Impacts of Agricultural Research on Poverty, Malnutrition and Resilience

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Report prepared for USAID/Bureau for Food Security, Office of Agriculture, Research and Policy

March 28, 2017

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Executive Summary

Agricultural research continues to be a good investment. The studies show that investments in international and national agricultural research account for almost all of the total factor productivity (TFP) growth in SSA and large shares of agricultural growth globally. The existing agricultural research institutions have, on average, delivered rates of return to public investment above 30-40%, which is much higher than the 5-10% available to other public investments or the 2-5% cost of borrowing public funds. Recent studies have found no decline in the rates of return to research in developing countries.

Agricultural research can be an effective tool for reduced poverty. *Ex post* econometric studies have shown that agricultural research is related to important declines in African and Asian poverty levels. Country case studies describe in more detail how improvements in the productivity of specific crops like rice, maize, common beans, peanuts and pigeon pea have reduced poverty. There are also examples of how poverty reductions can be due to improvements in dairy technology, livestock health and dairy policy, as well as postharvest technology improvements for cassava processing and maize storage.

Investments in agricultural growth and productivity more effective at reducing poverty than alternative investments. Recent global simulation models show that increasing agricultural production and productivity is a much more effective way of reducing poverty in poor countries than increasing productivity in the industrial sector. Other simulations show that of the investments in agricultural research, in irrigation, water storage, and infrastructure such as roads and communication; agriculture is the most effective but it is even more effective when coupled with the other investments.

Improved agricultural technology has reduced malnutrition. One recent study of 38 developing countries showed that the spread of modern staple crop varieties led to a large 9% decrease in all-cause infant mortality. Other studies document improved diet diversity due to the introduction of orange fleshed sweet potatoes in Mozambique and improved tomatoes and eggplant in Tanzania.

Research linking research to resilience is more limited but finds some success. Beyond the effect of higher incomes on poverty and malnutrition, a number of studies document the impact of pest resistant crops that reduce vulnerability of crops to biotic stress and vaccines in reducing livestock vulnerability to disease. Studies of drought resistant maize and submergence resistant crops suggest that they are promising, but may not spread rapidly unless they are bundled with other more obviously beneficial traits like higher yields. Finally, social science research has helped governments develop programs to reduce vulnerability such as index insurance for African and Asian agriculture.

Research priorities: Agricultural research must be a central component of any successful strategy to reduce poverty, improve nutrition and build resilience. Priority-setting processes used by investment managers to reach nutrition and resilience objectives more quickly could involve a sequence of investment criteria such as the following:

1. **Is the investment likely to improve real and diversified incomes for those at risk?** Does it raise real incomes for the poorest households, especially those with young couples and children who are also most vulnerable to malnutrition and to shocks, so they can have increased and more stable earnings with less land, water or capital, and more caregiver time and money available to meet child nutrition needs?
2. **Is the investment likely to lower and stabilize the real cost of nutritious food?** Does it reduce the market price of staples, legumes, fruits & vegetables, milk, eggs, meat & fish, and improve their availability in remote markets where & when diets are worst?
3. **Is the investment likely to improve non-food influences on nutritional outcomes?** Does it reduce agriculture-related disease exposure, including sanitation and food safety concerns such as aflatoxin contamination, and help empower women and other caregivers to meet their needs and care for others?

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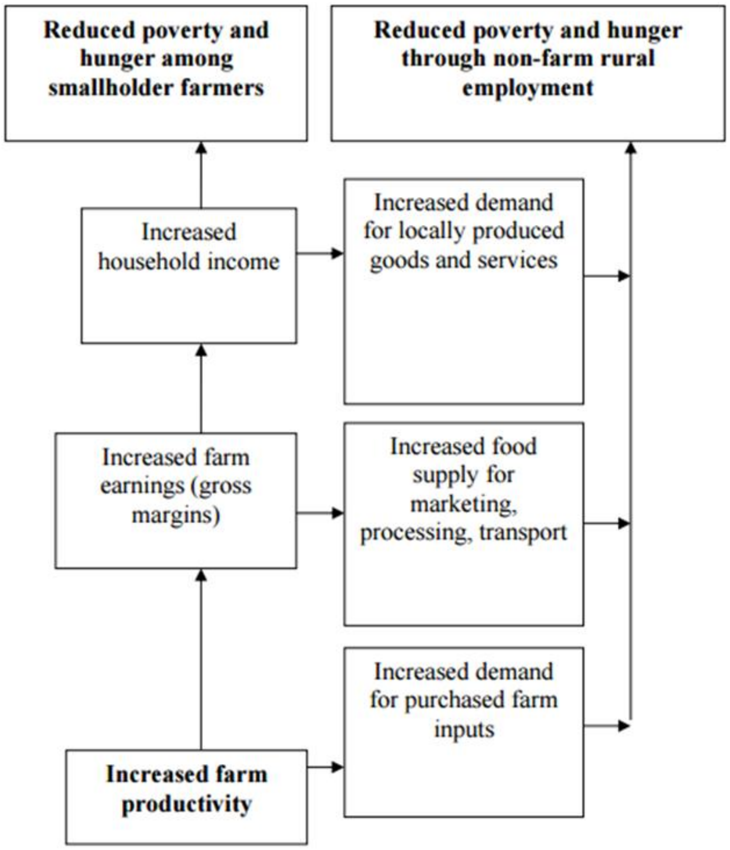
1. Pathways to impact

This literature review summarizes recent evidence on how public and private sector agricultural research and development (R&D) in low-income countries reduces poverty, alleviates malnutrition and builds resilience, through new crop and livestock technologies that increase the quantity and quality of agricultural output per unit of land, labor and other resources.

Studies reviewed here have shown that increases in the productivity of farming improve living standards for farmers and other rural households, expand agribusinesses and drive economic development, by raising the returns to farmers' land and labor, increasing demand for agribusiness services, and lowering the price of food. Increases in agricultural productivity achieved in recent years have also improved the quality and safety of the food supply, leading to improved nutrition outcomes. In so doing, agricultural research has spurred sustainable transformation of rural and urban environments in ways that confer resilience and limit vulnerability to climate and other shocks.

The evidence we summarize expands on the pathways illustrated in Figure 1 from Oehmke (2010), adding nutrition and resilience to the impacts of agricultural R&D on poverty and hunger.

Figure 1. Impacts of farm productivity on poverty and hunger



Source: Oehmke et al (2010)

The impact of agricultural R&D on poverty, malnutrition and resilience works via the discovery and adoption of innovations at specific times and places, leading farmers and agribusinesses to change what they do. Production and consumption of food is more inelastic than other goods, with relatively fixed quantities so that higher productivity often drives reallocation toward other activities. As a result, the impacts of R&D are typically indirect, operating through systemic change and structural transformation.

Public investments drive the pace and direction of change in each location through deliberate R&D to provide desirable new techniques and management practices. These are selectively adopted by farm families based on their needs. Many farmers use new technologies to free up resources for nonfarm activities, while some adopters use innovations to improve farm output and give other households access to more diverse and nutritious foods from month to month. The end result of successful agricultural research is transformation of the sector to fewer more specialized farmers, greater use of farm inputs and purchased foods, and less dependence on fragile local natural resources at any one place and time; a textbook description of this process is provided in Norton, Alwang and Masters (2014).

Studies documenting impact pathways from agricultural research to poverty reduction, improved nutrition and resilience use a variety of data sources and methodologies. In this review, we focus on four distinct kinds of evidence:

1) *Statistical analysis of aggregate data* typically at the national level, such as total agricultural output, poverty rates and prevalence of malnutrition. These econometric studies can test for impacts through structural change in local food systems, but agricultural research spending is closely correlated with other things so its causal effect is difficult to separate from the impacts of infrastructure investments, socioeconomic trends and other factors.
2) *Statistical analysis of household data* on the adoption of specific innovations and their correlation with measured outcomes such as farm production, household income, child nutrition and resilience. These studies can identify linkages between adoption and household-level outcomes, but rarely capture spillovers between households, rarely have randomized access to innovations to identify their causal effect, and rarely have enough sufficiently detailed, frequent and sustained data collection to address nutrition or resilience. They also address only technology adoption, and do not address the research process itself.
3) *Modeling and analysis of innovation systems*, to identify the causal linkages from science and technology (S&T) policy or R&D investments to the development and spread of new technologies. These studies can provide quantitative evidence only for some kinds of innovation such as patents or new variety releases; mostly these are qualitative studies of innovation systems.
4) *Modeling and analysis of specific markets* (in partial equilibrium) or entire economies (in general equilibrium), to isolate the effect of research and estimate its rate of return. This is the most common kind of study used to guide research, building on previous research to provide the mathematical structure of the model and estimated parameters such as elasticities.

The pathways by which agricultural R&D can reduce poverty, improve nutrition and build resilience are illuminated by evidence of various kinds, as reviewed below.

2. Summary of the evidence

Economists and other social scientists have long sought evidence for how agricultural change affects development outcomes. Funding for data collection is limited, so the evidence base about R&D impacts is based primarily on information originally collected for other purposes, such as national accounts or satellite imagery. Mechanisms of impact involve structural changes in agroecology, agribusiness and nonagricultural activity, so the contribution of R&D can be measured only in the context of a broader model of economic development, using a variety of statistical and modeling techniques to control for other factors including the political circumstances that facilitate R&D investment in the first place.

In this brief review, we focus primarily on the most recent publications of direct relevance to USAID investments in agriculture under the U.S. Government's Global Food Security Strategy. The team reviewed refereed journal articles or books which were published after 2000 and preferably since 2010. We included some gray literature that came from sources like IFPRI, World Bank and USAID. To collect the studies reviewed here, the team took a two-pronged approach. One prong consisted of contacting leading scholars who have contributed to this literature and asking for their recent papers and suggestions for papers written by others. These scholars included Derek Byerlee, Jock Anderson, Greg Traxler, Phil Pardey, Julian Alston, Jim Oehmke, Doug Gollin, Keith Fuglie, Leslie Lipper, Latha Nagarajan, Anwar Naseem and others. The other prong of the study was to search google scholar for papers related to impacts of agricultural research and agricultural technology on poverty, nutrition and resilience.

The annotated bibliography attempts to provide a short summary of important points of all the studies collected. The papers that are discussed below were chosen for the quality of the analysis but also to show the diversity of findings in terms of different developing countries and different commodities.

We begin with the literature tying agricultural R&D to productivity growth and poverty reduction, with subsections on how public research attracts private investment in the broader agricultural innovation system, how agricultural research compares to other targets for public investment, what case studies of specific innovations reveal about variations in research impacts, and synergies or substitutions between agricultural research and other kinds of public investment. We then turn to the more recent literature targeting narrower questions of how agricultural research affects nutrition and resilience, and conclude with implications for priority-setting in the future.

2.1 Poverty

One of the most influential studies linking expenditure on R&D to food production and poverty reduction at the national level is by Thirtle, Lin and Piesse (2003). Thirtle and Piesse (2007) updated the 2003 study by adding governance variables which substantiated their previous econometric results. They estimated a system of 5 equations using a data set of 45 developing countries. They find that research increases yield/ha, yield/ha increases GDP per capita, yield reduces the inequality in aggregate and in Asia and in Africa, but it increases inequality in Latin America. Finally, increasing GDP per capita and reducing inequality reduces poverty. Taken together their results show that for the entire sample R&D reduces poverty. These results hold for Asia and Africa but not in the Americas.

Alene and Coulibaly (2009) apply the Thirtle et al. approach in Sub-Saharan Africa with a system of three equations using data from 28 countries of SSA from 1980 to 2003. They showed that R&D expenditures by the CGIAR centers in Africa and by African governments on their research systems increased agricultural value added/hectare, that value added/hectare increases GDP per capita and finally that increases in GDP per capita reduces the percentage of people living on less than $1 per day. Overall, Alene & Coulibaly (2009) show that agricultural research reduced the poverty rate by 0.8% annually. By doubling research investments in SSA, poverty would be reduced by 9% annually, which would involve better input supply systems, infrastructure, efficient extension programs, and credit (Alene & Coulibaly, 2009).

Econometric studies using simultaneous equations of this type cannot identify causality in a statistically robust manner. Small changes in mathematical structure can yield different estimated effects, with little guidance from other evidence about which specifications are most reliable. In recent years, most economists have preferred to look at the individual components of the links between R&D, productivity, income, prices and poverty, and analyze each linkage separately using data on that particular linkage. The first set of studies below measure the relationship between public-sector research and farm productivity (TFP or Yield/ha). Others look at the relationship between adoption of new varieties developed by public or private research and yield/ha (or cost of production). A third set of studies then looks at the relationship between changes in yield/ha, incomes or food prices on measures of poverty.

Since 2000 Keith Fuglie and Nicholas Rada have conducted a series of econometric studies on the impact of public sector R&D on TFP and yield per ha. Some of these studies have been global in scope. Fuglie et al. (2012) used a time-series cross-sectional data set of 87 countries and found that public sector R&D, extension and education had a major impact on agricultural TFP. That same year 2012 Fuglie and Rada published a study covering 37 countries of sub-Saharan Africa (SSA). In this case they found that international research and national public research both contributed about equally to TFP growth. A more recent study of the same 37 SSA countries by Fuglie and Marder (2015) focused on adoption of improved crop varieties of 20 crops from 1970 to 2010. They found that the improved varieties (mostly from the CGIAR centers) had a major impact on productivity as did CGIAR R&D (separate from the varieties) but NARS R&D was not significant. Rada and colleagues also conducted country studies of the determinants of TFP growth in Brazil, India and Indonesia. In Brazil R&D EMBRAPA, Brazil's national government research enterprise) was a major contributor to TFP growth (Rada & Valdes 2012). In India (Rada and Schimelpfenig 2015) public research also made major contributions to TFP growth. In Indonesia Rada, Buccola and Fuglie (2011) did not find a measurable impact of public research on agricultural TFP growth but policy changes were important in increasing productivity.

Evenson and Gollin in *Science* (2003) compared the actual growth in agriculture with a counterfactual that assumes there was no modern variety (MV) development, in the sense of no green revolution at all (NGR) or just no international agricultural research center (NIARC) research of the type funded by USAID and other donors through the CGIAR. This table summarizes their results.

Table 1. Estimated worldwide impacts of modern variety (MV) adoption

	Comparisons to base case (percent changes)	
	With no MVs in developing countries (NGR)	With no IARC programs (NIARC)
Crop yields		
Developed countries	2.4 to 4.8	1.4 to 2.5
Developing countries	−19.5 to −23.5	−8.1 to −8.9
Cropped area		
Developed countries	2.8 to 4.9	1.6 to 1.9
Developing countries	2.8 to 4.9	1.6 to 1.9
Crop production		
Developed countries	4.4 to 6.9	1.0 to 1.7
Developing countries	−15.9 to −18.6	−6.5 to −7.3
Crop prices, all countries	35 to 66	18 to 21
Increase in imports by developing countries	27 to 30	6 to 9
Percent of children malnourished, developing countries	6.1 to 7.9	2.0 to 2.2
Calorie consumption per capita, developing countries	−13.3 to −14.4	−4.5 to −5.0

Source: Evenson and Gollin (2003).

