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Impact Pathways from Agricultural Research to Improved Nutrition and Health: Literature Analysis and Research Priorities

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Introduction[2]
Investment in agriculture is widely seen as "a critically important opportunity for reducing malnutrition." (Herforth et al. 2012) There have been repeated calls for the international community to place a higher priority on "unleashing" (IFPRI 2012), "leveraging" (Pell at al. 2011), "reshaping" (Fan and Pandya-Lorch 2012), or "realizing" (IFAD 2011) the opportunities offered by agriculture to enhance nutrition and health. The donor community has responded, bringing a larger budget share to bear on the agriculture sector since the mid-2000s, reversing the steep decline of the previous decade (OECD 2012). One of the stated aims of the renewed focus on agriculture is to encourage agricultural policies and programs to become "nutrition-sensitive" (BMGF 2012; USAID 2011), or more specifically, to make "agriculture work for nutrition" (FAO 2012).

The question is, how? Against a backdrop of demands for greater accountability, many donors and national governments are calling for evidence-based programming (Mallet et al. 2012). This has fueled a search for rigorous empirical information that can inform policymakers on what kinds of agriculture to invest in (through research or programming) that will have positive benefits for nutrition and health, particularly among mothers and children. So far, that search has come up short. According to Thompson and Amoroso (2010), there is still "insufficient understanding of the evidence base on how best to achieve this potential." Indeed, an assessment of 23 studies of agriculture interventions, commissioned by DFID found "no evidence of impact on prevalence rates of stunting, wasting and underweight among children under five." (Masset et al. 2011) Thus, knowledge about agriculture's impact on nutrition can be summarized in the words of Hawkes et al. (2012): "Despite the clear potential for agricultural change to improve nutrition in low and middle income countries, the evidence base for this relationship is poor. Recent systematic reviews of studies which have evaluated agricultural interventions for improving nutrition reveal little strong evidence of impact, and a need for more and better designed research."

This paper contributes to ongoing work at many institutions aimed at identifying priority knowledge gaps, determining the best research approaches needed to fill those gaps, and exploring how to better support policy and programme implementation with sound empirical evidence of 'what works'. The paper has four parts. First, a discussion of approaches used in conceptualizing causal pathways from agriculture to nutrition and health. Second, an overview of research-based evidence on agriculture impacts on nutrition and health. Third, a discussion of knowledge gaps and associated priority research questions. Finally, conclusions on proposed priority research questions.

Conceptualizing Causal Pathways from Agriculture to Nutrition
A recent World Bank paper proposed that while enhanced agricultural productivity is an important development goal in its own right, "merely producing more food does not ensure food security or improved nutrition." (Herforth et al. 2012) FAO (2012) also acknowledges that "agriculture interventions do not always contribute to positive nutritional outcomes." Recognition that growing more food is necessary but usually not sufficient to achieve good nutrition and health leads directly to hypothesis-building around what else might be required.
Most of the recent reviewers of the evidence of impacts of agriculture on nutrition have organized literature searches and analyses around theorized causal pathways that build on the understanding that 'food alone is not enough'. The genesis of such thinking was the UNICEF framework that conceptualizes immediate versus distal determinants of nutrition (Appendix 1). That framework

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places ‘inadequate dietary intake’ and ‘disease’ as two immediate drivers of undernutrition, although the ways in which diet and disease interact is left at a high level of abstraction. The same is true of FAO’s framework, which identifies food consumption and utilization as direct contributors to nutrition outcomes (Appendix 2). Both the FAO and UNICEF frameworks suggest that focusing on dietary adequacy in the context of improved health is needed to achieve enhanced nutrition.

However, understanding of what ‘adequate’ means has changed over time. For example, attention of researchers during the 1990s was largely directed towards enhancing the productivity of crops grown by smallholders who were assumed to benefit nutritionally from consuming more of those same crops. One reported success of the mid-1990s was that, “higher calorie intake has improved nutrition and health.” (CGIAR 1996) By the late 1990s, much agricultural research had shifted from the assumption that more calories meant better nutrition, toward tackling specific nutrient deficiencies. That was an era when biotechnology was gaining more attention as a potentially important tool “in the struggle to reduce…malnutrition” (CGIAR 1999). Specific crops, such as orange flesh sweet potatoes and quality protein maize (QPM), were targeted as vehicles for delivering defined nutrients (such as betacarotene or protein with an improved amino acid profile) into local food systems. The concept of biofortification also took off, based on premise that higher levels of micronutrients in target crops would meet the needs of people deficient in those nutrients. Orange Sweet Flesh Potato and QPM have both been shown to be efficacious and have had success in roll out in certain geographies (Low et al. 2007; Gunaratna 2010).

However, the establishment of the CGIAR Science Council in the early 2000s ushered in a less nutrient-centric focus. Seeking to understand “how agriculture affects human health [and] nutrition”, the Science Council proposed a research agenda consisting of 20 priorities selected accord to criteria that included “a refocusing on nutrition *outcomes* as opposed to nutrient inputs. The decision to focus on human impacts rather than simply the nutrient-enhancement of selected crops or promotion of ‘nutrient rich foods’ for sale, has allowed for greater discussion of cross-cutting issues crucial to nutrition, including gender and intrahousehold resource control, food safety, disease-nutrient interactions, and even the appropriateness of metrics used to assess agriculture-supported outcomes (ISPC 2012; CGIAR Consortium Office 2012). As a result, recent attempts at framing causal pathways have become increasingly elaborate as they attempt to identify intermediate outcomes (steps in the process) on which research activities should focus.

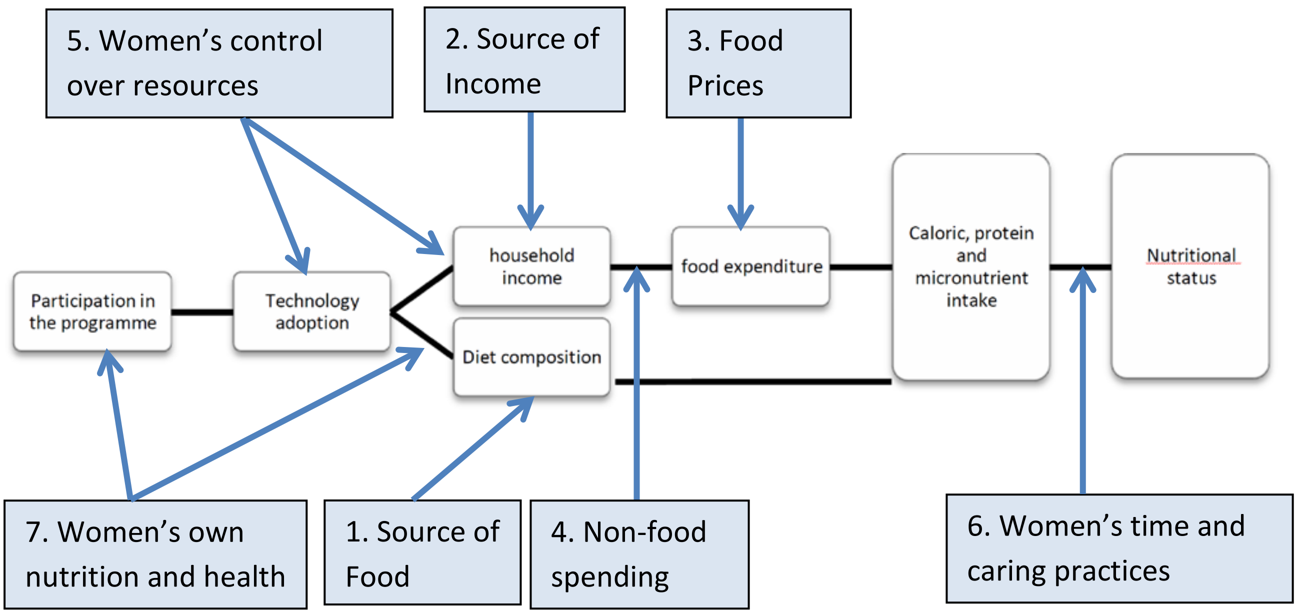
For example, the framework proposed by Gillespie et al. (2012) combines the UNICEF and FAO concepts, but it opens the door to more explicit attention to the arrows between boxes and not just to elements within boxes (Appendix 3). That is, the dotted lines in that diagram identify key issues which should not be ignored if agricultural research is to be successful, including drivers of taste in dietary choices, seasonality, women’s health (not just the child’s) and the role of sanitation. Similarly, the frameworks developed by Hawkes et al. (2012) and Chung (2012) elaborate on some elements not frequently highlighted, such a biomarkers of nutritional status (micronutrient deficiency) versus anthropometry, nutrient quality (bioavailability), value chain parameters, and the creation of demand for health services through knowledge and education (Appendices 4 and 5).

