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Agricultural research, technology and nutrition in Sub-Saharan Africa

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Abstract

The objective of this study is to examine the relationships between agricultural research, technology and nutrition in Sub-Saharan Africa (SSA), drawing upon a rich and insightful literature. African agriculture has the lowest productivity compared with other regions of the world. Huge productivity gains are possible and accrue where governments allocate the necessary resources to agricultural research and development. In SSA, however, public investment in agriculture is still far lower than needed. Food and Agriculture Organization of the United Nations (FAO) estimates show a rise in hunger globally as well as in Africa. The deterioration has been most severe in SSA. Agricultural development has enormous potential to make a significant contribution to reducing malnutrition and associated ill health. An assessment is carried out through a review of a large number of studies. These examined the factors determining adoption of innovative agricultural technology; their benefits and the underlying mechanisms; sustainability of the benefits; empowerment of women farmers and child nutrition; and the prospects of youth employment in agriculture and elsewhere. A case is then made for greater investment in agricultural research.

Keywords

Agricultural research, technology, production and diet diversity, nutrition, Sub-Saharan Africa

JEL Codes

Q16, Q18, Q55, O55

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1. Introduction

African agriculture has the lowest productivity compared with other regions of the world. The Green Revolution observed in Asia did not occur in Africa for reasons that include the different institutional context, greater diversity in cropping patterns (requiring higher investments in research), limited physical infrastructure, particularly irrigation, and defective rural financial systems (Mellor, 2014). Today, the consensus on agricultural development in Africa is based on the adoption of the Green Revolution package and the 'classical' pathway of modernisation – intensification based on modern inputs (improved seeds and inorganic fertilisers). This development option has been supported by international research agencies and adopted by governments. There is, however, growing evidence of difficulties in ensuring the sustainability of such a model (Jayne et al, 2014). It relies on non-renewable fossil fuels and the efficiency of costly fertilisers is reduced by soil degradation in many regions of the continent. This soil degradation is a consequence of continuous cultivation and the lack of crop rotation where high population densities exist, resulting in soil acidification and deficiencies in soil organic carbon and micronutrients (ILO, 2016).

Agricultural research has generated several kinds of technology with a high potential for impact, but the expected impact on farmers' productivity, livelihood and quality of life has not been fully realised. Institutional innovations are needed to improve productivity and make public agricultural institutions more responsive to markets, more accountable to the communities they serve, and better recognised as an important tool for achieving economic growth. Other studies have shown that huge productivity gains are possible and accrue where governments allocate the necessary resources to agricultural research and development. In Sub-Saharan Africa (SSA), however, public investment in agriculture is still far below what is needed, despite commitments by African governments to allocate 10% of their public spending on it. The challenge is to develop technology that is relevant to small farmers and to enable them to transform their farms into viable small businesses that make a vital contribution to local and national economies. This calls for client-oriented agricultural research.

The FAO defines prevalence of undernourishment as the percentage of the population with an average daily caloric intake over the year that is less than the minimum daily requirement. Depth of undernourishment measures the degree to which caloric intake of the undernourished falls below minimum dietary requirements. In a recent contribution, Pandey (2017) draws attention to slow progress in reducing undernourishment in Africa and its sub-region, SSA. Using three-year averages of FAO estimates, the total number of undernourished (NoU) declined from 1.01 billion in 1990–92 to 792.5 million in 2014–16. Thus the world had over 218.2 million fewer undernourished persons in 2014–16 than in 1990–92. The proportion of undernourished (PoU) declined from 18.6% to 10.8%, as also the depth of undernourishment (DoU) from 138 kilocalories (Kcal) per capita per day to 81Kcal. In contrast to this global progress, Africa remained home to 230 million NoUs in 2014–16 – much higher than the 181.7 million such people in 1990–92. In terms of global share of all NoUs, Africa has over 29% now, compared with just below 18% in 1990–92. The PoU, however, recorded a slow reduction from 27.6% to 19.8%, as did DoU from 204 Kcal to 151 Kcal. Thus undernourishment remains a serious concern for Africa.

Although it is difficult to ascertain whether this is a trend reversal, two recent FAO reports (2017a, b) show a rise in hunger globally as well as in Africa. The NoU in the world suffering from chronic food deprivation began to rise in 2014 –from 775 million people to 777 million in 2015 – and is now estimated to have increased further, to 815 million in 2016. The stagnation of the global average of the PoU from 2013 to 2015 is the result of two offsetting changes at the regional level: SSA's share of undernourished people increased, while there was a continued decline in Asia in the same period. However, in 2016, the PoU increased in most regions except northern Africa, southern Asia, eastern Asia, Central America and the Caribbean. The deterioration was most severe in SSA and south-eastern Asia (FAO 2017a, b).[1]

Undernutrition is widespread and a key reason for poor child health in many developing countries. In SSA, around 40% of children under the age of five suffer from stunted growth, that is, severely reduced height-for-age relative to their growth potential. Stunting is a result of periods of undernutrition in early childhood, and it has been found to have a series of adverse long-term effects in those who survive childhood. It is negatively associated with mental development, human capital accumulation, adult health, and economic productivity and income levels in adulthood (Larsen & Lilleør, 2017).

Vitamin A deficiency is associated with a higher risk of morbidity and mortality, and with ocular disorders such as night blindness, xerophthalmia and blindness, affecting infants, children and pregnant or lactating women. African regions account for the greatest number of pre-school children with night blindness and for more than one-quarter of all children with subclinical vitamin A deficiency (Hotz et al, 2012).

The central premise is that agricultural development has enormous potential to make a significant contribution to reducing malnutrition and associated ill health. With its close links to both the immediate causes of undernutrition (diets, feeding practices and health) and to its underlying determinants (such as income, education, access to water, sanitation and hygiene- and health services (WASH), and gender equity), the agricultural sector can play a strong role in improving nutrition outcomes (Gillespie and van den Bold, 2017).[2]

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[1] As noted in *The Economist* (11–17 November 2017, p 4), "too many economies depend on commodity exports. In 2016 weak commodity prices were partly responsible for a slowdown in economic growth across Sub-Saharan Africa to 1.4%, its most sluggish pace in more than two decades. With the population growing by about 3% a year, people on average got poorer last year".

[2] For a cogent and comprehensive but somewhat sceptical assessment, see Timmer (2015).

Several different pathways between agriculture and nutrition are identified with, some overlap.[3] Agriculture generates income that can be spent on nutrition-enhancing goods and services, although it is generally a more important source of income for the poor and undernourished, both directly and through the so called 'multiplier effects' on other sectors. Because of various market failures, however, farmers may choose to grow food that they consume, thus rendering agriculture a special sector for nutrition, but also opening up complex dynamic policy trade-offs. The macroeconomic linkages between agricultural production conditions and food prices drive consumption decisions. Few linkages go beyond price and income to focus on the linkages between child undernutrition and maternal socioeconomic and nutritional status. Agricultural production conditions can affect women's decision-making power and control of nutrition-relevant resources, as well as their ability to manage the care of young children, which is of huge importance for nutrition (Gillespie and van den Bold, 2017).

Food systems are changing rapidly. Globalisation, trade liberalisation and rapid urbanisation have led to major shifts in the availability, affordability, and acceptability of different types of food, which has driven a nutrition transition in many developing countries. Food production has become more capital-intensive and supply chains have grown longer as basic ingredients undergo multiple transformations. Expansion of fast-food outlets and supermarkets has resulted in dietary shifts. The consumption of low nutritional quality, energy-dense, ultra-processed food and drinks, and fried snacks and sweets has risen dramatically in the past decade. Combined with increasingly sedentary lifestyles, rates of overweight and obesity and associated diet-related chronic diseases have spiked (Carletto et al, 2015).

The concomitant shift to more market-oriented agricultural policies means that agricultural technology and markets play a more important role in determining food prices and rural incomes, and more food is consumed from the marketplace rather than from people's own production. The greater market orientation of food production and consumption has increased the bidirectional links between agriculture and nutrition: agriculture still affects nutrition, but food and nutritional demands increasingly affect agriculture. Increasing demands for energy-intensive products exacerbate the environmental impacts of food value chains: for example, excessive use of agricultural chemicals to extract more dietary energy from every hectare contaminates the very food produced, along with groundwater and the soil; and the rise in greenhouse gas emissions from livestock industries to feed the ever-increasing demand for meat and dairy products. Weather-related shocks could also result in greater crop failures and higher food prices (Carletto et al, 2015).

Evidence also points to improved impacts on nutrition if agricultural interventions are targeted at women and when specific work is done around women's empowerment.

Agriculture has a substantial role in meeting the youth employment challenge facing Africa, given the inability of the urban economy to absorb young entrants to the labour

[3] Six pathways are identified in Gillespie and van den Bold (2017).

force in rural areas. There will be vast opportunities for innovative young people in agricultural systems as they adapt to a range of challenges in the near future. These challenges relate to raising productivity in a sustainable way, integration into emerging high value chains, and healthy diets (Suttie, 2015).

The focus of this study is therefore on whether agricultural research through improved technology will directly or indirectly help to improve nutrition in SSA (or more broadly in Africa). A thorough review of recent evidence is carried out and a case is made for greater investment in agricultural research and complementary measures. Other related themes explored here are the potential among innovative women and young farmers for greater productivity and better nutritional outcomes. An assessment is given of how diversified food production, value chains and food preferences determine nutritional outcomes. Attention is paid to the sustainability of agricultural technologies. A thorough review of returns from agricultural research serves as the basis for greater investment in it. The study ends with a summary of the major findings from a broad policy perspective.

2. Determinants of Technology Adoption

The extant literature has focused on determinants such as relaxation of credit, input and infrastructural constraints, as well as building awareness of and providing easier access to information on new technologies. In particular, the evidence identifies empirically formal and informal channels that affect the decision process of technology adoption. Formal channels include extension services, information campaigns, demonstration trials by extension agents, membership of agricultural associations and participation in research programme activities (Hasan et al, 2015). Informal channels refer to all social networks of smallholder farmers, learning from neighbours' experiences, learning- by-doing and spill-over effects (Garbero et al, 2016).

Adoption follows a progressive decision path. Lindner et al (1982) were the first to analyse the time lag from availability of new technology to definite adoption decision. They identify three steps that comprise the entire time lag. The first is the awareness lag, when farmers discover the existence of new technology; the second is the evaluation lag, when farmers try out the innovation; and the third is the ultimate decision to adopt the new technology or not. Because of a lack of data, these authors evaluate the impact of distance from source of information and education on the first two lags. They find that the lower the distance from source of information, the higher is the probability of being aware of and trying out technologies and that education partly offsets the effect of distance, implying that more educated farmers may have access to information despite the distance. Subsequent studies have examined awareness and adoption rates (Diagne and Demont, 2007; Asuming-Brempong et al, 2011; Simtowe et al, 2012), while others (eg Moser and Barrett, 2006) focus on the try-out and adoption rates. Lambrecht et al (2014) examine the determining factors of all three lags.

In their analysis of both the determinants and impact of adoption, Diagne and Demont (2007) recognise the existence of two main sources of bias, namely *non-exposure bias* and *positive selection bias*. The former results from the fact that, given the limited initial diffusion of a new technology, farmers who have not been exposed to it cannot adopt it, but might have adopted it had they been exposed to it. Non-exposure bias may thus underestimate the true adoption rate of the entire population, given the limited diffusion of new technology. Positive selection bias instead results when farmers voluntarily get in touch with extension services and participate in the overall exposure to information diffusion of new technology. Hence, farmers who decide to get involved in the information accumulation process of new technologies are more likely to adopt them and are thus systematically different from those who do not self-select in the exposure. Moreover, some farmers or communities are targeted by research programmes and extension services whereas others are not, and targeted populations have a greater likelihood of adopting new technologies. Positive selection bias is therefore likely to overestimate the true adoption rate of the entire population. The authors use the average treatment effect (ATE) method.[4]

Studies based on measurement of ATE show a population adoption gap, meaning that the estimated demand for new technology is quite high, but its diffusion does not cover the entire population and does not satisfy the potential demand. Diagne and Demont estimate the adoption gap of New Rice for Africa (NERICA) in Cote d'Ivoire as equal to 18%, where only 4% of farmers are jointly exposed and have adopted NERICA. The adoption gap of NERICA in Ghana, estimated by Asuming-Brempong et al (2011), is instead equal to 44% and that of improved groundnut in Malawi, estimated by Simtowe et al (2012), is 12%.

Specifically, the main factors that determine the awareness of a new technology include the social characteristics of farmers and agro-ecological conditions in a targeted area. In particular, farmers who are more aware of a technology have higher education (Simtowe et al, 2012), live in proximity to research institutions and universities (Asuming-Brempong et al, 2011), and have more social capital, which includes participation in collective actions, membership of non-agricultural organisations and a network of credit channels (Lambrecht et al, 2014; Yokouchi and Saito, 2016).[5]

Both social characteristics and economic constraints determine the try-out step. This is positively influenced by determinants such as learning from others, higher liquidity

[4] In order to control for these two sources of bias, the authors implement the Average Treatment Effect method, which allows for the estimation of the population mean adoption outcome (ATE) and the average treatment effect on the treated (ATT). The difference between these two components gives the population non-exposure bias, also called the population adoption gap, which provides useful information on what would have been the adoption rate if the diffusion of technology had been complete. For a more detailed exposition, see Garbero et al (2016).

[5] For a review of the econometric methods used, see Garbero et al (2016).

(Moser and Barrett, 2006), and access to information and extension services (Lambrecht et al, 2014; Bezu et al, 2014; Kikulwe et al, 2012). In particular, younger farmers living near the market, with social capital and labour endowments, are more likely to experiment with a new technology (Lambrecht et al, 2014). The continued adoption step is largely influenced by economic constraints, demographic determinants and dissemination mechanisms, such as extension (Asuming-Brempong et al, 2011). Following Moser and Barrett (2006), in addition to liquidity, social capital (learning from others) and peer effects (attitude of conformity to neighbouring farmers' behaviour) play an important role in determining continued adoption. A third study (Lambrecht et al, 2014, however, reports that the continued adoption decision is mainly determined by credit and liquidity constraints, and by the quality of extension services.[6] The latter facilitates the adoption decision process, allowing farmers to continue with the new technology after the trial period. Economic and financial constraints hamper continued adoption.

While the decision process is essentially dynamic, and requires a dynamic framework, the majority of studies have relied on cross-sectional datasets, which do not allow for an analysis of a dynamic learning process. Further, those that do employ panel data do not examine the dynamic decision-making process. For example, Kikulwe et al (2012) simply determine the factors of adoption at the baseline year. Garbero et al (2016) fill this gap. This adds to existing knowledge by, first, analysing the determinants of technology adoption with a special focus on the dynamics of the adoption decision process. The role of path- or state-dependence is assessed, namely, the role of past experience in the adoption decision process. This aspect has not been sufficiently analysed in the agricultural technology adoption literature, with the exception of Cowan and Gunby (1996). Moreover, the impact of agricultural technology on farmers' welfare and agricultural productivity is estimated, using observational data and non-experimental methods in a dynamic framework and three years' panel data from Uganda. The endogeneity of the adoption decision is taken into account, along with selection on both observables and unobservables. Following Doss (2006), Garbero et al (2016) examine the drivers of technology adoption and its impact in a broader context. For the estimation of technology adoption, in addition to the most common socioeconomic explanatory variables, their study controls for the technology adoption decision made in the previous year in order to examine the preferences of households towards technology adoption in a dynamic setting. For the impact assessment, the authors estimate the effects of technology on poverty and other welfare indicators by taking into account households' adoption decision histories.