As shown by the table above, in the absence of MVs productivity (crop yields) in developing countries would have been 19.5 to 23.5 percent lower, crop production 16 to 19 percent less and crop prices would have been 35 to 66 percent higher. In the absence of MVs poverty in developing countries would have been 6 to 8 percent higher and in the absence of international agricultural research centers it would have been 2 percent higher. Those results are especially important in showing the complementarity between international agricultural R&D and national programs, as the provision of global public goods makes national programs more productive. A similar complementarity exists for private R&D as described in the following section.

Innovation systems and private-sector investment in agriculture

One of the main pathways by which public agricultural R&D reaches farmers is by providing opportunities for private firms to make profitable investments in commercializing new technology and providing the trained personnel, information and materials used by private seed companies and other agribusinesses. From the perspective of society there is evidence of underinvestment in private as well as public agricultural R&D (Hurley, Rao and Pardey 2014), implying a need for public investment and policies that encourage private agribusinesses invest in new technologies.

Pray and Fuglie (2014) address the impact of private innovation and industry-supplied agricultural inputs, which substitute for farm-supplied land and labor inputs and raise overall agricultural output. The extent to which industrial inputs raise agricultural total factor productivity (TFP) depends on the prices farmers pay for these inputs. If the productivity gains from adopting industrial inputs are fully captured by input manufacturers through the prices farmers pay for the inputs, no gains will be observed in the TFP of the agricultural sector. To the extent that farmers (or consumers, in the form of lower costs of food) capture some of the economic benefits of industry-supplied agricultural inputs, this will be reflected as higher agricultural TFP.

In a study of U.S. agriculture over 1970-1999, Huffman and Evenson (2006) found that private R&D contributed significantly to both crop and livestock TFP growth. They calculated the social returns to private R&D to be around 40%, significantly higher than private returns to private R&D but somewhat lower than social returns to public agricultural R&D at 56%.

For developing countries, Evenson et al. (1998) examined sources of growth in agricultural TFP in India during 1956-1987. They estimated changes in TFP in crop production for each district in 13 states of India and then regressed TFP against public and private R&D capital, current spending for extension, and other variables. Their measure of private R&D stock included both local and imported mechanical and chemical technology. They found that while public research and extension contributed most to productivity growth, private R&D accounted for about 11% of agricultural TFP growth over this period. More recently, Bervejillo et al. (2012) found significant impacts of both public and private agricultural R&D on agricultural TFP growth in Uruguay during 1985-2010.

Pray and Fuglie (2014) survey a number of commodity studies in developing countries showing positive impacts of private research. A study of privately-developed hybrid maize, sorghum and pearl millet in India, Pray & Ramaswami (2001) found a significant and positive impact on crop yield and farm income. Kathage et al. (2011) surveyed 695 farmers in Northern Highlands and Eastern Lowlands of Tanzania, and found that proprietary hybrids increased yields by 58% over open pollinated varieties despite virtually no use of fertilizer, pesticides, or irrigation. In a study of differences in poultry productivity across developed and developing countries and over time, Narrod & Pray (2001) found positive effects of private R&D.

Much recent attention on the impact of private R&D has focused on GM crops. Pray and Fuglie (2014) summarize the conclusions from the most recent studies. Adoption of GM traits has raised crop TFP either by raising yield, lowering input costs, or both. Adoption of herbicide tolerant traits have been associated with cost reduction (especially, reduction of mechanical tillage costs), while adoption of insect resistant traits led to both significant yield gains and cost reductions (especially, reduction in chemical pesticide applications). Yield gains from GM crop adoption have been relatively greater in developing countries, and both small and large farms have benefited from GM crop adoption.

Economic rates of return and the cost-effectiveness of agricultural research

Many impact studies have investigated the cost-effectiveness of agricultural research relative to other public investments. Isolating causal effects and the economic value of each specific investment is typically done using simulation models of one or more agricultural markets, to show how producers and consumers might respond to a given change holding all else constant. Simulating the evolution of a market over time reveals the rate of return to research investments, and their cost-effectiveness relative to other investments in reducing poverty and malnutrition. For example, Byerlee & Alex (2003) present evidence that more people were removed from poverty in China & India from improvements in R&D than by improving education, irrigation, rural development or roads.

Hundreds of studies of the economic rates of return to public sector agricultural research have been conducted in various contexts, leading to numerous systematic reviews that synthesize this body of evidence. Hurley, Rao and Pardey (2014) reviewed 372 impact studies of this type, revealing a median rate of return of 39% per year. Rao, Hurley and Pardey (2016) present results from a meta-analysis of 2,829 specific estimates of returns to agricultural R&D programs and projects in 78 countries. Controlling for research methodology, target commodity and type of institutions, they found that returns to research have not declined over time and that developing countries generally have higher rates of return (median of 41%) than developed countries (median return of 34%).

Focusing specifically on Africa, Pardey et al. (2016) review 113 studies in 25 countries from 1975 to 2014, finding similarly high internal rates of return with a median of 35 percent and mean of 42 percent. Using a different approach, Raitzer & Maredia (2006) use data from 23 studies to aggregate the total costs and benefits of CGIAR–NARS partnership investments in SSA for the period 1966–2004. They estimate cumulative costs to have been US$9.2 billion (in real dollars) with a present value in 2004 of US$17 billion, generating benefits of $26-28 billion. Most of these gains are from crop research. For livestock research by CGIAR centers Jutzi and Rich (2016) have provided a very useful summary of impact studies. They look at the impact of CG work on avian influenza, rinderpest eradication, goat parasites, dairy policy change, new forages, and natural resource management techniques. They find positive benefit cost ratios and/or high rates of return for most projects but some like the projects on control avian influenza had benefit cost ratios of less than one (Jutzi and Rich 2016, Table 4).

The impacts of agricultural research involve large spillovers between countries, from both the spread of innovations and market linkages through international trade. These typically magnify the gains found within countries. For example, Alston, Martin & Pardey (2014) find that a 1% increase in global agricultural productivity growth for 40 years would reduce the worldwide poverty rate by 7.6%. A related simulation study by Alston et al. (2014) looked at resilience to price shocks in world food markets, and how farm productivity can protect vulnerable groups in various African, Latin American, and Asian countries. With low farm productivity in those countries, world price rises were found to increase local poverty; with higher productivity, local farmers can respond to higher world prices with increased production, so the same shock actually decreases poverty. Higher farm productivity in developing countries reduces their sensitivity to world price changes and even reverses its direction. With local productivity growth, vulnerable households spend less of their income on food and are less dependent on agriculture for income and thereby gain resilience to both local and foreign shocks.

The leverage of agriculture for poverty reduction depends on the sector's relative size, and the degree to which farmers are poorer than nonfarmers. Christiaensen, Demery, & Kuhl, (2010) using data from developed and developing countries found that investments in the agriculture sector are about 3.2 times better at poverty reduction than investments in non-agriculture sectors. Focusing specifically on Africa, Diao et al. (2010) find that agriculture-led growth reduces poverty more than industry-led growth in Ethiopia, Ghana, Kenya, Rwanda, Uganda, and Zambia. This leverage eventually disappears as countries becomes richer, because a smaller fraction of their workforce remains in agriculture and farmers' incomes converge towards the earnings available in nonfarm employment. That process takes decades, however, and is itself driven by agricultural productivity growth. Looking within agriculture, the poorest invest a disproportionately large share of their income on staple foods, so improvements in staple food productivity are especially important for them. Higher-value crops and livestock then become increasingly important for continued success as incomes rise.

The persistence of high returns from public investments in agricultural R&D, especially in the poorest countries and especially for basic staples, is itself a puzzle. The evidence reviewed above implies that past governments have consistently underinvested in this sector, failing to take advantage of known opportunities to reduce poverty. Efficient allocations would have equalized rates of return. Persistent differences in rates of return can be explained only by differences in political support for agricultural R&D. Relative to other public investments, the gains from agricultural R&D tend to be widely dispersed among poorer people over time, and beneficiaries are typically not even aware that public investment helped them. Even when political leaders know they could use agricultural R&D to achieve their goals, they may choose policies whose payoffs are smaller but more visible and immediate. As demonstrated in studies such as McMillan and Masters (2003), governments often underfund agricultural R&D for decades, until systemic changes open a window of opportunity to make the high-return investments that were previously neglected.

Case studies of specific new technologies

The previous section showed that agricultural R&D has been an important source of new agricultural technologies in general, raising agricultural productivity and reducing poverty income and farm agricultural income growth. This section reviews case studies of specific innovations. A multitude of new agricultural technologies and management practices are being disseminated at any one time, and many new studies of these innovations are published every year. Table 2 summarizes some useful recent studies of the impacts on poverty conducted mostly in Africa with a few in Asia. Most studies that we found focused crop improvement as does the first part of this table. In addition there are a few studies on livestock (Rich et al 2010) and dairy improvement (Chagunda et al., 2016). In each case, by focusing narrowly on one crop or type of livestock they omit the systemic changes described earlier, and identify only one small aspect of research impacts in specific foods like improved pigeon peas, groundnuts and common beans as well as staple foods such as rice and maize.

There and even smaller group of studies that try to measure the impact of post-harvest or social science research on poverty. The second part of Table 2 reports on a few of them. Abass et al 2017 report in an econometric study of a survey of rural households in northeast Zambian that small scale cassava processing machinery developed and spread by IITA and the Zambian NARO reduced the number of rural people in poverty Kaitibie et al 2010 assessed the impact of changes in Kenyan milk regulatory which made it legal for small farmers, small processors, and small merchants to operate. These changes were promoted by Kenyan and ILRI social scientists with support of a dairy development project funded by DFID. The Kenyan government policy change allowed more people to enter the market and pushed down marketing margins which benefitted small farmers and consumers. The Table ends with a study of the food safety impacts on poor farmers in South Africa from insect resistant corn (Pray et al 2013). That study links the adoption of Bt corn to lower fumonisin levels in stored maize. At present grain with high fumonisin levels is consumed by the rural poor. By adopting Bt corn their fumonisin levels would be reduced which could reduce neural tube birth defects and esophageal cancer.

Table 2. Recent Examples of Impacts of Agricultural R&D & Technology on Poverty Reduction

Authors	*Location*	*Subsector*	*Method*	*Outcome*
Research on production agriculture				
Alene et al. 2009	West & Central Africa	Many crops public research	Econometric	Lifted 740,000 people from poverty annually with an increasing rate over time
Asfaw, Kassie, Simtowe & Lipper, 2011.	Tanzania	Pigeon pea public	Ex post adoption and poverty reduction	Adoption of improved pigeon pea varieties significantly decreased inequality & severity of poverty, by 4.4–8.1 percentage points
Chagunda et al., 2016	SSA	Improved dairy technology		In Sub-Saharan Africa (SSA), smallholder dairy improved with 3 approaches: ecological, genetic, and socio-economic intensification
Larochelle, 2015	Uganda/ Rwanda: Common beans	Common beans CIAT	Ex post adoption and poverty reduction	Impacts on poverty were 0.4% in Rwanda and 0.1% in Uganda, proportional to small area & small part of diet
Mendola, 2007	Bangla-desh	Rice public research	Ex post based on survey	HYV rice adopters are better off than non-adopters and receive almost twice the income.
Moyo, Norton, Alwang, Rhinehart, & Deom, 2007	Eastern Uganda	Peanuts. Public sector in Uganda, by ICRISAT in Malawi,	Ex ante impact analysis of adopting Rosette-resistant seed varieties by all peanut producers	Full adoption would give 10.5% decline in severity of poverty.
Oehmke et al., 2011	Kenya	USAID supported productivity programs for maize, livestock and vegetables	Ex post analysis using Tegemeo panel of HHs	Between 2004 and 2008, net poverty in the direct treatment group decreased by 4.9%. Among indirect beneficiaries of the programs, a net poverty rate reduction of 9.9%. In 2006- 2008, poverty among female-headed households potentially benefitting from the USAID programs declined from 76% to 67%.
Rich et al 2014	Chad and India	Rinderpest eradication programs	Ex post based on farm level surveys and models to simulate counterfactuals	Benefit cost ratio: Chad: 4.02 at farm-level; >18 at national level; India: 0.98-64.77 depending on period
Zeng et al., 2015	Ethiopia	Maize varieties from CGIAR	Ex post based on survey data	0.8-1.3% decline in poverty due to adoption but the poor benefitted least because of their small land holdings

Research post-harvest technology & policy				
Authors	***Location***	***Subsector***	***Method***	***Outcome***
Abass et al 2017	Zambia	Small scale cassava processing	Regression analysis of survey of farm households	Use of mechanization reduced number of people in poverty
Kaitibie et al 2010	Kenya	Changes in dairy policy	Consumer and producer surplus based on surveys	Small scale milk producers, processors and consumers benefit by increased efficiency of milk supply chain after regulatory changes
Pray et al 2013	S. Africa: Eastern Cape & KWN	Adoption of insect resistant (Bt) corn	Survey of mycotoxin in Bt & non-Bt plus consumption studies by Medical Research Centre	Bt corn has much lower fumonisin levels than non-Bt corn processed & eaten by poor farmers. Projected adoption of Bt would reduce exposure of poor to fumonisin which could reduce birth defects and esophageal cancer.

Agricultural research and other public investments: relative impacts on poverty and synergies.

Policy makers must decide not only whether investing in research provides returns that are greater than the cost of borrowing money. They must also decide whether there are better ways of reaching social goals like reducing poverty than agricultural research. In one of the most careful studies of alternative ways of reducing poverty, Mark Rosegrant and researchers from all of the CGIAR centers (Rosegrant et al. 2016) use parameters from studies like those describe above, IFPRI's impact model coupled with a GTAP model to simulate the costs and impacts on hunger, GDP, agricultural supply, and environmental measures of agricultural research and alternatives. Table 3 shows some of their simulations of expanded research expenditure and research efficiency and alternative investments in irrigation expansion, irrigation efficiency, soil water holding capacity and improving rural markets with transportation infrastructure. They find that medium investment increases in CGIAR research (Scenario MED) increase incomes and reduces poverty (hunger) more than the irrigation (Scenario IX), water holding capacity (scenario ISW) or infrastructure investments (Scenario RMM). More rapid growth in CG research in combination with increases in NARS research(scenario HIGH+NARS) reduces poverty measured by Hunger by 16 to 20 percent and increases GDP by 4.3 percent relative to the reference scenario. Additional advantages of research are that it is the low-cost option and reduces GHG emissions and water use.

