Global Food Security 6 (2015) 24–33

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Improving irrigation access to combat food insecurity and undernutrition: A review

Laia Domènech

International Food Policy Research Institute, 2033 K Street, NW, Washington, DC 20006-1002, USA

ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form
9 September 2015
Accepted 10 September 2015

Keywords:
Irrigation
Food security
Nutrition
Health
Women's empowerment
Sub-Saharan Africa

ABSTRACT

Interventions aimed at increasing water availability for livelihood and domestic activities have great potential to improve various determinants of undernutrition, such as the quantity and diversity of foods consumed within the household, income generation, and women's empowerment. This review analyzes the existing evidence concerning the role of irrigation in improving nutrition and health outcomes. Most of the studies examined showed a positive effect of irrigation interventions on food security. However, existing evidence is still insufficient to draw broad conclusions, largely because nutrition is yet to be considered an explicit objective of irrigation development. Nutrition-sensitive irrigation programs are needed to help realize the full potential of irrigation interventions and avoid adverse impacts on human health and nutrition.

1. Introduction

Malnutrition rates in Sub-Saharan Africa (SSA) are still high compared to other regions. Stunting, wasting, and underweight currently affect 39.6, 9.4, and 21.4% of the children under five in SSA due to lack of nutritious foods and high incidence of disease (UNICEF et al., 2012). More than 60% of the population lives in rural areas, and rainfed agriculture is the main or only source of livelihood for most rural households (Faurès and Santini, 2008). Rainfed cereal crops (for example, maize, sorghum, or millet) and roots and tubers are the main sources of food and income, but have limited nutritional content and low market value and, as a result, have low poverty and malnutrition reduction potential (Burney et al., 2013).

Due to lack of access to water, agricultural production is often interrupted during the dry season when many farmers must rely on food stocks accumulated during the rainy season and/or on food purchases. Irrigated agriculture can be an important entry point for malnutrition reduction, as water is frequently a limiting factor for crop and livestock production. Furthermore, in SSA the potential for expanding irrigated agriculture is large as only 6% of the total cultivated area is irrigated (You et al., 2011; Xie et al., 2014).

Single-sector approaches such as dietary or micronutrient supplementation and the promotion of caregiving practices have typically been used to improve children's nutrition and health, even though their success has been mixed (Humphrey, 2009; Dewey and Adu-Afarwuah, 2008). More recently, nutrition-sensitive programs that address some of the underlying causes of undernutrition, such as agricultural interventions and safety net programs, have increased in popularity (Ruel and Alderman, 2013). Irrigation interventions, however, have rarely been implemented as nutrition-sensitive interventions, as policymakers and donors continue to consider them only as yield and production enhancing technology strategies.

The potential of irrigation to improve nutrition and other outcomes depends on a series of factors such as the water source (groundwater, surface water, ponds), relative water availability (single season, supplementary, or full), type of technology (drip or sprinkler systems, deep or shallow tube wells, treadle pumps), size of the system (large-scale versus small-scale), access to agricultural inputs (land, credit, seeds, fertilizer, and so on), socio-economic features of the household, and institutional rules governing water access and maintenance of water systems (Lipton et al., 2003).

Several review papers have analyzed the available evidence regarding the effect of agricultural interventions on nutrition outcomes, particularly of children and women (Berti, Krasevec, and FitzGerald, 2003; World Bank, 2007; Masset et al., 2012; Girard et al., 2012; Webb, 2013); however, with the exception of home gardens, irrigation interventions were rarely considered in these reviews. This paper aims to address this gap by reviewing the existing literature on the topic.

Five main impact pathways linking irrigation to nutrition and

http://dx.doi.org/10.1016/j.gfs.2015.09.001
2211-9124/

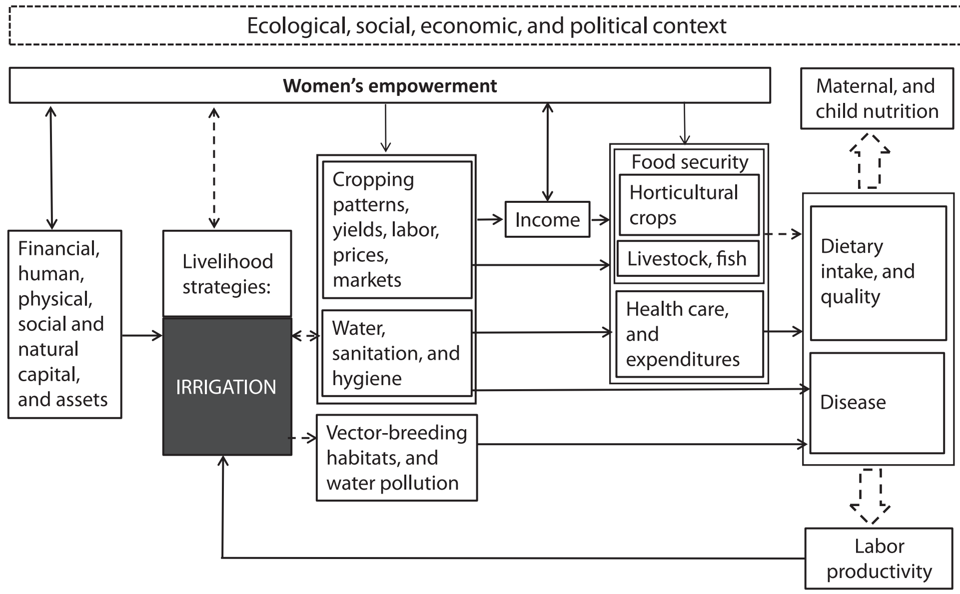

Fig. 1. Impact pathways from irrigation to better nutrition, health, and women's empowerment.

health outcomes are identified in this paper: (i) irrigation as a source of more and more diverse foods (through increased agricultural productivity and crop diversification); (ii) irrigation as a source of income (from market sales and employment generation); (iii) irrigation as a water source providing multiple use water services (such as WASH, livestock rearing and aquaculture); (iv) irrigation as new vector-breeding habitat and a source of water pollution (from agrochemicals); and (v) irrigation as an entry point for women's empowerment (through increased asset ownership and control over resources) (Fig. 1).

2. Methodology

We searched for peer-reviewed papers and gray literature using the following keywords*: (irrigation OR irrigated fodder) AND (nutrition OR health OR food security OR anthropometrics OR dietary diversity OR women's empowerment OR gender OR water supply & sanitation OR livestock)*. We used Google Scholar to conduct the search. Some studies were also found by cross-checking the reference lists of selected studies and by discussing the review project with other colleagues.

The final list of studies included in the review can be found in Table 1. We kept only studies published in English after 1985 that used primary data collection and included some measurement of food security, nutrition, health, and gender outcomes of irrigation interventions. Another inclusion criterion was a description of methods in sufficient detail. Original papers that measured the impact of home gardens on these outcomes were also included in the review, as home gardens typically need to be watered periodically, especially in arid and semiarid areas. Home gardens are also of particular interest for this review because they have great potential to increase household food security and women's empowerment (Girard et al., 2012).

In total, 28 papers were systematically reviewed. Almost all the studies reviewed focused on SSA, except for 5 that studied Asian cases. Dams and canal irrigation were the main type of irrigation used in 12 studies, while small-scale private irrigation was used in 8 studies. Microirrigation technologies were analyzed in five studies, home gardens in four, and wastewater irrigation was the focus of one study. Information on the main features of the irrigation system was missing in the rest of the studies (Table 1).