State dependence is defined as the direct effect of technology adoption status in the previous period on the current or contemporary technology adoption status. The measure of technology used is improved seeds. A key question that this study seeks to answer is whether state dependence is spurious or real. In the former case, state dependence results from observed or unobserved households' heterogeneity, whereas,

[6] For an insightful study of the effectiveness of different providers of extension services in Uganda, see Hasan et a. (2015).

in the latter, state dependence actually drives the technology adoption process. Household characteristics included in different specifications are: household size; sex and age of household head; number of dependants in the household; parcel size in hectares; household distance to village centre; distance from village centre to agricultural extension centre; household distance to a major road; whether the household head attended secondary school; asset index; occurrence of irregular rains; occurrence of erosion on arable land; source of technical agricultural information by district; agro-ecologic zone of the household; season; and region of the household. State-of-the-art econometric methods are used to examine state-dependence of technology adoption.[7]

The state-dependence of technology adoption is confirmed. The presence of state-dependence means that a previous choice over the type of technology used affects current choice. A household that adopted improved seeds in the period t-1 has a 4.79 percentage points higher probability of adopting improved seeds again in the period t compared to a household which did not adopt improved seeds in the period t-1. Moreover, the initial technology adoption decision significantly influences the current technology adoption decision, even more than the lagged adoption (7.8%).

Among household characteristics, the probability of technology adoption increases if the head of the household is male and better educated, and the household size is larger. Parcel size does not have any impact.

Somewhat surprisingly, distances from the village centre to the market and household distance from a major road have no effect on adoption, while distance from village centre to agricultural extension services lowered adoption. Extension plays a key role in facilitating adoption of new technology. Among all sources of extension advice, only extension services provided by National Agricultural Advisory Services (NAADS) have a positive effect on adoption. Regions characterised by being in the tropic-cool/sub-humid agro-ecological zone are negatively associated with the adoption of new technology.

3. Impact

Several studies have sought to analyse the determinants of uptake of and the reasons why farmers adopt technologies (Doss, 2006) and their causal effects on agricultural productivity. These studies have focused mostly on the impact of yield-increasing and cost-reducing technologies. Nevertheless, some of the yield-increasing technologies are also associated with quality-improving technologies (Kabunga et al, 2014), which consist in new seed varieties that not only increase productivity and reduce cost per unit of output, but also allow for a better quality of agricultural output in terms of nutritional characteristics and taste.

[7] For technical details, see Garbero et al (2016).

The relevant literature has also documented the pathways through which agricultural research enhances living standards and welfare outcomes in developing countries, namely, higher agricultural productivity, lower production costs, reduction in food prices, higher wages and employment, and lower losses from diseases or unfavourable climatic conditions. Hence, both producers and consumers are likely to benefit. A selection of these studies is reviewed below, drawing upon Garbero et al (2016) and other research.

A recent meta-analysis by Stewart et al (2015), examining the impact of agricultural technology, emphasises that the majority of the studies reviewed are plagued by methodological challenges and mostly analyse the role of agricultural research using observational data and non-experimental designs. In the absence of randomised experiments where farmers are randomly distributed to two groups, namely, adopters and non-adopters, farmers choose to adopt agricultural technologies on a voluntary basis, or are systematically selected by project implementers or development institutions based on their propensity to participate in the technology adoption decision. This implies that adopters and non-adopters may be systematically different, either through self-selection or more generally through selection based on observable or unobservable characteristics. This renders any assessment of the impact of adoption on welfare outcomes with *ex-post* observational data problematic.

Bezu et al (2014) account for the endogeneity of input subsidy and area under improved maize to estimate the impact of households' decision to use improved maize varieties on household welfare, using a three-year panel dataset.[8] Another notable study by Donstop-Nguezet et al (2011) seeks to capture the effects of the adoption of NERICA on productivity, income and the poverty of Nigerian rice farmers.[9]

Turning to the actual magnitude of the impact of the technologies concerned, the overall impression from the studies reviewed is positive, but these impact magnitudes vary by outcome variable and are sensitive to the choice of the estimator employed. For instance, improved chickpea and pigeon pea yields in Tanzania lead to increases in the average expected consumption per adult equivalent by 24.6% and 103%, respectively (Asfaw et al, 2012b). However, these authors, using the same dataset but adopting a different econometric method (Asfaw et al, 2012a), found that adoption of improved pigeon pea increases consumption expenditure by 31% for adopters on average and reduces the Foster-Greer-Thorbecke poverty indices, namely, the head-

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[8] They use the control function approach and instrumental variables to correct for the endogeneity of input subsidy and improved maize variety.

[9] They use two instrumental variable -based estimators: the first is the non–parametric Wald estimator proposed by Imbens and Angrist (1994) which requires only the observed outcome variable y, the treatment status variable d, and an instrument z. The second IV-based estimator is Abadie's (2003) generalisation of the LATE estimator of Imbens and Angrist (1994) to cases where the instrument z is not totally independent of the potential outcomes but will become so, conditional on **x**, a vector of covariates that determines the observed outcome y. However these methods do not seem to lead to an unbiased estimate of impact given the presence of weak instruments (Garbero et al, 2016).

count index, the poverty gap and the severity of poverty index by a range of 12% to 13%; 8% to 10%, and 4.4% to 8.1%, respectively. Some other studies assess impact of technology adoption on farmers' and households' income. Bezu et al (2014) found that a 1% increase in improved maize area in Malawi was associated with a 0.48% increase in income of adopters, a 0.34% increase in own maize consumption and a 0.24% increase in assets. Positive impacts on welfare are also to the result of size of land, while there is a negative impact of family size once the labour force is taken into account.

Tissue culture banana technology adoption in Kenya increased annual farm and household income by $500 and $662, respectively, an increase of a factor of 2 in farm income and of 89% in household income (Kabunga et al, 2014). The increase in total household income represents a positive spill-over from adopters to non-adopters. Larger household sizes negatively affect both per capita farm income and total household income, while land size and off-farm activities exhibit a protective effect on household income only; in addition, credit constraints were found to have a negative effect on household income. Last, adoption of tissue culture banana was also found to reduce food insecurity and severe food insecurity by 0.44 and 0.32 index points, respectively.

Adoption of NERICA was also found to positively increase household income in Nigeria, along with other variables characterising household demographic structure, such as gender, age and education of household head and household size (Donstop-Nguezet, 2011).

Several studies confirm that poorer and more educated households benefit more from technology adoption. Specifically, the empirical evidence highlights the positive impact of improved seed varieties on consumption expenditure and poverty (Asfaw et al, 2012b, a). Also, Bezu et al (2014) find that poorer households benefit more, while differences by gender are not significant. By contrast, the impact of NERICA adoption in Nigeria is larger for educated, elderly males in rainfed upland and lowland and in the irrigated technology areas (Donstop- Nguezet et al, 2011), although it is the poorest farmers who benefited most.

Using state-of-the-art econometric methods to account for the endogeneity of technology adoption, Garbero et al (2016), estimated the impact of agricultural technology adoption on per capita expenditure, poverty and maize yields in Uganda.[10] Daily per adult expenditure expressed in US$ purchasing power parity (PPP) increased by 5% thanks to improved agricultural technology. It also led to a reduction in the likelihood of being poor by 11%. Other measures of poverty (poverty gap and poverty severity) were also reduced. The impact on maize yields ranged between 21% and28% by season. An important insight is that, with state dependence, the value to farmers of

[10] These methods include propensity score matching, Heckman selection model and endogenous switching regression model (ESRM). For details, see Garbero et al (2016). See also Kassie et al. (2011).

adoption increases with the level of adoption. Adequate extension services could create positive feedbacks, leading to much higher adoption rates and significant welfare improvements.

Yet another study that breaks new ground is Mekonnen et al (2017).

The major determinants of technology adoption in Ethiopia have been identified as risk aversion, perceptions about new technologies, access to extension and advisory services, and access to credit, with human capital, livestock holdings, land size and security of tenure being other socioeconomic factors. However, little attention has been paid to the role social networks and especially social learning play in technology adoption. Mekonnen et al enrich the sparse literature by offering a fresh perspective and robust empirical evidence, based on a state-of-the-art econometric methodology. The novelty of this analysis lies in an assessment of the relative importance of networks of male and female members of the same households for social learning in technology adoption and for improved farm productivity.

Specifically, this study investigated whether individuals belonging to the same group tended to behave similarly in terms of adopting row-planting, a recent innovation in Ethiopian agriculture, as a result of: (1) endogenous or peer effects; (2) exogenous or contextual effects; and (3) correlated effects. In addition, the study tested for the effects of social networks on farm productivity. To overcome some of the problems related to identification, the study used a random assignment of matches within the sample, employed non-linear as well as dynamic empirical specifications, and controlled for exogenous characteristics of peers.[11]

The analysis was based on a household survey conducted by the authors between January and March 2014. The baseline survey used a mix of purposive and random sampling to select 390 households from three study sites Oromia region in Ethiopia: Bakko-Sibu Siree, Lume-Adaa and Hettosa-Tiyyo.

The results show that belonging to certain groups such as *iddirs* (funeral groups), maintaining a relationship with network members in terms of kinship or informal forms of insurance, or a high frequency of meetings with a network member all appear to increase the probability of a network connection being an information link. Moreover, there is robust evidence of network externalities in the adoption of row-planting, especially in the case of female networks and for farm productivity. Finally, extension services and other programmes that promote agricultural innovations and their diffusion need to identify the 'right' networks to be most efficient, such as female networks in the case of row-planting. The results thus imply that investment in the formation of groups, rather than simply using existing networks, may also be worthwhile.

Agricultural growth in Ethiopia as a major contributor to overall economic growth was a remarkable occurrence for Africa, which lags in agricultural performance globally and is

[11] For further details, see Mekonnen et al (2017).

increasingly dependent on imported staple foods to feed its population. An understanding of the Ethiopian experience offers important lessons for the rest of the continent.

From this perspective, Bachewe et al (2017) make an important contribution in two ways. First, they identify the sources of this growth using an adjusted Solow decomposition model, which allows measurement of the extent to which modern inputs contributed to this growth. Second, using a set of comprehensive datasets, they offer new (and update existing) evidence on changes in modern input adoption over the 2004–14 period. An upshot of this analysis is that, under certain conditions, significant agricultural growth can be achieved in Africa in a relatively short period. The influential view that the preconditions for fast, intensification-driven output growth might not be present in Africa is rejected. Indeed, it is argued that this situation is rapidly changing – partly driven by rapid population growth, increasing land scarcity, urbanisation, better transport and communication infrastructure, higher incomes and an emerging middle class – at least in parts of the continent. These changing incentives combined with an enabling environment might then lead to improved agricultural performance across the continent.

A methodological innovation is the modelling of the simultaneous use of more than one modern input. A multinomial probit model is used to assess factors associated with the adoption of chemical fertiliser only, improved seeds only, or both chemical fertilisers and improved seeds, in contrast to the reference category of adoption of neither input.[12]

Agricultural output more than doubled, thanks both to area expansion but, more importantly also to significant yield increases. The increased productivity is partly explained by the rapid uptake of several improved agricultural technologies. However, some of this agricultural growth cannot be explained by the increased adoption of modern inputs and other production factors. Significant growth in TFP, 2.3% per year on average, also contributed to this growth. Further, the adoption of modern technologies was rapid and their contribution to agricultural growth was especially high in the second half of the previous decade. In the first half, agricultural growth was largely driven by area expansion and TFP growth.

Major drivers for the increasing adoption of modern inputs seem to be multiple, and enabled by significantly higher expenditures in the agricultural sector. First, Ethiopia expanded its agricultural extension system in the previous decade, and had one of the highest extension agent-to-farmer ratios in the world. Second, access to markets rose substantially. Third, improved access to education led to a significant decrease in illiteracy in rural areas. Fourth, high international prices for export products, as well as improved modern input–output ratios for local crops, provided better incentives for the

[12] For further details, see Mekonnen et al (2017).

agricultural sector. These factors together accelerated adoption of improved technologies, and consequently agricultural productivity. However, other factors played a role as well, including good weather, better access to MFIs in rural areas, improved security of tenure and a well-functioning safety net (Mekonnen et al, 2017).

Gillespie and van den Bold (2017) assess welfare impacts for developing countries, based on a recent review of agriculture and nutrition links in six countries (three in South Asia, three in SSA), as part of the Leveraging Agriculture for Nutrition in South Asia (LANSA) and Leveraging Agriculture for Nutrition in East Africa (LANEA) initiatives. Here we confine ourselves to the latter.

LANEA illuminates agriculture–nutrition pathways in East Africa in general and in Kenya, Ethiopia, and Uganda, countries where agriculture retains an important role, in particular. In all three countries and in East Africa generally research focused on agriculture as a source of food, with particularly limited research and evidence on women's participation in agriculture and their own nutrition and health status. In Ethiopia it was difficult for households to achieve food security solely through household production. Land ownership had a positive impact on food security, with women's land tenure security particularly important in rural areas. Female-headed households were more likely to experience a decrease in asset holdings as a result of volatility in food prices, putting pressure on women's time. In addition, net purchasers of food were more vulnerable to food price increases, particularly the urban poor, and, finally, adolescent boys were favoured over adolescent girls in allocation of household resources. In Kenya interventions to improve vegetable, animal source foods (ASF), and fruit production produced mixed results, but ownership of livestock and milk consumption was associated with better nutrition outcomes. Poorer households, however, faced challenges with intensive dairy production because of high input costs. Although income from on- and off-farm employment and food-for-work was associated with better food security and variety and quantity of foods consumed, it did not always lead to improvements in nutritional status, particularly if health and child care practices were suboptimal. Taking into account the role of food prices, especially households without access to food produced locally struggled to achieve adequate food consumption, and it was difficult for them to meet nutritional requirements with their own food production, particularly when production was influenced by seasonality. Women's employment in agriculture was found to have positive impacts on nutrition in the household when women had decision-making power over resource allocation. In Uganda evidence from randomised controlled trials showed positive impacts from bio-fortified crops, including orange-fleshed sweet potato, on vitamin A status among women and children. Ownership of livestock was associated with better household food security in Kampala. Evidence also showed mixed impacts on the links between women's empowerment, intra-household decision making, and better nutrition outcomes.[13]

[13] For a list of important contributions, see Gillespie and van den Bold (2017). More on women's empowerment, and livestock as a source of nutrition below.

Larsen & Lilleør (2017) provide one of the few rigorous assessments of the impact on early childhood nutrition, measured as height-for-age, of an agricultural intervention that improved food security in the lean season among smallholder farmers in Northern Tanzania by providing them with a 'basket' of new technology options.

The agricultural intervention is called 'Rural Initiatives for Participatory Agricultural Transformation' (RIPAT). The specific instance of this evaluation was the first RIPAT programme (RIPAT I), implemented by a local NGO, RECODA, in eight villages in Arumeru District in the Arusha Region of Northern Tanzania between 2006 and 2009. The stated overall development goal of RIPAT is to reduce poverty and improve food security among smallholder farmers by facilitating high and sustainable levels of adoption of the improved agricultural and livestock technologies disseminated.

The technology options comprise new banana cultivation techniques; new improved banana and other perennial and annual crop varieties; conservation agriculture for improved land utilisation (such as minimum soil disturbance, cover crops, intercropping, rotation and diversification of crops); post-harvesting technologies; improved animal husbandry; multipurpose trees for fodder, fruit or firewood; soil and water conservation, including rain water harvesting; and savings groups. Each farmer was free to choose which technologies to adopt on his/her own farm according to his/her own needs, constraints and resources.

Height-for-age is a strong biological marker of the nutritional status of children during the first 1,000 days of their lives, from conception to two years of age. During this period, children have very high growth rates; consequently, when subject to spells of faltering growth, children quickly fall behind the height-for-age growth curves of their peers, with limited chances of catching up subsequently.

This study, using post-treatment data, analysed whether the three-and-a-half-year-long agricultural intervention led to an improvement in the height-for-age measures among such young children. A rigorous methodology was used to determine the impact of the basket of technologies on stunting.[14] The RIPAT intervention improved drought resilience among the participating families.