Table 3. Effects of R&D investment scenarios on poverty and other strategic objectives

Scenario	Avg. Annual Cost	2030						2050					
		SLO1	SLO2		SLO3			SLO1	SLO2		SLO3		
		GDP	Ag Supply	Hunger	Water Use	GHG	Forest	GDP	Ag Supply	Hunger	Water Use	GHG	Forest
MED	1.4	0.7	1.4	-6.5	0.0	-5.5	0.03	1.9	2.7	-9.3	-0.2	-15.4	0.13
HIGH	2.0	1.3	2.8	-12.4	-0.1	-7.5	0.04	3.4	5.7	-16.6	-0.4	-24.3	0.20
HIGH+NARS	3.0	1.6	3.7	-15.8	-0.1	-8.9	0.04	4.3	7.7	-20.2	-0.4	-26.5	0.22
HIGH+RE	2.0	2.6	6.4	-24.4	-0.2	-12.7	0.06	4.2	7.5	-20.0	-0.4	-26.9	0.22
REGION	2.5	1.1	2.4	-10.9	-0.1	-6.5	0.03	3.1	5.1	-15.4	-0.3	-22.6	0.18
IX	3.6	0.1	0.1	-1.3	2.6	-1.8	0.01	0.2	0.2	-1.1	2.9	0.7	-0.01
IX+WUE	8.3	0.4	0.9	-4.5	-7.2	-1.9	0.01	0.5	0.9	-2.7	-7.5	-0.2	-0.01
ISW	5.0	0.2	0.5	-2.1	-1.5	-0.5	0.00	0.5	0.9	-3.0	-2.9	-1.1	0.01
RMM	11.9	1.0	1.6	-5.8	0.1	6.4	-0.02	0.8	1.5	-4.2	0.0	8.9	-0.08
COMP	26.4	4.1	9.8	-30.6	-9.0	-11.5	0.07	5.7	11.5	-24.4	-11.0	-25.4	0.22

Less Advantageous — Neutral — More Advantageous

Note: costs are in billion USD, while other values are percentage differences in each indicator relative to the REF_HGEM scenario

Source: Rosegrant et al. 2016

Notes: Strategic objectives are SLO1: Reduced poverty, SLO2: Improved food and nutrition security and health, SLO3: Improved natural resource systems and ecosystem services. Policy scenarios are as defined in Table 4.

Agricultural research has high returns on average, but the benefits are particularly large when the enabling environment favors rapid adoption and scale-up of the resulting innovations. An important aspect of R&D impacts revealed by the Rosegrant et al. (2016) results is the interaction between agricultural research investments and other policy choices or environmental conditions. Each specific scenario is described in the table below. The last rows of Tables 3 and 4 show what can happen if investments in R&D are coupled with investments in irrigation, water use efficiency, and infrastructure. This could lead to a 30 reduction in poverty over the baseline in 2030.

Table 4. Summary of policy and investment scenarios

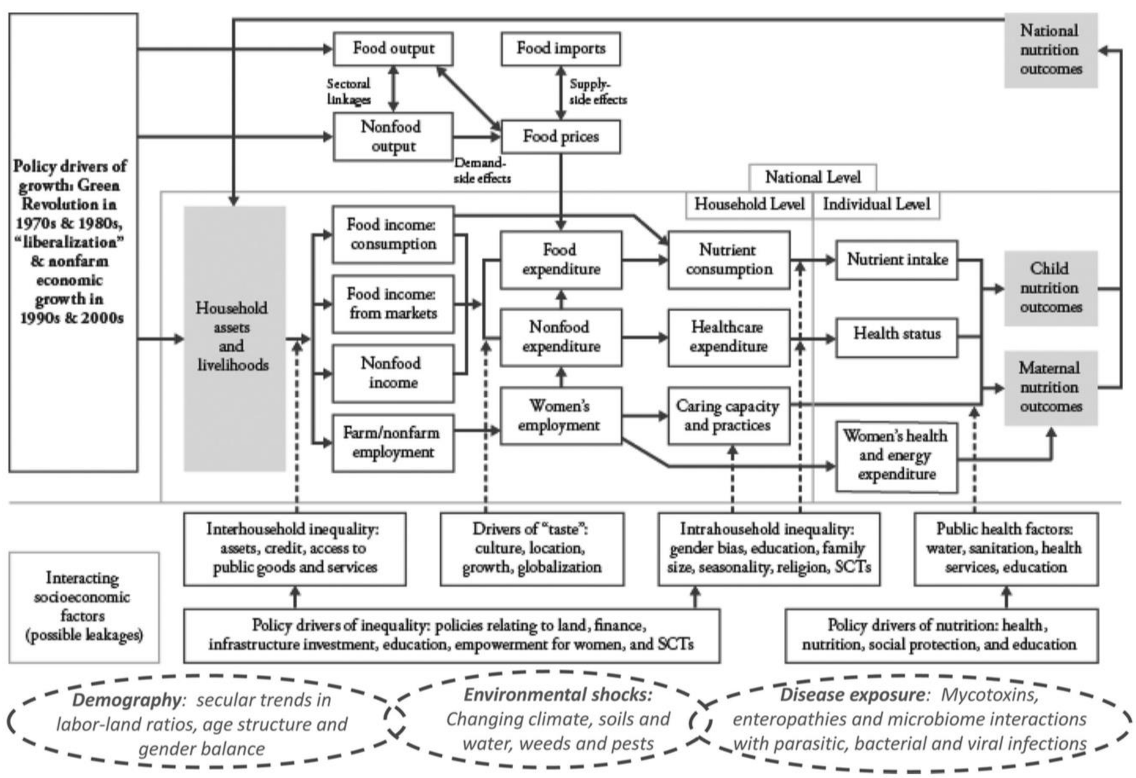
Scenario Grouping	Scenario	Scenario Description
Baseline	REF_HGEM	Baseline reference scenario with HGEM 8.5 future climate (primary baseline scenario)
Productivity Enhancement	MED	Medium increase in investment across the CGIAR portfolio
	HIGH	High increase investment across the CGIAR portfolio
	HIGH+NARS	High increase in investment across the CGIAR portfolio plus complementary NARS investments
	HIGH+RE	High increase in investment across the CGIAR portfolio plus increased research efficiency
	REGION	Regionally-focused high increase in CGIAR investments Targets the highest investments to South Asia and Sub-Saharan Africa with medium levels of investment increase in Latin America, and East Asia
Improved Water Resource Management	IX	Investments targets to expand irrigation in the developing world (HGEM RCP 8.5)
	IX+WUE	Irrigation expansion plus water use efficiency investments (HGEM RCP 8.5)
	ISW	Investments targeted to Increased soil water holding capacity (HGEM RCP 8.5)
Infrastructure and Agricultural Marketing	RMM	Scenario based on infrastructure improvements to improve market efficiency through the reduction of transportation costs and marketing margins
Comprehensive Investment	COMP	This comprehensive scenario is a combination of 4 scenarios: HIGH+RE; IX+WUE; ISW; and RMM (HGEM RCP 8.5)

2.2 Nutrition

As shown above, the path from R&D to productivity and poverty reduction is complex, mediated by the response of farmers and agribusinesses to each new opportunity. Tracing its effects on nutrition and resilience adds even more dimensions, since these impacts are mediated by the biological and social processes involved in dietary intake and health over time.

The figure below gives a sense of the complexity involved in agriculture-nutrition linkages. In this pathway diagram, agricultural investments on the left side of the figure increased food and nonfood output which reduced food prices, changing food expenditure which affects nutrient consumption, nutrient intake and ultimately affect child and maternal nutrition outcomes. The other pathway to improved nutrition is through improved household livelihoods and assets to income, from income to expenditures and women's employment on to nutrient consumption, healthcare expenditure and caring capacity and then to nutrient impact, health status and women's health and energy expenditure and finally to improved outcomes. Each of these pathways can be disrupted by intrahousehold inequality, culture, women's education and disease, and are also affected by external confounders such as demographic trends, environmental shocks and other changes in underlying conditions.

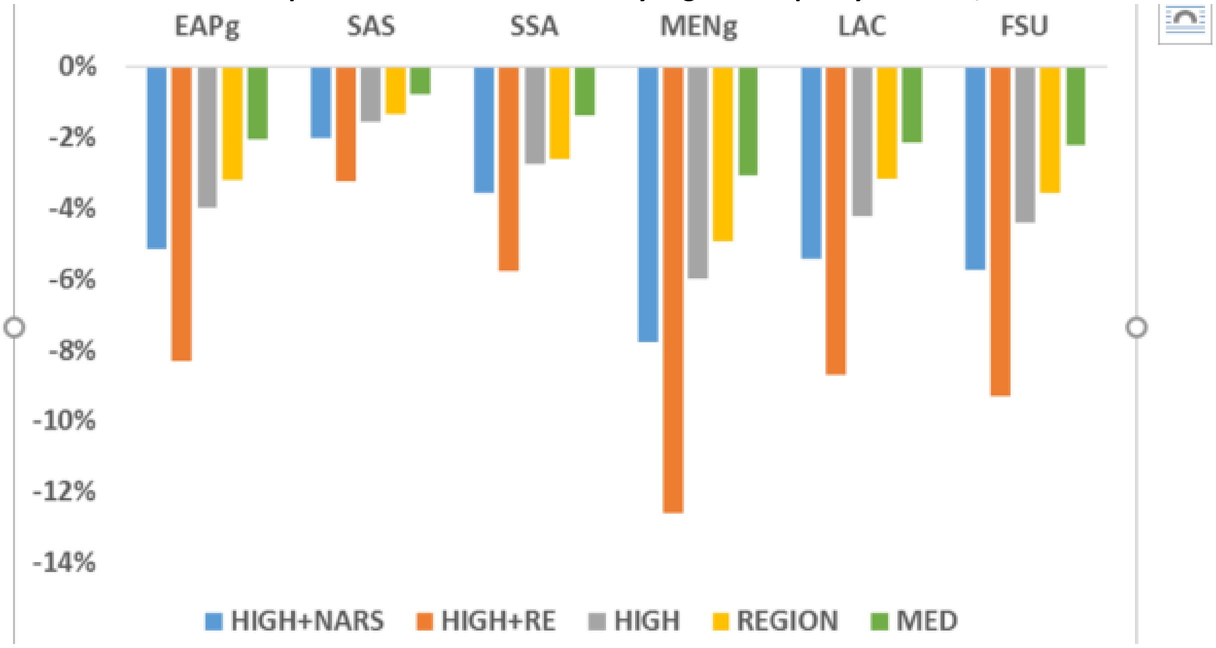
Figure 2. Pathways of impact from R&D to improved nutrition



Source: The causal framework in square boxes is from Gillespie, Harris and Kadiyala (2012), modified in Masters, Webb, Griffiths, & Deckelbaum (2014) with confounders in dashed ovals and italic text.

Some of the complex interactions shown in the figure above are modeled by Rosegrant et al. (2016), whose conclusions regarding the prevalence of malnutrition are summarized in the figure below.

Figure 3. Difference in the prevalence of malnutrition by region and policy scenario, 2050



Source: Rosegrant et al. (2016).

Notes: Scenarios are as defined in Table 3. Regions are EAP East Asia and Pacific; SAS South Asia; SSA Sub Saharan Africa; MEN Middle East and North Africa; LAC Latin America and Caribbean; FSU Former Soviet Union.

Agricultural R&D operates mainly through systemic changes rather than direct services to one person at a time, but some of its effects on nutrition can be evaluated by comparing households that are or are not exposed to a particular intervention or innovation. Harvey et al. (2014) reviewed 38 studies of different types of interventions to improve nutrition. All but one of the studies were in Africa and Asia. Their analysis of these studies shows that home gardens had an inconsistent effect on micronutrient status; aquaculture interventions also had a mixed effect on maternal iron outcomes; and livestock holdings on farms shows no evidence of an effect on micronutrient status. The studies of biofortified crops had consistently positive effects on micronutrient status of children, a mixed effect on micronutrient status in women, and some evidence on positively improving growth.

Individual households that adopt any given new technique or management practice do so because they gain something from it. Some adopters will use agricultural innovation to increase farm output, while others will use it to shift labor and other resources to nonfarm activity. Focusing specifically on India, Kadiyala et al. (2014) reviewed 78 studies and found evidence for links from increased food production to reduced malnutrition through three pathways: agriculture as a source of food, agriculture as a source of income for food and nonfood expenditures and agriculture as a way of reducing the cost of food.

Because each farmer's adoption of an agricultural innovation provides food for others as well as themselves, the only way to measure its effects on nutrition experimentally would be to deprive randomly chosen households of access to both food markets and new farm technology. This would be impossible as well as unethical to do in an artificial trial, but some kinds of naturally-occurring variation affect people in random fashion and permit analyses of this type. One study based on such natural experiments is Mulmi et al. (2016), using satellite imagery of vegetation in Nepal to test whether better agricultural conditions help children grow. They find that vulnerability to local fluctuations is reduced when households have more access to marketed food, demonstrating how increased agricultural productivity in one place can improve nutrition and resilience elsewhere by diversifying and lowering the cost of good nutrition. Mechanisms for this effect are presented in Masters (2016).

Research on agriculture-nutrition linkages involves a wide range of methods, as illustrated by the sample of other studies listed in the table below.

Table 5. Recent Examples of Impacts of Agricultural R&D on Nutrition

Authors	***Location***	***Subsector***	***Method***	***Outcome***
Barnwall et al. 2017	37 developing countries	Green Rev. technology	Econometric	Each 1 s.d. increase in MV diffusion led to a 9% decrease in infant mortality
Benefica et al. 2015	Mali	On farm income	Econometric	Farm income up 10%, consumption of calories up 1.7% and small increase in dietary diversity
Headey & Hoddinott , 2016	Bangla-desh	Rice yields	Econometric	Improvements in crop yield led to better feeding practices for infants and improved weight-for-height outcomes
Hethering-ton et al. 2017	Millenium Villages in Africa	Animal ownership	Ex post analysis	No measurable impact of animal ownership on nutrition, unlike other studies in Ethiopia and Uganda which find positive impact
Holtz et al. 2012	Mozam-bique	Orange fleshed sweet potato	RCTs of interventions	Variety introduction and training lead more sweet potato consumption and increased Vit. A consumption of children and mothers
Schreine-machers et al. 2017	Tanzania	AVRDC tomatoes & African egg-plant	Ex post analysis of economic surplus	Find substantial increases in vegetable production & consumption due to new varieties

The most directly relevant and important of these studies in this review is Barnwall et al. 2017, studying the net result of systemic changes from modern variety diffusion that raise incomes, lower food prices and accelerate agrifood transformation. They use the timing and location of new variety introduction, relative to the timing and location of 600,000 births in 37 developing countries, and find that each standard deviation increase in MV diffusion led to a large 9% decrease in all-cause infant mortality. These gains arise from the synergy between increased income, more abundant food supplies, and a shift to nonfarm employment, all of which reduce a child's dependence on the vagaries of nature. Motamed, Florax and Masters (2014) show how agricultural productivity drives the establishment of cities and the growth of nonfarm activity, while Darrouzet-Nardi and Masters (2017) identify the resulting decline in vulnerability within rural areas.

2.3 Resilience

USAID defines resilience as "the ability of people, households, communities, countries and systems to mitigate, adapt to, and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth" (USAID, 2012). There are a number of pathways by which agricultural research can increase resilience of farm households in developing countries. First, agricultural research can increase the incomes of the poor which would make households more resilient to shocks. Second, research could reduce vulnerability of crop and livestock to biotic and abiotic stress through developing resistant crop and livestock varieties, developing pesticides and vaccines, crop/livestock management strategies and increasing agroecological biodiversity. Third, social science research could help governments develop more effective policies and programs to reduce vulnerability such as famine relief programs, food stamps and crop insurance.

The first and most important pathway by which agricultural research builds resilience is through productivity growth and poverty itself, as discussed in the previous section. Higher average incomes and accumulated wealth, often in the form of human and social capital, allows a given shock to be absorbed with less damage. This can occur directly within households, but also at a systemic level when whole communities gain the market access, public services, improved infrastructure and other advantages of structural transformation.