A common factor across all such frameworks is the understanding that agriculture can influence nutrition and health through multiple pathways (direct and indirect), and that only one of those relates to the consumption of more food. For example, Headey et al. (2011), Gillespie et al. (2012) and USAID (2013) talk of seven pathways, which include agriculture as the direct and indirect (via income) source of food at household level, macro-level agricultural policy as a driver of prices, and agriculture as an entry-point for enhancing women’s control over resources, knowledge and status. More recently, Ruel et al. (2013) also refers to those same pathways, while emphasizing that the number of paths is not fixed, evidence of effects along the posited pathways is stronger for some than for others (meaning that much is still theorized rather than empirically based), and that there are additional ways by which agriculture can support nutrition through more distal mechanisms (supporting livelihoods, serving as programming platforms for other sectors, buffering consumption shocks, maintaining biodiversity, etc.) that are not fully accommodated by the '7 pathway' model.

That said, chains of causal inference have been woven into most analytical frameworks guiding the search for evidence on agriculture-nutrition interactions. For example, Masset et al. 2011 lay out a chain of connections from household participation in agriculture through direct and indirect impacts on food and income to nutritional status. Figure 1 presents their horizontal framework and identifies where the 'seven major pathways' apply to that framework.[3] Masset et al. 2011 used this framework to review the literature in their search for evidence of causal associations and/or plausible mechanisms for correlations along the chain. One of their conclusions was that "only few causal links have been successfully explored."

Hawkes et al. 2012 also used a framework, albeit a less linear one (Appendix 4). Those authors note that problems occur "when the links in a 'chain of evidence' or 'research chain' linking an intervention and a nutritional outcome is not complete" (Hawkes et al. 2012). Importantly, a lack of 'linkage research' aimed at uncovering mechanisms linking elements of a chain is arguably the defining feature of *all* work in this domain so far. Each of the reviews of evidence of linkages of the past decade has concluded that too many studies rely on "simplistic associations" and too few "include all the necessary aspects of the research chain." (Hawkes et al. 2012)

Figure 1: Logical framework for assessing impact of agricultural interventions on nutrition (as proposed by Masset et al. 2011) with 7 key pathways added.



An example of this is provided by Evidence Matters (2012), which uses biofortification of staple crops as an illustration of this point (Figure 2). On the one hand, evidence on bioavailability of specific nutrients in target crops is relatively good (the fourth box along the chain depicted in Figure 2), and evidence of consumer uptake is also good (particularly where it concerns vitamin A in

[3] The white boxes and dark lines are the original logical framework. The tinted boxes and pale lines represent each of the 7 major impact pathways and where they link to the framework.

orange sweet flesh potato). However, evidence of nutritional *impacts* of consuming such products by nutritionally vulnerable or nutrient-deficient consumers is identified as "very poor". Similarly, evidence that farmers are likely to adopt this new form of technology, thereby enabling large-scale distribution of nutrient-enriched cultivars in places where specific deficiencies are known, is also "very poor". In other words, connecting the links in this one pathway represents a priority for future research. Understanding efficacy (beyond nutrient bioavailability of one or two crops) remains very important, as does understanding likely cost and effectiveness at field level. Only then can a full pathway be empirically documented, and its cost-benefit be compared with alternative or complementary actions. The immediate problem is that many of the links across most of the seven major pathways remain poorly understood.

Figure 2: Standards of evidence for links in the chain from biofortification to nutrition.

Source: Evidence Matters 2012.

The Current State of Empirical Evidence

The recent surge of interest on how to leverage agriculture to maximize impacts on nutrition and health has fueled a search for empirical findings of 'what works'. There have been 10 significant evidence reviews since 2001 that incorporate published and unpublished literature going back to the 1980s. Most reviews set out to answer 'do agricultural interventions improve nutrition?' The range of interventions included is wide. Some focus on micronutrient outcomes (Ruel 2001), some on animal sources of food (LeRoy and Frongillo 2007; Kawarasuka 2010), some on diet diversification strategies (Haider and Bhutta 2008; Arimond et al. 2011), while others looked more generally at a range of productivity-enhancing interventions (Berti et al. 2004; Masset et al. 2004).

Table 1 offers summary characteristics of the 10 main reviews included here, along with extracted quotes relevant to their conclusions. There were, of course, many differences across the reviews in terms of units of observation (households, mothers, all women, children under five years of age or under two, etc.), the metrics of impact (increased production of nutrient-dense foods, diet diversity, anthropometry, clinical assessment of micronutrient deficiencies), and the threshold of evidence adopted (formal systematic reviews versus less rigorous reviews of case studies). However, whatever approach used, criteria adopted, types of activity considered, and analytical techniques used, these reviews came up with very similar conclusions:

i) Empirical evidence of positive net impacts on nutrition outcomes is scarce.
ii) Where positive impacts have been documented, mechanisms are poorly articulated.
iii) Positive impacts are more likely where integration of multiple sectors of activity was strong, yet understanding of the contribution of different elements remains weak.
iv) Impacts can be achieved via multiple pathways, but analysis of the roles of different pathways is still lacking.

v) Women's combined roles in agriculture, dietary choices and healthcare matter a great deal to child nutritional status, but few agricultural interventions target all three domains.
vi) The nutrition impacts of price/trade policies as mediated by agriculture and food choices at household level have been assumed rather than fully explored and measured.
vii) The lack of empirical evidence of agricultural impacts on nutrition outcomes may say more about poor study design and methods used than it does about the interventions considered. That is, a lack of evidence to date does not negate the possibility that evidence of positive impacts may still be found.

Many thousands of papers were reviewed to come up with these conclusions. But it is important to note that few were of sufficient quality to be retained for in-depth analysis. The gap between the large numbers of studies identified as relevant to the topic and those finally retained for analysis is explained entirely by the fact that so few meet even basic thresholds of methodological rigor. The vast majority of published studies lack statistical power (sample size) to identify impacts even if they tried to, few incorporated rigorous counterfactual analysis, many outcome indicators selected were not appropriate for the kind of intervention or pathway considered, and few consider heterogeneity of impact even when those were positive.

For example, Ruel (2001) reviewed 14 food-based interventions implemented in the 1990s that were "designed to increase either the production or intake (or both) of micronutrient-rich foods, with an emphasis on vitamin A and iron." The strategies included promotion of micronutrient-rich foods through home gardening, small animal husbandry, and aquaculture, as well as BCC (behavior change communication). In terms of regional spread, 8 of the studies were from Asia (3 south Asian countries), 5 from sub-Saharan Africa and 1 from Latin America (Peru). There was a concentration of studies, with 5 of the 14 studies derived from Bangladesh or Tanzania which restricting the geographic coverage of results. The author reported that few of the home garden and nutrition education studies actually measured the impact of their activities on intended outcomes. Of those that did, few could demonstrate a statistically significant impact, whether through the direct consumption route (Pathway 1), or through indirect (income-mediated routes – Pathway 2). Some home garden projects did report increased daily *intake* of vitamin C and iron, but did not document improved *status* of the consumers. The conclusion was that "although the question of whether home gardens have a positive impact on [nutrition] has been examined in a number of reviews, including some recent studies, evidence is still scant." (Ruel 2001)

Building on Ruel's work, Berti et al. (2004) broadened the scope of interventions considered (including irrigation and cash cropping schemes, large ruminant husbandry, as well as mixed garden-small ruminant interventions) in a systematic review that including papers earlier than 1995 (pushing back to the 1980s). The authors only included studies that did measure at least one nutritional outcome. Formal search protocols were applied and a quality (validity) control was conducted based on whether or not counterfactuals were used, sample sizes were appropriate to measuring intended differences in outcomes, and an appropriate choice of outcome variables had been made. Almost half (14 of 30) studies were conducted in Asia, 11 from Africa (of which 7 derived from Kenya or Ethiopia alone), and 5 from Latin America.

Table 1: Key Characteristics of Evidence Reviews of the Impacts of Agriculture on Nutrition (adapted from Webb and Kennedy 2012)

Review paper	**Systematic review?**	**Number of studies screened**	**Studies retained for review**	**Period of studies retained**	**Agriculture activities included**	**Important conclusions**
Ruel (2001)	N	Not specified	14	1995-1999	Home gardens, small ruminants, aqua-culture	➢ "Information now available to judge the effectiveness of food-based strategies…is inadequate." ➢ "Basic information on efficacy is needed."
Berti et al. (2004)	N	36	30	1985-2001	Home gardens, animal husbandry, irrigation, cash cropping, credit, land distribution	➢ "Mixed results in terms of improving nutrition." ➢ "Home gardening projects usually had a higher success rate than other types of intervention." ➢ "Negative effects were not uncommon."
LeRoy and Frongillo (2007)	Y	Not specified	14	1987-2003	Animal husbandry, aquaculture, poultry, credit, behaviour change (BCC)	➢ "'Measured of impact on nutritional status are rare." ➢ "Only 4 studies evaluated impact on nutritional status and found a positive effect." ➢ "Integrated [activities] generally found positive results."
World Bank (2007)	N	Not specified	52	1985-2007	All forms of agriculture activity	➢ "Agricultural interventions have not always been successful in improving nutritional outcomes."
Haider and Bhutta (2008)	Y	Not specified	29	1985-2004	Home gardens, animal husbandry, BCC	➢ "Dietary diversification strategies have not been proven to affect nutritional status or micronutrient indicators."
Kawarazuka (2010)	Y	Not specified	23	2000-2009	Aquaculture	➢ "Data on the linkage from improved dietary intake to nutritional status were scarce." ➢ "Nutritional outcomes were not clearly demonstrated."
Masset et al. (2011)	Y	7,239	23	1990-2009	Biofortification, home gardens, aquaculture, poultry, husbandry, dairy development.	➢ "Little evidence was available on changes in the diet." ➢ "We found no evidence of impact on prevalence rates of stunting, wasting and underweight among children."
Arimond et al. (2011)	N	>2,000	39	1987-2003	All forms of agriculture activity	➢ "Very few agricultural interventions with nutrition objectives have been successfully scaled up." ➢ "Many of the studies…were weakly designed."
Girard et al. (2012)	Y	3,400	37	1990-	Home gardens, biofortification, BCC, husbandry, poultry, aquaculture	➢ "Of the 37 studies reviewed here, only one was graded as high…when biases, weaknesses were considered. All remaining studies were graded low to very low." ➢ "Estimates for effects on stunting…were not significant."

