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Innovations to Overcome the Increasingly Complex Problems of Hunger

Joachim von Braun

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www.bmz.de/de/mediathek/publikationen/themen/laendliche_entwicklung/index.html.

Abstract

Hunger has become ever more complex, and therefore efforts to sustainably eradicate hunger and malnutrition depend on policies and programs that match these complexities. Innovations are critical for progress. However, they require increased public and private investments as well. Key elements of inclusive policies and partnerships are agricultural development in the hunger-affected rural areas and communities to improve productivity will remain a major part of solutions. Farmers' own innovation capacities need strengthening. Investment in food and agricultural research and development (R&D) is an important tool for broad-based innovation, for instance, related to improved seeds. Digital technology is a game changer for food and nutrition security. Innovations for improved market functioning and avoidance of price shocks require information and early warning systems, as well as better preparedness with improved trade and food reserves policies. The environmental and climate change aspects of agricultural and land and water use change need more attention for sustainable hunger reduction. More attention to innovative social protection and direct nutrition intervention programs is needed, including addressing the micronutrient deficiencies in rural and urban areas. Hunger in complex emergencies needs to bring together development policy with diplomacy and security policy. Innovation initiatives like any development investments must follow principles of good governance, achieving investment at low transaction costs, sound financial practices, and avoidance of diversions of funds.

Keywords: food security, nutrition, agricultural development, innovation, digital technology, social innovation

JEL codes: O3, O13, Q16, Q18

1 Innovations to reduce Hunger and Undernutrition: An Introduction

The challenge to end hunger is confronted with the fact that hunger has become more complex. Some characteristics of that increased complexity shall be highlighted here at the outset. The majority of hungry people live in rural areas and on small farms of emerging economies, while urban hunger and undernutrition is of growing importance, too. Overcoming hunger relates closely to the transformation of rural areas and of small farms' productivity, and to the quality of services reaching out to them, especially health and education services, and social safety nets. Hunger in emergencies and conflict situations is a growing political and social challenge. Micronutrient deficiencies are only recently increasingly recognized as a large food and health problem, affecting cognitive capacities. Ending undernutrition in South Asia requires different actions than in Africa. Environmental causes of hunger such as climate change may be increasing. Overall, hunger is on the decline as accounted for by the Global Hunger Index (IFPRI et.al 2016), but the various features of hunger and undernutrition remain large global problems (Table 1). They are most prevalent in low and middle-income countries, but also exist partly unnoticed in industrialized countries, such as the USA and European Union. All this calls for equally complex policies and programs, adjusted to regional and local circumstances.

Table 1: Hunger and Nutrition Problems

Problems	Number of people	Consequences
Hunger (undernutrition, calories)	Approx. 0.8 billion	Acute deficiency, political conflicts
Hunger in complex emergencies	Approx. 120 million	Early childhood nutrition shocks, Mother's health
Hidden Hunger (deficiencies of micronutrients, such as vitamins, iron, etc.)	Approx. 2 billion	Diseases, reduces productivity
Children's undernutrition (the first 1000 days)	Approx. 155 million	Stunting, reduced physical and cognitive development, 3.1 million deaths p.a.
Obesity and resulting chronic diseases	Approx. 2 billion	High costs of public health

(Data sources: FAO, 2017; Global Nutrition Report, 2017; FSIN, 2018; IFPRI, 2018)