The most common evaluation method used in the papers reviewed involved a comparison of outcomes between irrigation adopters and nonadopters. Sample selection bias was an important limitation of the evaluation design in many of the papers reviewed, but some of the papers minimized this problem by using propensity score matching methods. Self-selection bias is a common limitation of this kind of evaluation study because randomizing the households adopting irrigation technologies is often difficult. Households with higher education and income levels are more likely to adopt irrigation technologies and, accordingly, the outcome variables measured (for example, nutrition outcomes) may differ due to these unobservable characteristics and not due to the use of irrigation. Panel data (before/after) analysis was conducted in seven studies in order to monitor any changes induced by the intervention over time. Only four studies (five papers) followed the most typical experimental design, including both the before/after analysis and the adopter/nonadopter comparison. Some studies also collected qualitative data to allow for more descriptive analyses of irrigation outcomes.

3. Linkages among irrigation, nutrition, health, and gender

Irrigation can lead to crucial changes in the livelihood and food security of smallholders. The four food security dimensions—food availability, access, utilization, and stability—are likely to change as a result of increased water availability for crop production and other uses. Irrigation can have a direct impact on food availability because of increased productivity and changes in cropping patterns. Moreover, irrigation will likely increase the stability of the food supply because irrigation's main role is to enhance water control, thus reducing or eliminating potentially adverse impacts on production from too little rain. However, do more food available and possibly more income translate into increased food access and utilization? Greater availability of food can certainly favor greater food intake, but this might not always be true in an intrahousehold setting. Irrigated crops are often cash crops, and cash crops are often men's domain. If decisions regarding the crop are in male hands, including the sale and income from the sale, then intrahousehold food and nutrition outcomes might not improve (Quisumbing et al., 1995). Thus, gender dynamics and women's roles in irrigated agriculture are important determinants of food

Table 1
Main features of the studies reviewed. Source: Compiled by author.

Source	Study area	Type of irrigation	Main irrigated crops grown	Sample size	Measuring food security/nutrition outcomes main goal?	Experimental design	
						Adopters and nonadopters comparison	Before/after comparison
Adeoti et al. (2007)	Ghana	Treadle pumps	Vegetables	108 farmers	No	Yes	No
Aseyehegn et al. (2012)	Ethiopia (Tigray)	Microirrigation dams	Cereals and vegetables	130 households	No	Yes	No
Bagson and Wuleka Kuuder (2013)	Ghana (Kokoligu)	Dams	Vegetables (tomatoes, cabbage, lettuce, okra)	50 household heads	Yes	No	No
Benefice and Simondon (1993)	Senegal	Irrigation dams (flood irrigation)	Rice, tomatoes, and onions	110 extended family units	Yes	No	Yes
Burney and Naylor (2012)	Benin	Solar-powered drip irrigation	Vegetables in communal gardens	120 households	No	Yes	Yes
Burney et al. (2010)	Benin	Solar-powered drip irrigation	Vegetables in communal gardens	120 households	Yes	Yes	Yes
Clarke et al. (1997)	Ghana	NA	NA	188 individuals	No	Yes	No
Dillon (2008)	Mali	Canal irrigation with motorized pumps	Rice	245 households	No	Yes	Yes
Ersado (2005)	Ethiopia (Tigray)	Microirrigation dams	Cereals and vegetables	730 households	No	Yes	No
FAO (2000)	Zimbabwe	Surface and sprinkle irrigation	Horticultural crops	10 case studies	No	No	No
Kabunga et al. (2014)	Uganda	NA	Vegetables and fruits	3630 households	Yes	Yes	No
Kirogo et al. (2007)	Kenya	Surface irrigation	Horticultural production	118 households	Yes	Yes	No
Mangisoni (2008)	Malawi	Treadle pumps	Maize, beans, and vegetables	200 households	Yes	Yes	No
Namara et al. (2005)	India	Drip and sprinkler irrigation from groundwater	Fruits, groundnut, cotton, and vegetables	448 households	No	Yes	No
Namara et al. (2011)	Ghana	Shallow groundwater	Tomatoes and peppers	420 farmers	No	Yes	No
Njuki et al. (2014)	Tanzania and Kenya	Groundwater irrigation pumps	Vegetables	358 individuals	No	No	No
Nkhata (2014)	Malawi	Canal irrigation	Rice, maize, soybean, and cowpea	412 households	No	Yes	No
Olney et al. (2009)	Cambodia	Home gardens	Fruits and vegetables	500 households	Yes	Yes	Yes
Olney et al. (2015)	Burkina Faso	Home gardens	Fruits and vegetables	1282 children	Yes	Yes	Yes
Peter (2011)	Swaziland	Surface water	Sugarcane and vegetables	NA	Yes	No	No
Sinyolo et al. (2014)	South Africa	Canal irrigation	Maize and vegetables	256 households	Yes	Yes	No
Srinivasan and Reddy (2009)	India	Irrigation with wastewater	Vegetables, para grass, and rice	471 households	No	Yes	No
Steiner-Asiedu et al. (2012)	Ghana	Irrigation dams	NA	397 mother-child pairs	No	Yes	No
Upadhyay et al. (2005)	Nepal	Drip irrigation	Vegetables	131 households	No	No	No
van den Bold et al. (2013)	Burkina Faso	Home gardens	NA	220 households	Yes	Yes	Yes
Von Braun et al. (1989)	The Gambia	Pumps and tidal irrigation	Rice	900 farmers (214 households)	No	Yes	No
van der Hoek et al. (2002)	Pakistan	Canal irrigation	NA	200 households	Yes	No	No
van Koppen et al. (2012)	Ghana and Zambia	Small-scale private irrigation	High-value crops	734 households	No	Yes	No

Note: NA = not available.

access and utilization.

At the same time, the consumption of more nutritious foods might not be sufficient to achieve normal growth and cognitive development in children. Nutritious diets are certainly a requirement for children's healthy growth, but other conditions such as a healthy environment are also needed. Irrigation can have a dual effect on the environment, improving sanitary and water supply conditions but also competing with or polluting domestic water resources and increasing the incidence of some water-borne diseases, such as malaria. In the next section we attempt to explore all these linkages for the case of irrigation, drawing on the existing literature on the topic.

3.1. Irrigation use and increased agricultural productivity and crop diversification

Irrigation can improve crop productivity in three main ways: reduced crop loss due to access to more reliable water supply, multiple cropping as a result of being able to plant during the dry/lean season, and a greater area of cultivated land due to the use of areas where rainfed production was formerly unfeasible (Lipton et al., 2003). Furthermore, irrigated varieties are generally higher yielding than rainfed varieties, as water control allows for better application of complementary agricultural inputs, such as fertilizers and pesticides and because much research and development effort has been expended on varieties grown in irrigated environments. Finally, the type of irrigation system and inputs used have also great impact on agricultural productivity. Microirrigation technologies, for example, can lead to yield gains of up to 100% over conventional irrigation systems (Burney et al., 2010).

Out of the 28 studies used in the review, 14 gathered some data on agricultural productivity (Table 2). However, only a few studies included rainfed and irrigated agriculture productivity comparisons. In Ethiopia, Aseyehegn et al. (2012) documented that farmers using irrigation systems produced crops twice, and sometimes even three times, per year as opposed to a single cropping season with rainfed agriculture.

The types of crops grown are also likely to change with the introduction of irrigated agriculture because new crops can be planted in a second (dry) season and greater water availability enables farmers to grow crops that would be unsuitable for cultivation under rainfed conditions. Cash crops are frequently grown on irrigated lands. Namara et al. (2005) reported cropping pattern changes in India after the installation of microirrigation technologies, with microirrigation adopters producing more diverse crops, including high-value and water-intensive crops, than farmers

Table 2
Variables analyzed in the studies reviewed. Source: Compiled by author.