While investment in agriculture has a (relatively) high return on investment, in many cases increases in food production and consumption have not contributed significantly to improvement in nutrition and health. This is in part because of lack of hygiene and sanitation and because of poor medical services. Considering specifically agricultural interventions – mainly related to home gardening and animal/dairy production –

[14] Larsen & Lilleør (2017) follow the identification strategy in Duflo (2003) and exploit the fact that height-for-age captures early-life undernutrition in the first 1,000 days, from conception to two years of age. A difference-in-differences comparison of cohorts conceived before and after the phase-in of the project is carried out, where only the latter cohort lived all of their first 1,000 days under full project implementation. Under the assumption of a common growth profile for all children in the absence of treatment, the height-for-age measures allow the authors to control for systematic differences in nutritional levels between older children in treatment and comparison households before the onset of intervention activities.

evidence is mixed in terms of their impacts on nutrition. While there is evidence of positive impacts on intermediary nutrition outcomes, such as dietary diversity, household production and consumption, and on child and maternal intake of 'target' foods and micronutrients, impact on nutrition outcomes – particularly child anthropometry and micronutrient status – was much more limited, except in relation to vitamin A intake and status.

3.1. Production diversity, dietary diversity and nutrition

Lack of dietary diversity is viewed as the major cause of micronutrient malnutrition in SSA. Imbalanced diets resulting from consumption of mainly high carbohydrate based-food also contribute to productivity losses and reduced educational attainment and income. Consequently, micronutrient malnutrition is currently the most critical food and nutritional security problem, as most diets are often deficient in essential vitamins and minerals. In Tanzania, for example, most rural and urban households consume mainly staples as their main food, which are high in carbohydrates but low in micronutrients and vitamins. Staple food items increase energy availability but do not improve nutritional outcomes if not consumed together with micronutrient-rich foods (Kennedy et al, 2007).

Recent studies have attempted to establish the linkage between land use or cropping pattern and dietary diversity of households. Herforth (2010) and Jones et al (2014), for example, examined the relationship between farm diversity and dietary diversity among households in African countries and concluded that there is a strong relationship between dietary and farm diversity. However, there are a few limitations in this work. Consider the Jones et al (2014) study. The authors used a multiple linear regression model to analyse the interlinkages between farm production diversity and household dietary diversity. Although the authors found a positive relationship between the two constructs, many of the relevant covariates (education, age, location) were omitted, biasing the effect of production diversity. Second, the data used for analysis do not account for the proportion of consumption of household-produced food or for associated seasonal effects. Most importantly, production diversity cannot be treated as exogenous as it is a household choice variable.

Rajendran et al (2014) sought to fill some of these gaps. They hypothesised that: (1) large-scale farmers have more diverse dietary patterns; (2) a higher level of education among farmers leads to a positive and significant association with dietary diversity; (3) increased diversity of crops in farmers' fields leads to more diverse diets of the households; and (4) decision making and control of income by female-headed households leads to greater dietary diversity. These hypotheses were tested using multiple linear regression models by controlling for other covariates in the model, based on Tanzanian data. The farmers were categorised into 'vegetable-cum-maize- based households' and 'only maize-based households'. Farmers designated as the former grew vegetables, maize and other staples, whereas only maize-based households were those that cultivated maize and other staple crops, with no vegetables. To correct for the bias among these two groups, the authors randomly selected an equal proportion from each group – 15 farm households from each category, making a total of 30 farm households per village. Overall, 300 farm households that cultivated maize and vegetables in each of the 10 villages, selected from Babati, Kongwa and Kieto districts in Tanzania, were surveyed from July to August, 2013, using a structured questionnaire. A dietary diversity score, based on FAO guidelines (FAO, 2011), was used. The dietary diversity scores described in these guidelines consist of a simple count of food groups that a household or an individual has consumed over the preceding 24-hour recall period. Sixteen food groups were constructed, based on local food consumption. Individual dietary diversity scores aim to reflect nutrient adequacy, whereas the Household Dietary Diversity Score (HDDS) is a snapshot of the economic ability of a household to access a variety of foods (FAO, 2011). This study used two different measurements of variables, namely crop count and Simpson's Index to measure farm diversity in agricultural seasons (both dry and rainy seasons). The crop count sums the total number of different crop species cultivated by the households in a crop year (ie March 2012 to February 2013), whereas Simpson's Index describes evenness of distributed area under cultivation for different crop species in a cropping pattern.[15] It seeks to examine the effect of crop diversity on dietary diversity of farm households.[16] Neither crop count nor Simpson's Index was significantly associated with dietary diversity after controlling for other covariates in both models. Covariates such as number of people in household, monthly per capita expenditure on food, net cultivated area under irrigation for all crops, proportion of total vegetables consumed from domestic production and decision making and control of income by female-headed households exhibited strong influences on dietary diversity. These variables positively and significantly influenced dietary diversity in both cases. Briefly, crop diversity does not influence dietary diversity after controlling for other covariates.

There are a few issues, however, that undermine the robustness of the results. These limitations are similar to those encountered earlier. One is the use of farm diversity as an exogenous variable. In fact, farm diversity is a response to weather and price risks (a more diversified crop portfolio protects the farmer better against such risks), and to the relative profitability of different crops and animal husbandry. A more refined methodology is thus needed that adjusts for the endogeneity of these and other variables (the split between food and non-food expenditure). Another major limitation is that analysis of nutritional impact has to go beyond groups of food commodities consumed. There is an important linking role of food value chains that encompass the preferences of vendors (including supermarkets and other retailers) and consumers.

[15] Simpson's diversity index is commonly used to measure biodiversity. High scores (close to 1) indicate high diversity; low scores (close to 0) indicate low diversity.

[16] It used multiple linear regression models employing cross-section data collected through a primary survey. This model is designed to control for the effects of other covariates (ie individual and household characteristics, land ownership, irrigation, regional effects, non-farm income, expenditure on food and non-food items) in order to capture the net effect of farm diversity on dietary diversity.

What recent literature has shown is that even the poor respond to changes in relative food prices, as well as expressing a preference for variety in food.

A positive relationship between farm production diversity and dietary diversity is plausible, because much of what smallholder farmers produce is consumed at home. However, this is more plausible in a subsistence economy than in one in which market transactions are prominent. Instead of producing everything at home, households can buy food diversity in the market when they generate sufficient income. Farm diversification may contribute to income growth and stability. Further, as the majority of smallholder households in developing countries also have off-farm income sources, the link between production diversity and dietary diversity is further undermined. Finally, when relying on markets, nutrition effects in farm households will also depend on how well the markets function and who decides how farm and off-farm incomes are allocated to food. It is well known that income in the hands of women frequently results in more nourishing food – especially for children.

Sibhatu et al (2014) analysed the relationship between production and consumption diversity in smallholder farm households with data from four developing countries: Indonesia, Kenya, Ethiopia and Malawi. These four countries were selected mainly because of the availability of suitable and recent household data. The results are classified under (1) association between production and dietary diversity; (2) role of market access; and (3) role of selling and buying food.[17] Farm production diversity was positively associated with dietary diversity, but the effect was relatively small. In the pooled sample, producing one additional crop or livestock species led to a 0.9% increase in the number of food groups consumed. This effect, however, varied across the countries in question. In Kenya and Ethiopia, the coefficient estimates were very small and not statistically significant. In these two countries, average production diversity was quite high; further increasing farm diversity would hardly contribute to higher dietary diversity. One indicator of market access is the geographic distance from the farm household to the closest market where food can be sold or bought. The estimated coefficients were negative in all models, implying that households in remoter regions had lower dietary diversity. Better market access through reduced distances could therefore contribute to higher dietary diversity. Comparing the magnitude of the estimated coefficients in the pooled model reveals that reducing market distance by 10 km has the same effect on dietary diversity as increasing farm production diversity by one additional crop or livestock species.[18]

[17] A Poisson regression model was used.

[18] The interaction term between production diversity and market distance was not significant in most cases. The positive and significant interaction coefficient in the Malawi case suggests that the role of production diversity is more important in remoter regions, where farms tend to be more subsistence-oriented. This seems plausible, except that endogeneity of production diversity is an issue, as discussed below.

A more pertinent question is whether this also leads to more healthy diets. Depending on the type of food outlets available in a particular context, buying food may possibly be associated with rather unhealthy dietary diversification, for instance through increased consumption of fats, sweets or sugary beverages. This is examined by using alternative dietary diversity scores as dependent variables, including only more healthy food groups. The finding that better market access tends to increase dietary diversity also holds with this alternative specification. However, it is not self-evident that this specification is clearly superior for two reasons: one is the failure to distinguish between processed and unprocessed, say, vegetables (eg eating French fries or eating boiled potatoes) with vastly different nutritional implications; the second is that, at best, dietary diversity (restricted or unrestricted) is an approximation to nutrient intake, as there are substitutions both within and between food groups in response to income and price changes (a case in point is different grades of rice).[19]

Another approach is to measure what households sell and buy. This information is only available for the samples from Ethiopia and Malawi. A dummy was used as an additional explanatory variable that takes a value of one if the household sells at least part of its farm produce to the market. The estimated coefficient is positive and significant. It is also much larger than the production diversity coefficient. This comparison suggests that facilitating the commercialisation of smallholder farms may be a better strategy for improving nutrition than promoting more diversified subsistence production. Furthermore, the negative and significant interaction term confirms that market participation reduces the role of production diversity for dietary quality.

Accordingly, dietary diversity is measured in terms of the food purchased in the market. The farm production diversity coefficient is significantly negative, meaning that more diversified farms tend to buy less diversified foods in the market. This is perhaps not surprising: If the farm produces diverse foods itself, diversity from the market may not be needed to the same extent. However, diversified domestic production may substitute only partially for diversity from the market, because more than half of all of the food consumed in sample households is purchased.

Better market access in terms of shorter distances and more off-farm income opportunities increase the level of purchased food diversity. If off-farm income opportunities are greater in rural areas with short distances to market, the market access effect cannot be disentangled from the income effect. The interaction between level of farm income and participation in off-farm activities is often complex, as small farmers tend to work as labourers in the latter, while relatively affluent farmers dominate as owners in more remunerative enterprises.[20] The two important inferences

[19] See, for example, Timmer (1981), Behrman and Deolalikar (1989), Jha et al (2009) and Gaiha et al (2014).

[20] To test for such bias, the authors re-estimated the regression models, this time including socioeconomic and demographic characteristics – such as farm and household size, as well as age, education and gender of the household head – as additional explanatory variables. Some of these other factors are significant, but the estimated coefficients for farm production diversity and market access do not change much. The authors interpret this as evidence that the main

are, first, increasing on-farm diversity among smallholders is not always the most effective way to improve dietary diversity and should not be considered a goal in itself; and, second, in many situations, facilitating market access through improved infrastructure and other policies to reduce transaction costs and price distortions seems to be more promising than promoting further production diversification as such. There are three caveats, however. One is the endogeneity of production diversity. Unless this is corrected, the coefficients are likely to be biased or suspect.[21] The second is lack of uniformity of food baskets across countries/sub-regions (Masset et al, 2012). The third is that, regardless of how dietary diversity is measured, it cannot on its own capture nutritional effects. A direct test may yield more reliable estimates of nutritional outcomes in which the dependent variables are calories, proteins, fats and micronutrients (Gaiha et al, 2014).

Another estimation strategy that allows for simultaneity in production and consumption decisions is intuitively more appealing (Dillon et al, 2015). An appropriate procedure is to induce an exogenous change in production and assess its subsequent effects on diet. This study investigated the quasi-exogenous increase in on-farm diversity among Africa RISING beneficiary households in Malawi to examine the link between production and dietary diversity. Three groups of households were recruited into this research study: all the households testing innovations as of June 2013 ('beneficiary' group), randomly sampled households in project villages who did not participate in the project ('non-beneficiary' group), and randomly sampled households from non-project villages representing similar development domains to the Africa RISING villages ('control group). The main findings obtained are presented below.

Beneficiary households had more diverse farms, on average and across quartiles, relative to non-beneficiary and control group households. No statistically significant differences were found between beneficiary households and the other two groups in terms of the Household Dietary Diversity Index, which is measured by the count of food items consumed within the household. No statistically significant differences were found between beneficiary households and households in the other two groups in terms of the value of foods consumed during the reference week.

In brief, improvements in product diversity did not translate into better diets, as measured by the diversity and value of foods consumed within the household.

Two caveats are in order: (1) the Herfindahl Index would be a better measure of dietary diversity as it allows for shares of different food commodities in household food expenditure;[22] and (2) because of higher and rising shares of fatty and processed

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results do not suffer from omitted variable bias. These additional variables, however, do not resolve the endogeneity of production diversity. For example, farm diversity could be a risk-averse response to crop price uncertainty and the expansion of high value chains (eg tomato for making ketchup, coffee for upgrade to export quality).

[21] For a demonstration of how this could be done, see Imai et al (2013).

[22] For an application, see Gaiha et al (2014).

foods, the correspondence between dietary diversity and nutritional intake needs careful verification.

4. Livestock and nutrition

Animal-source foods (ASF) are nutritionally dense sources of energy, protein and other essential micronutrients. Thus ASF enable children and pregnant and breastfeeding women to obtain calories in adequate quantities, as well as high quality protein, micronutrients and better nutrition. ASF are also a major source of iron, zinc, calcium, riboflavin, vitamin A, vitamin B-12 and retinol, and increasing the intake of ASF and the micronutrients they contain has numerous positive benefits, including linear growth, improved educational attainment and health status, leading to long-term improvements in income and productivity.

Using nationally representative data for Uganda, Azzarri et al (2015) examine such linkages between livestock ownership, consumption and nutrition. Uganda offers a promising environment for this analysis thanks to a combination of high prevalence of livestock ownership, recent growth in the livestock sector and high levels of malnutrition – with a 33% stunting and 50% anaemia prevalence in children under five. The authors used household survey data from the 2005/06 Uganda National Household Survey (UNHS) and the 2009/10 Uganda National Panel Survey (UNPS). Three livestock categories – large ruminants (bulls, cows, calves), small ruminants (goats and sheep), and poultry (chickens turkeys, and ducks) were considered. The empirical analysis of child nutritional outcomes used standardised anthropometric indicators. Z-scores for height-for-age (HA), weight-for-age (WA) and weight-for-height (WH) were computed based on the 2006 World Health Organization's new Child Growth Standards. An innovative econometric methodology was used.[23]

The analysis confirms significant differences in the consumption patterns of ASF between livestock owners and non-owners: the number of large ruminants owned or managed has a positive effect on dairy consumption but not on beef consumption. While the number of small ruminants does not have a significant effect on consumption of goat and sheep meat, ownership of poultry affects chicken consumption positively. In particular, there was a positive effect of the number of poultry on chicken consumption and of the number of large ruminants on dairy consumption above and beyond the indirect effect of these livestock types through livestock income, controlling for welfare level (proxied by total per-capita consumption expenditure tercile). There was, however, a weak association between livestock ownership and child nutritional status, specifically related to the probability of being underweight and wasted (limited to

[23] The authors examined in the first stage whether the consumption of ASF depended on ownership of the three livestock categories using a tobit specification with random effects; and, in the second, the effect of ownership of livestock categories on child anthropometric outcomes using a probit.

children between 2 and 5 years of age), but no association with stunting. Also, while ownership of small ruminants reduced the probability of children aged 2–5 years being underweight, ownership of large ruminants partly countered that effect.

Yet another study (Koura et al, 2015) assesses the impact of animal source food interventions on nutrition-related outcomes in Ethiopia (in the Horn of Africa). The analysis examined the impact of a women-focused goat development project expanded to include interventions to promote vitamin A intake, nutrition and health education, training in gardening and food preparation, and distribution of vegetable seeds. Goat-owning households consumed all the milk produced: 87% of it by the adults as *hoja*. Children in the participating households had slightly more diversified diets; they were also more likely to consume milk more than four times a day. A methodological limitation is that no correction was made for self-selection bias.