Berti et al. (2004) found “mixed results” when looking for evidence of improved nutritional status in participating households. Some interventions reported significant improvements, especially those that included a nutrition education component (Pathways 6 and 7). That is, interventions directly affecting multiple pathways seemed to have more chance of impact on nutrition than single sector interventions (more successful programmes sought to impact “four or five types of capital in addition to the agriculture intervention”), and empowering women through knowledge and/or literacy was an important aspect of human capital enhancement. Of the 30 projects reviewed by Berti et al. (2004), 20 measured agriculture outcomes and 17 of these showed some improvement in at least one agriculture indicator.

Of the 17 higher quality studies that measured nutrition outcomes, nine had improving nutrition as an explicit objective –every one of these was a home gardening project, and each one included additional components focused on BCC and/or health service delivery. Those were, as a group, the most successful of the food-based interventions in terms of finding measured outcomes in intervention greater than in control groups. Overall, 5 studies showed improvements in anthropometry, 3 documented gains based on biochemical or clinical indicators of micronutrient status, and 3 reported improvements in terms of reduced child morbidity. However, it is important to note that Berti et al. (2004) commented that “negative effects were not uncommon”, and that while it is widely “assumed that agriculture interventions result in sustainable nutrition benefits, especially if they strengthen financial capital; however, this review does not substantiate this assumption.” A lack of disaggregation of data, lack of statistical power (small sample sizes), and lack of a clear understanding of confounders prevented a positive conclusion.

LeRoy and Frongillo (2007) took a somewhat different direction. Focusing specifically on the role of animal source protein in improving nutrition, they sought studies of interventions that promoted animal production. That systematic review generated 14 studies across a range of husbandry, small ruminant, aquaculture and/or BCC activities (10 of the 14 studies derived from Asia, 8 of which relate just to Bangladesh and India. The other 4 studies were from Africa). Most of the papers reported positive impacts on production (Pathway 1 combined with Pathway 6), but only 4 evaluated nutrition outcomes directly. Those 4 reported improvements in specific nutritional parameters (night blindness, serum retinol and ferritin levels, hemoglobin levels, and linear growth). However, none of them documented statistical significance attributable to the intervention, or made comparison with counterfactuals. The authors concluded, as had Ruel (2001) and Berti et al. (2004), that studies available for review “suffered from important limitations in their design, evaluation and analysis.” This means that while it appears that the interventions considered do increase both production and consumption of animal protein, conclusive evidence of subsequent impacts on nutrition remain elusive.

The World Bank (2007) review was a broader compilation of lessons learned from the literature. It was not systematized review (search methods, exclusion factors and individual study results were not specified, and conclusions drew heavily from the earlier reviews outlined above). However, it did include assessment of 52 studies that paid attention (with varying degrees of rigor) to agricultural impacts on food expenditure, caloric intake and anthropometry. The conclusion offered was that interventions aimed at increasing the production and productivity of staple foods had “limited and mixed” impacts on child nutrition. Similarly, programs focused on promoting animal source foods, many of which had been reviewed by LeRoy and Frongillo (2007), “showed mixed results,” and home garden activities “failed to achieve significant impacts on nutritional outcomes.”

Broadly speaking, that review was supportive of the attempt to achieve greater gains in nutrition through agriculture, but it stopped short of suggesting that the evidence base is sufficiently strong to identify best practice. That position has since been reiterated by Herforth et al. (2012) in another

World Bank paper which argues that "there is an urgent need to strengthen the understanding of how agricultural policies, projects, and investments can be designed and implemented to achieve nutrition goals."

That was the view taken by the Lancet series on maternal and child nutrition of 2008 (Bhutta et al. 2008), which included a review of diet diversification strategies designed to improve nutrition. Of 29 papers included, 20 derived from Asia (including Iran), 8 from Africa and only one Guatemalan study represented Latin America. Although most studies demonstrated benefits to producer households (mainly in terms of increased food production and consumption, especially when combined with a nutrition education component), significant impacts on nutrition were weak (Haider and Bhutta 2008). As a result, the Lancet's review concluded that "although some promising multidisciplinary nutrition interventions have been implemented, dietary diversification strategies have not been proven to affect nutritional status or micronutrient indicators on a large scale." (Bhutta et al. 2008) Such approaches were classified as 'optional' interventions to be used in appropriate settings, but the potential effects to be gained in terms of stunting or severe wasting were not modeled, and there was no attempt made to specify what settings might be more 'appropriate' than others.

The review by Kawarazuka (2010) was similar to that of LeRoy and Frongillo (2007) in that it focused narrowly on one domain within agriculture; namely, aquaculture. That selection was justified because the sub-sector had not featured prominently in previous reviews. The review considered 23 studies (published since 2000) that sought to document the impact of aquaculture activities on dietary intake and the nutritional status of poor households (following the nutrient-centric pathway conceptualization shown in Appendix 7). Eighteen of the 23 papers derived from studies in Asia, with the remaining 5 from Africa. The author found that many different interventions increased fish (and other forms of aquatic protein) consumption as well as household income. However, few studies even measured impact on nutritional status and conclusion was that "there is little evidence of the positive changes in nutritional status among households taking up aquaculture and that the nutritional impacts associated with small-scale fisheries "were not clearly demonstrated." The author reiterated the potential for aquaculture to support enhanced nutrition and called for research-based evidence to convincingly demonstrate efficacy and effectiveness of such interventions.

Masset et al. (2011) took on the largest review of this kind so far. The authors excluded studies that did not use control groups, but they cast a wide net in the search for studies meeting other necessary study design criteria. Indeed, over 7,000 studies were identified through specified inclusion criteria. That said, only 23 of those were retained for full analysis when exclusion criteria were applied. Thirteen of these were Asian studies while 8 more were from Africa. Additionally, there were 2 multi-country assessments: one was a meta-analysis of randomized control trials in 5 countries (2 in Africa, 2 in Latin America and 1 in Asia) which was rated by the authors as having medium validity, and another focused on 4 separate Asian studies of home-gardening activities, but garnering a low to medium validity assessment.

That review found "no evidence of impact on prevalence rates of stunting, wasting and underweight among children." A positive impact on vitamin A intake was noted for just 4 studies of home gardening activities. An additional 5 studies considered impacts on iron intake, but only 1 of those showed a positive impact at the 5% significance level. The authors went out of their way to state that "the absence of reported statistically significant impact of agricultural interventions on children's nutritional status…should not be attributed to the inefficacy of these interventions. Rather, it is the lack of power of the studies reviewed." Indeed, the authors' critique of standards of research on these topics is scathing. They note that not one study reported participation rates or the degree to which a program fully reached its target population (coverage). There was no disaggregation of effects by sub-populations to determine if the most vulnerable to nutritional deficiencies had been included. Anthropometric data were collected in 13 of the 23 studies, but only 8 of those reported prevalence rates of child stunting or wasting. The overall conclusion was that the current state of rigorous empirical evidence does not allow a definitive answer about the impacts on nutrition of even well-designed agricultural interventions.

The assessment undertaken by Arimond et al. (2011) integrated lessons learned from preview literature reviews (four of the co-authors of this assessment were authors of reviews described above). It also considered operational insights gained from more recent interventions. The authors described a set of interventions that show increased production of targeted (nutrient-rich) commodities, enhanced consumption of target foods, and some positive effects on nutrition outcomes for women and children. But they also caution that "impact on diet, nutrient intake and nutritional status…showed mixed results" and that "the evidence base is still limited." Once again, weak study designs limited the strength of findings, thereby compromising conclusions about impact. Suggestive evidence was presented of the potential for well-designed interventions that promote consumption of nutrient-rich foods, animal source protein, and agriculture-derived income controlled by women to support improve nutrition, but the potential for those links in the chain to translate into nutrition outcomes has yet to be convincingly documented.

Finally, Girard et al. (2012) assessed maternal, neonatal and child health outcomes of interventions "aimed at increasing the quantity and/or quality of household food production." A total of 36 published articles were identified, representing 27 unique projects (from Asia and Africa only). Of the total, 32 reported health and nutrition outcomes of children, and 17 reported outcomes on women. The studies were too heterogeneous to conduct a meta-analysis. However, agricultural programmes consistently reported significant improvements in diets and in vitamin A intakes for both women and children (the first part of the chain along Pathways 1 and 2). There was a sense that programmes educating and empowering women (Pathways 5, 6 and 7) have relatively more success than those that do not. Yet, summary estimates for effects on stunting, underweight and wasting "were not significant". Thus, the author concluded that concrete evidence of nutrition impact "is largely grounded in a limited number of highly heterogeneous…studies, most of which have significant methodological limitations."