Source	Agricultural production	Income	Livestock	Labor	Food security	Dietary intake	Anthropometrics	Clinical indicators	Morbidity indicators	WASH	Gender considerations
Adeoti et al. (2007)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes
Aseyehegn et al. (2012)	No	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes
Bagson and Wuleka Kuuder (2013)	No	Yes	No	No	Yes	No	No	No	No	No	No
Benefice and Simondon (1993)	No	No	No	No	Yes	Yes	Yes	No	No	No	No
Burney and Naylor (2012)	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes
Burney et al. (2010)	Yes	Yes	No	No	Yes	No	No	No	Yes	No	No
Clarke et al. (1997)	No	No	No	No	No	No	No	Yes	Yes	No	No
Dillon (2008)	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No
Ersado (2005)	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No
FAO (2000)	Yes	Yes	No	Yes	Yes	No	No	No	No	No	Yes
Kabunga et al. (2014)	No	Yes	Yes	No	Yes	No	No	Yes	No	Yes	Yes
Kirogo et al. (2007)	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No	No
Mangisoni (2008)	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Namara et al. (2005)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes
Namara et al. (2011)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Njuki et al. (2014)	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes
Nkhata (2014)	Yes	Yes	No	No	Yes	No	No	No	No	Yes	Yes
Olney et al. (2009)	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No
Olney et al. (2015)	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Peter (2011)	No	Yes	No	No	Yes	No	No	No	No	No	No
Sinyolo et al. (2014)	Yes	Yes	Yes	No	Yes	No	No	No	No	No	No
Srinivasan and Reddy (2009)	No	No	Yes	Yes	No	No	No	No	Yes	Yes	Yes
Steiner-Asiedu et al. (2012)	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No
Upadhyay et al. (2005)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes
van den Bold et al. (2013)[a]	No	No	Yes	No	No	No	No	No	No	No	Yes
Von Braun et al. (1989)	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
van der Hoek et al. (2002)	No	No	No	No	No	No	Yes	No	Yes	Yes	No
Van Koppen et al. (2012)	No	No	No	Yes	No	No	No	No	No	No	Yes

NA = not available; WASH = water, sanitation, and hygiene

[a] Other outcomes were evaluated in a broader study but not reported in this paper.

using traditional irrigation methods. Cash crops are typically sold in the market and can result in additional income to former subsistence farmers.

Irrigation can also be very important to boost vegetable production and consumption (see Fraiture and Giordano, 2014). In most of the papers reviewed, irrigation is either exclusively or to some extent used to grow vegetables and fruits (Table 1). Given the continued limited supply options in much of Africa, farmers can sell vegetables and fruits locally to gain additional income, with additional positive nutritional impacts on the rest of the community (Burney et al., 2013). In East Africa treadle pump users sold a greater proportion of irrigated crops as compared with rainfed crops. In Kenya and Tanzania, 73% and 83%, respectively, of the irrigated crops produced by men were commercialized. A significant share of the crops grown (tomato, kale, cabbage, amaranth) was sold in the local village market or to neighbors, thus increasing food availability in the community (Nkonya et al., 2011).

From a nutritional point of view, vegetables and fruits are very valuable products because of their high iron, vitamin A, zinc, and other micronutrient content. Homestead food production programs implemented by Helen Keller International and others successfully improved the amount of vegetables produced by intervention households (Olney et al., 2009; Iannotti et al., 2009). Because an important share of the food produced in homestead gardens is consumed within the household, homestead gardens can contribute significantly to improved and diversified diets.

However, irrigation adoption can sometimes also lead to monocropping, as reported by Hossain et al. (2005), who correlated the expansion of shallow wells for small-scale irrigation in Bangladesh with an increase in monocropping of rice and a reduction in the production of pulses and oilseeds, which are both important micronutrient and protein sources.

3.2. Irrigation and higher incomes

An increase in agricultural productivity as a result of irrigation adoption can lead to increased food availability either for own consumption or for marketing and income generation purposes. Irrigation can therefore be an important source of income since smallholder irrigation systems are frequently used to grow vegetables, fruits, and other cash crops that are usually marketable and highly profitable. As a result of increased agricultural productivity, demand for labor within the household and in neighboring communities may also increase, which is particularly significant during the dry season because job opportunities are less abundant. Irrigation can therefore increase the purchasing power of seasonal workers and members of low-income households, who may decide to use the additional income to purchase nutritious foods

Large, successful irrigation programs can also affect food prices. Nonirrigators, in both rural and urban areas, may benefit from reduced prices due to greater availability of staples and other food products (Lipton et al., 2003). However, in some remote communities, the lack of access to reliable markets may hinder income generation from irrigation activities (Chazovachii, 2012). All in all, having access to information about the demand and supply of agricultural products, how to preserve them, and the right time to sell these perishable products without loss of quality is critical for the success of smallholder irrigation.

Out of the 28 studies included in the review, 20 included some measure of income generated by irrigated agriculture. Mangisoni (2008) compared the annual income per hectare of treadle pump users and nonusers in Malawi. The net farm income per hectare was US$770 for treadle pump users compared to US$131 for nonusers. Von Braun et al. (1989) went further in their analysis and assessed the links among production, income, consumption, and nutrition in rice irrigation projects in the Gambia. The cultivation of rice increased the real income of farmers by 13%. The study also concluded that an additional 10% in annual income led to a 9.4% increase in food expenditures and a 4.8% increase in calorie consumption.

3.3. Irrigation, increased food availability, and improved diets

Irrigation can improve the amount of food available to the household through two main channels. The amount and diversity of home grown food can improve as a result of having access to irrigation water, and households may be able to purchase more food as a result of having more income from the sale of irrigated products. Most of the studies included in the review (22 out of 28) include some measure of food security and/or dietary intake indicators (Table 2). The high number of studies falling into this category is not surprising because this was one of the main inclusion criteria for the review. However, only 12 of the studies selected focused primarily on food security and nutrition outcomes (Table 1). The other studies aimed at analyzing the impact of irrigation on well-being or other socioeconomic aspects, and food security was only one of several outcomes studied. These more general studies present, for the most part, only broad measures of food (in)security, such as the number of days or months households are unable to meet household food needs (Adeoti et al., 2007; Bagson and Wuleka Kuuder, 2013; FAO, 2000; Namara et al., 2005; Njuki et al., 2014; Peter, 2011).

The studies with a stronger food security or nutrition focus generally provide more comprehensive indicators of food consumption and dietary adequacy, including information on food expenditures, daily caloric intake, or dietary diversity measures (Benefice and Simondon, 1993; Dillon, 2008; Ersado, 2005; Kirogo et al., 2007; Namara et al., 2011; Olney et al., 2009; Steiner-Asiedu et al., 2012; Von Braun et al., 1989) (Table 3).

The studies reviewed generally show that irrigation adoption leads to increased and improved diets. However, most of the studies do not specify whether the dietary improvement arises from more home grown food available or from an increase of marketable surplus leading to more food being purchased by the household (for some exceptions see Bagson and Wuleka Kuuder (2013) and Burney et al. (2010)). In the Sudano–Sahel region, Burney et al. (2010) analyzed the food security situation of beneficiaries of solar-powered drip irrigation systems installed in communal gardens. The consumption of vegetables during the dry

Table 3
Main indicators used to measure food security and dietary quality.

