattini et al. (1993a,b), and Briet et al. (2003) and explains that the clearing of forest lands for rice cultivation may provide more favorable conditions for the *Anopheles gambiae s.s.* or *An. Albitarsis s.s* but can reduce transmission in areas where *An. dirus* is the main vector. However, in situations where the forest clearing leads to tree crop plantations, the *An. dirus* could find suitable breeding conditions in the plantations similar to the vector's natural habitat in the forest. Specific plantation activities such as the tapping and collection of gum and resin in plantation in Southeast Asia at night have been found to expose plantation workers to mosquito bites and malaria infection (WHO 1996).

The global review observed that in the Amazon region of South America, forest clearing and changes in the acidity and chemical composition of the soil as a result of the slash-and-burn techniques provide suitable breeding conditions for the *An. darlingi* and an increase in the local risk of human malaria (Singer and Caldas de Castro 2001, cited in Guerra et al. 2006). The clearing of tropical forest areas in Columbia for "informal" agriculture (i.e., the cultivation of coca) has been associated with intense transmission foci (WHO 1996).

Yasuoka and Levins (2007) also cite a number of studies to show how forest cleared for sugarcane cultivation in villages in Kanchanaburi in Thailand led to the elimination of the shady breeding habitats for *An. dirus* but created widespread breeding grounds for *An. minimus*, which had greater sun preference. This resulted in high malaria transmission among the cultivators. Similar situations have occurred in the coffee and rubber plantations in southeast Thailand, where malaria became hyper-endemic in some cases (Yasuoka and Levins 2007). In Banjarnegara in Central Java in Indonesia, the development of Salak plantations has allowed forest mosquitoes to reach the local population creating resurgence in malaria transmission (Mitchell 2007).

Malaria in Brazil, the most endemic country in South America, is mostly confined to the tropical regions with the Amazon basin as the most endemic area. This has been attributed to massive deforestation in the tropical forest in the last 35 years due to the construction of the trans-Amazon highway, agricultural development, mining, logging, and immigration into the region. Increases in the incidence and prevalence of malaria in the Amazon have been recorded following the disappearance of the rain forest with Rondonia state being the hardest hit (Takken et al. n.d.).

Again, the rapid emergence of epidemic malaria in the Peruvian Amazon region with a 50-fold increase in the Loreto region between 1992 and 1997 has also been attributed to extensive deforestation through road construction accompanied by crop cultivation, promotion of aquaculture ponds, and human migration in the region. All these have combined to create suitable breeding sites including shallow pools left after floods recede, borrow pits after road construction, fish farms, swamps, and small pools on cleared land, making Peru the second most endemic country in the Latin America region (Guarda et al. 1999; Butler 2006).

In a macro-analysis of the association between deforestation and malaria using global data from 120 countries, Pattanayak and Yasuoka (n.d.) established a positive correlation between deforestation and malaria. The results revealed that more deforestation is positively correlated with higher levels of malaria. A follow-up regional analysis based on data from Brazil found that for the period 1985–1995, microregions with higher forest cover have lower rates of malaria while microregions with higher deforestation had greater rates of malaria.

In Africa, it has been concluded that "deforestation tends to increase malaria transmission by creating habitats that are suitable for the breeding of the very efficient, non-forest vectors." A similar observation, though a more complex position, was observed in the deforested regions of Southeast Asia and the Western Pacific (Guerra et al. 2006).

Malaria in Highland Regions

Traditionally, as has been noted in many studies, most tropical highlands had little or no malaria. This situation has changed with several highland areas in the tropics experiencing major malaria epidemics in the last 20 years (Lindsay and Martins 1998; Mueller et al. 2005). The increasing incidence of malaria in the highlands of Africa, especially in Eastern Africa, to a large extent has been attributed to agricultural practices that have resulted in changes in rainfall patterns, temperature, and vegetation. For example, the reemergence of malaria in the highlands of Western Kenya has been greatly blamed on the clearing of the forests for the development of tea estates and the migration of labor to the farms (Malakooti, Biomndo, and Shanks 2003; Reiter n.d.). The construction of access roads through the forests to the farms, the building of milldams on rivers, and the massive deforestation, among other factors, has caused a drastic change in the ecology, making it suitable for the breeding of anopheline mosquitoes. Similar observations have been made in the Amani hills of Tanzania, the Rukungiri and Kabale districts of Southwest Uganda, and in the Rwanda highlands (Kanzaria 2003; Githeko et al. 2003; Reiter n.d.). In his conclusion, Reiter (n.d.) confirmed that "the increasing prevalence of the disease is thus attributed to the changes in agriculture and ecology that accompanied a massive increase in population in the area of unstable endemic transmission."