The second pathway occurs within agriculture, as new technologies raise and also stabilize yields in the face of biotic stress from insects, disease and weeds, as well as abiotic stress from moisture, temperature, soil nutrients and other factors. Public sector research in the past focused much of its attention on breeding improved varieties of plants resistant to insects, disease and on management practices to control insects and weeds. Private sector research also played an important role in developing pesticides and GM crops to control insects, weeds, and disease. The biotech research summarized by Pray and Fuglie (2014) shows the impact of private research on controlling important pests and weeds.

Recently the public sector has shifted focus to abiotic stresses especially drought and floods. Recent evaluations have looked at the impacts of drought tolerant maize in Africa and submergence tolerant rice in Eastern India and Bangladesh. Kostandini and colleagues at CIMMYT have done a series of studies measuring the benefits of drought tolerant maize varieties and hybrids in Africa (Kostandini, Mills, & Mykerezi, 2011, Kostandini, La Rovere, & Abdoulaye, 2013). They use data from experiment stations to measure the reduced risk that yields will be greatly reduced during moderate droughts, make assumptions about adoption and find high rates of return. Dalton, Pray and Paarlberg (2011) using similar data found much lower rates of return to DT maize hybrids because their assessment of the yield increase in moderate drought was lower and adoption more problematic.

Evaluations of flood tolerance have centered around the submergence tolerance rice varieties that were developed by IRRI, U.C. Davis and Indian and Bangladeshi government research programs. The most studied is the variety Swarma-Sub1. Dar, de Janvry, Emerick, Raitzer, & Sadoulet, (2013) and Emerick, de Janvry, Sadoulet, & Dar (2016) have used data from RCT to show Sub-1's impact on protecting from submergence along the coast of Orissa in India. Unfortunately, like the drought tolerant maize, unless sub-1 is linked to other attractive traits it will remain a niche product (Lybbert and Bell 2010).

Agricultural research confers resilience not only within species but also through increasing biodiversity on farms and in the broader agroecosystem. Studies by Melinda Smale (2006) and colleagues in Mexico, India, Africa and other Asia countries have shown that sustainable intensification driven by improved varieties from the CGIAR centers can increase crop diversity and reduce yield variability, with a crucial role played by innovation systems and agribusinesses involved in seed multiplication and sale (Lipper, Anderson and Dalton 2010). Other research has shown resilience can be conferred through better soil and water management on farms, as in conservation agriculture, which several studies show can raise maize yields in both high and low rainfall periods (Michler et al. 2016). Higher and more stable yields per unit of land in one location also reduces demand for food from elsewhere, reducing the burden on worldwide ecosystem services

The third type of resilience conferred by agricultural R&D occurs through socioeconomic innovations that use new kinds of data for remote sensing, monitoring and response. Traditional weather forecasts have been greatly extended to include predictions based on global circulation models including El Nino Southern Oscillation (ENSO) events, and weather data or satellite imagery can also be used to write potentially attractive insurance policies. Janzen and Carter (2016) and (Jensen, Barrett, and Mude 2016) provide recent reviews of these social-science innovations. Continued improvement in field sensors, livestock tags, satellite imagery and crop growth models will eventually reduce the cost and increase the value of index insurance, but existing programs are not expected to be self-sustaining without large subsidies. Where subsidized insurance has been introduced it can reduce vulnerability and improve outcomes demonstrating the value of higher and more stable farm incomes that are more cost-effectively achieved by offering farmers new agricultural technologies and improved management practices.

3. Recommended priorities

The literature on agricultural development reveals clearly how past research investments have made large contributions to poverty reduction, nutrition improvement and resilience, through systemic transformation of local agriculture and food systems. The causal pathway for these impacts is that a flow of locally-adapted innovations gets adopted by farmers and agribusinesses, raising real incomes for those at risk of poverty and offering more stable, lower-cost access to healthy diets and living conditions around the year to those at risk of malnutrition.

The existing agricultural research institutions have, on average, delivered rates of return to public investment above 30-40%, which is much higher than the 5-10% available to other public investments or the 2-5% cost of borrowing public funds. These high returns are spread widely among the poor, and lifted hundreds of millions of people out of poverty, while significantly improving nutrition and resilience. The primary objective of previous agricultural research investments was clearly poverty reduction and securing access to basic staple foods. Steering the flow of innovations towards nutrition and resilience involves the following steps, many of which have been underway for more than a decade in both international centers and national research services.

First, research administration and governance structures overseeing research agencies can and do increasingly target nutrient-dense foods and resilience to shocks in vulnerable locations, rather than just the average level of staple food yields in productive locations. In so doing, it is essential for the new objectives to focus on year-round *access* to nutritious foods in vulnerable places, not necessarily local production in those places. The agricultural transformation that drives success depends on increasing specialization and trade, and nutrition outcomes clearly depend on the consumption of purchased food in addition to whatever is produced locally. Research that tries to make each location self-sufficient would be much less effective than research that targets the most productive livelihoods for those at risk of poverty, and their year-round access to nutritious foods that may be produced locally, nearby, or from a sufficiently diverse set of other locations to make food supplies resilient.

Second, crop and livestock improvement priorities can and do target foods in proportion to their fraction of food expenditures, adjusted for probability of success and elasticities of response. In other words, a food that accounts for 10% of poor peoples' food spending might get roughly 10% of agricultural research spending, but that would be adjusted up if researchers have above-average probability of discovering a useful innovation for that food (for example, because they know of several potential breakthroughs to be field tested), and also adjusted up if farmers have above-average responsiveness to improved techniques (for example, because inputs to increase output are readily available).

Third, to achieve the goals above it is necessary for research priorities to be informed by adequate agricultural market data. The direct output of any research and dissemination program is always the number and quality of innovations that are released for adoption by farmers, as measured by the gains from adoption. But choosing where to focus efforts depends on knowing how the market works. For example, beans and lentils or other leguminous grains are key sources of improved nutrition that are often stored and traded over quite long distances, so productivity gains can be concentrated in locations where high and stable output is possible. In contrast, milk and eggs are perishables that are less easily transported in poor countries, so productivity gains should be more geographically dispersed year-round for nutrition and resilience to be improved.

In summary, priority-setting processes used by investment managers to reach nutrition and resilience objectives more quickly could involve a sequence of investment criteria such as the following:

1. **Is the investment likely to improve real and diversified incomes for those at risk?** Does it raise real incomes for the poorest households, especially those with young couples and children who are also most vulnerable to malnutrition and to shocks, so they can have increased and more stable earnings with less land, water or capital, and more caregiver time and money available to meet child nutrition needs?
2. **Is the investment likely to lower and stabilize the real cost of nutritious food?** Does it reduce the market price of staples, legumes, fruits & vegetables, milk, eggs, meat & fish, and improve their availability in remote markets where & when diets are worst?

3. **Is the investment likely to improve non-food influences on nutritional outcomes?** Does it reduce agriculture-related disease exposure, including sanitation and food safety concerns such as aflatoxin contamination, and also help empower women and other caregivers to meet their needs and care for others.

This sequence of questions corresponds to a hierarchy of needs in the sense that each kind of improvement usually equips people to reach the next goal on their own. For example, increased crop yield usually does lead to higher real income for farmers, lower prices for buyers, and more time for child care–but this is not always the case, so knowledge of local circumstances is needed to determine when geographic and other targeting is needed. This approach to prioritization could make agricultural research even more effective than it has been in the past, allowing its ultimate success to be measured not just by rising production and falling prices of basic commodities in major market centers, but by more precise indicators of poverty reduction, nutrition and resilience at times and places where improvements are most needed.

Annex 1: Annotated Bibliography

1. Poverty

Abass, A., Amaza, P., Bachwenkizi, B., Alenkhe, B., Mukuka, I., & Cromme, N. (2016). Adding value through the mechanization of post-harvest cassava processing, and its impact on household poverty in north-eastern Zambia. *Applied Economics Letters*, 1–5

Small scale cassava processing mechanization reduced number of people in poverty in regression analysis of survey data on farm households in Zambia.

Alene, A. D., & Coulibaly, O. (2009). The impact of agricultural research on productivity and poverty in sub-Saharan Africa. *Food Policy*, *34*(2), 198–209.

- Agricultural research reduces the poverty rate by 0.8% annually, based on (Alene & Coulibaly, 2009) and doubling investments in SSA would reduce the poverty rate by 9% annually. The CGIAR had a substantial role in the development of many modern varieties. Elasticities link agricultural research to productivity to GDP per capita and finally to poverty. A 1% increase in agricultural research expenditures would increase productivity by 38%; a 1% increase in productivity leads to a 96% increase in per capita incomes; a 10% increase in incomes would decrease the poverty rate by 6%; and 37% of the economic benefits to the poor through this pathway are attributed to agricultural research (Alene & Coulibaly, 2009).

Alene, A. D., Manyong, V. M., Tollens, E. F., & Abele, S. (2007). Targeting agricultural research based on potential impacts on poverty reduction: Strategic program priorities by agro-ecological zone in Nigeria. *Food Policy*, *32*(3), 394–412.

- Adopting new agricultural technologies results in income, yield, and cost changes where yield and cost changes shifts supply. The household-level simulation study in Nigeria by (Alene, Manyong, Tollens, & Abele, 2007), assumed a 50% increase in research expenditures, a 50% change in net yield, and a 100% technology use intensity. The study suggests the dry savannah region would benefit most from research efforts in the following agricultural commodities (expected poverty reduction rates in parenthesis): cowpea (3.820%); millet (2.468%); sorghum (2.276%); groundnut (1.596%); and livestock (3.496%) (Alene et al., 2007). In the moist savannah, focused research should be on (expected poverty reduction rates in parenthesis): maize (6.803%); yam (4.763%); and rice (3.821%) (Alene et al., 2007). In both the humid and moist savannah, cassava and yam with a 6.463% and 2.005% expected poverty reduction, respectively (Alene et al., 2007).

Alston, J. M., Martin, W. J., & Pardey, P. G. (2014). Influences of agricultural technology on the size and importance of food price variability. In *The economics of food price volatility* (pp. 13–54). University of Chicago Press. Retrieved from http://www.nber.org/chapters/c12804

- Cumulative world agricultural TFP growth over a 48-year period was 1.7% per year with total benefits of $3,658 billion and half of this is from public and private investments in agricultural R&D (Alston et al., 2014).
- On average, an individual in a low income country spends about 47% of their marginal income on food, whereas an individual in a rich country spends about 13% of their marginal income on food (Alston et al., 2014).
- If the annual U.S. public investment in agricultural R&D from the 1950s onward was 10% less

than it was, Americans would see a small decrease in average daily calorie consumption of food and therefore weight 1.75lb less, the cost of obesity would be $3.8 billion less, and $28.7 billion foregone benefits (Alston et al., 2014). Reducing agricultural R&D expenditure is not an effective way of reducing obesity due to R&D lags in realizing benefits, so any policy change would not affect prices, obesity, or consumption for two or three decades (Alston et al., 2014).

- A 1% increase in global agricultural productivity growth for 40 years would reduce the poverty rate by 7.6% (Alston, Martin, & Pardey, 2014). The simulation study by (Alston et al., 2014) looked at price shocks in food markets and how it would affect vulnerable groups under scenarios of high productivity growth and low productivity growth in various African, Latin American, and Asian countries. External price shocks in highly productive country scenarios decreased poverty by 0.15%, while the low productivity scenario increased the poverty rate by 1.56%, this shows that more productivity reduces sensitivity to price change. Productivity growth lowers real prices so that vulnerable households spend less of their income on food and these households become less dependent on agriculture for income so that higher productivity is poverty reducing.

Anderson, J. R. (1999). Poverty, land degradation and rural research policy. In *Proceedings of International Workshop Assessing the impact of Agricultural Research on Poverty Alleviation, San Jose, Costa Rica*. Retrieved from http://ciat-library.ciat.cgiar.org/paper_pobreza/018.pdf

- Descriptive study on the impacts of agricultural research on poverty reduction.

Anderson, J., & Roumasset, J. (1996). FOOD Insecurity and Stochastic Aspects of Poverty [MPRA Paper]. Retrieved January 25, 2017, from https://mpra.ub.uni-muenchen.de/13323/

- Descriptive study on the stochastic aspects of poverty.

Asfaw, S., Kassie, M., Simtowe, F., & Lipper, L. (2011). Poverty reduction effects of agricultural technology: A micro-evidence from Tanzania. *Food and Agricultural Organization of the United Nations, Agricultural Development Economics Division, Working Paper*. Retrieved from http://www.csae.ox.ac.uk/conferences/2011-EdiA/papers/304-Asfaw.pdf

- The adoption of improved pigeon pea varieties significantly decreases inequality (severity) of poverty in the range of 4.4–8.1 percentage points (Asfaw, Kassie, Simtowe, & Lipper, 2011). This technology adoption is constrained by lack of access of information and local seed supply, so there is a need for policy to support this adoption via extension services and technology promotion.

Bervejillo, J.E., J.M. Alston and K.P. Tumber. 2012. The benefits from public agricultural research in Uruguay. Austral. J. Agric. Resour. Econ. 56:475-497.

- Evaluated the INIA, the national agricultural research system of Uruguay and the internal rate of return (IRR) on public investments was between 23 to 27% per year for agricultural R&D.

Byerlee, D. (2000). Targeting poverty alleviation in priority setting for agricultural research. *Food Policy*, *25*(4), 429–445. https://doi.org/10.1016/S0306-9192(00)00021-X

- Descriptive study.

Byerlee, D., & Alex, G. (2003). Designing investments in agricultural research for enhanced poverty impacts. The World Bank.

- Median rates of return: Africa 34, Asia 50, Latin America 43, Middle East/North Africa 36, All developing countries 43, All developed countries 46, All 44 (Byerlee & Alex, 2003).

Byerlee, D., Diao, X., & Jackson, C. (2005). Agriculture, rural development, and pro-poor growth: Country experiences in the post-reform era. *Agriculture and Rural Development Discussion Paper*, *21*, 1–72.

- Descriptive study on pro-poor agricultural research.

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- Findings from time-series, cross-section regression analysis reveal that while economic growth generally was an important contributor to poverty reduction, the sector mix of growth mattered substantially, with growth in agricultural incomes being especially important.

Christiaensen, L., Demery, L., & Kuhl, J. (2010). The (evolving) role of agriculture in poverty reduction. *UNU-WIDER, Working Paper*, (2010/36). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.631.2768&rep=rep1&type=pdf

- Investments should be made in the agriculture sector, especially for the $1 per day poverty measure, because it is about 3.2 times better at poverty reduction than investments in non-agriculture sectors (Christiaensen, Demery, & Kuhl, 2010). Growth in staple foods seem to have more of an impact that export commodities.

Dethier, J.-J., & Effenberger, A. (2012). Agriculture and development: A brief review of the literature. *Economic Systems*, *36*(2), 175–205. https://doi.org/10.1016/j.ecosys.2011.09.003

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- Simulation study in Africa.

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- SSA 37 countries, 20 crops, 1970 to 2010. Adoption has a major impact on productivity as does CG R&D but not NARS R&D. If improved food crop varieties increased from 0 to 100%, then TFP would increase by 47%.

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- Every $1 spent on agricultural R&D has given returns of $3 to $5 in benefits for large and mid-sized African countries (Fuglie & Rada, 2012). The CGIAR has been a key player in increasing agricultural productivity growth in SSA and has generated an internal rate of return (IRR) of 58% per year or $6 in benefits per $1 in expenditures.