Indicators	Sources
Months of food shortage	Bagson and Wuleka Kuuder (2013), Mangisoni (2008) and Namara et al. (2011)
Food expenditure and share of food expenditure	Burney et al. (2010), Burney and Naylor (2012), Ersado (2005), Sinyolo et al. (2014) and Von Braun et al. (1989)
Energy (caloric) intake	Dillon (2008), Benefice and Simondon (1993), Kirogo et al. (2007), Steiner-Asiedu et al. (2012) and Von Braun et al. (1989)
Dietary diversity score	Namara et al. (2011), Olney et al. (2009) and Olney et al. (2015)
Food insecurity scores	Burney et al. (2010), Burney and Naylor (2012) and Kabunga et al. (2014)

season increased among program beneficiaries, and irrigators were 17% less likely to feel chronically food insecure one year after the implementation of the project. Mangisoni (2008) analyzed the food security situation of treadle pump users and nonusers by comparing the maize deficit – defined as less than 270 kg of maize equivalent per year per capita – of treadle pump users and nonusers. Maize deficit was detected in only 9% of the users, compared to 60% of the nonusers. Some studies also use household food expenditures and the percentage of household expenditure devoted to food as indicators of food security. For example, Sinyolo et al. (2014) found that irrigators spent about 25% more on food than nonirrigators.

More complex measures of food security and nutrition, such as daily caloric intake, dietary diversity indicators, and weighed food records, are used in only nine of the studies reviewed (Benefice and Simondon, 1993; Dillon, 2008; Kirogo et al., 2007; Namara et al., 2005; Njuki et al., 2014; Olney et al., 2009, 2015; Steiner-Asiedu et al., 2012; Von Braun et al., 1989), all of which had assessment of nutrition outcomes as a primary objective. The evaluations of the impact of the Hellen Keller International homestead food production program on household and child nutrition conducted by Olney et al. (2009) and Olney et al. (2015) in Cambodia and Burkina Faso are the only studies that include both household and individual dietary diversity measures. Olney et al. (2009) conclude that in comparison to the control group, the program increased household consumption of micronutrient-rich foods such as dark green leafy vegetables and yellow or orange fruits, and maternal and child intake of some of these foods (for example, eggs and dark green leafy vegetables). Following the implementation of the homestead food production program, household dietary diversity scores had also increased more in the intervention group than in the control group. Similarly, Dillon (2008) compared the daily caloric intake of households with and without access to canal irrigation in Mali. Households with access to irrigation increased their daily caloric intake by 1836 cal, while those without irrigation decreased their daily caloric intake by 925 cal between 1998 and 2006.

However, some of the studies selected for review report mixed or inconclusive results in terms of the impact of irrigation on food security and nutrition. Namara et al. (2011) compared the Household Dietary Diversity Score (HDDS) of farmers practicing rainfed agriculture with that of farmers practicing groundwater irrigation in Ghana. Farmers were asked about the household consumption of a set of 12 food groups during the 24-h period prior to the interview. Nonsignificant differences between rainfed farmers (6.3) and irrigated farmers (6.5) were found.

As previously mentioned, the installation of irrigation systems can sometimes also lead to monocropping, and in this case, irrigation may have negative impacts on nutrition. According to Hossain et al. (2005), who used secondary data in their analysis, an increase in rice production resulting from investments in small-scale irrigation in Bangladesh led to increased rice intake and reduced dietary diversity among the poorest households.

Irrigation systems can also improve the intake of animal-source foods as a result of higher revenues and improved livestock productivity. Livestock and other small animals can use water from irrigation systems for drinking and bathing (Meinzen-Dick, 1997). Irrigation can also increase the amount of feed available for livestock in the dry season and, as a result, expenditures on forage may decrease. In Africa, 14% of the irrigated land is used to grow irrigated fodder, mostly in Egypt, Sudan, and other parts of the northern and southern regions (Frenken, 2005). Irrigated fodder production can help increase livestock and dairy productivity and, consequently, lead to important nutritional benefits for young children through increased consumption of animal-source foods (Murphy and Allen, 2003). Livestock are also an important asset against income shocks, such as crop failures resulting from natural disasters. Fodder irrigation was not practiced in any of the irrigation projects reviewed, but 14 of the papers selected included some sort of information on the relationship between irrigation and livestock productivity. In Tigray (Ethiopia) income gains from livestock were 14% higher among irrigation users compared to nonusers, suggesting that irrigation had a positive impact on livestock productivity (Aseyehegn et al., 2012). Dillon (2008) also found positive impacts of irrigation on livestock accumulation in northern Mali. However, other studies, such as Olney et al. (2009), Namara et al. (2011), and Sinyolo et al. (2014), did not find any significant impact of irrigation on livestock production.

Irrigation systems (canals, ponds, dams) can also provide habitats for fish, crustaceans, and mollusks (Meinzen-Dick, 1997), which can be important sources of micronutrients for some communities. Despite the high nutritional value of fish, little attention was devoted to fish production and consumption in the studies reviewed.

3.4. From food consumption to nutritional and health returns

A more varied diet is usually associated with positive effects on birth weight, child anthropometric status, and hemoglobin concentrations (Hoddinott and Yohannes, 2002). While several studies present evidence that irrigation leads to increased and improved diets, evidence about the linkage between irrigation and the nutritional status of individuals remains limited, as few studies collected data on these indicators. Of the 28 studies reviewed, only 8 collected anthropometric data to assess the nutritional status of children; 2 also collected data for the mothers (Von Braun et al., 1989; Olney et al., 2009). Information on health outcomes is also limited. Eight studies present data on morbidity-related indicators such as health expenditures or incidence of disease, and only 4 studies present clinical data, essentially anemia prevalence.

Olney et al. (2009) showed that having an improved home garden led to increased production and consumption of micronutrient-rich foods in Cambodia. However, the study found no evidence of program impact on child and maternal anthropometrics or anemia prevalence. Nevertheless, other positive effects on health were documented. A lower prevalence of fever among children from intervention households in the two weeks prior to the survey was reported during the endline survey.

The first cluster-randomized controlled trial of its kind to assess the impact of a homestead food production program and a nutrition and health behavior change communication (BCC) program on anthropometry, mean hemoglobin and diarrhea prevalence was conducted by Olney et al. (2015) in Burkina Faso. Compared to the control, they found marginally significant impacts in wasting and hemoglobin and statistically significant impacts on diarrhea prevalence in the group receiving visits from a health committee member. However, no significant impacts were found on stunting and underweight prevalence which may be explained by the short duration of the study and the impossibility of targeting women during pregnancy.

Kirogo et al. (2007) compared the nutritional and anthropometric status of children under five from households with and without irrigation in Kenya. The prevalence of stunting and underweight was higher among children from households without irrigation, although differences were not significant. Significantly higher HAZ (height-for-age Z-score) was estimated among higher-income households with irrigation, and significantly higher WAZ (weight-for-age Z-score) was estimated among commercial households with irrigation in comparison to equivalent groups without irrigation. These results suggest that enhanced food production as a result of irrigation leads to higher food availability and improved nutritional status, but results are not conclusive.

Benefice and Simondon (1993) compared anthropometric data collected in 1983 with data collected in 1991 after the introduction of flood irrigation in the Middle Valley of Senegal. No significant differences in the prevalence of wasting were encountered among children under five. However, thinness among children of five to ten years and among adults had been reduced. The authors attributed the lack of improvement in anthropometric indicators among small children to the lower progress made in Senegal in water supply and sanitation as compared to food production improvements. They argued that older children are better protected against infections associated with lack of adequate water and sanitation and, therefore, improvements in food consumption are more likely to translate into a better nutrition status in that group (for example, lower prevalence of wasting).