In Southeast Asia, malaria and forest activity is a well-known association, and Erhart et al. (2004) cite several studies to confirm the strong association between forest activities and the risk of malaria infection in the region. Erhart et al. (2004) noted that population movement to the central and southern provinces of the forested Tay Nguyen highlands to engage in the highly profitable agricultural and woodcutting activities in the region have contributed to maintaining malaria transmission in central Vietnam.

A similar observation has been made in the highlands of Papua New Guinea, where the clearance of forest for various economic and social projects, including the establishment of coffee and tea plantations, as well as the mass movement of farm labor between highlands and malarious lowlands have been blamed for the serious malaria outbreaks in the region (Mueller et al. 2005; Reiter n.d.). Clearing of forest lands for rubber plantations in the hilly areas of Malaysia equally led to increased incidence and severity of malaria (Yasuoka and Levins 2007). In Indonesia, resurgence in malaria incidence has been recorded in the Menoreh hills and the foothills of the Dieng Plateau of Central Java. These areas are surrounded by rice paddies and are suitable for the breeding of malaria mosquitoes (Mazie et al. 2002).

WHO (1996) has also reported increasing risk of malaria infection as a result of population movement and forest clearing in upland areas of India and Thailand for the cultivation of upland rice. The report further indicates that forest clearing and shifting cultivation by the hill tribes in northern Thailand, especially for the cultivation of opium, exposes them to high risk of malaria infection.

According to Service (1991) agricultural stagnation in the highland areas of Costa Rica has forced farmers to work on farms in the more malarious lowland areas. Elsewhere in the San Martin and Junin areas of Peru, increased malaria transmission has been linked to rice cultivation and migration. Very often, immigrant workers in the rice fields return home to the highland areas with the parasite in their blood and spread it to their families (PAHO 1990, cited in Service 1991).

Wetland Cultivation

The reclamation of wetlands for cultivation in Africa has also contributed to the problem. The cultivation of the valley bottoms from the hillsides across East Africa as a result of rapid population and demand for more food has changed the local ecology. These wetlands were covered with natural papyrus, which limits the breeding of *An. gambiae* because of the dense vegetation and the oil layer. The elimination of the papyrus and the reclamation of the swamps have led to increase in temperatures, promoting the breeding and survival of the mosquitoes and thereby increasing malaria transmission in the affected areas (Kanzaria 2003; Githeko et al. 2003). A study in the highland area of southwestern Uganda found that changes in land use affected malaria transmission. On the average, all the malaria indexes studied (e.g., mosquito density, biting rates, sporozoite rate, and entomological inoculation rates) were higher near cultivated swamps than near natural swamps. This was because the draining of the swamps for cultivation purposes affected the vegetation and the local climate (e.g., increase in temperature). This has created favorable breeding grounds for the mosquitoes (Lindblade et al. 2000). The Kilombero Valley in southeastern Tanzania has also been described as a highly malaria-endemic tropical wetland dominated by subsistence agriculture (Hetzel et al. 2008).

Crop Cover

There are some expectations that the thickets formed by crop cover could be a favorable environment for the breeding of mosquitoes. It may be possible for mosquitoes to breed in the leaf axils (e.g., pineapple, banana, cocoyam, and maize), tree holes, and bamboo stumps. Though there is little evidence of this, these continue to be potential breeding sources. However, it is known that maize pollen provides nutrition for larval anopheline mosquitoes (Kebede et al. 2005). In exploring the epidemiological relationship between increased malaria transmission and intensified maize cultivation in the Bure District of northwestern Ethiopia, the results show that the incidence of malaria was about 10 times higher in high maize-cultivation areas than in areas with less maize. The conclusion was that the intensity of maize cultivation was associated with exacerbated human risk of malaria in Bure (Kebede et al. 2005).