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- 87 countries TFP. Public R&D and Education and extension influence productivity. Research prior to 2000 found that productivity growth in developed countries outpaced that of developing countries, however, post-2000 the TFP growth in developed, developing, and countries in transition are all about 2% per year.
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- This article uses data from 27 private companies and 9 public organizations focusing on tomato and chili pepper breeding. The study found that 61 tomato and 39 chili pepper hybrids contain "World Vegetable Center materials" in its genealogy and represent 14% and 13% of the seeds in the tomato and chili pepper markets, respectively. This potentially reaches half a million farmers in India.

Hurley, T. M., Rao, X., & Pardey, P. G. (2014). Re-examining the reported rates of return to food and agricultural research and development. *American Journal of Agricultural Economics*, aau047.

- Rates of return for investments in agricultural R&D have been reported by many studies as being high across all research and commodity categories, this is despite the decrease in public R&D spending over the years and a decline in food prices from the spike in 2010-2012. These high rates of return are seen with caution because extending these returns to 2050 shows astronomical returns that are simply unlikely. For example, from 2000 with $4.1 billion spent on agricultural R&D spending from the USDA and state experiment stations, and with a 59.8% IRR projects a worth of $56.3 quintillion in 2050. And using a lower rate, 37.3% still gives a value of $31.4 quadrillion in 2050.

Ivanic, M., & Martin, W. (2010). Poverty impacts of improved agricultural productivity: Opportunities for genetically modified crops. AgBioForum, 13(4), 308–313.

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Johnson, M., Masters, W., & Preckel, P. (2006). Diffusion and spillover of new technology: a heterogeneous-agent model for cassava in West Africa. *AGRICULTURAL ECONOMICS*, *35*(2), 119–129.

- Adopting new cassava varieties in the Ivory Coast reduced the number of farmers producing under $10 per year from 20% to under 10% of the sampled households

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- Useful review of 13 impact studies of research and other interventions by international center involved in livestock research

Kaitibie, S., Omore, A., Rich, K., & Kristjanson, P. (2010). Kenyan dairy policy change: Influence pathways and economic impacts. World Development, 38(10), 1494–1505.

●This study examined the impact of ILRI's Smallholder Dairy Programme (SDP) in Kenya, which aimed at liberalizing informal milk marketing in Kenya and documenting the policy processes associated with the intervention. An interesting innovation of this study was in its attempt in quantifying policy processes, and assessing different counterfactual scenarios relatedto delays in policy implementation. This paper used an economic surplus model to compute economic benefits, with shifts in the supply curve in milk markets attributed to policy change dynamics. The authors reported a baseline net present value of USD 230 million over 1997-2039 and an IRR of 55%. Methodologically, this paper makes strong contributions in trying to frame policy change in a quantitative context, although future research will be needed to more finely tease out and attribute specific policy changes to intervention benefits.

Kassie, M., Shiferaw, B., & Muricho, G. (2011). Agricultural technology, crop income, and poverty alleviation in Uganda. *World Development*, *39*(10), 1784–1795.

- Adopters of improved groundnut varieties (new technology) in Uganda see 35% increases in yield (from 649 to 873 kg/ha), higher surplus (200kg) than non-adopters (62kg), 41% cost reduction (from 1114 to 655 UGX per kg), increases labor by 56 days per hectare, increases household income by about US$130 to $254, and reduces poverty by 7-9 percentage-points (Kassie, Shiferaw, & Muricho, 2011)

Khan, H., & Shah, M. (2012). Irrigation, Farm Productivity and Poverty Reduction in KPK: Understanding Direct and Indirect Impacts and Linkages. *Procedia Economics and Finance*, *2*, 292–298. https://doi.org/10.1016/S2212-5671(12)00090-1

- Irrigation has benefited the poor through higher agricultural productivity; higher yields increased cropping intensity, increased income, consumption and savings as well as higher farm and off- farm employment. The indirect linkages operate via regional, national and economy–wise effect.

Larochelle, C., Alwang, J., Norton, G.W., Katungi, E., Labarta, R.A. 2015. Impacts of Improved Bean Varieties on Poverty and Food Security in Uganda and Rwanda. In Thomas S. Walker and Jeffrey Alwang (Eds), *Crop Improvement, Adoption and Impact of Improved Varieties in Food Crops in Sub-Sahara Africa* (pp. 314-337). Boston, MA: CGIAR – CABI.

- Small impact of improved beans on poverty. 0.4% reduction in Rwanda and 0.1% in Uganda (which has a small area planted with beans & beans are a small part of diet)

Liebenberg, F., Pardey, P. G., & Kahn, M. (2011). South African agricultural R&D investments: Sources, structure, and trends, 1910–2007. Agrekon, 50(2), 1–26.

Masters, W. A., Bedingar, T., & Oehmke, J. F. (1998). The impact of agricultural research in Africa: aggregate and case study evidence. *Agricultural Economics*, *19*(1), 81–86.

- Reviews the impact of agricultural research in Africa.

McMillan, M. S., & Masters, W. A. (2003). An African Growth Trap: Production Technology and the Time-Consistency of Agricultural Taxation, R&D and Investment. *Review of Development Economics*, *7*(2), 179–191. https://doi.org/10.1111/%28ISSN%291467-9361/issues

- Explains why low R&D for tree crops relative to annual crops

Mendola, M. (2007). Agricultural technology adoption and poverty reduction: a propensity-score matching analysis for rural Bangladesh. *Food Policy*, *32*(3), 372–393.

- Found that the adoption of rice HYVs had a positive effect on farm household income, such that HYV adopters are better off than non-adopters and receive almost twice the income.

Minten, B., & Barrett, C. B. (2008). Agricultural Technology, Productivity, and Poverty in Madagascar. World Development, 36(5), 797–822. https://doi.org/10.1016/j.worlddev.2007.05.004

- In Madagascar, 10 to 60% of improved productivity of rice welfare gains were captured by farmers. Cash crops such as cloves and vanilla may be labor intensive but they do result in higher real wages for rural farmers.

Moyo, S., Norton, G. W., Alwang, J., Rhinehart, I., & Deom, C. M. (2007). Peanut research and poverty reduction: Impacts of variety improvement to control peanut viruses in Uganda. *American Journal of Agricultural Economics*, *89*(2), 448–460.

- The ex ante impact analysis of adopting Rosette-resistant seed varieties by peanut producers households in Eastern Uganda. The poverty severity index falls 2% with this full adoption of the new varieties, which represents a 10.5% decline in poverty severity (Moyo et al., 2007). As adoption increases, the poverty gap falls so that more households are moved out of poverty. Research benefits from Rosette-resistant peanut seed adoption are calculated, at 3%, 5% and 7% discount rates, to be $47 million, $38.8 million and $32.3 million, respectively. Effort needs to be made to help stimulate the adoption of new technology by the low-income producers.

Newman, K. (2014). *What is the evidence on the impact of research on international development*. London: DFID.

Norton, G.W., Alwang, J. and Masters, W.A., 2014. *Economics of Agricultural Development: World food systems and resource use*. Routledge, 3rd ed.

- Standard textbook describing the process of agricultural transformation over time. Chapter 12 focuses on agricultural research.

Oehmke, J. F., Jayne, T. S., Aralas, S. B., Mathenge, M., & others. (2010). Impacts of USAID/Kenya supported agricultural productivity interventions on household income and poverty reduction. *Unpublished Manuscript. Michigan State University and Tegemeo Institute (Kenya)*.

- Three USAID/Kenya interventions to reduce poverty in Africa are discussed.

Oehmke, J.F., T.S. Jayne, S.B. Aralas and M. Mathenge. Impacts of USAID/Kenya supported agricultural productivity interventions on household income and poverty reduction. Michigan State University and Tegemeo Institute for Agricultural Policy Research, 2010.

- USAID-supported activities improved smallholder farmers incomes to reduce poverty.

Pal, S. (2011). Impacts of CGIAR Crop Improvement and Natural Resource Management Research: A Review of Evidence. *Agricultural Economics Research Review*, *24*(2), 185–200.

Table 2. Summary of important crop research impact assessment studies

Study	Technology	Region	Study period	Type of analysis	Benefits
Lantican, Dubin and Morris (2005)	Wheat breeding research	Global	1988-2002	Value of additional wheat production	• Annual benefits US$ 2-6.1 billion (2002 dollars) • Benefits attributable to CIMMYT US$ 0.5-1.5 billion annually with a B-C ratio of 50 (most conservative estimate)
Hossain, Gollin, Cabanilla, Cabrera, Johnson, Khush and McLaren (2003)	Rice breeding research	Asia and Latin America	1965-1999	Net yield gains based on field-level data	• Yield gain of 0.94 t/ha (or US$ 150/ha) with annual gains of US$ 10.8 billion in South Asia and South-East Asia • Annual benefits US$ 500 million for Latin America • Significant increase in rice yield per day and tolerance to biotic stress
Zeddies, Schaab, Neuensch-wander and Herren (2001)	Biological control of cassava mealybug	Africa	1974-2013	Value of crop loss reduction, or saving of alternative crop i.e. maize	• Cassava loss reduction of US$ 26/ha with a total yearly gain of US$ 235 million (1994); B-C ratio of 199 • B-C ratio 170 with an yearly saving of US$ 200 million (1994) worth of maize • Benefits are much higher if the losses are compensated through cassava or maize imports
Morris, Mekuria and Gerpacio (2003)	Maize breeding research	Global	Late 1990s	Value of additional production	• Annual gains due to germplasm improvement US$ 668 million to US $ 2.0 billion • Annual benefits due to CIMMYT germplasm in the range of US$ 557 million to US $ 770 million
Aw-Hassan and Shideed (2003)	Barley germplasm improvement	Global	1980-2000	Economic surplus	• Annual gross research benefits US$ 92 million in 1997 • IRR 32 per cent

Pardey, P. G., Andrade, R. S., Hurley, T. M., Rao, X., & Liebenberg, F. G. (2016). Returns to food and agricultural R&D investments in Sub-Saharan Africa, 1975–2014. *Food Policy*, *65*, 1–8.

- The average IRR to agricultural research in SSA observed over 113 studies from 1975-2014 is $42.3% per year.

Piesse, J., & Thirtle, C. (2010). Agricultural R and D, technology and productivity. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 3035–3047.

https://doi.org/10.1098/rstb.2010.0140

- Developing countries have prospects of agricultural productivity growth if they have the right technological capacity and infrastructure.

Pingali, P., & Kelley, T. (2007). Chapter 45: The Role of International Agricultural Research In Contributing To Global Food Security And Poverty Alleviation: The Case Of The CGIAR. In *Handbook of Agricultural Economics, Volume 3: Agricultural Development: Farmers, Farm Production & Farm Markets* (p. 2381).

- Review of other studies.

Pray, C., Rheeder, J., Gouse, M., Volkwyn, Y., van der Westhuizen, L., & Shephard, G.S. (2013). Bt maize and fumonisin reduction in South Africa: potential health impacts. In J. Falck-Zepeda, G. Gruere and I.Sithole-Niang. (eds) *Genetically modified crops in Sub-Saharan Africa: Lessons from Economic and Policy Research.* Washington DC: IFPRI. Pp 43 –59.

Study shows reduced the levels of the mycotoxin fumonisin in insect-resistant corn grown by small farmers in KwaZulu Natal. This is linked to current exposure levels by farmers and rural consumers and the levels of birth defects and cancer that are associated with these levels of fumonisin. The authors then project how much of a reduction in fumonisin exposure would take place if poor farmers grew insect resistant corn.

Rada, N., S, T. Buccola K. O. Fuglie Government Policy and Agricultural Nicholas E. Productivity in Indonesia Am J Agric Econ (2011) 93 (3): 867-884.

- They use a 1985–2005 provincial panel dataset together with a stochastic output distance frontier framework to examine how government policies have affected the nation's agricultural productivity, decomposing it into its technical progress and efficiency components. Government's primary contributions to technology growth have come through price and trade policies rather than public research. Most technology growth, however, appears to be due to informal technology diffusion.

Rada, N., & Valdes, C. (2012). Policy, technology, and efficiency of Brazilian agriculture. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2112029

- EMBRAPA’s R&D explains much of TFP growth in Brazil.

Raitzer, D. A., & Maredia, M. K. (2012). Analysis of agricultural research investment priorities for sustainable poverty reduction in Southeast Asia. Food Policy, 37(4), 412–426.

- In Southeast Asia, research resources may be under-invested due to the fact that only one tenth of national expenditures are for productivity improvements in rice, even though it provided more than one-third of projected benefits to poor.

Raitzer, D. A., Sparks, A. H., Huelgas, Z. M., Maligalig, R., Balangue, Z., Launio, C., … Ahmed, H. U. (1989). Is rice improvement still making a difference. *Assessing the Economic, Poverty, and Food Security Impacts of Rice Varieties Released from*.

- Quantifies the economic benefits from improvements in crop genetics for pro-poor growth.

Renkow, M., & Byerlee, D. (2010). The impacts of CGIAR research: A review of recent evidence. *Food Policy*, *35*(5), 391–402.CGIAR research on genetic research have shown the most promising positive pro-poor impacts from international agricultural R&D.

- Summarizes benefits to the poor from plant breeding, by multiple studies.

Rich, K. M., Roland-Holst, D., & Otte, J. (2014). An assessment of the ex-post socio-economic impacts of global rinderpest eradication: Methodological issues and applications to rinderpest control programs in Chad and India. Food Policy, 44, 248–261.

Uses new models of the diffusion of disease to develop counterfactuals to the action diffusion with rinderpest eradication programs. These programs had high benefit cost ratios in all scenarios in Chand and even high benefit cost ratios in India in most scenarios.

Rosegrant, M., & E. (2016). Quantitative Foresight Modeling to Inform the CGIAR Research Portfolio. Unpublished report by IFPRI to USAID.

- Based on major simulation project with input from all CGIAR center, this study compares impacts of CGIAR research and National Agricultural Research Organizations with investments in irrigation, water storage, and infrastructure and finds that research is more effective at increasing income, reducing poverty and greenhouse gas emissions.

Schreinemachers, P., Rao, K. P. C., Easdown, W., Hanson, P., & Kumar, S. (2016). The contribution of international vegetable breeding to private seed companies in India. *Genetic Resources and Crop Evolution*, 1–13.

- The share of mungbean prevalence has increased compared to other pulses and beans. Mungbean appears to be a profitable investment because of the high IRR, ranging in the sensitivity analysis based on the reduction of production costs for farmers due to adoption of new improved varieties. The IRR ranges from 119.9% to 80.4% for a 25% to 10% reduction in costs, respectively.

Schreinemachers, P., Sequeros, T., & Lukumay, P. J. (2017). International research on vegetable improvement in East and Southern Africa: Adoption, impact and returns. *Agricultural Economics*.

- Reported as of 2014 in Tanzania, crop improvement investments created economic benefits of $255 million and eggplant $5 million for tomato and African eggplant, respectively. The IRR for tomato and African eggplant are 26% and 12%, respectively, with the eggplant projected to increase to 26% by 2024 due to the newly released (2007) varieties delayed benefits. High returns are expected for investments in nutritional challenges.

Suphannachart, W., & Warr, P. (2011). Research and productivity in Thai agriculture. *Australian Journal of Agricultural and Resource Economics*, *55*(1), 35–52.