Irrigation may also favor higher investments in healthcare, education, water, and sanitation as a result of higher incomes. However, current evidence of this linkage is scarce or inconclusive. Burney et al. (2010) found nonsignificant changes in healthcare expenditures for irrigators compared to nonirrigators.

3.5. Multiple use of irrigation water, WASH, and better nutrition and health

Irrigation water may be used for different domestic purposes such as drinking, washing, bathing, and hygiene or for other productive purposes such as livestock rearing, aquatic production, or small businesses (Meinzen-Dick, 1997). Sometimes the multiple uses of irrigation water emerge in an unplanned way, but other times multiple-use considerations are incorporated into the design of irrigation systems in order to fulfill users' needs and avoid damage to the system or conflicting situations (Renault et al., 2013; van Koppen et al., 2009).

Due to the multiple uses of irrigation water, irrigation programs can sometimes lead to improved WASH (water, sanitation, and hygiene) in communities suffering from lack of access to adequate water supply and sanitation. An example of this is found in the Bwanje Valley Irrigation Scheme in Malawi. As part of the irrigation program, 13 boreholes for domestic use were constructed in the intervention communities (Nkhata, 2014).

As pointed out in the previous section, the nutritional status of children depends not only on food consumption and dietary adequacy but on other factors such as water supply and sanitation and incidence of disease (Benefice and Simondon, 1993; Von Braun et al., 1989). The main pathways from poor WASH to child undernutrition are diarrhea, nematode infections, and environmental enteropathy (Dangour et al., 2013). In this sense, the results of a meta-analysis conducted in a recent Cochrane Review point at a slight but statistically significant effect of WASH interventions on HAZ in children under five years of age (Dangour et al., 2013).

Despite its relevance for nutrition and health, only eight studies included in the review documented to some extent the WASH situation of the households using irrigated agriculture, and among those that did so, most collected little information on the topic. Only one of the studies systematically assessed the effect of irrigation on the WASH and health condition of the intervention households (Van der Hoek et al., 2002). The authors concluded that greater water availability for domestic purposes as a result of irrigation adoption was associated with a lower prevalence of diarrhea and stunting among Pakistani children.

3.6. Irrigation and other health-related considerations

Although irrigation interventions can have many positive effects on health, some potential negative effects also need to be examined. Irrigation schemes may alter vector-breeding habitats and, as a result, the risk of vector-borne diseases such as malaria, dengue, and schistosomiasis may change as well. Among the studies selected for review, only Ersado (2005) measured the effect of irrigation on the prevalence of water-borne diseases. Ersado analyzed the impact of microdam construction on malaria and schistosomiasis incidence in Tigray (Ethiopia). Malaria incidence was significantly higher in intervention villages—32% among households in microdam villages, compared to 19% in control villages. Remarkably, and in spite of the higher incidence of water-borne diseases and associated higher health expenditures and time lost being sick in intervention areas, the authors concluded that the marginal benefit of the investment in irrigation offset the costs.

Several other studies analyze the effect of irrigation systems on vector-borne diseases (see literature reviews from Ijumba and Lindsay, 2001; Keiser et al., 2005), and the results depict a complex picture. The effect of irrigation on the incidence of vector-borne diseases depends on multiple factors, such as the epidemiologic setting, the ecology of the area, and the socioeconomic status of the population (Keiser et al., 2005; Wielgosz et al., 2012). Keiser et al. (2005) analyzed the results of 11 studies conducted in irrigation areas of stable malaria transmission in Africa. None of the studies found evidence of increased prevalence of malaria in irrigated villages as compared with nonirrigated villages. A lower incidence of malaria was even reported in some of the studies; this lower incidence was attributed to improved socioeconomic status, effective vector-control programs, and changes in health-related behavior. Another explanation for the lower incidence of malaria in certain contexts was found in the use of insecticide-treated nets and the differing presence of cattle in irrigated villages. Unprotected cattle seemed to attract mosquitos diverted by insecticide-treated nets. However, a greater risk of malaria incidence was found in irrigation villages with unstable malaria prevalence, where people have little or no immunity to malaria parasites (Keiser et al., 2005). Similarly, Ijumba and Lindsay (2001) concluded that irrigation systems do not seem to increase malaria risk in Africa, with the exception of areas of unstable transmission.

Negative outcomes of irrigation on health may also result from the increased use of complementary inputs, such as pesticides, fertilizers, and other chemical products, due to the higher input intensity of irrigated agriculture. Pesticides may cause acute poisoning through intentional or accidental exposure and through long-term exposure. The number of studies analyzing the effect of irrigation adoption on pesticide use and associated health impacts remains limited. Only one of the studies included in the review examined these linkages. Clarke et al. (1997) researched the prevalence of symptoms associated with organophosphorus pesticides and carbamates among irrigation workers in Ghana. The study revealed that the three symptoms of headache, blurred vision, and nausea/vomiting were significantly higher (at 5% significance level) among irrigators as compared with a control group of teachers, which suggests that farm laborers and owners of irrigated lands are more likely to be exposed to harmful chemicals (Clarke et al., 1997).

3.7. The gender implications of irrigation

The gender of the person who has control over and access to assets has important implications for health and nutrition outcomes because men and women usually have different preferences about how to allocate resources. For instance, women tend to invest more in household nutrition, education, and health (Meinzen-Dick et al., 2012). In addition, women are usually responsible for food preparation and childcare. Thus, empowering women can make an important contribution to improved food security and child nutrition (Quisumbing et al., 1995; Malapit et al., 2013; Sraboni et al., 2014). However, women often have limited access to land, water, labor, capital, technology, information, and other assets (Molden, 2007; Goh, 2012) and therefore, they are less likely to benefit from irrigation interventions.

The impact of irrigation interventions on women's empowerment will largely depend on whether women are farm decision-makers or simply family laborers (van Koppen, 2002). In other words, if women mobilize inputs themselves and are included in irrigation institutions, they are more likely to benefit from irrigation interventions. Of the 28 studies selected for review, 13 discuss to some extent the gender implications of irrigation and the main roles of women in irrigated agriculture; however, only 4 papers have gender analysis as the main goal.

van den Bold et al. (2013) study the impact of a homestead food production program on the ownership, use, and control of men's and women's assets in Burkina Faso. The program primarily targets women, with the aim of reducing child undernutrition. After the program, men continued to own most of the land, but the number of agricultural assets and small animals owned by women had increased significantly in intervention villages compared to control villages. Women were also the main decisionmakers regarding the crops grown in the home garden and the chickens reared. The revenue generated from the sales of these products was also controlled by women and, therefore, greater availability and intake of food within the household and improved child nutrition were expected.

In Ethiopia, male-headed households were 38% more likely to participate in irrigation activities than female-headed households, because the latter had lower income and faced a shortage of labor and market information. Consequently, women frequently ended up renting or sharing out their land (Aseyehegn et al., 2012). Securing women's land rights can favor adoption of irrigation technologies by women, as shown in van Koppen et al. (2012). Land ownership was an important determinant of irrigation adoption among female-headed households in Zambia and Ghana (van Koppen et al., 2012).

Lower access to cash and information about irrigation technologies was another important constraint for women's participation in irrigation in Kenya and Tanzania. Women were found to purchase less than 10% of the KickStart pumps in Kenya and Tanzania (Njuki et al. 2014). The same study showed that in some areas the use of manual pumps, in particular pedaling the pump, is considered culturally inappropriate for women. Some women also reported that manual pumps were hard to operate. Finally, the study analyzed women's decisionmaking power over crop choices and control over income from irrigated crops. Decisions related to high-income crops were usually made by men, while women had more autonomy on crops for home consumption, such as leafy vegetables. Men preferred planting cash crops (for example, tomatoes) because these can be sold in bulk for cash, while women preferred planting leafy vegetables such as kale, spinach, and amaranth because these crops can be used for home consumption and can also be sold regularly in small quantities near the homestead. Women usually had control over income from the sale of these crops.