<u>What to Conclude from the Existing Research?</u>

The reviews of evidence are broadly consistent: the current state of knowledge about nutritional improvements attributable to agriculture-based interventions is weak and mixed. This reflects partial, often imperfect, knowledge of links along the chain from agriculture to nutrition, regardless of pathway. On the one hand, researchers have paid too little attention to study design and methodological rigor and are therefore unable to demonstrate positive impacts even if those have been achieved. On the other hand, too few interventions have invested in appropriately measuring the human impact, let alone cost-effectiveness, which would allow for comparisons across possible alternative pathways.

It should be pointed out that even where partial evidence exists, most of it derives from just a handful of countries in Asia and east/southern Africa. Among papers retained for review by the authors considered, very few identified any research in West Africa or Latin America. In sum, the situation today is little different from the time when Ruel (2001) stated that "enormous information gaps still exist concerning the efficacy and the effectiveness of most of the strategies reviewed." As a result, although there remains widespread faith in the potential for investments in agriculture to help improve nutrition and health, the evidence for this remains insubstantial.

Research Priorities
Evidence gaps are many. These are grouped here into three main categories: 1) lack of specificity regarding causal mechanisms and types of impact (different nutrition outcomes) along pathways; 2) an incomplete elaboration of links or pathways; 3) lack of understanding of the relative contribution of various elements of food-based strategies to empirically documented human impacts, costs, and feasibility at scale. Each of these is considered in more detail below.

1. <u>Causal mechanisms and types of impact</u>

Masset et al. 2011 showed that agricultural interventions have been "successful in promoting consumption of specific foods", while Ruel (2001), Gunaratna et al. (2010). Masset et al. (2011), Girard (2012) and Gillespie et al. (2012) have all compiled evidence that where consumption of foods rich in specific nutrients (particularly vitamin A and protein) is increased, the status of that particular nutrient can be enhanced in the consumer. While such findings are generally used to support Pathway 1 thinking, they come mainly from interventions that included BCC components. What is more, nutrient status could have been enhanced via means other than increased consumption of foods. Secondly, enhancements of one particular nutrient at a time do not in themselves equate with enhanced nutrition overall. But, too few studies have documented changes in outcomes such as stunting (linear growth), wasting (short-term nutrient depletion), or low birth weight (inter-generational effects), the role of direct consumption deserves more attention.[4] In this sense, it will be important to un-package the links between consumption and nutrition. There are multiple dimensions. More attention is needed on:

i) Bioavailability of nutrients within the matrix of different foods. Some work has been done in the past on how much green leafy vegetable has to be consumed to achieve recommended consumption levels of iron and vitamin A, but such work has not been extended to the many nutrients that are key to growth (little is known about zinc, phosphorous, selenium, potassium and other nutrients at the fore of international attention). Similarly, which fruits and which vegetables matter more than others in the delivery of key nutrients is poorly known, since most approaches to diet diversification make no distinction among types within this category of foods.
ii) Interactions among nutrients are poorly understood in the context of meals, as opposed to individual foods. Absorption of iron can be impaired without sufficient vitamin C or in the presence of high levels of phytates and other anti-nutrients. Absorption of vitamin A is limited without sufficient intake of fat, and certain minerals can impede each other's effectiveness if present in unbalanced ratios. How meals are affected by higher production and consumption of target crops is unknown.
iii) Dose-response work is crucial to understand 'how much' additional animal protein or iron is sufficient to either resolve deficiencies or to meet defined needs. How much more fruit or vegetable has to be grown and consumed to achieve at least minimum changes in nutrient levels? How much change in nutrient levels is enough to justify the investment? Does it matter which fish species are consumed to nutrient profiles? What is the differential bioavailability of proteins from different animal sources?
iv) Which measures of nutritional well-being are most appropriate as markers of success for food-based approaches? Since the nutrition community is focused on linear growth in

[4] Even in the case of biofortification, which represents a one-nutrient-at-a-time approach, it has been proposed that such technology be treated as "a promising technology for improving nutrition, but no more than that for now." Evidence Matters (2012)

children aged 6 to 24 months, what kinds of agriculture activity would best support this prime goal? What additional metrics or biomarkers of nutrition (and morbidity?) would be appropriate to assess in the context of agricultural programming?

v) What anti-nutritional factors need to be accounted for and resolved when seeking to deliver nutrients? This has two dimensions: food-borne toxins, on the one hand, and phytates and other confounding elements in the food matrix, on the other. While enhancing nutrient content of cultivars represents a supply-side solution to certain deficiencies, removing impediments to physiological utilization of those nutrients is of equal importance. Toxins in and on food represent an important emerging dimension of food security work (USAID 2011). Some toxins are within foods (such as cyanogenic compounds in the leaves and roots of crops like cassava and certain beans), while others grow on foods (such as various mycotoxins or molds, often produced by fungi that colonize crops on the field or in storage). Some work has been done on breeding species that contain lower levels of, or resist, toxin growth, but much remains to be done. New evidence suggests that chronic exposure through consumption of toxin-laden foods may be a significant contributor to impaired growth, hence stunting (see below). Similarly, high levels of phytates, fibers and other anti-nutritional factors impede bioavailability and physiological utilization of many nutrients. How these play out in relation to enhanced levels of nutrients in target crops, and in meals containing nutrient-enhanced foods, is poorly understood. This represents a critical mechanism in translating supply to impact.

While much of this may be seen as basic science, choices in research around which crops/animals to promote and approaches used in food-based strategies need to be informed by empirical knowledge of what is being supplied (in terms of nutrients) compared with defined needs. Only then can policymakers have plausible expectations about contributions towards human impacts.

2. <u>Elaboration of additional links or pathways</u>

Beyond the direct consumption of nutrients, mechanisms of change need to be better understood to be able to interpret the value of one approach versus another. First, context matters since additional links may be at play beyond those assessed as part of an agricultural intervention. For example, enhanced vitamin A status may derive more from value chain activities that makes vitamin A-fortified vegetable oil or other fats available to more consumers rather than higher consumption of vitamin A-rich foods.

Similarly, unless account is taken of the distribution of vitamin A supplements in study sites, assumptions that higher consumption of nutrient-rich fruits, say, resulted in enhanced vitamin A status of children may be fallacious.[5] The same is true for other nutrients, such as iron where deworming or anti-malarial bed-net interventions may achieve greater results in reducing child anemia than provision of additional iron content in target foods (like beans). This suggests a need for clarity on:

vi) Appropriate study designs and metrics required to empirically document nutrition and health impacts along various pathways.

vii) Determinants of nutrition and health outcomes disaggregated by food-based pathways and other potential mechanisms.

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[5] In 2011, 75 per cent of children aged 6 to59 months old in developing countries were fully protected against the impact of vitamin A deficiency with two doses of vitamin A (UNICEF 2013). Of the 55 countries with data in 2011, 31 had reached the 80 percent target of full coverage of vitamin A supplementation.

Second, attention to ‘missing links’ or alternative pathways to positive or negative impacts is also needed. For instance, the idea of agriculture as a *source of income* (Pathways 2 and 5) is conventionally viewed in terms of increased wages earned within agriculture or marketed sales of products generated. The logic, as recently expressed by the Economist, is straightforward: “agricultural growth is one of the best ways to generate income for the poorest who need the most help buying nutritious food.” (Economist 2011) However, Gillespie et al. (2012) reviewed 26 papers exploring links between income derived through agriculture, food expenditure and child nutritional status in India. They found that while agricultural productivity enhancement does typically increase production, income and consumption, none of the three attributes automatically translates into the nutrient needs of vulnerable groups being met, or to nutritional status impacts. Ruel et al. (2013) also note that while agricultural programmes have an important role in improving food security and healthy diets, there is “inconclusive evidence of effects on child nutritional status.” Thus, research is still required on:

viii) Expected (plausible and measurable) impacts on defined nutrition outcomes derived from enhanced productivity in, and income from, different sub-sectors of agriculture.
ix) Determinants of decisions on income use depending on the source of that income within the agricultural sector, by gender, by season.

In many parts of the world women have shifted into agriculture in response to the out-migration of men (FAO 2011). The remittances sent home can increase total household income and consumption even if income from agriculture does not grow despite women’s greater authority over, and control of, resources in the agricultural sector. In other words, child nutrition outcomes can improve along with women’s involvement in agriculture, although the pathway for change derives from activities that may be totally divorced from the farm sector.