- The rate-of-return (ROR) to public investment in agriculture research and commodity research investments is about 30% which is above the opportunity cost of public funds and thus implies underinvestment in research.

Thirtle, C., & Piesse, J. (2007). Governance, agricultural productivity and poverty reduction in Africa, Asia and Latin America. *Irrigation and Drainage*, *56*(2–3), 165–177. https://doi.org/10.1002/ird.310

- Agriculture growth is key to poverty reduction; especially since R&D expenditures are relatively low cost for the benefit provided. In Africa and Asia, increased in yield from R&D increases per capita incomes by 73% and 67%, respectively (Thirtle & Piesse, 2007).

Thirtle, C., Lin, L., & Piesse, J. (2003). The impact of research-led agricultural productivity growth on poverty reduction in Africa, Asia and Latin America. *World Development*, *31*(12), 1959–1975.

Walker, T., Ryan, J., & Kelley, T. (2010). Impact Assessment of Policy-Oriented International Agricultural Research: Evidence and Insights from Case Studies. *World Development*, *38*(10), 1453–1461. https://doi.org/10.1016/j.worlddev.2010.06.005

- Descriptive study on evidence of agricultural research impacts.

Zeng, D., Alwang, G.W., Shiferaw, Norton B., Jaleta, M., Yirga, C. 2015. Maize Technologies and Rural Poverty Reduction in Ethiopia. In Thomas S. Walker and Jeffrey Alwang (Eds), *Crop Improvement, Adoption and Impact of Improved Varieties in Food Crops in Sub-Sahara Africa* (pp. 294-313). Boston, MA: CGIAR – CABI.

- 0.8-1.3% decline in poverty due to adoption, poor benefitted least because small land holdings

2. Nutrition

Balagamwala, M., & Gazdar, H. (2013). Agriculture and nutrition in Pakistan: Pathways and disconnects. *IDS Bulletin*, *44*(3), 66–74.

- Despite economic growth, Pakistan experiences high rates of undernutrition, similar to that of the "South Asian paradox." Agriculture employs 45% of workers in Pakistan.

Barnwall, P., Dar, A., Goltz, J., Fishman, R., McCord, G., & Mueller, N. (n.d.). The Green Revolution and Infant Mortality: Evidence from 600,000 Births.

- PNAS - showed that higher Modern Varieties (MV) use reduces the infant mortality rate. A 14% increase in the amount of MVs would hypothetically reduce the IM from the sample mean of 10% to 9%. Areas where 50% of the crops are MVs, the IM if 2.7% lower than places with no MVs. The effect on nutrition is 5 times larger in Latin America and 8 times larger in the Middle East & North Africa (MENA) than in SSA. In MENA, discrimination between male and female babies brings about the bias to allocate more resources to the male babies, so especially pronounced in MENA, the male babies have better nutrition than the female babies. For both male and female children, higher MV use in their country of origin is associated with a reduced likelihood of infant mortality (IM). Fifty percent more MV use in a country results in a 2.7% reduction in IM risk. Male babies had a lower IM rate than female babies, probably due to discrimination with allocating scarce resources to male babies.

Benfica, R., Kilic, T., & others. (2015). The Effects of Smallholder Agricultural Involvement on Household Food Consumption and Dietary Diversity: Evidence from Malawi. In *2015 Conference, August 9-14, 2015, Milan, Italy*. International Association of Agricultural Economists. Retrieved from http://ageconsearch.umn.edu/bitstream/211218/2/Benfica-The%20Effects%20of%20Smallholder%20Agricultural%20Involvement-89.pdf

- Agricultural involvement in the household has an effect on diet and consumption in rural Malawi. On-farm incomes increases of 10% increases consumption by 2.9%, calorie per capita per day by 1.7% and diversifies diets (Benfica, Kilic, & others, 2015). Energy dense and low protein cereal and grains consumption increases while roots/tubers, vegetables/fruits, oils/fats, and meat/fish/milk consumption decreases with increased income. Nuts/pulses and sugars were not significant in this study. Income diversification could impact nutritional diversification because higher income households rely less on agriculture as a sole source of income and can purchase other foods in markets.

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., De Onis, M., … others. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet*, *382*(9890), 427–451.

    - Summarizes information in low and middle income countries on maternal and child malnutrition, nutrient deficiencies, and obesity

Chagunda, M. G., Mwangwela, A., Mumba, C., Dos Anjos, F., Kawonga, B. S., Hopkins, R., & Chiwona-Kartun, L. (2016). Assessing and managing intensification in smallholder dairy systems for food and nutrition security in Sub-Saharan Africa. *Regional Environmental Change*, *16*(8), 2257–2267.

- In Sub-Saharan Africa (SSA), smallholder farmers are key in the dairy value chain; 3 technological approaches (ecological, genetic, and socio-economic intensification) have been used to improve productivity.

Christides, T., Amagloh, F. K., & Coad, J. (2015). Iron Bioavailability and Provitamin A from Sweet Potato- and Cereal-Based Complementary Foods. *Foods*, *4*(3), 463–476.

- Cream-flesh sweet potato ComFa and orange-flesh sweet potato ComFa do not seem to be a good source of iron but they might be a good for Vitamin A uptake in diets due to beta-carotene.

Darrouzet-Nardi, A.F. and Masters, W.A., 2017. Nutrition Smoothing: Can Proximity to Towns and Cities Protect Rural Children against Seasonal Variation in Agroclimatic Conditions at Birth? PLOS ONE, 12(1), p.e0168759.

- Identifies resilience within rural areas conferred by transformation of agrifood systems associated with proximity to towns and cities.

Dawe, D., Robertson, R., & Unnevehr, L. (2002). Golden rice: what role could it play in alleviation of vitamin A deficiency? *Food Policy*, *27*(5), 541–560.

- Golden rice should either be used in complement to existing vitamin A fortification interventions and be widespread throughout Asia in order to meet dietary needs. Under certain circumstances, golden rice is a cost-effective option to increasing vitamin A uptake.

Gillespie, S., Hodge, J., Yosef, S., & Pandya-Lorch, R. (2016). *Nourishing millions: Stories of change in nutrition*. Intl Food Policy Res Inst.

- Chapter 6: From the Ground Up, Cultivating Agriculture for Nutrition by Sivan Yosef: Biofortified crops could help improve nutritional status. Iron-biofortified rice and beans consumed in the Philippines increases iron intake by 20%. Distribution of biofortified orange sweet potatoes have been successful in improving vitamin A intake in Mozambique and Ugand. In Mozambique, the prevalence and duration of diarrhea decreased due to this biofortification. Zambia would save US$24 per DALY (disability-adjusted life year) by adopting biofortified orange maize. A review of 18 studies have shown improvements in weight, on average 0.39 kilograms over a 19-month period due to interventions. HFP together with educational programs with a focus on including women could bring about more positive impacts than home gardening interventions.
- Chapter 7: Social Protection and Nutrition by Scott Drimie and Sivan Yosef: Targeting mothers rather than fathers in nutrition improvement programs seems to have a better overall effect on improving child nutritional status. Providing food supplements and cash transfer could help improve the ability to access and increase food intake of nutritious foods such as: meat, eggs, dairy, fruit and vegetables. Behavior change communication should be combined with increased access to nutritious foods in order have the most impact. Children between 12 and 36 months old had increased growth rates when receiving aid from nutrition programs than their peers but the amount of biofortified food provided was too low to be the main reason why this improvement occurred. The PSNP (Productive Safety Net Program) in Ethiopia reached 8 million vulnerable and food insecure people in 2011 resulting in a decrease of food insecurity; helped mitigate the impact of external shocks; improved the diet of 75% of the participants; and helped participants consume 1,800 or more calories per day. Doubling cash transfers helped increase childhood growth, reduce stunting and obesity, and enhanced intake of meat and fresh produce. Chars Livelihoods Program gave very poor women in households in Bangladesh money to spend

on food and after 10 weeks their children were taller, weighed more, and had a larger upper-arm circumference than their peers.
- Chapter 10: Local to National, Thailand's Integrated Nutrition Program by Stuart Gillespie, Kraisid Tonisirin and Laura Zseleczky: Thailand's national nutrition program is seen as one of the most successful national programs. Child growth, weight, and increased iron intake among pregnant women were just a few of the successes.
- Chapter 12: Getting To Specifics, Bangladesh's Evolving Nutrition Policies by Peter Davis, Nicholas Nisbett, Nazneen Akhtar, and Sivan Yosef: Households in Bangladesh are dependent on dry cereals for much of their caloric intake and the food spikes of 2008 and 2013/2014 made it even harder for households to have adequate nutritional intake.

Haddad, L., Achadi, E., Bendech, M. A., Ahuja, A., Bhatia, K., Bhutta, Z., … others. (2015). The global nutrition report 2014: actions and accountability to accelerate the world's progress on nutrition. *The Journal of Nutrition*, *145*(4), 663–671.
- IFPRI research: This article summarizes the results from the first Global Nutrition Report (GNR) in 2014 discussing global malnutrition.

Harvey, M., Dangour, A., Lambert, R., Alemu, M., Ashton-Griffiths, E., Green, T., Lang, Z., Maini, R., Mayer, H., Philpott, A., Spink, P., Taylor, A. (2014). Can agriculture interventions promote nutrition? Agriculture and nutrition evidence paper. *Can agriculture interventions promote nutrition? Agriculture and nutrition evidence paper,* DFID 1-70.
- This paper provides a critical review of the strength and quality of the evidence base linking agriculture-based interventions and nutrition outcomes. In total, 38 studies published over the period 1980-2013 are included: 15 on home gardens, five on aquaculture, six on livestock, eight on cash crops and eight on biofortified crops (some studies address more than one intervention). The evidence base is derived roughly equally from Africa and Asia with one study from Latin America.
- Home garden interventions, aquaculture interventions, livestock interventions, cash cropping, all have inconsistent effects on childhood growth. Home gardens have an inconsistent effect on micronutrient status; aquaculture interventions have a mixed effect on maternal iron outcomes; and livestock on farms shows no evidence of an effect on micronutrient status. Biofortified crops have a positive effect on improving micronutrient status in children, a mixed effect on micronutrient status in women, and some evidence on positively improving growth.

Headey, D. D., & Hoddinott, J. (2016). Agriculture, nutrition and the green revolution in Bangladesh. *Agricultural Systems*, *149*, 122–131. https://doi.org/10.1016/j.agsy.2016.09.001
- This review tried to link growth in rice yields to nutrition in Bangladesh with district level panel. Yield changes were driven by IRRI rice varieties and investments in irrigation. Not much evidence on staples productivity and nutrition are in the literature currently.
- Investments in staple foods helped to reduce food deprivation of 42% in 1990-1992 to 27% in 2010-2012 in Bangladesh.

Herforth, A., & Ahmed, S. (2015). The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. *Food Security*, *7*(3), 505–520.
- Increasing income, food availability and reducing food prices could help to increase nutrition in certain environments. The main conclusion across the literature is that own-price elasticities

have more of an effect than cross-price elasticities on the impact for food consumption of certain food groups – meaning that the best way to improve diets by diversification is through the reduction of food prices. If staple grain prices decrease, households will have more real income, which will lead to increased diet diversification including animal-source food (ASF), and consumption of junk food in certain areas. The 4 factors that impact consumption are: availability, affordability, convenience, and desirability of food. Income may have negative effects on health due to increased ability to consume junk food, where individuals also become more susceptible to obesity and weight-related diseases. Improving food environments is key going forward.

Herforth, A., & Ballard, T. J. (2016). Nutrition indicators in agriculture projects: Current measurement, priorities, and gaps. *Global Food Security*, *10*, 1–10.

- Maternal and child health nutrition (MCHN) programs realized a 2.4% reduction in stunting, so if implemented properly, agriculture-nutrition programs could reduce stunting by 20% within 5 years.

Hetherington, J. B., Wiethoelter, A. K., Negin, J., & Mor, S. M. (2017). Livestock ownership, animal source foods and child nutritional outcomes in seven rural village clusters in Sub-Saharan Africa. *Agriculture & Food Security*, *6*(1), 9.

- One of few studies that provides a descriptive analysis for SSA in regards to relationship links between livestock ownership, ASF consumption and changes in child nutrition status.
- Provitamin A carotenoid-biofortified maize reduced diarrhea and orange sweet potato enhanced pupillary performance in children. These types of interventions to improve nutritional status come in the form of single micronutrients in certain crops. Multiple studies show that if a household has livestock, dairy cattle, or a certain crop, then that household tends to consume more of the commodity than non-owners. However, this study clustered village data in several African countries to find that there was no significant association in ASF consumption and nutrition status improvement among children (Hetherington et al., 2017). It is possible that this pathway is effective in improving nutrition but needs to be explored further.

Hotz, C., Loechl, C., de Brauw, A., Eozenou, P., Gilligan, D., Moursi, M., … Meenakshi, J. V. (2012). A large-scale intervention to introduce orange sweet potato in rural Mozambique increases vitamin A intakes among children and women. *British Journal of Nutrition*, *108*(01), 163–176.

- In Mozambique, orange sweet potato has been shown to improve nutritional vitamin A status in infants, children, and women in this randomized, controlled effectiveness study. Household level orange sweet potato production and consumption were promoted for 1 and 3 year time periods. For infants, children, and women their orange sweet potato intake was 46, 48, and 97 g/d and their vitamin A intakes were 263, 254, and 492 retinol activity equivalents per day. Eighty-percent of Vitamin A intake comes from orange sweet potato.

Hotz, C., Loechl, C., Lubowa, A., Tumwine, J. K., Ndeezi, G., Masawi, A. N., … others. (2012). Introduction of β-carotene–rich orange sweet potato in rural Uganda resulted in increased vitamin A intakes among children and women and improved vitamin A status among children. *The Journal of Nutrition*, *142*(10), 1871–1880.

- Two-year intervention programs in Uganda were effective in increasing vitamin A intake amount infants, young children, and women. This was a randomized, controlled effectiveness study.

- Children have an improved vitamin A status. Rural farmers were willing to substitute one-third of their sweet potato intake for the orange sweet potato and during the follow-up represented 44 to 60% of their Vitamin A intake. In children, there was a 9.5% decrease in observed serum-retinol.

Kadiyala, S., Harris, J., Headey, D., Yosef, S., & Gillespie, S. (2014). Agriculture and nutrition in India: mapping evidence to pathways. *Annals of the New York Academy of Sciences*, *1331*(1), 43–56.

- Indian agriculture development can improve nutrition.

Kanter, R., Walls, H. L., Tak, M., Roberts, F., & Waage, J. (2015). A conceptual framework for understanding the impacts of agriculture and food system policies on nutrition and health. *Food Security*, *7*(4), 767–777.

- This article creates a synthesis conceptual framework, based on 37 conceptual frameworks that were reviewed by the authors, to link agriculture and food systems to nutritional outcomes and health. This is for low, middle, and high income areas and the framework is intended to help guide policy makers who want to analyze the direct and indirect impacts of agricultural policies.

Low, J. W., Arimond, M., Osman, N., Cunguara, B., Zano, F., & Tschirley, D. (2007). A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. *The Journal of Nutrition*, *137*(5), 1320–1327.