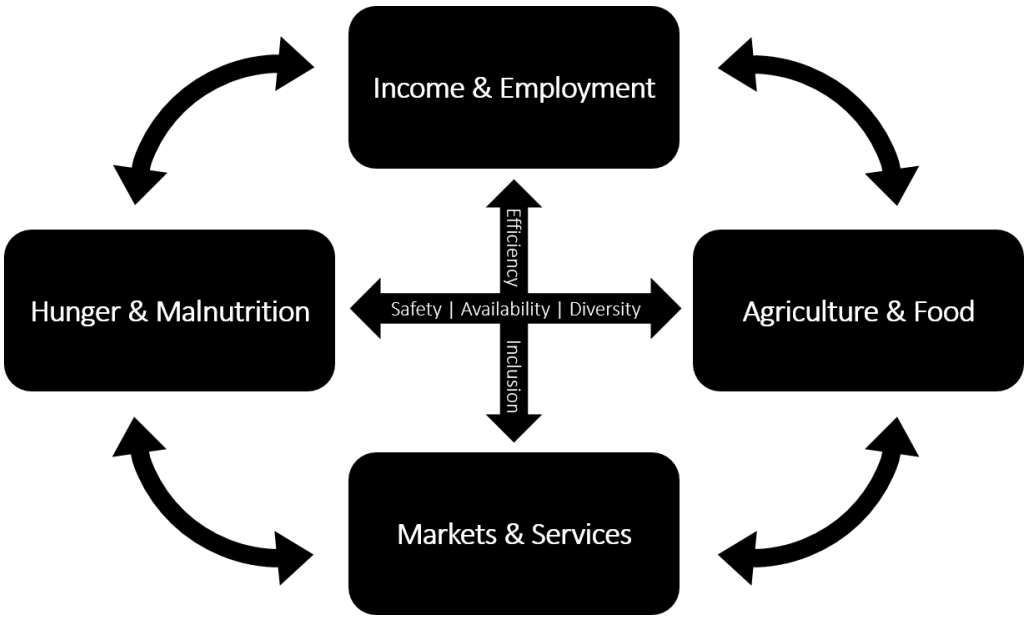
This paper aims to assess alternative pathways toward overcoming hunger with an emphasis on innovation. Innovation is the fundamental driver of human development, and food and agricultural innovations play essential roles to overcome hunger sustainably and effectively. Innovation is the accumulation and application of any new knowledge by a heterogeneous group of actors in social and economic contexts via complex interactions (Spielman 2005). However, innovation is not just a matter of technology and productivity. Hayami and Ruttan (1971) stress the importance of public institutions in the innovation process that is mainly driven by dynamic responses to the economic conditions and relative scarcity of resources in an economy. Innovations must tackle the problem of the complexity of hunger and find

effective and cost-efficient solutions to the problem. Transfers for short-term assistance are needed in emergencies and are a must to save lives. Aid that does not build local capacities or draws down nature capital will not sustainably reduce hunger. New thinking about policy, institutional and organizational innovations, and technical innovations, i.e. biological, mechanical, and information technological innovations, must come together in order to end hunger by 2030, as called for by the Sustainable Development Goals. Fortunately, new large initiatives have been taken, for instance by the German Government to achieve a "World without Hunger". These initiatives must be sustained for the time until 2030 to actually reach the Sustainable Development Goal No.2 to end hunger and achieve food security as well as improved nutrition while promoting sustainable agriculture.

2 Innovation in a Conceptual Framework of Food and Nutrition

In view of the matter's complexities, an effective policy to end hunger needs a framework that helps in understanding causal relations of hunger determinants and in shaping priorities for action. Currently there are two conceptual frameworks that dominate the policy discourse about food and nutrition security, where agriculture and nutrition links are implicitly touched upon. In the framework provided by FAO, food and nutrition security depends on the availability of food through production and trade, on access to food due to purchasing power or self-production, on the utilization of food for nutrition, and on the stability of the food system, especially of related markets and prices (FAO et.al 2014). The framework developed by UNICEF and applied in the Lancet nutrition series (Black et al. 2008) identifies the basic and immediate causes of maternal and child undernutrition. These frameworks do not capture political economy determinants of nutrition which require more attention (Pinstrup-Andersen 2013). Furthermore, structural issues such as discrimination, marginalization, and conflicts require a broader framework of marginality to capture those complex causes of nutrition deficiencies (von Braun and Gatzweiler 2014). Such problems are deeply rooted in institutional and governance deficiencies. In certain contexts, it seems hardly feasible to achieve improved nutrition without addressing these deficiencies. This concerns international arrangements as well as national and local level nutrition-sensitive inter-sectoral policies and their implementation (IFPRI 2016). Where relevant, these political dimensions need to be taken into account explicitly rather than treating them as distant framework conditions. Moreover, food and agriculture are becoming embraced by the larger bio-economy (von Braun 2015). An aggregate but comprehensive conceptual framework is put forward here (Figure 1).