Similarly, the role of market dynamics and prices (Pathway 3) is not straightforward. Considerable research has in the past been conducted on the effects of agriculture and food price policies on the production and consumption decisions of poor households (Pinstrup-Andersen and Walker 2011). Nevertheless, the many non linearities in policy-price-consumption decisions are poorly understood. During the food price crisis of 2007/08, the United Nations calculated the impact of a 10 percent increase in internationally-traded staple food prices for a range of developing countries. The welfare impacts for rural households were often negative since poor rural households are frequently net purchasers of food and price rises for agricultural products may not off-set food price increases. However, that is not always the case. In Vietnam and Madagascar, for example, net welfare for the rural poor improved along with the rise in global food prices (FAO 2008). In Pakistan, a large net decline in welfare for the rural poor was driven by a steeper decline in welfare among households in the poorest expenditure quintile than among those in the top quintile; but in Ghana, net negative effects on rural welfare were largely similar across all expenditure quintiles. In other words, the ramifications of price effects are not generic, and therefore mechanisms along possible pathways have to be much better understood if they are to be manipulated via policies or agricultural strategies aimed at buffering price unpredictability.

What is more, the translation of prices on food and non-food choices (substitution effects) is also poorly understood. Iannotti and Robles (2011) showed that there was on average an 8 percent drop in total energy intakes as a result of the global food price crisis in households sampled from 7 Latin American countries. In Guatemala, for example, the decline was closer to 10 percent for energy consumption in response to higher prices. However, Iannotti et al. (2012) also found that impacts on diet quality and micronutrient status varied widely. Household disparities in nutrient intakes prior to the crisis (2006) were greatest for vitamin B-12 and vitamin A, nutrients found to be highly correlated with income. However, with rising food prices it was zinc that showed the greatest increase in probability of dietary inadequacy. In other words, policy and price links to nutritional status varies by nutrient, by the price and cross-price elasticity of various foods, and by the impact of price changes conditioned on prior conditions. This suggests a need for research on:

x) Determinants of purchased food choices in contexts of, a) steeply declining income (price and other crises), b) longer-term impacts on dietary choices subsequent to crises, c) trends in the role of fortified and otherwise nutritionally-enhanced foods within the diets of the poor, d) trends in diet shifts towards processed/packaged foods across all expenditure quintiles—in terms of understanding farmer choice of seeds top grow.

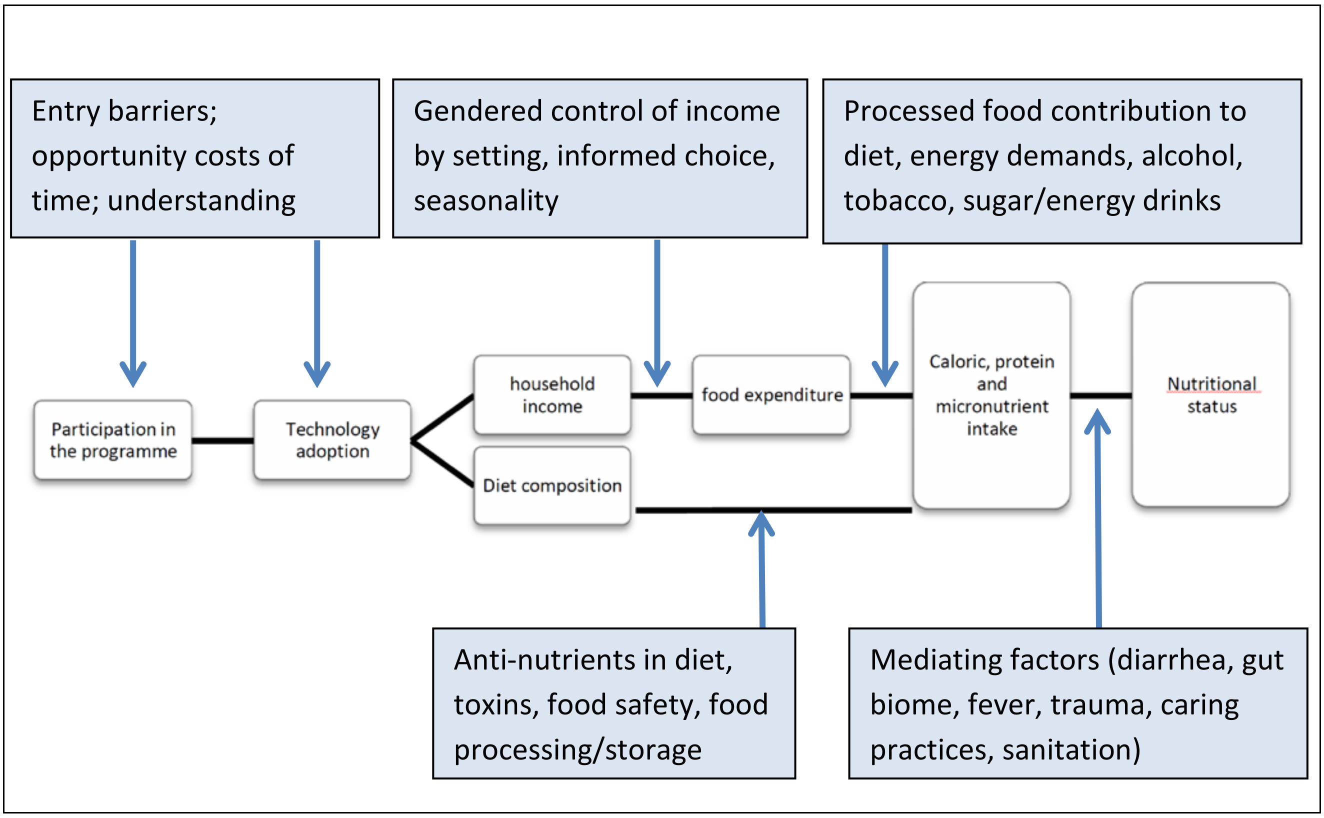
xi) Uses of household income derived from any source, in relation to household agricultural investments and diet choices.

xii) Elasticities of demand for micronutrient-rich (and protein-rich) foods across seasons, expenditure quintile, gender of household head.

Third, certain key mechanisms involved in nutrition outcomes need to be treated as pathways in their own right, not just as caveats. Take the Masset et al. (2011) conceptual diagram presented in Figure 1 above. Figure 3 takes that same diagram and points to links in the chain where significant additional information is needed to understand proposed causal mechanisms. This suggests a need for further research on:

xiii) Gendered and poverty-determined entry barriers to participation in proposed programmes and resulting variability in programme fidelity and intensity of new technology usage among households containing nutritionally-vulnerable demographics;

Figure 3: Adaptation of Logical Framework proposed by Masset et al. (2011)



xiv) Opportunity costs of time associated with programme participation/technology adoption (investment and recurring time costs) by expenditure quintile;
xv) Knowledge, attitudes and practices associated with the use of farm-derived income by gender, poverty status, seasonality, etc.;
xvi) Potential contributions (positive or negative) to nutrient consumption of processed foods (changes in rural consumption patterns, competing uses of the consumption budget);
xvii) Food quality/safety issues relating to ingested toxins on agricultural products and practices that may cancel out higher nutrient density or productivity gains;
xviii) Environmental factors that play a crucial role in mediating between nutrient consumption and nutritional outcomes.

The importance of mediating environmental factors has only recently been highlighted as relevant to nutrition. Spears (2013) recently argued that germs in faeces can contribute significantly to child stunting. This is partly due to diarrhea (loss of nutrients) and partly to enteropathy (chronic changes in the gut biomes that impact the lining of the intestines which impairs nutrient absorption and function). Separately, Smith et al. (2013) documented a trial that implicates the gut microbiome as a causal factor in certain kinds of severe child malnutrition. That is, the microbiota examined under conditions of nutrition and health stress appear to cause selective inhibition of one or more enzymes, making energy metabolism difficult for "children when they are exposed to a micro- and macronutrient-deficient low-calorie diet" Smith et al. (2013).

Such mechanisms of malnutrition were postulated by Pinstrup-Andersen (2011) in his elaboration links between food systems and health. He specifically pointed to toxins and zoonotic pathogens (mentioned above) as well as microbes and sanitation as important, usually underexamined, factors in determining both growth retardation and health outcomes. While Pathway 3 (of the 7 main paths proposed by Gillespie et al. 2012) talks of income used to increase private demand for improved healthcare (an indirect route towards enhanced nutrition), it is clear that removing negative factors in health and food environments may be necessary to enhance the investments made by poor households in higher food consumption of nutrients.

3. <u>Unpackaging agriculture and integrated programmes</u>

Just as nutrition and health have many dimensions, agriculture represents a broad sector of diverse activities. More needs to be known about the direct/indirect impacts to be anticipated from various sub-sectors. According to the reviews described in the previous section, the principal motors of agriculture's contributions to nutrition are, a) productivity growth (mainly of staples, but also of cash crops, horticulture and animal production), b) enhanced nutrient content of products consumed by the nutritionally-vulnerable poor, c) entry points to deliver enhanced status to women (via their control of agriculture-mediated capital or when agriculture programmes serve as a platform for provision of targeted non-farm services and resources), and d) as a mechanism for enhancing safety of the food environment through reduced toxin ingestion, improved processing and storage, and reduced farm-related externalities (environmental enteropathy).