Thus if we go by the findings of Azzarri et al (2015) for Uganda, from a policy perspective, promoting (small) livestock ownership has the potential to affect human nutrition in SSA countries, but the direction and size of the effect is still controversial. In contexts where markets are imperfect, supporting livestock ownership may be conducive to improving diets by a direct access channel, as well as providing further livelihood opportunities and increased income.

5. Bio-fortification

Soil micronutrient deficiencies are thought to be severe in SSA, where 75% of the total arable land has serious soil fertility problems. Insufficient micronutrient availability in soils in these regions not only causes low crop productivity, but also poor nutritional quality of the crops, which contributes to malnutrition in the human population.

Diets in SSA (especially among resource poor households) are often low in diversity and dominated by staple crops such as maize, rice, cassava, sorghum, millet, banana and sweet potato. Such diets are poor in micronutrients (minerals and vitamins) and consequently micronutrient deficiencies are widespread (FAO, 2015). The chronic lack of micronutrients causes severe but often invisible health problems, especially among women and young children: hence 'hidden hunger'.

In SSA, micronutrient deficiencies contribute 1.5–12% of the total Disability Adjusted Life Years (DALYs). Alarming numbers suffer from iron deficiency anaemia, which affects more than half of the female population in countries such as DR Congo, Ghana, Mali, Senegal and Togo. Selenium contributes to the human diet through uptake by crops from the soil. Even mild to moderate deficiencies of micronutrients can lead to severe human health problems, generally related to sub-optimal metabolic functioning, decreased immunity and consequently increased susceptibility to infections, growth failure, cognitive impairment and, finally, reduced productivity (de Valença et al, 2017). Direct interventions comprise dietary diversification, micronutrient supplementation, modification of food choices and fortification. Bio-fortification increases the content and/or bioavailability of essential nutrients in crops during plant growth through genetic and agronomic pathways (Garcia-Banuelos, and. Sida-Arreola E.Sanches, 2014, Saltzman et al. 2013).

Vitamin A deficiency is associated with a higher risk of morbidity and mortality, and with ocular disorders such as night blindness, xerophthalmia and blindness, affecting infants, children and pregnant or lactating women. Among populations at risk, vitamin A deficiency is estimated to affect more than 200 million women and children. African regions account for the greatest number of pre-school children with night blindness and for more than one-quarter of all children with subclinical vitamin A deficiency (Hotz et al, 2012).

Although the primary cause of vitamin A deficiency is inadequate quantities in the food supply, there have been relatively few large-scale, agricultural, food-based interventions implemented to address the problem, and fewer still have been adequately evaluated. For example, homestead and/or community garden production of vitamin A-rich fruits and vegetables has been promoted in a few populations with some success.

Sweet potato varieties most commonly cultivated in Africa are white or pale yellow, with no or little provitamin A, and have a relatively high dry matter content. However, provitamin A-rich varieties, known as orange sweet potato (OSP), have been bred through the process of bio-fortification or have been introduced and evaluated, and are suitable for Africa in terms of preferred agronomic and consumer traits. Due to the high content of beta-carotene in some African-grown OSP varieties, the relatively high seasonal consumption of sweet potato can contribute substantially to increased vitamin A intake adequacy.

Mozambique is a country with modest use of sweet potato as a staple food. However, the prevalence of vitamin A deficiency is very high, and the coverage of vitamin A supplementation varies. Zambe´zia Province in Central Mozambique is more reliant on roots and tubers than on maize, has among the highest rates of stunting and underweight in the country and the lowest rates of vitamin A supplementation.

A nearly three-year long, large-scale intervention to introduce several OSP varieties using agricultural extension and market development activities and product development, combined with demand creation and nutrition education, was implemented in rural communities in Zambe´zia Province. The study implemented two models of intervention to compare the effect of different durations of inputs on outcomes. In the detailed and meticulous scrutiny of this intervention, Hotz et al (2012) hypothesised that intakes of OSP and vitamin A would be greater when exposure to key intervention components was extended to three years compared with one year. A prospective randomised, controlled effectiveness evaluation of both models was carried out.[24]

This large-scale intervention had a substantial impact on the dietary intake of OSP among women and pre-school children. The increase in OSP intake in the intervention groups was largely attributed to a direct substitution of white and yellow sweet potato varieties. The incorporation of OSP in the diet translated to a large, significant increase in vitamin A intakes by these subgroups and hence reduced the prevalence of inadequate vitamin A intakes. There were no major differences in the impact on OSP or vitamin A intakes between the model 1 and model 2 groups, indicating that the magnitude of impact observed in the study was not diluted by the less intensive intervention in model 2.

The similar substitution rates across age groups suggest that OSP was equitably shared among women and children of different ages.

The wide acceptance of OSP in populations where white or yellow sweet potatoes are usually consumed has been observed elsewhere in SSA, and can thus be plausibly generalised.

The increases in OSP intake were similar between the two intervention models. This implies that additional project inputs to supervise and support the village-level promoters in repeating agriculture and nutrition education sessions through the second and third years of the intervention did not translate into additional impact in the amount of OSP consumed, vitamin A intake or the prevalence of inadequate vitamin A intake. This is an important policy finding, as the additional cost of maintaining direct, community-level contact by project staff beyond the first year of intervention is not justified in these sweet potato-producing areas and the maintenance of district-level activities and mass media may be sufficient to maintain behaviour change after the first year.

Some constraints to implementing agronomic bio-fortification are briefly noted. Development of the bio-physical, economic, social and political environment is necessary to facilitate proper technologies, allocation of resources and food-processing systems. A key issue is the commercialisation of smallholder agriculture to create markets for the extra production, because otherwise investments in (extra) mineral fertiliser are not economically feasible. Mapping of micronutrient deficiencies in order to provide field-specific fertilisation recommendations remains a challenge. Furthermore, knowledge and tools should be accessible and affordable for farmers in rural African regions. Finally, new fertiliser products and management practices need to be matched with local socio-cultural environments in order to enhance adoption. It is important to

[24] An intervention to introduce household-level cultivation of OSP was implemented between 2006 and 2009 in 144 selected villages in four districts, combined in three strata (Milange, Gurue and Mopeia/Nicoadala) of Zambe´zia Province. This was a large-scale intervention reaching more than 12,000 farm households and was designed to learn lessons about scaling up the distribution of OSP.

raise awareness about proper food processing and consumption that stimulate micronutrient uptake into the human body.[25]

6. Home gardens

Over recent years there has been growing interest in strengthening and intensifying local food production in order to mitigate the adverse effect of global food shocks and food price volatilities. Consequently, home gardens are being viewed as a strategy to enhance household food security and nutrition. Home gardens are an integral part of local food systems and the agricultural landscape of developing countries all over the world and have endured the test of time.

Studies of homestead food production programmes have found improvements in production of targeted nutrient- rich foods within households, but have not found any impact on child nutrition. A critical intermediate step requiring assessment is whether production of these more diverse foods leads to their actually being eaten, thereby improving the diversity and quality of children's diets in these households.[26] Reviews of interventions aiming to increase the diversity of agricultural production and assess impact on diet and nutrition have found in general that the specific foods or food groups targeted by an intervention go into the diets of target beneficiaries, but have not demonstrated an impact on nutritional status (anthropometry) – mainly because the original evaluations were not properly designed to capture such an effect.

The household garden is a small-scale production system supplying plants and animals for consumption and utilitarian items not affordable or readily obtainable through retail markets, field cultivation, hunting, gathering, fishing or wage earning. Featuring ecologically adapted and complementary species, household gardens are marked by low capital input and simple technology. Home gardens can be described as a mixed cropping system that encompasses vegetables, fruits, plantation crops, spices, herbs and ornamental and medicinal plants, as well as livestock; they can serve as a supplementary source of food and income.

The most fundamental social benefit of home gardens stems from their direct contribution to household food security by increasing availability, accessibility and utilisation of food products. Home gardens are maintained for easy access to fresh plant and animal food sources in both rural and urban locales. Food items from home gardens substantially fulfil family energy and nutritive requirements on a continuous

[25] As some of the discussion overlaps with sustainable technology discussion, some details are omitted here to avoid repetition.

[26] Homestead gardens are found in backyards, farmyards, kitchens, small patches of available land, vacant lots, and along roadsides and the edges of fields. They are generally close to a house and source of water and are managed by family members using low-cost inputs. Their products include fruits, vegetables, herbs, condiments, and sometimes secondary staples such as legumes and sweet potatoes, most of which are grown for household consumption. The nutrition impacts of homestead gardens have been relatively well documented (Abebe et al. 2006).

basis. Resource-poor families often depend more on home gardens for their food staples and secondary staples than those endowed with a fair amount of assets and resources such as land and capital. For poor and marginalised families unable to afford expensive animal products to fulfil their nutritional needs, home gardens offer a cheap source of nutritive foods.

Various studies conclude that, while adding to the caloric quantity, home gardens supplement a staple-based diet with a significant portion of proteins, vitamins and minerals, leading to an enriched and balanced diet, particularly for growing children and mothers. Additionally, plants from the gardens – especially spices and herbs - are used as flavour enhancers, teas and condiments. Furthermore, the integration of livestock and poultry activities into home gardening reinforces food and nutritional security for the families as milk, eggs and meat from home-raised animals provide the main and, in many instances, the only source of animal protein. In some places, home gardeners are also engaged in mushroom cultivation and beekeeping, and even small fresh water fish ponds may be incorporated into the garden space, adding to the share of proteins and other nutrients available for the family.

Even though there are only a few published works on the subject, home gardens have been proposed as an option for food and nutritional security in disaster, conflict and other post-crisis situations. Home gardens based on enset (false banana) and coffee constitute an integrated farming system that not only provides subsistence and complementary food products for Ethiopian families, especially during famines, but also the primary means of employment for the household.

In a post-conflict setting, assistance and reconciliation mechanisms work best and result in environmental, social and economic benefits when there is a cultural or traditional linkage between the target population and the intervention. Hence, home garden projects offer a realistic solution, as in most countries home gardening is a regular day-to-day activity among the households, especially for women. In addition, home gardens, when properly managed, provide a four-in-one solution to the food and nutrition problem by increasing household food availability, enabling greater physical, economic and social access, providing an array of nutrients, and protecting and buffering the household against food shortages (Galhena et al, 2013).

A generous portion of the plants found in home gardens have some medicinal value and they can be used to treat many common health problems in a cost-effective manner. For instance, home gardens in Bukoba district, Tanzania contained plant species grown entirely for medicinal purposes. Based on a study conducted by Brun et al (1989) in Senegal, evaluating the food and nutritional impact of home gardening, it was found that, although the gardens did not make a major contribution to food consumption and nutrition, they were instrumental in improving the women's income and social status as well as their awareness of evolving food habits in urban areas.

Evidence from south-eastern Nigeria shows that tree crops and livestock produced in home gardens accounted for more than 60% of household income. In many cases the sale of produce from home gardens improves the financial status of the family, providing additional income, while contributing to social and cultural amelioration. The fact that home production requires fewer inputs and investment is extremely important for resource-poor families with limited access to production inputs. Yet moderately rigorous crop and livestock production in home gardens can generate as much revenue per unit area as field crop production.

Home gardens provide multiple environmental and ecological benefits. They serve as the primary unit initiating and utilising ecologically friendly approaches to food production while conserving biodiversity and natural resources. Home gardens are usually diverse and contain a rich composition of plant and animal species. A study of home gardens in southern Ethiopia identified a significant concentration of plants used as vegetables, fruits, herbs, medicines, yams and spices.

Kumar et al (2015) point out that evidence is needed on the direct links between food production within a household, ingestion of that food by individual household members, and subsequent effects on nutritional status. The motivation for this study was to address the gap in our understanding of how diversity of agricultural production affects the dietary diversity and nutritional status of children living in farming communities in SSA, using household survey data from a rural district in central Zambia. An innovative econometric methodology was used that allows for the endogeneity of dietary diversity and anthropometric outcomes but treats production diversity as exogenous. In a more refined methodology, endogeneity of production diversity also has to be taken into account. To examine whether greater *household* production diversity trickles down to dietary diversity among young children, the authors examined the relation between household production diversity and dietary intake among children aged 6–23 months. They also examined the link between production diversity and nutritional status of children aged 6–23 months and 24–59 months.

The three production diversity variables assessed were significantly associated with individual dietary diversity outcomes in young children aged 6–23 months.[27] These results suggest that the diversity of diets consumed by infants and young children is directly related to diversity in agricultural production in these semi-subsistence households. Production diversity is not associated with nutritional status (as measured through anthropometry) in younger children, but in children over the age of 24 months there is a more consistent pattern between agricultural production diversity and linear growth. In older children, agricultural production diversity is positively associated with Height for Age scores and inversely associated with stunting. These associations, while small, are consistent, and are in line with what is known about biological processes affecting children of different ages. Diversity of agricultural production thus has an

[27] Production diversity is measured in terms of: (1) total number of crops (including field crops and fruits and vegetables) cultivated; (2) total number of agricultural activities engaged in (production of field crops, production of fruits and fruits/vegetables, rearing animals and production of animal-source foods); and (3) production of seven different food groups that correspond to those groups used in the child dietary diversity index.

important impact on dietary diversity in young children in subsistence households, and subsequently on nutritional status as these children age.

Another study (Gillespie and van den Bold, 2017) reports mixed evidence on the impact of home gardening and animal/dairy production on nutrition. While there is evidence of positive impacts on intermediary nutrition outcomes, such as dietary diversity, household production and consumption, and child and maternal intake of 'target' foods and micronutrients, the impact on nutrition outcomes – particularly child anthropometry and micronutrient status – was much more limited, except in relation to vitamin A intake and status.

A third detailed study (Kidala et al, 2000) focuses on Tanzania. It assessed the impacts of promotion of home production, consumption and storage of vitamin A-rich foods, of health and of nutrition education. The authors observed lower serum vitamin A and higher helminths in the treatment areas. Overall, after the treatment, higher intakes of vitamin A-rich foods were associated with higher serum Vitamin A. There was a significantly higher percentage of households with homestead gardens and production of vitamin A-rich vegetables in treatment areas. In addition, the authors observed better knowledge, attitudes and practices about use of vitamin A, and higher proportions using solar driers for vitamin A foods, as well as higher seven-day frequency of intake of vitamin A foods. A limitation was the lack of correction for self-selection bias.

A meta-review with a strong methodological flavour and cautious interpretation of results was carried out in Masset et al (2012).

In a broad-brush but rigorous review of 23 studies on the impact of agricultural interventions on child nutrition, they made several insightful comments for policy design and implementation. Central to the review are examples of interventions (such as home gardens and the production of bio-fortified crops) with the explicit goal of improving the nutritional status of children. One limitation is that it is a distillation of the studies reviewed without going into contextual specificities.

A large majority of the studies are of home gardens (n=15), with much smaller numbers for bio-fortification (2), small-scale fisheries and aquaculture (3), dairy development (1), and animal husbandry and poultry development (1). Rigorous evaluations of the effect of dairy development, animal husbandry and fisheries projects are extremely rare. In the case of bio-fortification programmes, the lack of evidence is largely a result of the novelty of the interventions.

In most cases, home garden programmes increased the consumption of fruit and vegetables, aquaculture and small fisheries interventions increased the consumption of fish, and dairy development projects increased the consumption of milk. A difficulty is that an increase in the consumption of the food item targeted by the intervention does not imply an improvement in the overall diet, because substitution effects in consumption occur. For example, in one case, although the consumption of vegetables, rice and fish increased after the intervention, the consumption of pulses decreased. This suggests that the diversity of the diet, or analysis of the full consumption basket, are better indicators than is consumption of the specific food promoted by an intervention.