Burney et al. (2010) shows how empowering women through irrigation can be an important pathway for improving household nutrition. The authors evaluated the contribution to food security of an irrigation project targeting women's agricultural groups. Women participating in the project kept 18% (8.8 kg per month) of the food grown and sold the rest in the local market. Their standard of living increased as compared to nonirrigator women—their consumption of vegetables reached the U.S. Department of Agriculture's recommended daily allowance, and additional income was used to purchase staples and protein for household consumption during the dry season.

Irrigation interventions can also change farmers' time use with positive as well as negative trade-offs for women, which will largely depend on the local context. Upadhyay et al. (2005) found that women using microirrigation technologies in Nepal spent significantly more time producing vegetables than their male counterparts, who only contributed 12% of the time. An increase in women's agricultural workload may have a negative impact on the amount of time women can devote to caregiving activities, and in that case irrigation can presumably have a negative effect on child nutrition and health (Von Braun et al., 1989; Steiner-Asiedu et al., 2012). In contrast, irrigation can also reduce the time women spend fetching water for domestic and livestock uses and therefore allow more time for other activities such as income-generating, caregiving, or social activities (Upadhyay et al., 2005; Njuki et al., 2014).

4. Designing nutrition-sensitive irrigation interventions: the way forward

In most of the papers reviewed, irrigation seemed to contribute to improved food security, but the positive impact of irrigation interventions on nutrition outcomes was seldom established, most likely because insufficient attention was given to nutrition goals during the design of the irrigation interventions. Poverty reduction and productivity gains are usually the most important drivers of irrigation programs, but with the exception of homestead production programs, most of the irrigation programs evaluated in the papers reviewed did not have nutrition improvement as an explicit goal. Incorporating nutritional, health, and gender considerations into the design of new irrigation programs and policies would be an important step toward realizing the full potential of irrigation interventions.

Beneficiaries of irrigation programs often receive training on how to operate and maintain irrigation systems, but nutrition aspects are rarely considered. Adding food and nutrition education components to these training programs, such as recommendations on which crops to plant to improve child nutrition and how to better preserve and cook irrigated crops, would help reinforce the pathway from improved agricultural productivity to better nutrition and health.

More guidance and support to minimize the increased risk of infection with water-borne diseases such as malaria and schistosomiasis would also pay off in terms of health gains. Awareness campaigns to promote safe practices near irrigation areas, such as the use of insecticide-treated bed nets, would help minimize the risk of malaria infection. In addition, healthcare centers in communities near irrigation schemes, in particular in areas with unstable malaria transmission, should be adequately equipped to deal with the potential increase in water-borne diseases (Ijumba and Lindsay, 2001).

Specific policies that promote multiple uses of irrigation water can also be instrumental in improving nutrition and health outcomes. Recent evidence points to a lack of water supply and sanitation and associated environmental enteropathy as underestimated factors influencing the nutritional and health status of children. Therefore, adding a water supply component to the design of irrigation interventions can be beneficial for child nutrition and health. Irrigation water is also sometimes used as drinking water for livestock and for aquatic production or for irrigated fodder production. Linking irrigation projects to livestock and/or fish production can also have important nutritional benefits, as consumption of animal-source foods has been shown to significantly improve child nutritional status (Hoddinott et al., 2014; Rawlins et al., 2014). In brief, the positive effects of irrigation interventions on nutrition and health outcomes could be multiplied with better integration of different sectors of activity such as agriculture, water supply and sanitation, health, and education.

Finally, it is also critical to integrate gender considerations into policy design in order to favor women's involvement in irrigated agriculture. Instead of designing "gender blind" irrigation programs (like many of the programs reviewed in this paper), program designers should incorporate specific provisions to target and empower women. Men generally have better access to irrigation technologies and own most irrigation assets (Njuki et al., 2014). As a result, the income generated from irrigated agriculture is usually controlled by men and spent according to their preferences. Women tend to invest more in household nutrition and health and, therefore, improving women's access to and ownership of irrigation technologies and control over irrigated produce can have a positive effect on nutrition and health outcomes. Securing women's land rights and improving women's access to credit and information are also critical steps in promoting women's access to irrigation pumps and other irrigation technologies. Lastly, it is also important to design irrigation components such as manual pumps according to women's needs and local cultural norms.

5. Conclusion

Irrigation interventions can improve nutritional outcomes through multiple pathways, including increased productivity and availability of food supplies and improved diets (in quantity and quality). The current post-2015 development agenda calls for action from both developing and developed countries to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture (SDG2) as well as promote sustainable water management (SDG6). Linking these two Sustainable Development Goals (SDGs) may provide multiple benefits in favor of improved nutrition, particularly in chronically food-insecure countries in Sub-Saharan Africa.

However, the pathways linking nutritional and health gains with irrigation remain understudied. Most of the studies included in the review showed a positive effect of irrigation interventions on food security. However, results regarding the relationship between irrigation, nutrition, health, and gender outcomes were inconclusive, which is partially attributed to the fact that few studies include comprehensive measures of these outcomes. For example, few studies present data on dietary diversity, anthropometrics, morbidity, and clinical indicators.

Many of the studies included in the review contained some methodological flaws worthy of note. In some cases, small samples did not allow for firm conclusions to be drawn. Self-selection bias and lack of comparable controls were also limitations in several studies. However, avoiding self-selection in irrigation evaluations remains difficult because randomization of the beneficiary households is often not feasible in irrigation interventions. Some studies tried to solve the problem with the use propensity score matching methods. Finally, most studies did not collect panel data and therefore were unable to control for unobservable effects. All in all, we conclude that more rigorous evaluations of the impact of irrigation interventions on nutrition outcomes are needed. Developing such evidence will be important for the successful implementation of new irrigation projects, especially in Sub-Saharan Africa, where the potential to expand irrigation is large and where recent projections indicate that childhood undernutrition levels will continue to grow over the next two decades.

Six main aspects should be considered when designing more nutrition-sensitive irrigation interventions: (1) food security and nutrition gains should be stated goals of irrigation programs; (2) training programs and awareness campaigns should accompany irrigation interventions to promote nutrient-dense food production and consumption as well as minimization of health risks; (3) multiple uses of irrigation water should be recognized in order to improve access to water supply and sanitation and livestock and aquatic production; (4) women's empowerment and women's participation in irrigation programs should be promoted; (5) homestead food production should be encouraged; and (6) policy synergies between different sectors (agriculture, nutrition, health, water supply and sanitation, education) should be sought.

Acknowledgments

The author would like to thank Claudia Ringler and Simone Passarelli for their valuable comments on an earlier version of this paper. This paper has been written under the project "Feed the Future Innovation Lab for Small-Scale Irrigation" funded by the United States Agency for International Development and contributes to the CGIAR Research Program on Water, Land, and Ecosystems. Laia Domènech has received funding from the Generalitat de Catalunya (Beatriu de Pinòs, 2011 BP_A 00329).