Investments in each of these main domains will likely have positive impacts on both production and consumption parameters, but their relative contributions to nutrition and health outcomes need to be disentangled, as do their combined net effects. This suggests a need for research on:

xix) Women's control of income from agriculture and non-agriculture sources is an important factor in nutrition outcomes of children, but does its role in determining nutrition change in the context of urban/peri-urban agriculture?

xx) Subsectors of agriculture are best combined with which non-agricultural sectors (health, education, water provision, etc.)?

xxi) Global price shocks (rises and volatility) translate to consumption of so-called 'non-tradeables' (such as finger millets and sorghum, teff, roots and tubers, etc.)

xxii) Price effects on demand for high quality complementary foods (post breastfeeding foods for infants) in the context of dietary transition, time constraints to food preparation, seasonality of product availability, etc.

xxiii) Innovative mechanisms by which agriculture could deliver nutrients other than through crops, such as nutrient-fortification of fertilizers, micronutrient-fortified water in irrigation or livestock feeding.

xxiv) Agriculture as a platform for delivery of messaging on nutrition knowledge and practices, not simply extension. Integration with health delivery systems to allow for common and mutually-reinforcing messaging to men as well as women.

Conclusions

This review of the literature on impact pathways from agriculture to improved nutrition and health confirms the existence of important evidential lacunae that will continue to hamper activities in agriculture aimed at supporting nutrition until they are appropriately addressed. The FAO has recognized that actions aimed at "increasing production of staple crops, are by themselves often not enough to accelerate reductions in hunger and malnutrition" (Thompson and Meerman 2010). The problem is that even a narrower focus on subsectors of agriculture producing outputs of higher nutrient density than others (such as horticulture and livestock, or more recently biofortification), suffers the same reality. The provision of higher levels of one or other nutrient, or one or other commodity, had not yet been shown to translate into enhanced physiological outcomes.

Once again, it is important to emphasize that the current lack of evidence does not mean that agriculture *does not* support gains in nutrition and health, rather that the evidence of positive impacts is still weak. Even that conclusion would be confounded by the host of methodological weaknesses that have been identified in the existing studies in this area. Thus, the lack of rigorous evidence suggests three important conclusions:

First, the quality as well as the volume of research on this topic *has* to be improved.

Second, research has to be improved in new ways that allow for elaboration of, a) specific mechanisms not just broad pathways, b) contextual counterfactuals (that may have more to do with the result than a narrow focus on single interventions might suggest), and c) appropriate metrics to allow for measurement of net, often non-linear, effects.[6]

Third, demand is high for empirical evidence of how to leverage agriculture's potential to promote enhanced nutrition and health. Funding streams have shifted recently towards the agriculture sector, and multisectoral actions with nutrition intent are high on many donor agendas.

That means ensuring, a) designing evidence-capture in ways that will pass the bar of methodologically rigor when included in future systematic reviews, b) ensuring that appropriate

[6] Fanzo et al. 2012 propose that "there is an urgent need to research and advance innovative strategies to better understand, measure and promote…nutrition." Similarly, Herforth et al. (2012) affirm the need for research that allows a tracking of impact on multiple outcomes at once (such as diet, nutritional status, productivity, and income); designing studies that can attribute impact to specific approaches; and collecting information on costs and cost-effectiveness."

nutrition outcomes are selected in relation to the kinds of research and intervention pathways concerned, c) focusing on understanding mechanisms (multiple intermediate links in the chain) and not just theoretical pathways leading to poorly defined outcomes, d) linking agriculture research much more closely with public health systems research that can help fill in knowledge gaps about dose-response and confounding/mediating factors in the food system environment, and e) spreading research to regions and countries not well-represented in the existing portfolio of studies (namely, semi-arid and hill/mountain areas, West Africa, Latin America and Oceania, regions of low population density, and peri-urban settings).

For the coming decade, pathways research will arguably be relatively less important than *mechanisms* research since so much remains to be understood about the reasons why, and contexts in which, nutrients available in foods do (or do not) become the building blocks for defined and measurable nutrition outcomes. Similarly, while it remains important, continuing research on products (enhancing nutritional value of individual crops) has to be placed more appropriately in the wider context of human impacts that derive from choices relating to both farm and non-farm investments, activities and consumption.

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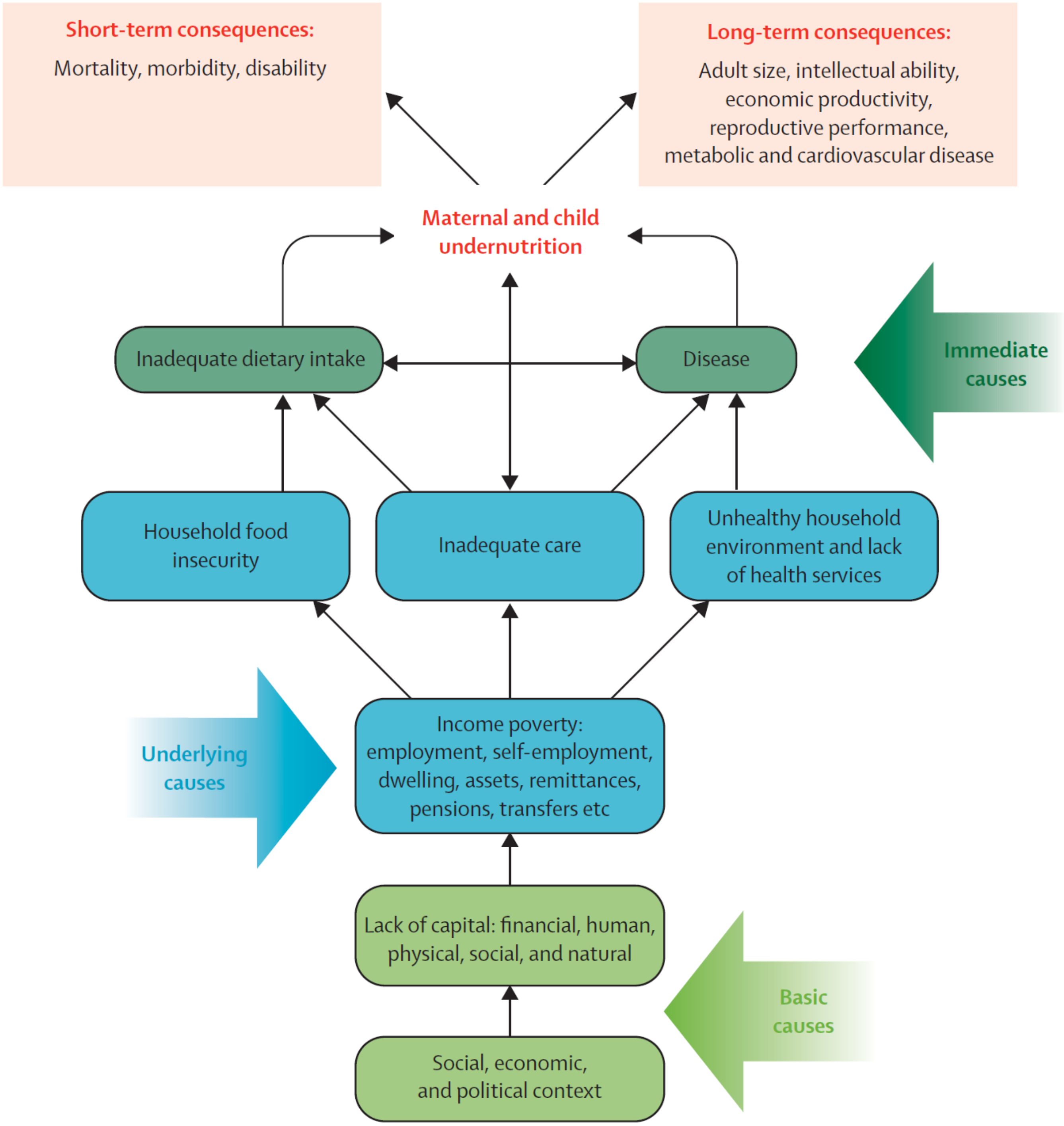
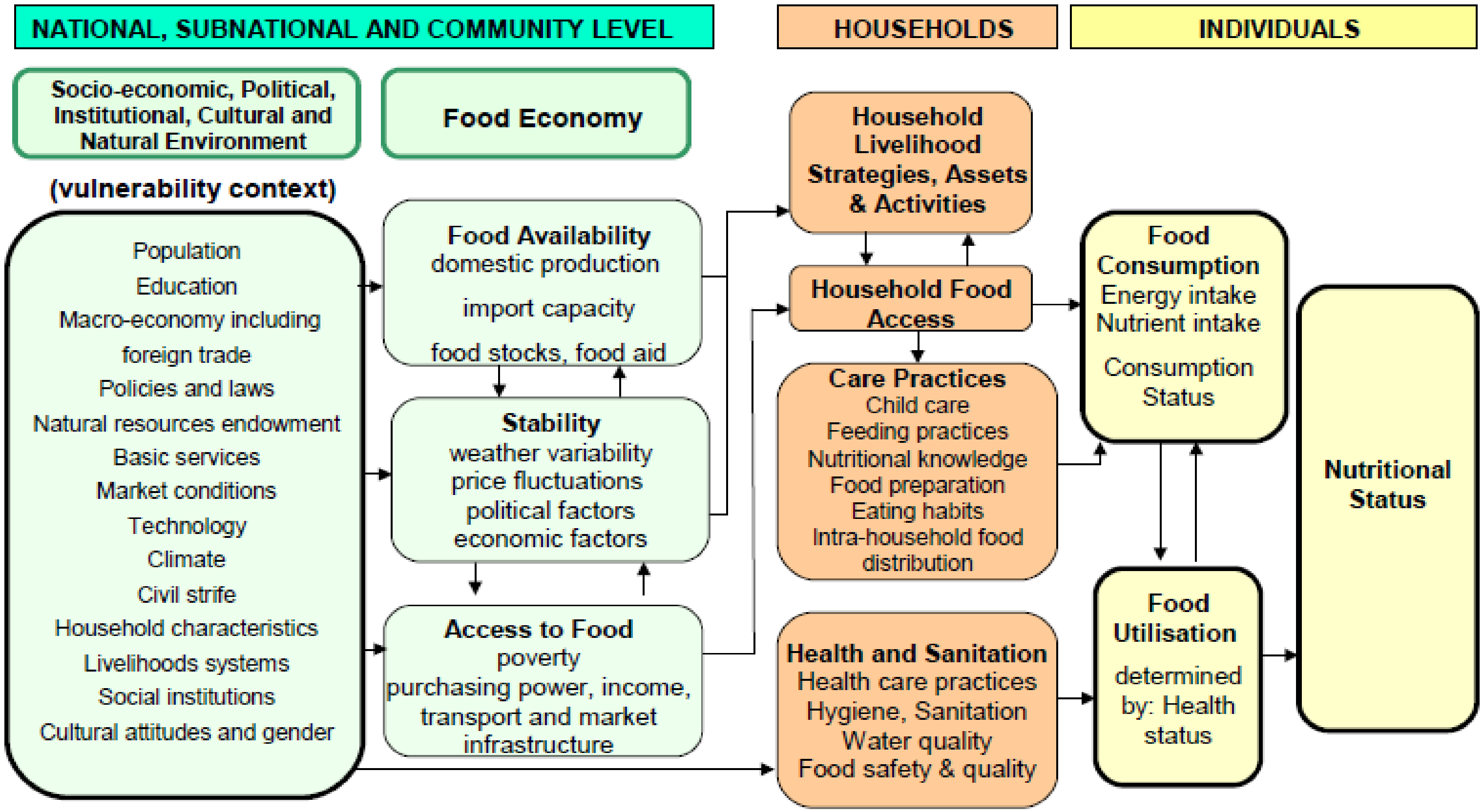
Appendix 1: Adapted UNICEF conceptual framework