Two studies assessed the effect on children's iron intake and found no statistically significant differences in the average haemoglobin concentrations between children in the project and control groups. Another study assessed the effect of fish consumption on iron intake at the household level and found a modest effect by using food-to-micronutrients conversion tables. The observed effect would have been even smaller after consideration of the actual bodily absorption of the iron ingested.[28]

Nine studies reported effects on concentration of serum retinol from blood samples. However, only four of these studies reported means and standard deviations of observations on children in project and control areas. The difference between the mean serum retinol concentration in the project and control group for each study was reported with a 95% confidence interval. Overall, the effect of the interventions was a difference of 2.4 μg/dL in serum retinol between project and control areas (z test of significance 6.35; $P<0.001$). This summary effect is the weighted mean of the effects found by the individual studies. This meta-analysis provides some support for the hypothesis that agricultural home gardens interventions improve vitamin A intake among children under the age of five.

Anthropometric data were collected by 13 of the 23 studies included in the review, but only eight studies used these data to calculate the prevalence of stunting, underweight and wasting. Only one study found a statistically significant effect on the prevalence of stunting, whereas three studies found a positive effect on the prevalence of underweight and two found a positive effect on wasting.

Overall, these results provide little support for the hypothesis that agricultural interventions help to reduce undernutrition. However, they should not be interpreted as evidence of the absence of an effect.

In sum, the interventions reviewed had a positive effect on the production of the agricultural goods promoted, but there was no effect on households' total income. The interventions were successful in promoting the consumption of specific foods, but not in dietary changes. There was no effect on the absorption of iron and some on absorption of vitamin A. The effects on the prevalence of stunting, wasting and underweight among children under 5 years of age were limited and mixed.

7. Women's empowerment, agriculture and nutrition

Women are vitally important agents, both in their roles as producers and as custodians of household welfare. Their importance, moreover, is generally greater in the lowest-income settings and among households with high dependency ratios, ie those in which

[28] For details of the studies cited, see Masset et al (2012).

a large proportion of household members are nonearning and often nutritionally vulnerable dependents.

The resources and income flows that women control often have positive impacts on household health and nutrition. In some countries, women lack access to economic opportunities outside the domestic sphere to which traditional customs often confine them, especially in rural areas. They are also often severely constrained by time and the multiple – often simultaneous – roles they play as producers and caregivers. Agricultural programmes and policies that empower and enable women and that involve them in decisions and activities throughout the life of the programme achieve greater nutritional impacts (World Bank, 2007).

Let us now review the evidence for selected African countries.

Although women comprise more than 50% of the agricultural workforce in most of the Eastern and Southern Africa (ESA) region, the productivity gap between men and women farmers persists. To illustrate how wide the gap is: in Tanzania, Malawi and Uganda narrowing the gender gap in agricultural productivity has the potential to raise the gross domestic product by US$105 million, $100 million and $65 million, respectively (UN Women, FAO, IFAD and WFP 2015). Women farmers typically use lower levels of purchased technological inputs, such as fertiliser and high-yielding seed varieties. That women lack access to these key technological inputs explains a significant portion of the productivity gap. They are often hesitant to adopt these technologies if they do not control the benefits that accrue from adopting. Moreover, women also face unique challenges, because of their lifecycle and reproductive roles. These further influence their participation on- and off-farm.

In Kenya, new varieties of sweet potatoes rich in beta-carotene were introduced to women farmers with an end goal of improving vitamin A intake among young children, thereby preventing vitamin A deficiency. The Kenyan study showed a significant increase in the intake of vitamin A-rich foods among children whose mothers received both the production-focused intervention of planting materials and access to agricultural extension services, and the consumption-focused intervention of nutrition education and training in food processing and preparation. By contrast, there was a decrease in vitamin A food intake (30%, but not statistically significant) for children whose mothers received only the production-focused inputs. This example suggests that women's farm production offers an entry point for interventions that can improve nutrition, and that interventions which increase women's agricultural productivity and improve their health and nutrition knowledge may yield more benefits than ones that target only productivity or only knowledge.

Once food is produced and enters the household, women are principally responsible for processing it. Food processing can often improve the nutritional quality of foods and increase dietary diversification. Women process oilseeds, such as sunflower or sesame seeds, to produce cooking oil; transform cassava into *gari*; smoke and dry fish and meat; and process and preserve fruits and vegetables. Thus, women's roles in food processing offer yet another entry point for interventions that can enhance family nutrition (Kurz and Johnson-Welch, 2001.)

A few case studies, however, reveal some unexpected outcomes (World Bank, 2007). Although the World Bank study draws upon a rich literature from different regions, we focus more on African evidence. Failure to understand cultural norms and the gender dynamics within the household may result in unanticipated outcomes. In the Gambia, for example, a project geared to increasing women's rice production was so successful that the land it was grown on was reclassified internally within the household. This resulted in output from that land being sold by men as opposed to women. Women therefore lost their original income stream, but did retain an increased labour commitment. Vegetables and legumes are often regarded as women's crops. Recognising this, a project in Togo was successful because it promoted the introduction of soybeans as a legume rather than as a cash crop. Promotion as a cash crop would have resulted in the crop switching to male control. Interventions promoting the production of animal source foods also assessed their impact on maternal income or women's control over income. The results were mixed. For example, an intervention involving intensified dairy farming in Kenya showed that an important share of the additional income was controlled by women, whereas in Ethiopia men's incomes benefited significantly more from intensified dairying than did women's. Whether women's income is likely to increase depends on the livestock or aquaculture production system, the nature of the intervention, and on cultural beliefs and practices relating to gender. Even if the intervention is targeted at women's livestock and aquaculture activities, women lose control over the income generated by those activities.

Successful interventions are more likely to take into account the range of factors that differentially enable or constrain men and women in terms of access to resources like land and services like credit. These constraints often limit their roles as decision makers in the household or community. The significance of gender equity is particularly critical, because women's status and decision-making power directly affect the nutritional status of their children.

Poor levels of human capital, health and nutrition significantly constrain women's ability to work as efficient agricultural producers. Low levels of human capital may influence women's productivity in two ways. First, they may take longer to perform the same agricultural task. Second, they may not use certain technologies if they lack the information and knowledge required to use it. In fact, a significant portion of the on-farm productivity gap in Malawi is explained by the labour productivity gap, which is larger than the land productivity gap. Women are found to spend more time working on the farm, which diminishes the size of the overall productivity gap, but increases the labour productivity gender gap because women take longer to perform the same task compared to men (Palacios- López and Lopez, 2014).

Evidence further suggests that, on average, women have lower access to extension compared to their male counterparts (Quisumbing et al, 2014), which compounds the problem of the lower education levels of women. When they do have access to extension, they are more likely to adopt new technologies.

Rural women are less likely to have land under their control than rural men. Improving tenure security and access to land has direct consequences for bolstering investments in long-term financial capital-demanding technologies. Tenure security in nine West African countries led to significantly improved tree planting and investments in land, but did not affect short-term investments such as use of purchased, productive inputs. The influence that women have on agricultural decision making is, however, higher when women own land individually.

Several factors, such as collateral requirements, mobility restrictions, significant transaction costs and cultural barriers, impede women from accessing financial products and credit. Moreover, they may also make less demand for credit if seeking financial products in formal systems and being entrepreneurial implies stepping outside the boundaries of prevalent social and cultural norms. In such contexts, interventions that provide women farmers with access to financial products through familiar structures, such as rural savings and credit cooperative organisations, may induce women to seek credit thanks to the prevalence of strong peer effects.

A useful way of shortening the link between technology innovation and adoption by women is to make them centre stage in the technology innovation and product design process. In Tanzania, for example, a solar-powered irrigation pump has been developed that irrigates about one acre of land in six to 12 hours a day. The pump is portable and can be easily transported between fields, offering an opportunity for developing custom hiring irrigation service businesses for women entrepreneurs and women-led cooperatives. Policy should also take into account not just cultural appropriateness but also the fact that women have multiple objectives when working on the farm and are more likely to adopt technologies that prioritise their household food and nutrition security.

In Mozambique, an experimental evaluation of the fertiliser subsidy programme reveals a relatively low uptake of fertiliser and improved seed varieties by farmers, potentially as a result of other credit or information limitations. Indeed, adoption of new technologies by women farmers requires a set of complementary policies such as innovative financing mechanisms, along with providing actual knowledge about technologies and bringing the technologies to the doorstep. When simultaneously implemented, such complementary policies are more likely to enhance technology adoption by women.

In Western Kenya, farmers were encouraged to use fertiliser by providing them with time-limited fertiliser discounts in the form of free delivery, right after the harvest season. An evaluation suggests that such small nudges were much more effective in encouraging fertiliser use than were much larger price subsidies during the planting season.

Encouragement and nudges through women's social networks induce adoption as women rely more on their informal social networks than men. Strengthening women's land rights, starting from shifts in inheritance laws to land rental laws, is essential to women trusting that their investments in agricultural technologies will support their long-term personal, household and community-level goals. Evaluation of South Africa's Land Redistribution for Agricultural Development programme suggests that beneficiaries experienced a 25% increase in their consumption expenditures. Moreover, while their living standards initially dropped, after more than three years the beneficiaries experienced benefits of the order of 150% in their living standards.

There are improved impacts on nutrition if agricultural interventions are targeted at women and when specific work is done around women's empowerment (for example, through behaviour change communication), mediated through women's time use, women's own health and nutrition status, and women's access to and control over resources as well as intra-household decision-making power (Gillespie and van den Bold, 2017).

8. Value chain analysis and nutrition

Recent reviews of the contribution of agriculture to improving nutrition show that, although agricultural programmes have immense potential to improve nutrition, this potential is yet to be realised. Limitations in the design and implementation of agriculture interventions, as well as a lack of clarity in terms of nutrition goals and interventions, are partly responsible for the paltry evidence. Even more importantly, the lack of rigour in most of the existing impact evaluations prevents any clear conclusions regarding the contribution of agriculture to improving nutrition (Ruel et al, 2013).

Value chain concepts are useful in designing strategies to achieve nutrition goals. Central to this approach is identifying opportunities where chain actors benefit from the marketing of agricultural products with higher nutritional value. However, value chain development focuses on efficiency and economic returns among value chain transactions, and the nutritional content of commodities is often overlooked.

A food value chain is a form of food supply chain, or the series of processes and actors that take a food from its production to consumption and disposal as waste. In a value chain the emphasis is on the value (usually economic) accrued (and lost) for chain actors at different steps in the chain, and the value produced through the functioning of the whole chain as an interactive unit. A value chain is commodity-specific, and thus involves only one particular food that is relevant within a diet.

Improved chain relations and overall chain performance could yield tangible benefits in terms of economic returns and, potentially, poverty reduction (Gelli et al, 2015). As value chains are crucial in determining food availability, affordability, quality and acceptability, they have the potential to improve nutrition. What is required is to identify opportunities where value chain actors benefit from supplying the market with agricultural products of higher nutritional value. Value chain development, however, has rarely focused attention on consumers – consumers are simply considered as purchasers driving the ultimate source of demand. In this light, the value chain strategy is likely to be enriched by a stronger consumer focus and, in particular, a focus on consumer nutrition and health. The empirical evidence on the role of value chains in improving nutrition is, however, scanty and mixed.

Basically, nutrition results from the quality of the overall diet, not just from the nutrient content of an individual food. In value chains, the focus is generally commodity-specific, rather than on how to integrate multiple chains to contribute to an enhanced quality of diet. There may be offsetting impacts such that, if one value chain works better and consumption of the associated food increases, consumption of other foods declines.

Another major concern is the lack of clarity in terms of the pathways linking value chain activities to nutrition. This includes understanding the requirements that need to be fulfilled in order for value chains to bring about increased consumption of nutritious food. In turn, it is necessary to understand what constraints prevent these requirements from being met and the interventions that are likely to be most effective in overcoming these constraints.

The availability (quantity available on the market), affordability (price) and quality (including nutrition content and food safety) of the food concerned influence consumption at the interface between the value chain and the food environment. The intake of nutritious food complements the consumption of other foods in the diet, which may be self-produced or purchased on the market. The nutritious food may be shared within the household or consumed by only a few household members. Increasing the demand for nutritious foods would also lead to expanding marketing opportunities for producers. This increased demand stimulates agricultural production, particularly for smallholders who face market-access constraints, especially as increased demand may be a relatively stable revenue channel and a low-risk venture for producers.

When the supply of nutritious foods is limited, interventions could expand supply through advanced production technologies, or mechanisms to reduce input costs so that production of those crops is relatively more profitable. Other supporting measures include the provision of insurance, access to credit and land titling. Examples of relevant interventions that enhance nutritional value include fortification, enrichment, processing multiple foods into more nutritious products, food safety and detoxification, labelling and sensitisation.

In sum, on the demand side, the central issue is how to promote consumption of nutritious foods by target populations that may not be able to afford a healthy diet. Similarly, on the supply side, an important concern is the feasibility of targeting the poorest smallholders and informal enterprises along the value chain, particularly involving women.

A few examples are discussed below to elucidate the potential of value chains for enhancement of nutritional value and the constraints that must be addressed. Chronic undernutrition is pervasive in Nigeria, with rates of stunting and underweight alarmingly high and little progress over the past decade. There are major disparities in nutrition outcomes between the wealthy and poor people, between the north and south, and between urban and rural areas. Micronutrient deficiencies are widespread across social groups. Vitamin A deficiency, for example, is associated with 25% of child and maternal deaths. Together with direct nutrition interventions, it is necessary to improve the functioning of food value chains and provide access to nutrient-dense foods to the urban and rural poor.

Robinson et al (2014) map current value chains for two products, cowpeas and soybeans, and complementary products, focusing on whether they meet a set of key criteria: availability, affordability, acceptability and nutritional quality. Their study examines in detail each stage of the value chains for these products: production and supply, wholesale, processing, distribution/retail and consumer groups, and it identifies the constraints facing them. For the present study, we confine ourselves to cowpeas. Cowpeas make a substantial contribution to the nutrition of poor populations in Nigeria.[29] Markets for cowpea products are mainly informal and the majority of products are produced by small-scale businesses and sold locally. Few formal-sector businesses have invested in cowpea products, and there is limited innovation in value-added products. A merit of cowpea foods is that they are readily acceptable to diverse populations, widely available across the country and can be distinguished from less nutritious alternatives. However, affordability and availability of cowpeas is constrained by major supply-side problems. Cowpea prices fluctuate between seasons, thanks to the susceptibility of grains to degradation and low use of improved storage technologies. Although simple, safe and low-cost technologies are available in the form of improved storage bags, these are not prominent in the wholesale and transport stages of the value chain. Moreover, existing preservation techniques make use of pesticides that create risks of toxic contamination.

There is substantial involvement among businesses across Nigeria in producing cowpea products. The vast majority of these businesses operate in the informal economy, often at a very local scale. In addition to processors, businesses are also involved in agricultural inputs and in storing, transporting and wholesaling cowpeas.

[29] Cowpea grains contain an average of 24% protein and 62% soluble carbohydrates. They are rich in thiamine, folates and iron, and also contain zinc, potassium, magnesium, riboflavin, vitamin B6 and calcium, as well as the amino acids lysine and tryptophan. Nutrient-density varies among cowpea varieties in Nigeria, and some varieties have been highlighted as especially good sources of micronutrients (Robinson et al, 2014).

Processors of cowpea products use four standard distribution models to reach consumers: street food vendors, restaurants and fast food companies, institutional providers (such as schools or hospitals), and supermarkets.

In order to overcome supply-side constraints, Robinson et al (2014) make a few specific recommendations. These include, first, raising yields of cowpeas. Factors underlying poor yields comprise the high cost of inputs for cowpea production, limited use of improved seeds, infestation by pests, drought and irregular rainfall, and inconsistent government policies, especially on input subsidies and incentives. Second, the price of cowpeas during the high season can be as much as double that during the low season. Although cowpeas are overall the most affordable protein source in most of Nigeria, during the high season they are not affordable to poor populations. Improving use of storage technologies along the value chain, including in on-farm facilities, transportation and storage facilities in markets would help alleviate this constraint. Third, value chain actors use pesticides to reduce weevil damage, but these chemicals persist throughout the value chain and have caused poisoning and even death in people eating cowpea. There are safe and effective storage solutions in Nigeria (ie PICS bags).