5. CONCLUSIONS

The impact of diseases such as malaria on livelihood and agricultural productivity could be reduced depending on the agricultural and health support systems available to affected households. Scientific evidence on the nature and extent of the effects of malaria is needed to enable health and agricultural policymakers to make informed decisions. Strategies to mitigate the financial burden of malaria—particularly on the poorest households, which are least likely to afford the necessary expenditures—should be combined with appropriate communication and behavior change activities both to reduce the costs of malaria-related commodities and to support appropriate use of those commodities.

Malaria control has been increasingly recognized as an integral part of a comprehensive development framework. The perceived risk of infection has negative effects on decisions related to trade, investment, risk-adverse behavior in crop choices, and agricultural techniques. In the decades following the Global Malaria Eradication Program (1955–1969), the geographic range of the disease contracted substantially to the tropical areas, and political commitment and resources allocated for malaria control and research dwindled (UN 2005).

Malaria can be controlled by modifying or manipulating agricultural water systems. In the early 1900s, better maintenance and improvements of irrigation and drainage systems reduced malaria cases by more than half in Egypt, India, and Indonesia. Today, there are many options to mitigate the negative effects of agricultural water development while maintaining agricultural productivity. They include providing location-specific knowledge of drainage techniques, intermittently wetting and drying rice fields, alternating rice with a dry-land crop, and using livestock as “bait” for mosquitoes.

Estimates suggest that interventions to tackle malaria generate benefits that far outstrip costs. The benefits to human welfare are matched by economic gains where healthy people can contribute substantially to household production, especially agriculture in developing countries where land and labor are the main inputs. Thus, the impact of health spending is immediate and does not suffer from time-lag aspects as in education (Deaton 1993).

Efforts by initiatives such as the Multilateral Initiative on Malaria (MIM) to combat the burden of malaria through strengthening research capacity in Africa are laudable. Increasingly there are global efforts to use research findings to inform malaria prevention, treatment, and control. Given the current public recognition and political will in support of malaria eradication, there is the need for more investment in support of malaria research—especially in the shared linkages between agriculture and malaria. Agriculture is the mainstay of rural livelihoods, and yet there are some agricultural practices such as irrigation that inadvertently create the right environment for the vectors of the malaria parasite. Malaria prevention methods must therefore be adopted in a more holistic way to encompass all the various systems including environmental and climatic changes to ensure its complete eradication in tropical regions of the world.

Thus, information on the economic burden of malaria; willingness to pay for malaria treatment and prevention; and the knowledge, attitudes, perception, and practices of people can help in designing and targeting interventions efficiently and equitably, and in justifying investment in research and control. Such data can facilitate the understanding of the financial and opportunity costs of malaria episodes, the determinants of treatment-seeking behavior, and the differential economic impact on population subgroups. The information can be used as toolbox for capacity strengthening to accelerate the control (treatment and prevention) of malaria in the endemic areas of the world and for advocacy to increase funding for malaria control.

From the foregoing discussion, several issues and questions emerge that can only be addressed by focusing research on this topic. First, there is a need for further evidence of the knowledge, attitudes, practices, and perceptions regarding malaria. This would serve as the background for conducting research in this area and to provide materials for preparing manuals for capacity strengthening of farm households of the dual effects of agriculture and malaria. One major area of research is to examine how agricultural practices (e.g., land management, forest management, water harvesting and storage or irrigation) affect the transmission of malaria, either positively or negatively. A second question flows in the reverse direction: How does the incidence of malaria affect agricultural productivity? These could be either direct effects limiting agricultural activity or indirect effects of malaria on the adoption of agricultural technology or improved agricultural practices and ability to keep farm and household assets. A related question would be to develop a better understanding of the economic impacts of malaria. What is the impact on economic growth of the reduction in agricultural productivity caused by malaria? Lastly, there is a research gap in the area of capacity strengthening, which can be addressed by action research to increase learning and capacity research on malaria and its linkages with agricultural development. Many of the research results can be used to formulate pragmatic policies by policymakers in the health and agriculture sectors to control malaria and improve agricultural productivity and growth for enhanced human livelihood.

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