Source: Black et al. 2008.

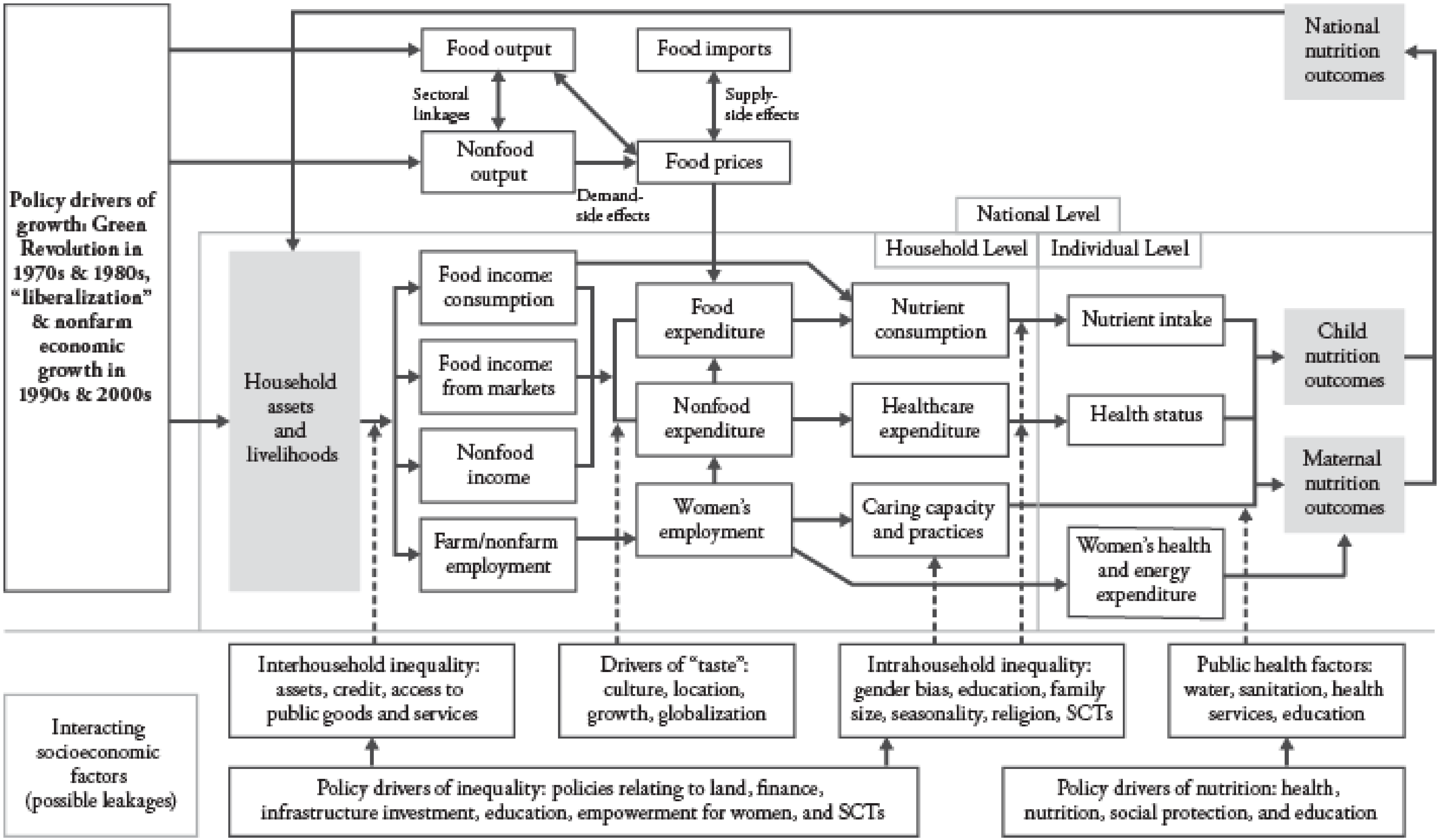
Appendix 2: FAO/FIVIMS Framework: linkages between the overall development context, the food economy, households, and individual measures of well-being



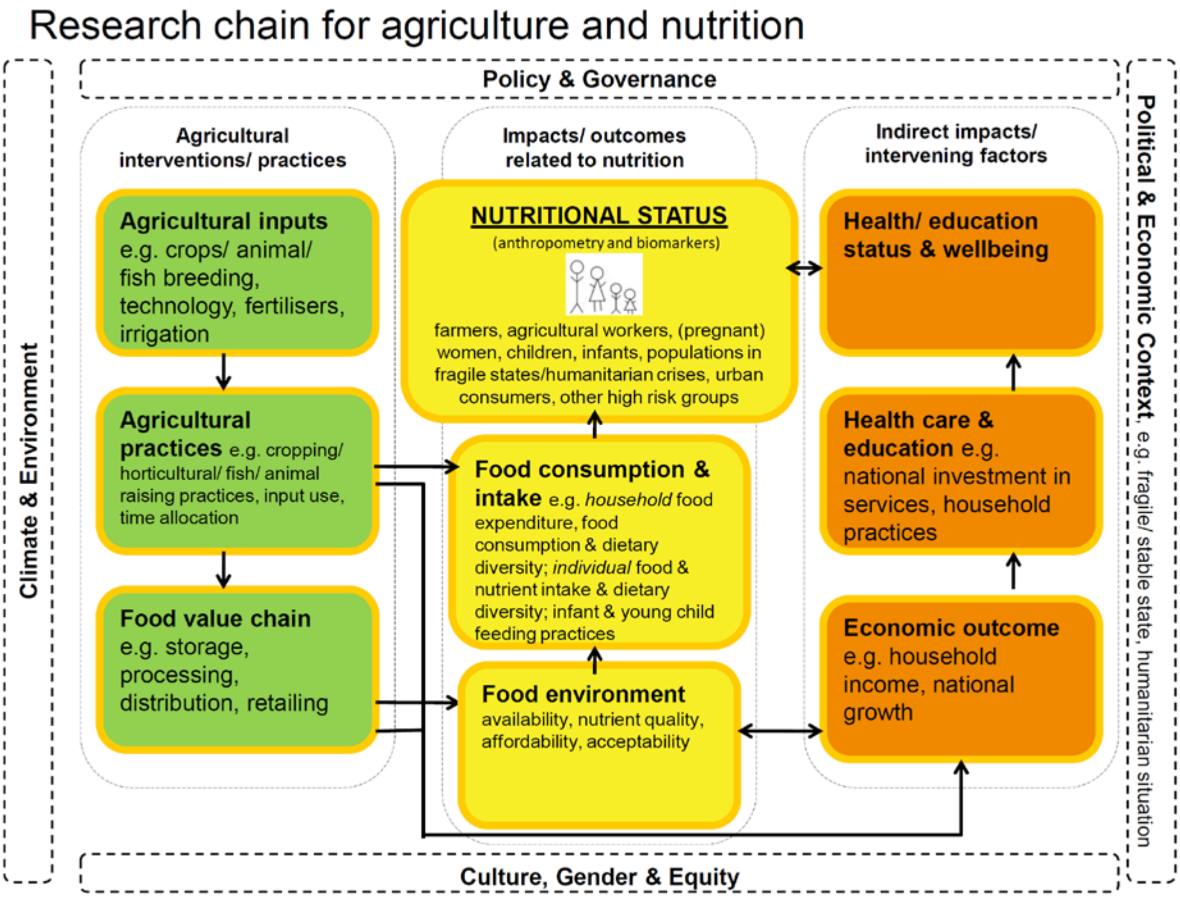
Source: FAO and FIVIMS http://www.fivims.org/index.php?option=com_content&task=view&id=7&Itemid=1