9. Sustainable technologies

Two aspects are of prime importance: scaling up successful agricultural practices; and prioritising sustainable intensification approaches and integrating them into agricultural technology in the local context. Less-favoured areas need to receive attention in policy matters, especially in the context of the threat to agriculture from climate change and/or globalisation of agricultural trade.

Two specific concerns are restoration of soil fertility and judicious use of water. Both conservation technologies can also be pursued in some low-productivity areas. However, they have not caught the attention of policy makers. Extension of both these measures would help raise productivity and save resources in these areas.

A few examples illustrate the potential and constraints. The Ethiopian economy relies on its agricultural sector as a fundamental instrument for poverty alleviation, food security and economic growth. However, this sector is prone to land degradation – depletion of soil organic matter, soil erosion and lack of adequate plant nutrient supply. These problems are getting worse in many parts of the country, particularly in the highlands. Furthermore, climate change is likely to accelerate land degradation in Ethiopia. Although there is substantial evidence on the adoption and productivity impacts of soil and water conservation measures in Ethiopia, the evidence on adoption and productivity impacts of other land management practices, including minimum tillage (MT) and commercial fertiliser (CF) use, is scanty. Specifically, evidence is lacking on the relative contribution of these practices to agricultural productivity in low vs high agricultural potential areas.

Kassie et al (2010) fills this gap by examining the productivity gains associated with the adoption of MT and CF use in the high and low agricultural potential areas of the Ethiopian highlands. To do this, the authors used household- and plot-level data from the Tigray and Amhara administrative regions.[30] They employed both semi-parametric and parametric methods. The parametric analysis is based on matched samples of adopters and non-adopters obtained from the Propensity Score Matching (PSM) process.[31]

The results provide evidence of a strong impact of MT on agricultural productivity, compared with the impact of CF, in the low agricultural potential areas. In the high agricultural potential region, however, CF has a very significant and positive impact on crop productivity, whereas MT has no significant impact.

From a policy perspective, these findings highlight the need for moisture-conserving technologies in semi-arid environments. Specifically, the productivity advantages of MT in the low-potential areas come from its ability to conserve soil moisture in dry environments. Further, the findings suggest that CF is less profitable in this area because of inadequate soil moisture. In addition, the non-profitability of CF in low-potential areas indicates that investing in CF in these environments is a financial risk, which has considerable relevance for resource-constrained areas such as rural Ethiopia.

More importantly, the analysis suggests that different strategies are needed for different environments. For instance, in the low agricultural potential areas, government and non-governmental organisations should focus more on promoting MT as a yield-augmenting technology. Relying on external inputs (such as chemicals and fertilisers) in low-potential areas, which has been the strategy in the past, is not likely to be beneficial unless moisture availability is enhanced.

Good soil conditions that enhance micronutrient availability for crop uptake are essential for the success of agronomic bio-fortification. Optimising soil conditions is often recommended via Integrated Soil Fertility Management, which is defined as a set of soil fertility management practices that necessarily include the use of mineral fertilizer, organic inputs and improved germplasm. The combination of mineral fertilisers and organic inputs is beneficial, because they have complementary functions and enhance mutual effectiveness. Animal manures, for example, are a good source of many micronutrients. Manzeke et al (2014) report that, when Zn-enriched fertiliser was applied together with cattle manure and forest leaf litter, there were larger increases in maize grain yield and Zn concentration in the grain. Long-term application of organic

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[30] The Tigray region is typical of the low moisture and generally low agricultural potential areas. The dataset of the Amhara region allows an intra-regional comparison of the performance of SLM practices because the dataset covers both low and high agricultural potential areas.
[31] For further details, see Kassie et al (2011).

matter to the soil not only increases its total Zn content but also the proportion of labile Zn, which is the readily available form for plant uptake.

Agronomic bio-fortification has so far been most effective with Zn and Se. Many African soils suffer from multiple micronutrient deficiencies, as a result of their inherent soil properties and continuous cropping without nutrient replenishment. Current fertilisation programmes in African countries primarily focus on NPK fertilisers, but many soils are non-responsive to NPK because of (multiple) micronutrient deficiencies. Soil modification with small amounts of (multiple) micronutrients is a sustainable strategy to increase yields and the nutritional quality of crops (Vanlauwe et al, 2015). A review of experiments from 10 African countries on the impact of Zn-enriched fertilisers showed that soil Zn application increased the Zn concentration in maize, rice and wheat grains by, respectively, 23%, 7% and 19%, and by 30%, 25% and 63% through foliar application (Joy et al, 2015). Moreover, another agronomic benefit is that seedlings from seeds with high Zn concentration have better growth performance and resilience against environmental stress, so positive impacts on productivity may be seen in the next cropping generation.

The application of micronutrient-enriched fertilisers has minimal negative environmental impacts. Most micronutrients are not susceptible to leaching because they are strongly bound in the soil. When micronutrient demand and supply are well matched, negative environmental effects are unlikely. In fact, crop health improves when micronutrient deficiencies in the crop are alleviated. The improved general crop health enhances growth and nutrient uptake efficiency, as well as resilience against pests and diseases, thus reducing the need for pesticides and herbicides.

An important question is whether agronomic bio-fortification is an effective, feasible and sustainable approach to alleviate micronutrient deficiencies, especially in comparison with other intervention strategies such as genetic bio-fortification, food fortification, supplementation and dietary diversification. An unequivocal answer is difficult as the literature is sparse.

A particularly interesting example is of legumes in Malawi as a potentially important source of nutrition and restoration of soil fertility. Legumes are good sources of a range of macro- and micronutrients, and they substantially improve the quality of grain/root/tuber-based diets for both young children and other family members. The use of legume plant residues can improve soil fertility and potentially contribute to future harvests. Among the few studies, a notable one is the Soils, Food and Health Communities Study (SFHC) in northern Malawi’s Soils Food and Health Communities Project. The SFHC study explored whether a legume system intervention could improve soil fertility, food security, child nutrition food security, and child nutrition (Kerr and Chirwa, 2004). However, there is no update on its outcomes.

10. Youth employment in rural areas

There is no agreed definition of youth. The 15–24-year-old age range is commonly used, notably by the UN agencies, but the African Union defines youth as the 15–35-year-old age group.

The 15–24 age group represents 20% of SSA's population today and, unlike in other regions, this youth share will remain high and stable (19% in 2050). In absolute terms, SSA's youth will grow from nearly 200 million in 2015 to nearly 400 million in 2050, and its share in the labour force will remain the highest in the world, even if following a declining trend. Representing 37% today – in comparison with 30% in India, 25% in China and 20% in Europe – it should still account for 30% in 2050 (ILO, 2016).

Agriculture has a substantial role in meeting the youth employment challenge facing Africa. Even in a most optimistic scenario, non-farm and urban sectors are unlikely to absorb more than two-thirds of young labour market entrants over the next decade. But there will be vast opportunities for innovative young people in agricultural systems as they adapt to a range of challenges in the near future. These challenges relate to raising productivity in a sustainable way, integration into emerging high value chains and healthy diets (Sumberg et al. 2012).

While the challenges are daunting, the potential benefits of addressing them are enormous. Higher prices, more integrated value chains, widening connectivity to markets in some areas, and greater private and public engagement in the sector are creating new opportunities (Suttie, 2015). A major barrier is, however, strong negative preferences/attitudes of the youth towards agriculture.

Tadele and Gella (2012) made an attempt to capture the attitudes and aspirations of rural in- and out-of school young people towards agriculture, based on field work in two regions in Ethiopia: Amhara Region, East Gojjam Zone – Gozamin Woreda (Chertekel Kebele); and Southern Nations, Nationalities and Peoples Region (SNNPR), Alaba Tembaro Zone, Qedida Gamella Woreda (Geshgolla Kebele). Focus group discussions were carried out with older farmers (men and women), young farmers (men and women), school students in grades 7 and 8 (aged around 16–18 years, boys and girls), and young people who had left school but were not farming (boys/men and girls/women, in some cases college students, aged around 20–25 years). We will confine ourselves mostly to the views of the young.

The farmer was described variously as 'someone who labours to feed others'; tied to his land; and lacking, participants perceived, any other option than simply being a farmer. Life as a farmer was tied to life in a village, which most respondents saw as hard and demanding. Yet there was considerable heterogeneity in the views of the young. Participants in both sites agreed that agriculture had changed significantly over the past decade. The introduction and adoption of agricultural inputs such as improved seeds, fertilisers and better farming methods (such as slash ploughing, sowing seeds in rows, water pumps and modern beehives) have produced significant increases in productivity and earnings.

There were competing narratives on whether agriculture was becoming more desirable to young people as a result. On the one hand, participants felt that these developments were making agriculture more and more profitable and therefore more appealing. But they felt that there was a huge obstacle in engaging in it – scarcity of land. Although the dominant view was that young people are not interested in agriculture, some participants pointed out that this was not always the case.

Disaggregation of farming preferences by age, gender, in- and out-of-school offers interesting contrasts. Young boys and girls currently attending school mostly viewed agriculture as a dead end: an option they were either unwilling to consider at all or only as a last resort. Specifically, the life of the farmer was perceived as tiring and hard, a life of endless toil with little gain. Girls attending school were more negatively inclined towards farming. They described the lives of their parents as traditional and backward and wished for a better life, which they sought to attain through their education. In addition, shortages of land discouraged them more. A slightly more positive attitude towards agriculture was evident among young people who had left school, either failing to complete high school for various reasons or to qualify for higher-level education. Although this group of respondents were equally aware of the grimness of traditional agriculture and the life of the common farmer, many were not dismissive of agriculture as a possible future livelihood, while a few even saw it as a preferred livelihood option, under improved conditions. Negative attitudes towards agriculture were not confined to the young. Although older farmers and officials acknowledged that agriculture can be a very lucrative livelihood, none wanted their children to follow in their footsteps. This was the case even for those whose lives had improved and who thought that agriculture was now as good a livelihood as any other, if not better. Given negative attitudes of family and society about agriculture, informal work in urban areas is preferred by young people who have attended school, even if it is low paying and as back-breaking as agriculture.[32]

Apart from the inability of the urban economy to accommodate a huge influx of labour from the rural agricultural sector, the government considers rural educated youth as instrumental in bringing about a transformation in agricultural skills, knowledge and productivity. However, there is a sense of injustice and deprivation among young people, especially those who are already in agriculture and struggling to find plots and those willing to go into agriculture but unable to do so, with no means of accessing farmland. Thus, the government has not effectively addressed either the attitude of

[32] Rural youth rarely consider farming to be a 'best job' or even a 'good job' when one takes into account the very low returns provided by agriculture and the harsh conditions of work with hand tools. In fact, agriculture is probably one of the most difficult ways to make a living and, above all, it does not offer a desirable social status. Recognising agriculture as a viable employment option is even more challenging when economic and social restrictions related to access to productive resources are taken into account. All these limitations are exacerbated for young women who, in general, have no prospect of land access thanks to rules of inheritance, and who know that they will mainly have to work for their husbands (ILO, 2016).

many young people towards agriculture or the obstacles preventing their entry into the sector.

Access to land was the top concern for young people in both sites studied, and the government needs to consider how to facilitate land acquisition for young people interested in agriculture. No less important is the imperative to address the infrastructural needs of rural people and to catalyse the social and economic transformation of rural areas which would, in the long run, make agriculture more attractive. Despite such negativity, it is argued that agriculture has a substantial role in meeting the youth employment challenge facing Africa, as noted by Suttie (2015).

Africa's complex agro-ecologies and highly diverse production systems demand a level of agricultural research that is only feasible through the reversal of decades of underinvestment in it. For now, growth in agricultural productivity will have to come from wider use of superior technologies that have worked elsewhere – improved seeds, breeds, cropping methods, conservation practices and equipment. Over the past decade, more farmers across Africa have started to adopt such technologies, but at a slow pace.

As demand for food rises, growth in total factor productivity is checking the rise in real food prices and helping create jobs. Without sustaining productivity growth through agricultural research, the development of farming skills, and the adoption of new and better varieties, growth in output will come through increased use of purchased inputs such as fertiliser and agro-chemicals. Short-term gains in productivity, however, will be costly, will increase the real price of food and erode potential gains to producers, consumers and society at large.

Africa offers ample opportunities for simultaneous increases in average farm size and in employment. Declining average farm size in Africa suggests that constraints on land markets are already hindering the prospects for young people and are becoming stronger (World Bank, 2015).

Broadly, there are four options for young farmers: continue on the family plot but with a different mix of enterprises; establish their own operations on new land; combine farming with other part-time work; or wage employment on large or mid-size commercial holdings. These options and pathways vary in their requirements for land, capital and skills. The first two – full-time employment on the family farm and full-time farming on a new holding – are the most prevalent.[33]

In this pathway, the skills and labour of multiple young adults in the household could enable specialisation. Given demand for their labour, those capable of earning off-farm wages could do so, thus adding to the household's capital. Superior technologies, such as conservation tillage, require high investment of labour at peak periods, and a

[33] A household survey in nine African countries in 2008 showed that 51% reported that inheriting land already under cultivation was the most common means for young people to obtain land, while 16% would be allocated land not previously cultivated, 9% would rent or borrow land, and 12% would buy land (Proctor and Lucchesi, 2012).

household with several young adults could undertake the required work. A combination of pooled off-farm earnings, a shift in farming technology to higher-value and more commercial products, and aggregation of household labour at peak periods would enable small farms to absorb young adults constructively.

The second pathway involves a group of young people leaving the farm of their childhood and establishing a new and separate holding, ideally larger than the parcel they left. Those more likely to succeed in such an undertaking would probably be relatively experienced in farming and hence at the older end of the age range for 'youth'. These farmers would require land, start-up capital and advisory services or training to handle technical and managerial responsibilities.

In the third pathway, young people may be independent part-time farmers, either managing their own holdings or contributing to family operations described under pathway 1, with enough capital to establish themselves as sellers of services, a trader or an occasional wage worker. Higher-value agriculture will use services more intensively and create employment for those who can provide them. Demand for transport, plant protection, veterinary services, mechanised field operations and advice could be met by young men and women with the capital and skills to start a small business.

In the fourth pathway, young people take wage work, whether formal or informal, on large commercial farms or in the processing and service sectors. These young people need skills to handle a range of tasks and equipment. At a minimum, for the most basic low-skilled work, they need good health to perform in gruelling working conditions. Such wage work could be combined with other activities, or it could be a temporary option until better opportunities appear.

To create opportunities commensurate with the number of young people who will need employment, constraints on the acquisition of capital, land and skills must be removed or relaxed.

A few selected initiatives are delineated below. Allowing alternative forms of collateral, such as chattel mortgages, warehouse receipts and the future harvest, can ease the credit constraints, especially for young farmers. The OHADA7 Uniform Act on Secured Transactions, in effect in 17 SSA countries, was amended at the end of 2010 to allow borrowers to use a wide range of assets as collateral, including warehouse receipts and movable property such as machinery, equipment and receivables that remain in the hands of the debtor. Leasing also offers young farmers some relief, as it requires either no or less collateral than typically required by loans. A case in point is DFCU Leasing in Uganda, which gave more than US$4 million in farm equipment leases in 2002 for items such as rice hullers, dairy processing equipment and maize milling equipment. Despite leasing's potential to relieve constraints on access to mechanical technology, few firms have entered this business. Some outgrower arrangements pre-finance inputs and assure marketing channels. In Mozambique, Rwanda, Tanzania and Zambia, Rabo Development (a subsidiary of Rabobank) offers management services and technical assistance to financial institutions, which, in turn, finance supply chains with a range of agricultural clients. Participants include commercial farmers, farmers with little commercial presence, and an intermediate group of farmers with ambitions to grow commercially.