- After 2 years of the nutritional program in Mozambique, 90% of households produced orange sweet potato and mean plot area increased from 33 to 359 m^2 and children in the program consumed orange sweet potato 3 or more days in the previous week compared to non-program households. Program household children had sufficiently higher vitamin A; median 426 µg retinol activity equivalent verses 56µg in non-program households. Mean serum retinol increased 0.100 µmol/L. orange sweet potato would have the best results if used in combination with other intervention methods in SSA.

Maestre, M., Poole, N., & Henson, S. (2017). Assessing food value chain pathways, linkages and impacts for better nutrition of vulnerable groups. *Food Policy*, *68*, 31–39.

Box 2. Agriculture–nutrition pathways in India

1. **Agriculture as a source of food:** Farmers produce for own consumption.
2. **Agriculture as a source of income for food and nonfood expenditures:** As a major direct and indirect source of rural income, agriculture influences diets and other nutrition-relevant expenditures.
3. **Agricultural policy and food prices:** Agricultural conditions can change the relative prices and affordability of specific foods and foods in general.
4. **Women in agriculture and intrahousehold decision making and resource allocation** may be influenced by agricultural activities and assets, which in turn influences intrahousehold allocations of food, health, and care.
5. **Maternal employment in agriculture and child care and feeding**: A mother's ability to manage child care may be influenced by her engagement in agriculture.
6. **Women in agriculture and maternal nutrition and health status:** Maternal nutritional status may be compromised by the often arduous and hazardous conditions of agricultural labor, which may in turn influence child nutrition outcomes.

Masters, W. A., Webb, P., Griffiths, J. K., & Deckelbaum, R. J. (2014). Agriculture, nutrition, and health in global development: typology and metrics for integrated interventions and research. *Annals of the New York Academy of Sciences*, *1331*(1), 258–269.

- Review of research methods/conceptual frameworks to help design multisector interventions in order for researchers to use the best method for their project.

Masters, W.A. (2016), Economic Causes of Malnutrition, pages 92-1-4 in *Good Nutrition: Perspectives for the 21st Century.* Karger (www.karger.com/Article/Pdf/452378)
Mayne, J., & Johnson, N. (2015). Using theories of change in the CGIAR Research Program on Agriculture for Nutrition and Health. *Evaluation*, *21*(4), 407–428.

- This article reviews evidence-based theories of change as tools in the CGIAR Research Program on agriculture for nutrition and health.

Merrey, D. J. (2014). *An evaluation of CGIAR centers' impact assessment work on irrigation and water management research*.

- A few reasons for the lack of impact assessments on CGIAR in livestock-related research are: underinvestment in impact studies; time lag in realizing beneficial impacts; difficulty in parsing out the allocation of CGIAR's role in impacts; and statistical challenges in quantifying complex systems.

Nguema, A., Norton, G. W., Fregene, M., Sayre, R., Manary, M., & others. (2011). Expected economic benefits of meeting nutritional needs through biofortified cassava in Nigeria and Kenya. *African Journal of Agricultural and Resource Economics*, *6*(1), 70–86.

- Biofortified cassava was found as a better alternative to increase Vitamin A and iron in diets in Nigeria and Kenya than other types of interventions. Consumption of biofortified cassava is also more cost effective than "direct dietary supplementation" for iron and Vitamin A.

Reinsma, K., Nkuoh, G., & Nshom, E. (2016). The potential effectiveness of the nutrition improvement program on infant and young child feeding and nutritional status in the Northwest and Southwest regions of Cameroon, Central Africa. *BMC Health Services Research*, *16*(1), 654.

- The Nutrition Improvement Program (NIP) was implemented and children were 7 times more likely to be breastfed in NIP sites than non-NIP sites (Reinsma, Nkuoh, & Nshom, 2016). Children were 5 times more likely to be stunted in non-NIP sites (Reinsma et al., 2016). So, caregivers who are given nutrition counseling are more likely to breastfeed their child and those children are less likely to be stunted.

Shanmugasundaram, S., Keatinge, J. D. H., & d Arros Hughes, J. (2009). The mungbean transformation diversifying crops, defeating malnutrition (Vol. 922). Intl Food Policy Res Inst.

- Mungbean consumption will be key in Asia for a secure and sustainable future. This will come slowly but mungbean research should continue.

Somanathan, A., & Mahmud, I. (2008). *Multisectoral approaches to addressing malnutrition in Bangladesh: The role of agriculture and microcredit*. World Bank Washington, DC.

- Cross-country, national level analysis, results show that a 1% increase in agricultural yields lowers the $1-per-day poverty between 0.64 and 0.91%. This World Bank report uses evidence from Bangladesh and other countries to see the impact on malnutrition and which programs/policies may reach vulnerable groups to reduce inequalities in nutrition. Some of the policy recommendations made by the report were: certain agricultural and microcredit programs are better suited for nutrition components than others; targeting microcredit programs that women would be involved in and increase their incomes; empowerment of women; participatory learning should be incorporated, especially for women, in nutrition and microcredit programs; local-level needs should be met; nutrition interventions should be combined with microcredit and "safety net" programs to reach the poorest.

Stein, A. J., Sachdev, H. P. S., & Qaim, M. (2008). Genetic engineering for the poor: Golden Rice and public health in India. *World Development*, *36*(1), 144–158.

- Ex ante evaluation of golden rice consumption in India predicts that vitamin A deficiency could be halved due to consumption and it would be a cost-effective solution.

Steyn, N. P., & Mchiza, Z. J. (2014). Obesity and the nutrition transition in Sub-Saharan Africa. *Annals of the New York Academy of Sciences*, *1311*(1), 88–101.

- Review of obesity trends in SSA countries and the different factors affecting obesity, including diet composition.

Talukder, A., Haselow, N. J., Osei, A. K., Villate, E., Reario, D., Kroeun, H., … Quinn, V. (2010). Homestead food production model contributes to improved household food security and nutrition status of young children and women in poor populations. Lessons learned from scaling-up programs in Asia (Bangladesh, Cambodia, Nepal and Philippines). *Field Actions Science Reports. The Journal of Field Actions*, (Special Issue 1). Retrieved from http://factsreports.revues.org/404

- Results from a homestead food production ((HFP) programs combined with nutrition education in 30,000 households in Bangladesh, Cambodia, Nepal, and Philippines between 2003 and 2007, were that anemia in 6-59 month old children was reduced in the program households. In Bangladesh, a significant decrease was seen going from a starting percentage of 63.9% anemia prevalence in program households to 45.2%. In the Philippines, the anemia prevalence among program households started at 42.9% and after the program was 16.6%. Nepal's anemia prevalence was unchanged and Cambodia decreased slightly. The HFP program could increase micronutrient consumption to improve health and nutrition of vulnerable women and children.

Waage, J., Hawkes, C., Turner, R., Ferguson, E., Johnston, D., Shankar, B., … others. (2013). Current and planned research on agriculture for improved nutrition: a mapping and a gap analysis. In *Proc Nut Soc* (Vol. 72, p. E316).

- Reviews 151 current and planned research projects on agriculture for improved nutrition and identifies gaps for future research.

Webb, P., & Kennedy, E. (2014). Impacts of agriculture on nutrition: nature of the evidence and research gaps. *Food and Nutrition Bulletin*, *35*(1), 126–132.

- Reviews literature on impact pathways from agriculture research to nutrition and health and concludes there is a current lack of evidence but this does not necessarily mean that agriculture does not support nutrition and health gains.

Wesseler, J., & Zilberman, D. (2014). The economic power of the Golden Rice opposition. Environment and Development Economics, 19(06), 724–742.

- This paper calculates that by delaying production of vitamin A rice in India, which could have been released in 2000, 1.4 million deaths could have been avoided

Yamano, T., Arouna, A., Labarta, R. A., Huelgas, Z. M., & Mohanty, S. (2016). Adoption and impacts of international rice research technologies. *Global Food Security*, *8*, 1–8.

- Stress-tolerant rice varieties with traits controlling for submergence, drought, and salinity levels, have been disseminated in South Asia since 2008 from the STRASA (stress-tolerant rice for Africa and South Asia) project through the help of NGOs and government agencies. Some of the varieties included were: Swarma-Sub1, Samba Mahsuri-Sub1, and IT64-Sub1 for India; BR11-Sub1 and Swarna-Sub1 for Bangladesh; and Samba Mahsuri-Sub1 and Swarna-Sub1 in Nepal. Drought-tolerant rice varieties Sah- baghi dhan was disseminated in India, Bangladesh (named BRRI dhan56), and Nepal (Yamano et al., 2016). Low-income farmers tend to have land in flood-prone land and tend to benefit more from submergence tolerant rice varieties than better-off farmers. Swarna-Sub1, the submergence tolerant rice variety on average yielded 45% more under submergence lasting 10 days than that of the conventional variety, but the two had no yield differences under normal conditions.
- NERICA (New Rice for Africa) is best suited for the African agricultural landscape, originally used for uplands but since 2005 is used for lowland areas and irrigated areas (Yamano et al., 2016). Total area under NERICA is 0.5 million ha in 2009, or about 8% of total rice area (Yamano et al., 2016). Fifty-percent of farmers who used NERICA varieties in 2004 stopped in 2006 because if there is little rainfall, this variety yields less The IRRI is responsible for developing part of the national agricultural research centers (NARC) varieties between 1985 and 2009 with NPV for the Philippines, Vietnam, and Indonesia between $4.3 and $9.9 billion mostly from MVs in irrigated areas (Yamano et al., 2016).

Yosef, S., Jones, A. D., Chakraborty, B., & Gillespie, S. (2015). Agriculture and Nutrition in Bangladesh Mapping Evidence to Pathways. *Food and Nutrition Bulletin*, *36*(4), 387–404.

- Dietary diversity and women's role in agriculture need to be measured in agriculture and nutrition pathways

Zimmermann, R., & Qaim, M. (2004). Potential health benefits of Golden Rice: a Philippine case study. *Food Policy*, *29*(2), 147–168.

- This simulation study in the Philippines shows that golden rice should be a complement to other interventions to improve vitamin A status. Annual health benefits range between US$16 and 88 million, and R&D investment rates of returns range 66% to 133%. These results should be seen as preliminary results.

3. Resilience

Campbell, B. M., Vermeulen, S. J., Aggarwal, P. K., Corner-Dolloff, C., Girvetz, E., Loboguerrero, A. M., … others. (2016). Reducing risks to food security from climate change. *Global Food Security*, *11*, 34–43.

- Although climate change impacts on food security are uncertain, the authors caution that actions need to be taken to combat these impacts.

Ali, A., Erenstein, O., & others. (2016). Irrigation water saving through adoption of direct rice sowing technology in the Indo-Gangetic Plains: empirical evidence from Pakistan. *Water Practice and Technology*, *11*(3), 610–620.

- Estimates impacts of direct rice sowing (DRS) and finds that DRS technology requires less water, labor, and has a beneficial yield impact.

Baldos, U. L. C., & Hertel, T. W. (2014). Global food security in 2050: the role of agricultural productivity and climate change. *Australian Journal of Agricultural and Resource Economics*, *58*(4), 554–570.

- Partial equilibrium model based on data from 1991 to 2001, population and TFP were found to be drivers of malnutrition. This was used to create future scenarios to understand impacts of exogenous variables on food security. The scenarios show improvement in global food security in 2006-2050. Projected increases in agricultural productivity result in a 24% increase in global average dietary energy intake.

Barthel, S., & Isendahl, C. (2013). Urban gardens, agriculture, and water management: Sources of resilience for long-term food security in cities. *Ecological Economics*, *86*, 224–234.

- Descriptive study of ancient agriculture practices that reflects on the issues of today; agriculture and food security should be an integral part of urban city development.

Brusberg, M. D., & Shively, R. (2015). Building drought resilience in agriculture: Partnerships and public outreach. *Weather and Climate Extremes*, *10*, 40–49.

- Descriptive paper – concludes that the U.S has being moving from reactive to proactive since the 1990s in terms of addressing drought impacts. Activities have been implemented such as: NIDIS and the creation of the US Drought Monitor; partnerships between USDA, NOAA, and the National Drought Mitigation Center.

Chantarat, S., Mude, A. G., Barrett, C. B., & Carter, M. R. (2013). Designing index-based livestock insurance for managing asset risk in northern Kenya. *Journal of Risk and Insurance*, *80*(1), 205–237.

- Discusses how to design livestock insurance.

Clarke, D. J., Clarke, D., Mahul, O., Rao, K. N., & Verma, N. (2012). Weather based crop insurance in India. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2016750

- World Bank policy research working paper, gives an overview of the weather index insurance market in India.

Coetzee, C., Van Niekerk, D., & Raju, E. (2016). Emergent system behaviour as a tool for understanding disaster resilience: The case of Southern African subsistence agriculture. *International Journal of Disaster Risk Reduction*, *16*, 115–122.

- There is still confusion among the literature on what exactly "resilience" entails, but (Coetzee, Van Niekerk, & Raju, 2016) concludes that resilience measures are undertaken by farmers that include small-scale irrigation, farmers' associative mechanisms, improved crop varieties and crop practices.

Collier, B., Skees, J., & Barnett, B. (2009). Weather index insurance and climate change: opportunities and challenges in lower income countries. *The Geneva Papers on Risk and Insurance Issues and Practice*, *34*(3), 401–424.

- Weather index insurance can help battle climate change, especially in regions where weather risks are creating significant welfare and economic losses.

Dar, M. H., de Janvry, A., Emerick, K., Raitzer, D., & Sadoulet, E. (2013). Flood-tolerant rice reduces yield variability and raises expected yield, differentially benefitting socially disadvantaged groups. *Scientific Reports*, *3*, 3315.

- Gains in efficiency through reduced yield variability and increases in yield could be realized by farmer adoption of flood-tolerant rice. It is particularly beneficial to poor and disadvantaged groups in India.

DeFries, R., Mondal, P., Singh, D., Agrawal, I., Fanzo, J., Remans, R., & Wood, S. (2016). Synergies and trade-offs for sustainable agriculture: Nutritional yields and climate-resilience for cereal crops in Central India. *Global Food Security*, *11*, 44–53.

- Uses district level to estimate nutritional yields for protein, energy, and iron and the sensitivity of yields to monsoon rainfall and temperature. Rice is the dominant crop but is sensitive to rainfall variation and is the least land efficient in providing iron. Sorghum and maize have high nutritional yields and millet is the most climate resilient.

Elabed, G., Bellemare, M.F., Carter, M.R. and Guirkinger, C., 2013. Managing basis risk with multiscale index insurance. *Agricultural Economics*, 44(4-5), pp.419-431.

Emerick, K., de Janvry, A., Sadoulet, E., & Dar, M. H. (2016). Technological innovations, downside risk, and the modernization of agriculture. *The American Economic Review*, *106*(6), 1537–1561.

- This article shows that in India, a new rice variety that has flood tolerance positively effects agricultural productivity even in non-drought years.

Evenson, R. E., Pray, C., & Rosegrant, M. W. (1998). *Agricultural research and productivity growth in India* (Vol. 109). Intl Food Policy Res Inst.

Gabre-Madhin, E. Z., & Haggblade, S. (2004). Successes in African agriculture: results of an expert survey. *World Development*, *32*(5), 745–766.

- To battle poverty in Africa, sustainable agriculture should be part of the solution.