References

Adeoti, A., Barry, B., Namara, R., Kamara, A., Titiati, A., 2007. Treadle Pump Irrigation and Poverty in Ghana, IWMI Research Report. International Water Management Institute, Colombo, Sri Lanka, p. 117.
Aseyehegn, K., Yirga, C., Rajan, S., 2012. Effect of small-scale irrigation on the income of rural farm households: the case of Laelay Maichew District, Central Tigray, Ethiopia. J. Agricu. Sci. 7 (1), 43–57.
Bagson, E., Wuleka Kuuder, C.J., 2013. Assessment of a smallscale irrigation scheme on household food security and leisure in Kokoligu; Ghana. Res. Humanit. Soc. Sci. 3 (1), 17–27.
Benefice, E., Simondon, K., 1993. Agricultural development and nutrition among rural populations: a case study of the middle valley in Senegal. Ecol. Food Nutr. 31, 45–66.
Berti, P.R., Krasevec, J., FitzGerald, S., 2003. A review of the effectiveness of agriculture interventions in improving nutrition outcomes. Public Health Nutr. 7 (5), 599–609.
Burney, J., Naylor, R., 2012. Smallholder Irrigation as a Poverty Alleviation Tool in Sub-Saharan Africa. World Dev. 40 (1), 110–123.
Burney, J., Naylor, R.L., Poste, S.L., 2013. The case for distributed irrigation as a development priority in Sub-Saharan Africa. Proc. Natl. Acad. Sci. 110 (31), 12513–12517.
Burney, J., Woltering, L., Burke, M., Naylor, R., Pasternak, D., 2010. Solar-powered drip irrigation enhances food security in the Sudano–Sahel. Proc. Natl. Acad. Sci. 107 (5), 1848–1853.
Chazovachii, B., 2012. The impact of small scale irrigation schemes on rural livelihoods: the case of Panganai irrigation scheme Bikita District Zimbabwe. J. Sustain. Dev. Afr. 14 (4), 217–231.
Clarke, E.E.K., Levy, L.S., Spurgeon, A., Calvert, I.A., 1997. The problems associated with pesticide use by irrigation workers in Ghana. Occup. Med. 47 (5), 301–308.
Dangour, A.D., Watson, L., Cumming, O., Boisson, S., Che, Y., Velleman, Y., Cavill, C., Allen, E., Uauy, R., 2013. Interventions to improve water quality and supply, sanitation and hygiene practices, and their effects on the nutritional status of children. Cochrane Database Syst. Rev. 8, CD009382.
Dewey, K.G., Adu-Afarwuah, S., 2008. Systematic review of the efficacy and effectiveness of complementary feeding interventions in developing countries. Matern. Child Nutr. 8, 24–85.
Dillon, A., 2008. Access to Irrigation and the Escape from Poverty: Evidence from Northern Mali. IFPRI Discussion Paper 00782. International Food Policy Research Institute, Washington, DC.
Ersado, L., 2005. Small-Scale Irrigation Dams, Agricultural Production, and Health: Theory and Evidence from Ethiopia. World Bank Policy Research Working Paper 3494. World Bank, Washington, DC.
FAO (Food and Agriculture Organization of the United Nations), 2000. Socio-economic Impact of Smallholder Irrigation Development in Zimbabwe: Case Studies of Ten Irrigation Schemes. FAO Subregional Office for East and Southern Africa, Harare, Zimbabwe.
Faurès, J.M., Santini, G. (Eds.), 2008. Water and the Rural Poor: Interventions for Improving Livelihoods in Sub-Saharan Africa. Food and Agriculture Organization of the United Nations, Land and Water Division, Rome.
Fraiture, C., Giordano, M., 2014. Small private irrigation: a thriving but overlooked sector. Agric. Water Manag. 131, 167–174.
Frenken, K. (Ed.), 2005. Irrigation in Africa in Figures. AQUASTAT Survey – 2005. Food and Agricultural Organization of the United Nations, Rome.
Girard, A.W., Self, J., McAuliffe, C., Olude, O., 2012. The effects of household food