Microinsurance in Africa almost doubled between 2006 and 2009 from a very small base. Microinsurance differs from traditional insurance by being available through well trusted yet innovative channels and by offering low premiums, products with simple designs, flexible payments for premiums and prompt settlement of claims. For example, more than 11,000 Kenyan maize farmers, some with barely one acre, have obtained insurance policies that cover significant losses when drought or excess rain destroys their harvest.

None of these innovations in rural finance is relevant exclusively to young people. Nor should young people be segregated as a group and offered financial services designed specifically for them. The risks of working with the young are high, and separating them from a larger pool for sharing risks would make them even less attractive to financial institutions. Indeed, any and all innovations in finance that facilitate sustainable outreach to small farmers and rural entrepreneurs should be supported. When necessary, additional features should be added to enable these programmes to serve young people.

The two aspects of land administration that matter most to young entrants to the labour force are the need to improve security of tenure and the need to relax controls on rental. Land redistribution will also enhance young people's access to land. In general, policies and measures that help poor people to gain access to land will also help young people.

Young Africans must be equipped with basic reading, writing and numeracy skills, and the ability to use digital technology to access and interpret information. Beyond these basics, the skills required for individuals in pathways 1 and 2 may differ from the skills required in pathways 3 and 4. The majority of farmers, who will have little more than a primary school education, will need access to effective agricultural extension services to sharpen their skills. It is anticipated that a growing and diversifying agricultural sector will create jobs that demand increasingly advanced technical and professional skills, from processing and marketing to agricultural research.

Returns to schooling in rural areas rise with the pace of technological innovation in farming. More educated farmers are often the first to adopt new seed, tillage practices, fertiliser and animal breeds. In addition, it is necessary to improve both basic education and agricultural vocational education for women and to enhance rural women's access to extension services. Essentially, the agriculture that will attract the young will have to be profitable, competitive and dynamic. These same characteristics are needed for agriculture to deliver growth, to improve food security and to preserve a fragile natural environment (World Bank, 2015).

The development of agro-food businesses represents a significant opportunity for youth employment and for local development, thanks to powerful growth linkages to the rest of the economy. The growing food demand in Africa is a major avenue for agro-processing, which can easily be developed using small and medium-sized enterprises (SMEs) and with intermediate technology. This option requires less capital, is more labour intensive and facilitates the proliferation of units in rural boroughs and small towns, offering employment and entrepreneurial opportunities, local value added and new incomes. Agro-processing SMEs can also facilitate the resolution of post-harvest problems, which are a significant issue in SSA, resulting in a loss of revenue for farmers.

In addition, agro-industrial enterprises can provide inputs and services to the farm sector, stimulate market-induced innovation through farmers' participation in value chains and networks, and motivate other enterprises in the production of goods and services. They can be effective contributors to the local economy, the diversification of which will open new opportunity spaces for youth with more diversified and attractive jobs (ILO, 2016).

In the Niger Delta, for instance, the IFAD-supported Community Based Natural Resource Management Programme is promoting a new category of entrepreneur-cum-mentor called the 'N-Agripreneur'. These N-Agripreneurs are energetic university graduates who own and run medium-scale enterprises at different stages of food value chains. They deliver business development services to producers, especially young people, who are interested in agro-based activities such as farming as a business, small-scale processing, input supply and marketing. Their success is reflected in more interconnected, stable and prosperous communities and local food systems, as well as in jobs for the (mostly young) entrepreneurs (Suttie, 2015).

In order to enable young people to respond to the environmental, economic and nutrition challenges of the future, they must develop suitable capacities. A case in point is information and communication technologies (ICTs), which can develop young people's capacities, while improving communication and easing access to information and decision-making processes. Investing in extending these technologies to rural areas, in particular targeting young people – who are generally more adaptable to their use – has allowed them to keep themselves up-to-date with market information and new opportunities.

11. Returns on agricultural research and technology

Agricultural research has generated several kinds of technology with high potential for impact, but the expected improvement in farmers' productivity, livelihood and quality of life has not been fully realised. Institutional innovations are needed to improve productivity and make public agricultural institutions more responsive to markets, more accountable to the communities they serve, and better recognised as an important tool for achieving economic growth. Other studies have shown that huge productivity gains are possible and accrue where governments allocate the necessary resources to agricultural research and development. In SSA, however, public investment in agriculture is still far below what is needed, despite commitments by African governments to allocate 10% of their public spending to it. The challenge is to develop technology that is relevant to small farmers and to enable them to transform their farms into viable small businesses that make a vital contribution to local and national economies. This calls for client-oriented agricultural research.

An aggregate investment of $7,120 million (1990 US dollars) produced benefit–cost ratios higher than 1, indicating efficient investments. The study also showed that research projects have generated more than 90% of the total Consultative Group on International Agricultural Research CGIAR benefits (Raitzer, 2003). Over 80% out of this is attributed to plant genetic improvement, with the remainder to cassava mealy bug biological control. A negligible proportion is attributed to policy research. Similarly, the average internal profitability rate for investments made in research and dissemination of Sahel varieties of rice in the Senegal River Valley is estimated at over 221%, which is considerably higher than the cost of access to capital valued at 18% for the period 1995–2004.[34]

A thematic review of the rates of return is illuminating.

11.1 Impact of crop and livestock commodity research on economic growth

Maize improvement in West and Central Africa (1971 to 2005) – improved varieties were derived from the CGIAR and their National Agricultural Research Systems (NARS) partners' research – saw an increase in adoption of improved varieties from less than 5% in the 1970s to about 60% in 2005, with annual economic benefits estimated at $2.9 billion, an increasing trend over time, and an overall rate of return to research investment (CGIAR and national) of 43%.

Improved varieties of cowpeas, which provide both food and livestock feed, are being widely adopted in the dry savannah of West Africa, with estimated benefits of $299 million to $1.1 billion likely to accrue during 2000–2020.

Eastern and Southern Africa have also registered impressive gains where improved varieties of common bean, developed with farmer participation, have been adopted on about 50% of the total bean area over 15 years. A study conducted in 2008 estimates that the new varieties are strengthening food security and raising incomes in 5.3 million rural households. The benefits of bean improvement research for Africa are estimated to have a current value of roughly $200 million, compared to costs of about $16 million (CGIAR, 2011).

[34] For sources, see Seck et al (2013).

NERICA, which combines the high yields of Asian rice with African rice's resistance to local pests and diseases, has spread to about 250,000 hectares in upland areas, helping to reduce national rice import bills and generating higher incomes in rural communities.

In Mozambique, the introduction of new orange-fleshed sweet potato significantly increased the intake of vitamin A among young children. In Kenya, Farm Concern International undertook women-targeted work on commercialisation of traditional leafy vegetables, which was later shown to be effective in increasing consumption of the micronutrient-rich vegetables. Millet also was found to be very beneficial because of its high content of the minerals phosphorus, manganese and magnesium.

The development of a vaccine against an 'orphan' livestock disease in Africa has huge potential benefits. The production and delivery of this vaccine for East Coast fever – a tick-transmitted disease that threatens some 25 million cattle in 11 countries of eastern, central and southern Africa – is now in the hands of private sector partners. It is expected to save more than a million cattle, with benefits worth up to $270 million a year in the countries where the disease is now endemic.

11.2 Impact of natural resource management research on economic growth

A set of case studies published in 2007 indicates that such research is giving highly positive returns on investment, based partially on the benefits for agricultural productivity. If methodologies were available for gauging the environmental benefits as well, the returns would no doubt be much higher. By 2002, more than 66,000 farmers in Zambia had adopted an agro-forestry system called 'fertiliser tree fallows', which renews soil fertility using on-farm resources. The system has been shown to boost maize production while reducing production risks and soil erosion, with benefits of up to $20 million, compared with an investment of about $3.5 million.[35]

11.3 Impact of agricultural research on nutrition

Berti et al (2004) reported that most agricultural interventions increased food production, but did not necessarily improve nutrition or health. Furthermore, in the past few years, there has been an increase of interest in how to shape agriculture for more impacts on nutrition, particularly among mothers and children. Several reviews concluded that the current state of empirical evidence for impacts on nutrition ascribed to defined agricultural interventions is weak and mixed.[36] The statistical significance of impacts has been documented in a few cases, mainly in terms of micronutrient status (usually Vitamin A). However, net effects across all nutrients have not been documented and there is an apparent lack of sound, empirical evidence on the efficacy, effectiveness at scale and cost-effectiveness of all kinds of agricultural intervention on nutrition. This remains a barrier to policy advocacy.

[35] For further details, see Seck et al (2013).
[36] For further details, see Seck et al (2013).

11.4 Impact of agricultural research on poverty reduction and food security

Thirtle et al (2003) explored the relationship between agricultural productivity and poverty in 48 developing countries between 1985 and 1993. They found that a 1% improvement in crop yields reduced the proportion of people living on less than US$1 per day by 0.6%. Rice varietal improvement research has contributed tremendously to increasing rice production in several countries. In each country, the benefits from rice research are, on average, 10 times higher than the total agricultural research investment. Research has also helped to lift large numbers of the rural poor above the poverty line. According to more recent impact assessment studies in SSA, national and international organisations are making a big impact in reinforcing food security and alleviating poverty through rice research. Rice varietal improvement contributed, on average, $375 million per year to the region's economy. Overall, improved varieties have increased net revenues by $93 per hectare, with the highest gains in irrigated and rain-fed lowland ecologies. The annual returns to investment in rice research now exceed 20%.

There are many reports of NERICA's positive impact on farmers' livelihoods across SSA, from Guinea in West Africa to Uganda in East Africa. Impact studies also reveal that rice research contributes effectively to the realisation of almost all the Millennium Development Goals, including halving levels of poverty and hunger, promoting education, improving health, reducing child mortality, empowering women and ensuring environmental sustainability (Seck et al, 2013).

Another important staple is maize. Maize improvement research had a benefit–cost ratio of 21 in the region. This means that every dollar invested in maize research generated additional food worth $21. Estimates for country-level benefit–cost ratio ranged from 11 (Mali) to 84 (Nigeria), with an average rate of return of 43% in West and Central Africa. Since maize and rice are major staples in large regions of Africa, it is clear that investment in agricultural research is yielding perceptible impacts on food security and poverty reduction.

In general, however, agricultural research has had a mixed impact on wellbeing in this region. For example, there is no emphasis on research by the NARS on reducing undernutrition. Thus there are cases of malnutrition in the face of abundant food supply because of the lack of integrating research on crop production, nutrition and health. Further, research on the processing of farm produce in SSA is missing from the agenda of all the programmes. The absence of programmes for attracting increased private-sector participation in African agricultural research is compounded by insufficient investment in university education for science and technology (Mokwunye, 2010).

Nevertheless, the rates of return are high for agricultural research. As several impacts are inter-related, for example women's empowerment, nutrition, poverty and sustainability, the rates of return may imply that these can be neatly separated thematically. This would be an oversimplification and misleading. However, if social valuations of these benefits differ, the social rates of return on agricultural research are likely to be substantially higher. Another refinement would be to assign probabilities to these outcomes so that their certainty equivalent values could be computed.[37]

12. Discussion

African agriculture has the lowest productivity compared with other regions of the world. The Green Revolution observed in Asia did not occur in Africa for many reasons relating to the different institutional context, greater diversity in cropping patterns (requiring higher investments in research), limited physical infrastructure, particularly irrigation, and defective rural financial systems.

Agricultural research has generated several kinds of technology with a high potential for impact, but the expected effect on farmers' productivity, livelihood and quality of life has not been fully realised. Huge productivity gains are possible and accrue where governments allocate the necessary resources to agricultural research and development. In SSA, however, public investment in agriculture is still far below what is needed, despite commitments by African governments to allocate 10% of their public spending to it.

Although it is difficult to ascertain whether this is a trend reversal, recent FAO reports (FAO et al, 2017a, b) show a rise in hunger globally as well as in Africa. The number of undernourished (NOU) in the world suffering from chronic food deprivation began to rise in 2014 – going from 775 million people to 777 million in 2015 – and is now estimated to have increased further, to 815 million in 2016. The deterioration was most severe in SSA and south-east Asia (FAO et al, 2017a, b).

In SSA, micronutrient deficiencies contribute 1.5–12% of the total Disability Adjusted Life Years (DALYs). Alarming numbers suffer from iron deficiency anaemia, which affects more than half the female population in countries such as DR Congo, Ghana, Mali, Senegal and Togo. Selenium contributes to the human diet through uptake by crops from the soil. Even mild to moderate deficiencies of micronutrients can lead to severe human health problems, generally related to suboptimal metabolic functioning, decreased immunity and, consequently, increased susceptibility to infections, growth failure, cognitive impairment and reduced productivity (de Valença et al, 2017

[37] For an integrated analytical framework for impact assessment of agricultural research combining the main themes and pathways, see Mathur and Gaiha (2003).

In addition, around 40% of children under the age of five suffer from stunted growth, that is, severely reduced height-for-age relative to their growth potential. Stunting is a result of periods of undernutrition in early childhood, and it has been found to have a series of adverse long-term effects in those who survive childhood. It is negatively associated with mental development, with human capital accumulation, with adult health, and with economic productivity and income levels in adulthood (Larsen & Lilleør, 2017).

We have argued that agricultural development has enormous potential to make significant contributions to reducing malnutrition and associated ill health. With its close links to both the immediate causes of undernutrition (diets, feeding practices and health) and its underlying determinants (such as income, food security, education, access to WASH and gender equity), the agricultural sector could play a much stronger role than in the past in improving nutrition outcomes.

An assessment was carried out through a review of a large number of studies examining the factors determining adoption of innovative agricultural technology, their benefits and underlying mechanisms, sustainability of the benefits, empowerment of women farmers and child nutrition, and prospects for youth employment in agriculture and elsewhere. A case was then made for greater investment in agricultural research.

The main factors that determine the awareness of a new technology include farmers' social characteristics and agro-ecological conditions in a targeted area. In particular, farmers who are more aware of a technology have higher education, live in proximity to research institutions and universities, and have more social capital, such as participation in collective action, membership of non-agricultural organisations and a network of credit channels.

Both social characteristics and economic constraints determine the try-out step. This is positively influenced by factors such as learning from others, higher liquidity, and access to information and extension services. In particular, younger farmers living near the market, with social capital and human capital endowments, are more likely to experiment with a new technology.

The continued adoption step is largely influenced by economic and demographic factors, and by dissemination mechanisms such as extension. The role of path- or state dependence is assessed, namely, the role of past experience in the adoption decision process. Moreover, the initial technology adoption decision significantly influences current technology adoption decisions, even more than does lagged adoption (Garbero et al, 2016).

A rich shelf of innovative technologies by itself is not enough. Agricultural extension is expected to play a key role in facilitating the adoption of new technology. However, there are few examples of successful extension. There is growing evidence that the private sector is taking over some of the functions which were formerly performed by governments –especially in African countries facing severe budget constraints. Two policy concerns are the reform of extension services, and the creation of enabling conditions for the private sector to have a more influential role in targeting marginal and women farmers for better nutritional outcomes.

The pathways through which agricultural research enhances standards of living and welfare outcomes comprise higher agricultural productivity, lower production costs, reduction of food prices, higher wages and employment, and lower losses from diseases or unfavourable climatic conditions. Hence, both producers and consumers are likely to benefit. However, many of the studies reviewed lack analytical rigour, casting serious doubts about their inferences (Masset et al, 2012). Subject to this caveat, some of the principal findings are reviewed below.