Greatrex, H., Hansen, J., Garvin, S., Diro, R., Le Guen, M., Blakeley, S., Osgood, D. (2015). Scaling up index insurance for smallholder farmers: Recent evidence and insights.

- Reviews 5 case studies on smallholder farmers in India.

Gregorio, G. B., Senadhira, D., Mendoza, R. D., Manigbas, N. L., Roxas, J. P., & Guerta, C. Q. (2002). Progress in breeding for salinity tolerance and associated abiotic stresses in rice. *Field Crops Research*, *76*(2), 91–101.

- Discusses the state of research in germplasm with tolerance for all major abiotic stresses. Breeding procedures to incorporate abiotic stress tolerance into high yielding cultivars were formulated because breeding for abiotic stress tolerance is costly and time consuming. Marker assisted selection (MAS) will be beneficial going forward.

Iftekharuddaula, K. M., Ahmed, H. U., Ghosal, S., Amin, A., Moni, Z. R., Ray, B. P., … Septiningsih, E. M. (2016). Development of early maturing submergence-tolerant rice varieties for Bangladesh. *Field Crops Research*, *190*, 44–53.

Islam, S., Cenacchi, N., Sulser, T. B., Gbegbelegbe, S., Hareau, G., Kleinwechter, U., … others. (2016). Structural approaches to modeling the impact of climate change and adaptation technologies on crop yields and food security. *Global Food Security*, *10*, 63–70.

- Abiotic stress tolerant crop varieties may be able to mitigate the yield decrease resulting from climate change. Climate change would lead to a 6% yield decrease in rainfed maize in 12 African countries, but drought tolerant maize varieties in climate change scenarios increases yields by 25%.

Ismail, A. M., Singh, U. S., Singh, S., Dar, M. H., & Mackill, D. J. (2013). The contribution of submergence-tolerant (Sub1) rice varieties to food security in flood-prone rainfed lowland areas in Asia. *Field Crops Research*, *152*, 83–93.

- The Sub1 rice varieties had a 1 to 3 ton per ha yield advantage over non-Sub1 varieties for various flood durations and under complete submergence.

Janzen, S. A., & Carter, M. R. (2013). *After the drought: The impact of microinsurance on consumption smoothing and asset protection*. National Bureau of Economic Research. Retrieved from http://www.nber.org/papers/w19702

- Households in Kenya with insurance and a large amount of assets were 64% less likely to reduce food consumption due to drought and households with insurance and a small number of assets were 43% less likely to reduce food consumption to cope with drought.

Jensen, N., & Barrett, C. (2016). Agricultural Index Insurance for Development. *Applied Economic Perspectives and Policy*, ppw022.

- This manuscript discussed index insurance and gives recommendations for addressing information gaps and improving index insurance quality globally.

Jensen, N. D., Barrett, C. B., & Mude, A. G. (2016). Index Insurance Quality and Basis Risk: Evidence from Northern Kenya. *American Journal of Agricultural Economics*, aaw046.

- In northern Kenya, index based livestock insurance (IBLI) helped to mitigate exposure to shocks but is not a magic bullet solution.

Karlan, D., Osei, R., Osei-Akoto, I., & Udry, C. (2014). Agricultural decisions after relaxing credit and risk constraints. *Quarterly Journal of Economics*, *129*(2), 597–652.

- In Ghana, farmers were given the option to receive cash grants, rainfall insurance, or both. When provided with insurance, farmers were able to mitigate loss.

Kostandini, G., La Rovere, R., & Abdoulaye, T. (2013). Potential impacts of increasing average yields and reducing maize yield variability in Africa. *Food Policy*, *43*, 213–226.

- Adoption of DTM (drought tolerant maize) could help decrease poverty, reduce drought-related food crisis, especially in SSA.

Kostandini, G., La Rovere, R., & Guo, Z. (2016). Ex ante welfare analysis of technological change: The case of nitrogen efficient maize for African soils. *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie*, *64*(1), 147–168.

- IMAS (Improved Maize for African Soils) project in Kenya and South Africa have a yield advantage in regions with low or no fertilizer-use (Kostandini, La Rovere, & Guo, 2016). Results show benefits totaling US$586 million in benefits to both producers and consumers in Kenya and South Africa and could help 1 million people move out of poverty by 2025.

Kostandini, G., Mills, B., & Mykerezi, E. (2011). Ex Ante Evaluation of Drought-Tolerant Varieties in Eastern and Central Africa. *Journal of Agricultural Economics*, *62*(1), 172–206.

- Transgenic drought-tolerant maize varieties: total producer and consumer ex ante benefits from increases in mean yields and reduced variance in Kenya, Uganda, and Amhara regions of Ethiopia from the adoption of drought resistant maize, sorghum, millet, respectively, are a total of: $86, $7.5, and $5.5 million.

Lamine, C. (2015). Sustainability and resilience in agrifood systems: reconnecting agriculture, food and the environment. *Sociologia Ruralis*, *55*(1), 41–61.

- In France and Brazil, review of case studies that looks at the link between agriculture, food and the environment for the development of more resilient pathways.

Lipper, L., Anderson, C. L., & Dalton, T. J. (2010). *Seed trade in rural markets: implications for crop diversity and agricultural development*. Earthscan.

- These studies show the importance of local markets in getting improved seed out to farmers which increases crop biodiversity and output.

Lybbert, T. J., & Bell, A. (2010). Stochastic benefit streams, learning, and technology diffusion: Why drought tolerance is not the new Bt. Retrieved from http://www.agbioforum.org/v13n1/v13n1a02-lybbert.htm

- Marginal farmers are likely to be slow adopters of Drought-Tolerant varieties (DT).

Lybbert, T., & Sumner, D. (2010). Agricultural Technologies for Climate Change Mitigation and Adaptation. Retrieved from http://www.ictsd.net/downloads/2010/06/agricultural-technologies-for-climate-change-mitigation-and-adaptation-in-developing-countries_web.pdf

- Climate change mitigation strategies for developing countries.

Mackill, D. J., Ismail, A. M., Pamplona, A. M., Sanchez, D. L., Carandang, J. J., & Septiningsih, E. M. (2010). Stress tolerant rice varieties for adaptation to a changing climate. *Crop, Environment and Bioinformatics*, *7*, 250–259.

- Swarna-Sub1 rice varieties had a 20% survival rate when submerged for 14 days followed by prolonged flooding of 20cm. this variety performed well in shallow and 50-cm stagnant flooding and can tolerate flooding that either occurs gradually or late season flooding, while other MSBC varieties have only a moderate tolerance to this type of flooding.

Michler, J., Baylis, K., Arends-Kuenning, M., & Mazvimavi, K. (2016). Conservation Agriculture and Climate Resilience. Unpublished paper. U of Illinois Retrieved from https://works.bepress.com/kathy_baylis/77/

- Panel data from Zimbabwe; Studies how conservation agriculture (CA) receives higher yields compared to conventional farmers in high and low rainfall periods. Policy should advocate CA for these climate resiliency benefits.

Mobarak, A. M., & Rosenzweig, M. R. (2013). Informal risk sharing, index insurance, and risk taking in developing countries. *The American Economic Review*, *103*(3), 375–380.

- Evaluates rick and the role of index insurance in India.

Motamed, M.J., Florax, R.J. and Masters, W.A., 2014. Agriculture, transportation and the timing of urbanization: Global analysis at the grid cell level. *Journal of Economic Growth*, 19(3), pp.339-368.

- Identifies role of local agricultural productivity in accelerating the establishment and growth of towns and cities

Mulmi, P., Block, S. A., Shively, G. E., & Masters, W. A. (2016). Climatic conditions and child height: Sex-specific vulnerability and the protective effects of sanitation and food markets in Nepal. *Economics & Human Biology*, *23*, 63–75. https://doi.org/10.1016/j.ehb.2016.07.002

- This article shows how climate change and crop production affect height of children in Nepal.

Padgham, J., Jabbour, J., & Dietrich, K. (2015). Managing change and building resilience: A multi-stressor analysis of urban and peri-urban agriculture in Africa and Asia. *Urban Climate*, *12*, 183–204.

- Discusses urban food security and adaptations to climate change.

Pailler, S., Naidoo, R., Burgess, N. D., Freeman, O. E., & Fisher, B. (2015). Impacts of community-based natural resource management on wealth, food security and child health in Tanzania. *PloS One*, *10*(7), e0133252.

- Estimates the impact of 3 different community based natural resource management (CBNRM) government programs in Tanzania on poor and wealthy populations using a differences-in-differences model. Food security is improved in CBNRM households than non-CBNRM households. Wealthy households benefit more from this program than poor households, and benefits increase over time with the program. The program hasn't been used long enough to determine yield outcomes and changes. Wealth and health outcomes are not significantly different. And no single CBNRM presents better results than another.

Pardey, P. G., Beddow, J. M., Kriticos, D. J., Hurley, T. M., Park, R. F., Duveiller, E., … Hodson, D. (2013). Right-sizing stem-rust research. *Science*, *340*(6129), 147–148.

- The multitude of authors from a variety of institutions published their evaluation of research on wheat-stem rust in a two-page article that was published in the prestigious journal Science. The authors estimated that while losses due to wheat stem rust would be less than estimates published by others, but there was still insufficient research on the topic. They estimated that the global funding was half of what was needed, and the authors call out USDA for recent cut-backs on this topic. The authors suggest that their research methodology could be used to estimate the needed "research investment streams" needed to sustain or improve food security globally.)

Parshad, M., & Nair, R. (2011). Implementation of Weather-Based Crop Insurance in India: Problems and Prospects. *ASCI Journal of Management*, *41*, 66–69.

- India has the world's largest crop insurance program in terms of numbers of farmers that are covered. Describes the difference between two index-based insurances: area yield and weather insurance.

Rejesus, R. M., Martin, A. M., & Gypmantasiri, P. (2014). Enhancing the impact of natural resource management research: Lessons from a meta-impact assessment of the Irrigated Rice Research Consortium. *Global Food Security*, *3*(1), 41–48.

- Meta-impact analysis of NRM (natural resource management) research. Shows that IRRC (irrigated rice research consortium) NRM research rates of returns on investment from 1997 to 2012 ranges from 6 – 30% and benefit-cost ratios (BCR) ranging from 1:1 or 4:1. Research investments totaling $18.5 million resulted in economic benefits of $70.5 million.

Septiningsih, E. M., Pamplona, A. M., Sanchez, D. L., Neeraja, C. N., Vergara, G. V., Heuer, S., … Mackill, D. J. (2009). Development of submergence-tolerant rice cultivars: the Sub1 locus and beyond. *Annals of Botany*, *103*(2), 151–160.

- Discusses the development of Sub1 rice variety and the characteristics of the trait. Scientific paper.

Setimela, P. S., Magorokosho, C., Lunduka, R., Gasura, E., Makumbi, D., Tarekegne, A., … Mwangi, W. (2017). On-Farm Yield Gains with Stress-Tolerant Maize in Eastern and Southern Africa. *Agronomy Journal*. Retrieved from https://dl.sciencesocieties.org/publications/aj/articles/0/0/agronj2015.0540

- New drought-tolerant (DT) hybrids showed yield advantages in early and mid-late maturing stages and during stress conditions. This article discusses minimum tillage in maize farming in Ethiopia and shows that it results in less labor needed, and reduces labor by 14.4 and 8.2 person-days-per-ha.

Smale, M. (2005). *Valuing crop biodiversity: on-farm genetic resources and economic change*. CABI.

- This group of studies shows that improved varieties from the CGIAR centers can increase crop diversity and reduce yield variability

Sparger, J. A., Norton, G. W., Heisey, P. W., & Alwang, J. (2013). Is the share of agricultural maintenance research rising in the United States? *Food Policy*, *38*, 126–135.

- Climate change may bring about "maintenance" issues in nature that need to be addressed.

Annex 2: Complete Bibliography

Abass, A., Amaza, P., Bachwenkizi, B., Alenkhe,B., Mukuka, I., & Cromme, N. (2017) Adding value through the mechanization of post-harvest cassava processing, and its impact on household poverty in north-eastern Zambia. *Applied Economics Letters*, 24:9, 579-583, DOI: 10.1080/13504851.2016.1213356

Alene, A. D., Coulibaly, O. (2009). The impact of agricultural research on productivity and poverty in sub-Saharan Africa. *Food Policy*, 34198-209. doi:10.1016/j.foodpol.2008.10.014

Alene, A. D., Manyong, V., Tollens, E. F., & Abele, S. (2007). Targeting agricultural research based on potential impacts on poverty reduction: Strategic program priorities by agro-ecological zone in Nigeria. *Food Policy*, 32394-412. doi:10.1016/j.foodpol.2006.07.004

Ali, A., Bahadur Rahut, D., Erenstein, O. (2016). Irrigation water saving through adoption of direct rice sowing technology in the Indo-Gangetic Plains: empirical evidence from Pakistan. *Water Practice and Technology*, *11*(3), 610–620. doi:10.2166/wpt.2016.058

Alston, J. M., Martin, W. J., & Pardey, P. G. (2014). Influences of agricultural technology on the size and importance of food price variability. *The economics of food price volatility* (pp. 13–54). University of Chicago Press. Retrieved from http://www.nber.org/chapters/c12804

Anderson, J. R. (1999). Poverty, land degradation and rural research policy. *Proceedings of International Workshop Assessing the impact of Agricultural Research on Poverty Alleviation, San Jose, Costa Rica*. Retrieved from http://ciat-library.ciat.cgiar.org/paper_pobreza/018.pdf

Anderson, J., & Roumasset, J. (1996). Food Insecurity and Stochastic Aspects of Poverty [MPRA Paper]. Retrieved January 25, 2017, from https://mpra.ub.uni-muenchen.de/13323/

Asfaw, S., Kassie, M., Simtowe, F., & Lipper, L. (2011). Poverty reduction effects of agricultural technology: A micro-evidence from Tanzania. *Food and Agricultural Organization of the United Nations, Agricultural Development Economics Division, Working Paper*. Retrieved from http://www.csae.ox.ac.uk/conferences/2011-EdiA/papers/304-Asfaw.pdf

Balagamwala, M., & Gazdar, H. (2013). Agriculture and nutrition in Pakistan: Pathways and disconnects. *IDS Bulletin*, *44*(3), 66–74.

Baldos, U. C., & Hertel, T. W. (2014). Global food security in 2050: the role of agricultural productivity and climate change. Australian Journal Of Agricultural & Resource Economics, 58(4), 554-570. doi:10.1111/1467-8489.12048

Barnwall, P., Dar, A., Goltz, J., Fishman, R., McCord, G., & Mueller, N. (n.d.). The Green Revolution and Infant Mortality: Evidence from 600,000 Births, *Working Paper.*

Barthel, S., & Isendahl, C. (2013). Urban gardens, agriculture, and water management: Sources of resilience for long-term food security in cities. *Ecological Economics*, *86*, 224–234. doi:10.1016/j.ecolecon.2012.06.018

Benfica, R., Kilic, T., & others. (2015). The Effects of Smallholder Agricultural Involvement on Household Food Consumption and Dietary Diversity: Evidence from Malawi. In *2015 Conference, August 9-14, 2015, Milan, Italy*. International Association of Agricultural Economists. Retrieved from http://ageconsearch.umn.edu/bitstream/211218/2/Benfica-The%20Effects%20of%20Smallholder%20Agricultural%20Involvement-89.pdf

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