Appendix 3: Pathways from agriculture to nutrition

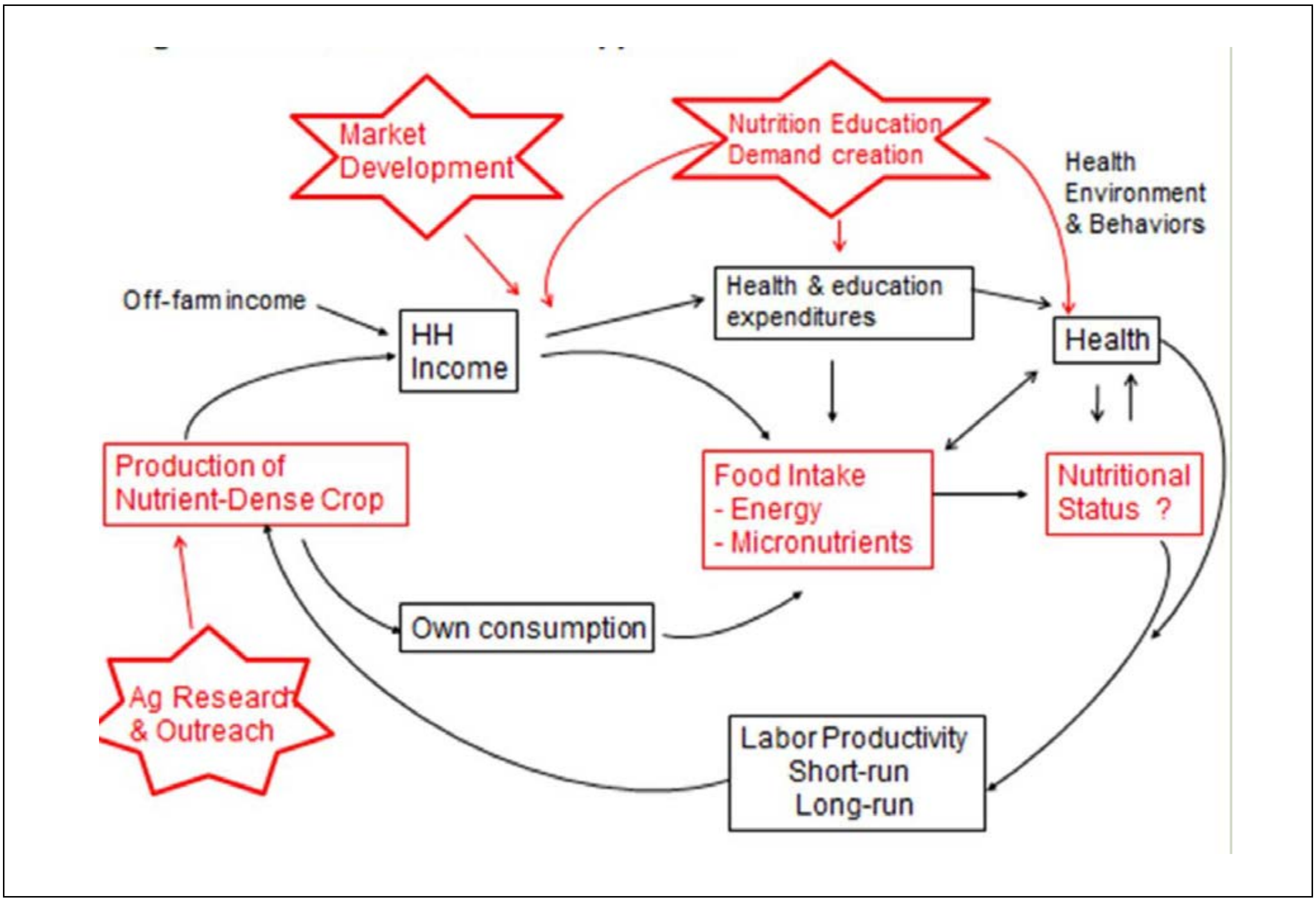
Source: Stuart Gillespie, Jody Harris, and Suneetha Kadiyala, 2012



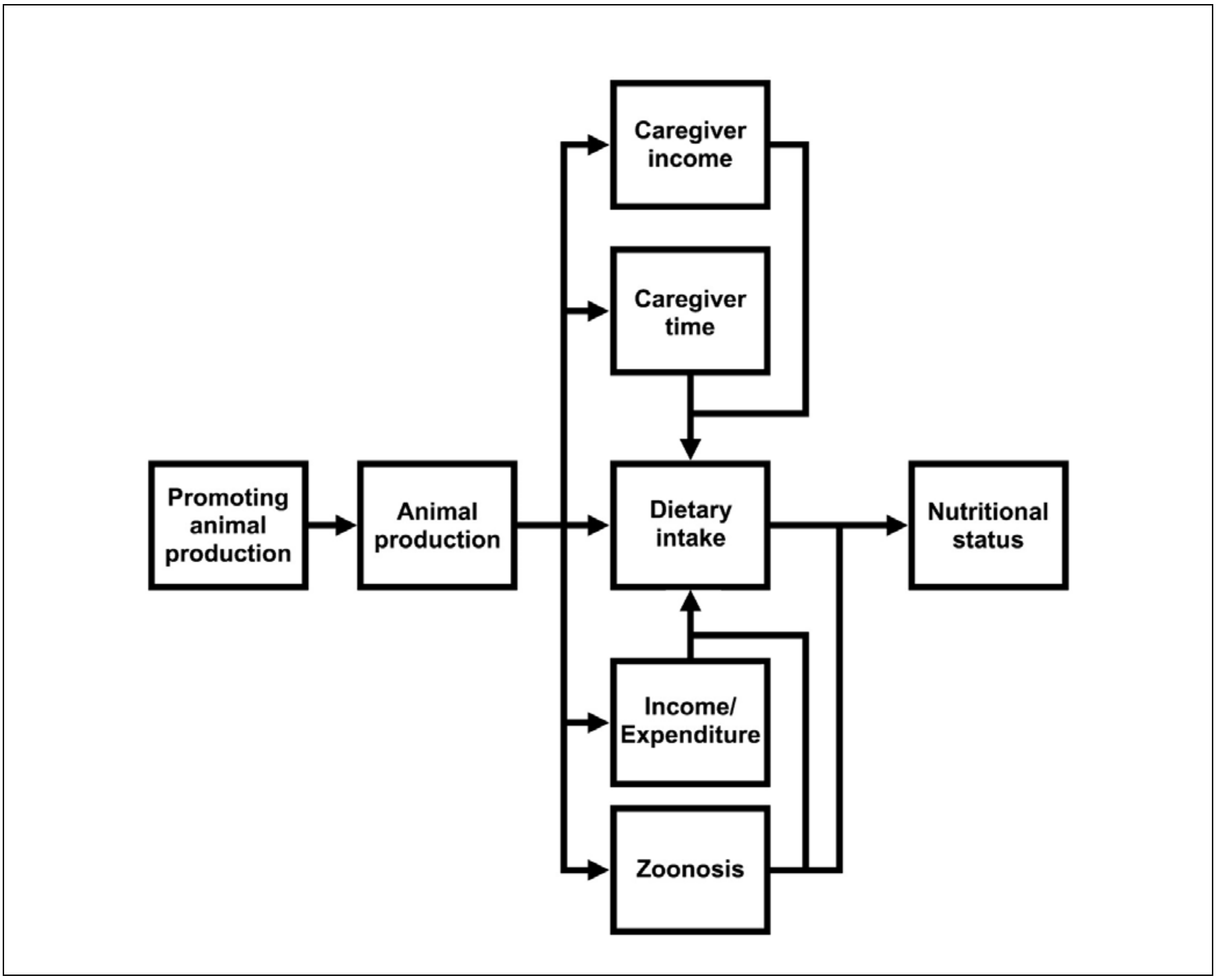
Appendix 4: Research pathways from agriculture to nutrition
Source: Hawkes et al. 2012



Appendix 5: Pathways from agriculture to nutrition
Source: Chung 2012



Appendix 6: Pathways between livestock production and nutritional outcomes.
Source: LeRoy and Frongillo 2007.



Appendix 7: Pathways between aquaculture production and nutrition.
Source: Kawarazuka 2010.