Improved chickpea and pigeon pea in Tanzania lead to more than moderate increases in the average expected consumption per adult equivalent. An increase in improved maize area in Malawi is associated with an increase in income among adopters, in domestic maize consumption and in assets. Tissue culture banana technology adoption in Kenya increases annual farm and household income substantially, as well as reducing food insecurity. In Nigeria the adoption of NERICA positively increases household income, along with other variables characterising household demographic structure, such as gender, age and education of the head of the household and household size. The impacts of improved seeds on per capita expenditure, poverty and maize yields in Uganda were significant, while evidence from randomised controlled trials showed positive impacts from bio-fortified crops, including orange-fleshed sweet potato, on vitamin A status among women and children. There were mixed impacts on the links between women's empowerment, intra-household decision making and better nutrition outcomes. In Kenya, interventions to improve vegetable, ASF and fruit production showed mixed results, but ownership of livestock, and milk consumption, were associated with better nutrition outcomes. In contexts where markets are imperfect, supporting livestock ownership is conducive to improving diets by a direct access channel, as well as providing further livelihood opportunities and increased income.

Height-for-age is a strong biological marker of the nutritional status of children during the first 1,000 days of their lives, from conception to two years of age. During this period, children have very high growth rates; consequently, when subject to spells of faltering growth, children quickly fall behind the height-for-age growth curves of their peers, with limited chances of catching up subsequently.

An assessment of impact of the basket of technologies, offered under RIPAT, on stunting in northern Tanzania is insightful. The technology options comprised new banana cultivation techniques; new improved banana and other perennial and annual crop varieties; conservation agriculture for improved land utilisation (such as minimum soil disturbance, cover crops, intercropping, rotation and diversification of crops); post-harvesting technologies; improved animal husbandry; multipurpose trees for fodder, fruit or firewood; soil and water conservation, including rain water harvesting; and savings groups. A key to RIPAT's success was that each farmer was free to choose which technologies to adopt on his/her own farm according to his/her own needs, constraints and resources.

Drought resilience improved among the participating farmers in northern Tanzania. Moreover, there was a significant positive impact on the height-for-age z-scores of young children who had been fully exposed to the project in their early life. Similarly, there was a substantial reduction in stunting prevalence among the young group of RIPAT children of around 18 percentage points.

An important policy insight that emerges is that, since the impacts were measured almost five years after the start of the project, which lasted three and a half years, these are sustainable impacts, but not necessarily rapid impacts. There is thus potential for agricultural interventions in alleviating undernutrition and they can indeed be very effective.

Lack of dietary diversity is viewed as the major cause of micronutrient malnutrition in SSA. Imbalanced diets resulting from consumption of mainly high carbohydrate based-diets also contribute to productivity losses and reduced educational attainment and income. Consequently, micronutrient malnutrition is currently the most critical food and nutritional security problem, as most diets are often deficient in essential vitamins and minerals.

In some cases, crop diversity does not influence dietary diversity after controlling for other covariates. However, the methodology is suspect, since there is little recognition of the fact that farm diversity is a response to weather and price risks (a more diversified crop portfolio protects the farmer better against such risks), and to the relative profitability of different crops and animal husbandry. Another major limitation is that the analysis of nutritional impact has to go beyond groups of food commodities consumed. Even among smallholders a positive relationship between farm production diversity and dietary diversity is found to be weak (Kenya, Malawi and Ethiopia). If market transactions are prominent, instead of producing everything at home, households can buy food diversity in the market when they generate sufficient income.

An assessment of the implications of smallholders’ buy and sell decisions is thus useful. If a household sells part of its production, this results in greater dietary diversity (Ethiopia and Malawi). On the other hand, if farm production is more diverse, the household tends to buy less diverse food from the market. However, diversified domestic production can substitute for diversity from the market only partially, because more than half of all of the food consumed in sample households is purchased.

Two inferences follow: (1) increasing on-farm diversity among smallholders is not always the most effective way to improve dietary diversity and should not be considered a goal in itself; and (2) in many situations, facilitating market access through improved infrastructure and other policies to reduce transaction costs and price distortions seems to be more promising than promoting further production diversification.

In SSA, micronutrient deficiencies contribute 1.5–12% of the total DALYs. As noted above, alarming numbers suffer from iron deficiency anaemia. Direct interventions comprise dietary diversification, micronutrient supplementation, modification of food choices and fortification. Bio-fortification increases the content and/or bioavailability of essential nutrients in crops during plant growth through genetic and agronomic pathways.

Vitamin A deficiency is associated with a higher risk of morbidity and mortality, and with ocular disorders such as night blindness, xerophthalmia and blindness, affecting infants, children and pregnant or lactating women. African regions account for the greatest number of pre-school children with night blindness and for more than one-quarter of all children with subclinical vitamin A deficiency.

Even though currently food fortification and supplementation are the most commonly used strategies to alleviate micronutrient deficiencies among humans, bio-fortification (agronomic and/or genetic) is considered to have more potential in the long term because it seems more cost-effective and practical.

Sweet potato varieties most commonly cultivated in Africa are white or pale yellow, with no or little provitamin A, and have a relatively high DM content. However, provitamin A-rich varieties, known as orange sweet potato (OSP), have been bred through the process of bio-fortification or have been introduced and evaluated, and are suitable for Africa in terms of preferred agronomic and consumer traits. Thanks to the high content of beta-carotene in some African-grown OSP varieties, the relatively high seasonal consumption of sweet potato can contribute substantially to increased vitamin A intake adequacy.

A nearly three-year long, large-scale intervention to introduce several OSP varieties using agricultural extension and market development activities and product development, combined with demand creation and nutrition education, was implemented in rural communities of Zambe´zia Province, Mozambique. A detailed and rigorous evaluation of this intervention shows a substantial impact on the dietary intake of OSP among women and pre-school children. The increase in OSP intake in the intervention groups was largely attributed to a direct substitution of white and yellow sweet potato varieties. The incorporation of OSP in the diet translated to a large, significant increase in vitamin A intakes by these subgroups and hence reduced the prevalence of inadequate vitamin A intakes.

There were no major differences in the impact on OSP or vitamin A intakes between the groups exposed for three years or one. The cost saving in the less intensive version is enormous and of considerable policy significance.

The similar substitution rates across age groups suggest that OSP was equitably shared among the women and children of different ages.

The wide acceptance of OSP in populations where white or yellow sweet potatoes are usually consumed has been observed elsewhere in SSA, and can thus be plausibly generalised.

Focusing on home gardening and animal/dairy production, evidence is mixed in terms of their impacts on nutrition. While there is evidence of positive impacts on intermediary nutrition outcomes, such as dietary diversity, household production and consumption, and child and maternal intake of ‘target’ foods and micronutrients, the impact on nutrition outcomes – particularly child anthropometry and micronutrient status – was much more limited, except in relation to vitamin A intake and status. The fact that home production requires fewer inputs and investment is extremely important for resource-poor families with limited access to production inputs. Yet moderately rigorous crop and livestock production in home gardens can generate as much revenue per unit area as field crop production. Home gardens provide multiple environmental and ecological benefits.

A useful policy insight emerges from a review of studies of home gardens selected on certain criteria. In many cases, home garden programmes increased the consumption of fruit and vegetables, aquaculture and small fisheries interventions increased the consumption of fish, and dairy development projects increased the consumption of milk. A difficulty is that an increase in the consumption of the food item targeted by the intervention does not imply an improvement in the overall diet, because substitution effects in consumption occur. For example, in one case, although the consumption of vegetables, rice and fish increased after the intervention, the consumption of pulses decreased. This suggests that indicators of the diversity of the diet or analysis of the full consumption basket are better indicators than is consumption of the specific food promoted by an intervention. Indeed, as argued here, there is a strong case for going beyond food baskets to their nutritional content.

Women are vitally important agents, both in their roles as producers and as custodians of household welfare. The resources and income flows that women control often have positive impacts on household health and nutrition. Agricultural programmes and policies that empower and enable women, and that involve them in decisions and activities throughout the life of the programme, achieve greater nutritional impacts. However, failure to understand cultural norms and the gender dynamics within the household may result in unanticipated outcomes. In Gambia, for example, a project geared to increasing women’s rice production was so successful that the land it was grown on was reclassified internally within the household. This resulted in output from that land being sold by men as opposed to women. Women therefore lost their original income stream, but remained committed to working long hours.

There are improved impacts on nutrition if agricultural interventions are targeted at women and when specific work is done around women’s empowerment (for example, through behaviour change communication), mediated through women’s use of their time, their own health and nutrition status, and their access to and control over resources, as well as their intra-household decision-making power. Further, encouragement and nudges through women’s social networks induce adoption as they rely more on their informal social networks than men.

The link between production and dietary diversity is incomplete without acknowledging the important role of value chains in nutritional outcomes. An important fact, however, is that a value chain is commodity-specific, and thus involves only one particular food that is relevant within a diet. What is thus required is to identify opportunities where value chain actors benefit from supplying the market with agricultural products of higher nutritional value. But value chain development has rarely focused attention on consumers – the latter are simply considered as purchasers driving the ultimate source of demand. In this light, the value chain strategy is likely to be enriched by a stronger consumer focus, and, in particular, a focus on consumer nutrition and health. The empirical evidence on the role of value chains in improving nutrition is, however, scanty and mixed.

Briefly, on the demand side, the central issue is how to promote consumption of nutritious foods by target populations that may not be able to afford a healthy diet. Similarly, on the supply side, an important concern is the feasibility of targeting the poorest smallholders and informal enterprises along the value chain, particularly those involving women.

From the perspective of sustainable development, two major concerns are scaling up successful agricultural practices, and prioritising sustainable intensification approaches and integrating them into agricultural technology in the local context. Less-favoured areas need to receive attention in policy matters, especially in the context of the threat to agriculture from climate change and/or globalisation of agricultural trade.

Focusing on conservation technologies, attention needs to be given to restoration of soil fertility and judicious use of water. Both conservation technologies can also be pursued in some low-productivity areas. However, they have not caught the attention of policy makers. Extension of both these measures would help raise productivity and save resources in these areas.

Although there is substantial evidence on the adoption and productivity impacts of soil and water conservation measures in Ethiopia, the evidence on adoption and productivity impacts of other land management practices, including minimum tillage (MT) and commercial fertiliser (CF) use, is scanty. Nevertheless, a few insights have emerged from a detailed assessment. MT has a strong impact on agricultural productivity, compared with the impact of CF, in the low agricultural potential areas. In the high agricultural potential region, however, CF has a very significant and positive impact on crop productivity, whereas MT has no significant impact. Hence different strategies are needed for different environments. For instance, in the low agricultural potential areas, government and non-governmental organisations should focus more on promoting MT as a yield-augmenting technology. Relying on external inputs (such as chemicals and fertilisers) in low-potential areas, which has been the strategy in the past, is not likely to be beneficial unless moisture availability is enhanced.

Many African soils suffer from multiple micronutrient deficiencies, as a result of their inherent soil properties and of continuous cropping without nutrient replenishment. Current fertilisation programmes in African countries primarily focus on NPK fertilisers, but many soils are non-responsive to NPK as a result of (multiple) micronutrient deficiencies. Soil modification with small amounts of (multiple) micronutrients is a sustainable strategy to increase yields and the nutritional quality of crops. A review of experiments from 10 African countries on the impact of Zn-enriched fertilisers showed that soil Zn application increased the Zn concentration in maize, rice and wheat grains. Moreover, another agronomic benefit is that seedlings from seeds with a high Zn concentration have better growth performance and resilience against environmental stress, so positive impacts on productivity may be seen in the next cropping generation.

The application of micronutrient-enriched fertilisers has minimal negative environmental impact. Most micronutrients are not susceptible to leaching because they are strongly bound in the soil.

An important question is whether agronomic bio-fortification is an effective, feasible and sustainable approach to alleviating micronutrient deficiencies; especially in comparison with other intervention strategies such as genetic bio-fortification, food fortification, supplementation and dietary diversification. An unequivocal answer is difficult as the literature is sparse. Nevertheless, a few observations are in order.

A key issue is the commercialisation of smallholder agriculture to create markets for the extra production, because otherwise investments in (extra) mineral fertiliser are not economically feasible. Mapping of micronutrient deficiencies in order to provide field-specific fertilisation recommendations remains a challenge. Furthermore, knowledge and tools should be accessible and affordable for farmers in rural African regions. Finally, new fertiliser products and management practices need to be matched with local socio-cultural environments in order to enhance adoption. It is important to raise awareness about proper food processing, and consumption that stimulates micronutrient uptake into the human body

The 15–24-year-old age group represents 20% of SSA’s population today and, unlike in other regions, this youth share will remain high and stable. Agriculture has a substantial role in meeting the youth employment challenge facing Africa, given the inability of the urban economy to absorb fully the young entrants to the rural labour force. It is argued that there will be vast opportunities for innovative young people in agricultural systems as they adapt to a range of challenges in the near future. These challenges relate to raising productivity sustainably, integration into emerging high value chains and healthy diets. A major barrier is, however, strong negative preferences and attitudes among young people towards agriculture. Unfortunately, governments have not effectively addressed either the attitude of many young people towards agriculture or the obstacles preventing their entry into the sector. To create opportunities commensurate with the number of young people who will need employment, constraints on the acquisition of capital, land and skills must be removed or relaxed.

Some options that may help the young, as well as others, include allowing alternative forms of collateral, such as chattel mortgages, warehouse receipts and the future harvest; leasing, which requires either no or less collateral than typically required by loans; outgrower arrangements that pre-finance inputs and assure marketing channels; and microinsurance, offering low premiums, flexible payments and prompt settlement of claims. However, an exclusive focus on the young in these innovative financial arrangements may add to the risks for financial institutions. Indeed, any and all innovations in finance that facilitate sustainable outreach to small farmers and rural entrepreneurs should be supported. Where necessary, additional features should be added to enable these programmes to serve young people.

The two aspects of land administration that matter most to young entrants to the labour force are the need to improve security of tenure and the need to relax controls on rental. Land redistribution will also enhance young people's access to land.

Young Africans must be equipped with basic reading, writing and numeracy skills, and the ability to use digital technology to access and interpret information. A growing and diversifying agricultural sector will create jobs that demand increasingly advanced technical and professional skills, from processing and marketing to agricultural research. Development of agro-food businesses represents a significant opportunity for youth employment and for local development, thanks to powerful growth linkages to the rest of the economy.

A case can be made for higher investment in agricultural research. A few examples illustrate the high returns. First, maize improvement in West and Central Africa provided a return of 43%. Second, in SSA, national and international organisations are making a big impact in reinforcing food security and alleviating poverty through rice research. Overall, improved varieties have increased net revenues by $93 per hectare, with the highest gains in irrigated and rain-fed lowland ecologies. The annual returns to investment in rice research now exceed 20%.

Impact studies also reveal that rice research contributes effectively to the realisation of almost all the Millennium Development Goals, including halving levels of poverty and hunger, promoting education, improving health, reducing child mortality, empowering women and ensuring environmental sustainability.

Yet agricultural research has had a mixed impact on wellbeing in this region. Specifically, there is no emphasis on research by the NARS on reducing undernutrition. Thus there are cases of malnutrition in the face of abundant food supply because of the lack of integrating research on crop production, nutrition and health.

13. Concluding observations

To conclude, institutional innovations are needed to improve productivity and make public agricultural institutions more responsive to markets, more accountable to the communities they serve and better recognised as an important tool for achieving economic growth. Huge productivity gains are possible and accrue where governments allocate the necessary resources to agricultural research and development. In SSA, however, public investment in agriculture is still far below what is needed. The challenge is to develop technology that is relevant to small farmers and to enable them to transform their farms into viable small businesses that make a vital contribution to local and national economies and improve nutrition. But better nutritional outcomes are contingent on clear research priorities established through an integrated and empirically valid analytical framework that encompasses the pathways identified and assessed here.

Although the effects of agricultural interventions on nutrition are largely limited or missing, it would be a mistake to infer that the absence of a significant effect implies that there is no effect. They may be few in number but their use of rigorous methodologies yields significant effects on nutrition.

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