production strategies on the health and nutrition outcomes of women and young children: a systematic review. Paediatr. Perinat. Epidemiol. 26 (Suppl. 1), S205–S222.
Goh, A.H.X., 2012. A Literature Review of the Gender-Differentiated Impacts of Climate Change on Women's and Men's Assets and Well-Being in Developing Countries. Collective Action and Property Rights Working Paper 106. International Food Policy Research Institute, Washington, DChttp://dx.doi.org/10.2499/CAPRiWP106.
Hoddinott, J., Headey, D., Dereje, M., 2014. Cows, Missing Milk Markets and Nutrition in Rural Ethiopia. Ethiopia Strategy Support Program 34. International Food Policy Research Institute and Ethiopian Development Research Institute, Washington, DC.
Hoddinott, J., Yohannes, Y., 2002. Dietary Diversity as a Food Security Indicator. Food Consumption and Nutrition Division Discussion Paper. International Food Policy Research Institute, Washington, DC.
Hossain, M., Naher, F., Shahabuddin, Q., 2005. Food security and nutrition in Bangladesh: progress and determinants. Electron. J. Agric. Dev. Econ. 2 (2), 103–132.
Humphrey, J.H., 2009. Child undernutrition, tropical enteropathy, toilets, and handwashing. Lancet 374, 1032–1035.
Iannotti, L., Cunningham, K., Ruel, M., 2009. Improving Diet Quality and Micronutrient Nutrition: Homestead Food Production in Bangladesh. IFPRI Discussion Paper 00928. International Food Policy Research Institute, Washington, DC.
Ijumba, J.N., Lindsay, S.W., 2001. Impact of irrigation on malaria in Africa: paddies paradox. Med. Vet. Entomol. 15, 1–11.
Kabunga, N., Ghosh, S., Griffiths, J.K., 2014. Can Smallholder Fruit and Vegetable Production Systems Improve Household Food Security and Nutritional Status of Women? Evidence from Rural Uganda. IFPRI Discussion Paper 01346. International Food Policy Research Institute, Washington, DC.
Keiser, J., Caldas de Castro, M., Maltese, M.F., Bos, R., Tanner, M., Singer, B.H., Utzinger, J., 2005. Effect of irrigation and large dams on the burden of malaria on a global and regional scale. Am. J. Trop. Med. Hyg. 72 (4), 392–406.
Kirogo, V., Kogi-Makau, W., Muroki, N.M., 2007. The role of irrigation on improvement of nutritional status of young children in Central Kenya. Afr. J. Food Agric. Nutr. Dev. 7 (2), 1–16.
Lipton, M., Litchfield, J., Faurès, J.M., 2003. The effects of irrigation on poverty: a framework for analysis. Water Policy 5, 413–427.
Malapit, H.J.L., Kadiyala, S., Quisumbing, A.R., Cunningham, K., Tyagi, P., 2013. Women's Empowerment in Agriculture, Production Diversity, and Nutrition: Evidence from Nepal. IFPRI Discussion Paper 01313. International Food Policy Research Institute, Washington, DC.
Mangisoni, B., 2008. Impact of treadle pump irrigation technology on smallholder poverty and food security in Malawi: a case study of Blantyre and Mchinji Districts. Int. J. Agric. Sustain. 6 (4), 248–266.
Masset, E., Haddad, L., Cornelius, A., Isaza-Castro, J., 2012. Effectiveness of agricultural interventions that aim to improve nutritional status of children: systematic review. BMJ 344, d8222.
Meinzen-Dick, R., 1997. Valuing the multiple uses of water. In: Kay, M., Franks, T., Smith, L. (Eds.), Water: Economics, Management and Demand. E. & F. N. Spon, London, pp. 50–58.
Meinzen-Dick, R., Behrman, J., Menon, P., Quisumbing, A., 2012. Gender: A Key Dimension Linking Agricultural Programs to Improved Nutrition and Health. In: Fan, S., Pandya-Lorch, R. (Eds.), Reshaping Agriculture for Nutrition and Health. 2020 Conference Book. International Food Policy Research Institute, Washington, DC, pp. 135–144.
Molden, D. (Ed.), 2007. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. Earthscan and International Water Management Institute, London and Colombo, Sri Lanka.
Murphy, S.P., Allen, L.H., 2003. Nutritional importance of animal source foods. J. Nutr. 133 (11), 3932S–3935S.
Namara, R.E., Awuni, J.A., Barry, B., Giordano, M., Hope, L., Owusu, E.S., Forkuor, G., 2011. Smallholder Shallow Groundwater Irrigation Development in the Upper East Region of Ghana. Research Report 134. International Water Management Institute, Colombo, Sri Lanka.
Namara, R.E., Upadhyay, B., Nagar, R.K., 2005. Adoption and Impacts of Microirrigation Technologies: Empirical Results from Selected Localities of Maharashtra and Gujarat States of India. Research Report 93. International Water Management Institute, Colombo, Sri Lanka.
Njuki, J., Waithanji, E., Sakwa, B., Kariuki, J., Mukewa, E., Ngige, J., 2014. Can Market-Based Approaches to Technology Development and Dissemination Benefit Women Smallholder Farmers? A Qualitative Assessment of Gender Dynamics in the Ownership, Purchase, and Use of Irrigation Pumps in Kenya and Tanzania. IFPRI Discussion Paper 01357. International Food Policy Research Institute, Washington, DC.
Nkhata, R., 2014. Does Irrigation Have an Impact on Food Security and Poverty? Evidence from Bwanje Valley Irrigation Scheme in Malawi. Malawi Strategy Support Program. Working Paper 04. International Food Policy Research Institute, Washington, DC.
Nkonya, E., Iannotti, L., Sakwa, B., Wielgosz, B., Gandhi, V., Kato, E., Peterman, A., Jin, M., 2011. Baseline Study of KickStart Treadle Pumps in East Africa. International Food Policy Research Institute, Washington, DC (Unpublished).
Olney, D.K., Talukder, A., Iannotti, L.L., Ruel, M.T., Quinn, V., 2009. Assessing the impact and impact pathways of a homestead food production program on household and child nutrition in Cambodia. Food and Nutr. Bull. 30 (4), 355–369.
Olney, D.K.A., Pedehombga, A., Ruel, M.R., Dillon, A., 2015. A 2-year integrated agriculture and nutrition and health behavior change communication program targeted to women in burkina faso reduces anemia, wasting, and diarrhea in children 3–12.9 months of age at baseline: A cluster-randomized controlled trial. J. Nutr. 145 (6), 1317–1324.
Peter, G., 2011. The impact of small scale irrigation schemes on household food security in Swaziland. J. Sustain. Dev. Afr. 13 (6), 102–117.
Quisumbing, A.R., Brown, L.R., Feldstein, H.S., Haddad, L., Pena, C., 1995. Women: The Key to Food Security. Food Policy Report. International Food Policy Research Institute, Washington, DC.
Rawlins, R., Pimkina, S., Barrett, C.B., Pedersen, S., Wydick, B., 2014. Got milk? The Impact of Heifer International's Livestock Donation Programs in Rwanda on nutritional outcomes. Food Policy 44, 202–213.
Renault, D., Wahaj, R., Smits, S., 2013. Multiple Uses of Water Services in Large Irrigation Systems. Auditing and Planning Modernization: The MASSMUS Approach. Food and Agriculture Organization of the United Nations, Rome.
Ruel, M.T., Alderman, H., 2013. Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? Lancet 382 (9891), 536–551.
Sinyolo, S., Mudhara, M., Wale, E., 2014. The impact of smallholder irrigation on household welfare: the case of Tugela Ferry irrigation scheme in KwaZulu-Natal, South Africa. Water SA 40 (1), 145–156.
Sraboni, E., Malapit, H.J., Quisumbing, A.R., Ahmed, A.U., 2014. Women's empowerment in agriculture: what role for food security in Bangladesh? World Dev. 61, 11–52.
Srinivasan, J.T., Reddy, V.R., 2009. Impact of irrigation water quality on human health: a case study in India. Ecol. Econ. 68, 2800–2807.
Steiner-Asiedu, M., Abu, B.A.Z., Setorglo, J., Asiedu, D.K., Anderson, A.K., 2012. The impact of irrigation on the nutritional status of children in the Sissala West District of Ghana. Curr. Res. J. Soc. Sci. 4 (2), 86–92.
UNICEF, W.H.O. (World Health Organization), World Bank. 2012. UNICEF–WHO–World Bank Joint Child Malnutrition Estimates. UNICEF, WHO, and World Bank, New York, Geneva, and Washington, DC.
Upadhyay, B., Samad, M., Giordano, M., 2005. Livelihoods and Gender Roles in Drip-Irrigation Technology: A Case of Nepal. Working Paper 87. International Water Management Institute, Colombo, Sri Lanka.
van den Bold, M., Pedehombga, A., Ouedraogo, M., Quisumbing, A.R., Olney, D. 2013. Can Integrated Agriculture-Nutrition Programs Change Gender Norms on Land and Asset Ownership? Evidence from Burkina Faso. IFPRI Discussion Paper 01315. International Food Policy Research Institute, Washington, DC.
van der Hoek, W., Feenstra, S.G., Konradsen, F., 2002. Availability of irrigation water for domestic use: impact on prevalence of diarrhea and nutritional status of children. J. Health Popul. Nutr. 20 (1), 77–84.
van Koppen, B., 2002. A Gender Performance Indicator for Irrigation: Concepts, Tools, and Applications. Research Report 59. International Water Management Institute, Colombo, Sri Lanka.
van Koppen, B., Hope, L., Colenbrander, W., 2012. Gender Aspects of Small-Scale Private Irrigation in Africa. IWMI Working Paper 153. International Water Management Institute, Colombo, Sri Lanka.
van Koppen, B., Smits, S., Moriarty, P., Penning de Vries, F., Mikhail, M., Boelee, E., 2009. Climbing the Water Ladder: Multiple-Use Water Services for Poverty Reduction. TP Series 52. IRC International Water and Sanitation Centre and International Water Management Institute, The Hague, the Netherlands.
Von Braun, J., Puetz, D., Webb, P., 1989. Irrigation Technology and the Commercialization of Rice in the Gambia: Effects on Income and Nutrition. IFPRI Research Report 75. International Food Policy Research Institute, Washington, DC.
Webb, P., 2013. Impact Pathways from Agricultural Research to Improved Nutrition and Health: Literature Analysis and Research Priorities. Food and Agricultural Organization of the United Nations and World Health Organization, Rome.
Wielgosz, B., Mangheni, M., Tsegai, D., Ringler, C., 2012. Malaria and Agriculture: A Global Review of the Literature with a Focus on the Application of Integrated Pest and Vector Management in East Africa and Uganda. IFPRI Discussion Paper 1232. International Food Policy Research Institute, Washington, DC.
World Bank, 2007. From Agriculture to Nutrition: Pathways, Synergies and Outcomes. World Bank, Agriculture and Rural Development Department, Washington, DC.
Xie, H., You, L., Wielgosz, B., Ringler, C., 2014. Estimating the potential for expanding smallholder irrigation in Sub-Saharan Africa. Agric. Water Manag. 131, 183–193.
You, L., Ringler, C., Wood-Sichra, U., Robertson, R., Wood, S., Zhu, T., Nelson, G., Guo, Z., Sun, Y., 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. Food Policy 36 (6), 770–777.