Figure 1: Framework of relationships that determine nutrition and food security



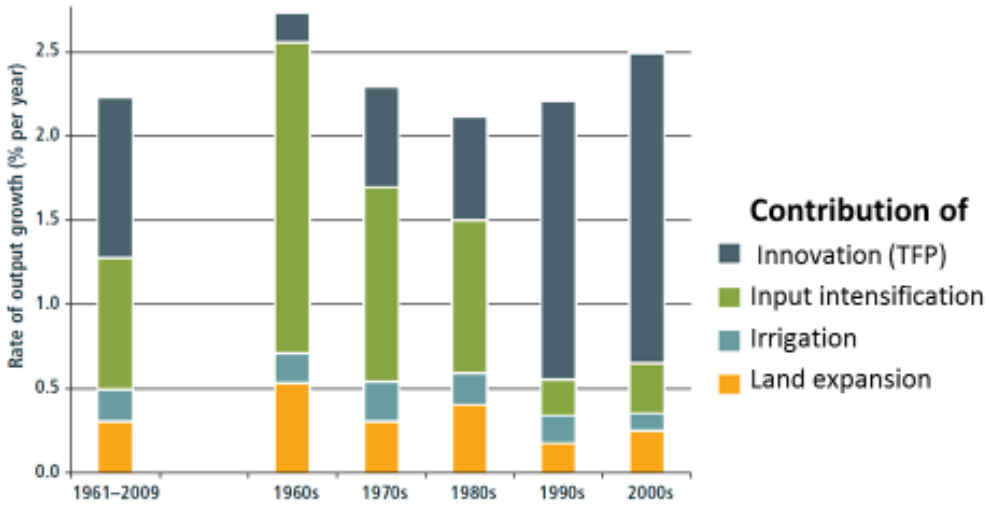
Source: von Braun (2017)

The concept takes a broad perspective on the food and agricultural sector, income and employment, markets and services, and hunger and malnutrition. Institutions, information, and behavior are cross-cutting issues that influence linkages in all of the domains that describe the framework. Even in a rather aggregate framework such as presented above, at least six critical linkages need consideration when addressing hunger and malnutrition (see arrows in Figure 1). Actually, all linkages depict two-way relationships. Overarching and surrounding the Figure 1 are environmental as well as macroeconomic framework conditions. Related linkages exist at a large or even global scale, such as greenhouse gas emissions through land use change, and at a local scale, such as water and sanitation in the context of irrigated agriculture. All the links operate with diverse dynamics under short- or long-term time lags which require attention in policies and programs. Even the links between agricultural and food production and nutrition can be rather short-term, e.g. with acute food safety problems. Agriculture–income links may be more long-term, if agricultural resources such as soils are enhanced or degraded (Nkonya et. al 2016). The dimensions of the agriculture–food and nutrition linkages need to consider structural problems, such as access to markets and resources including land. And there are risks that affect the resilience of poor people and low-income countries, often eroding societal cohesion. Furthermore, a multitude of drivers beyond agriculture shape food security in positive or risky ways, e.g. bio-energy systems, biomass based raw material uses in industries, financial markets integrated with food commodity markets, novel non land-based foods, and more. Generally, all four dimensions in Figure 1 and their interrelations can benefit from innovations making the food and nutrition system more effective, efficient, and resilient. While agriculture remains a fundamental driver of food and nutrition in rural areas, income and employment is of growing importance as a driver in urban contexts. Three contextual changes are particularly significant now and may be even more so in the future: first, urbanization and rural–urban change with extended value chains combined with retail industry expansion world-wide, secondly, the transformation of the small farm economy in emerging economies, and thirdly growing hunger in complex emergencies and political conflict situations. These changes also relate to migration and mobility of people. Rural and urban hunger need to be addressed simultaneously. Ever stronger linkages between urban and rural areas represent a challenge for sustainable development and food security. Malnutrition in urban slums will need increased attention, especially with a focus on micronutrient rich foods that the poor can afford to purchase as well as sanitation and clean water services. A sole focus on food quantities and its quantities, respectively, will not be adequate in these contexts.

3 Innovations in Policy and Food Systems to Fight Hunger

Innovations that impact on the whole economic, social and food system context have huge positive effects for reduction of hunger. At an aggregate global level, innovations have become more and more important for improved food security. This is clearly visible in one component of food security, i.e. the sources of growth of food availability for the global population. Innovation contributes now about three quarters of growth, and inputs and land and water resources have scaled back while overall growth was maintained (Figure 2).

Figure 2: Sources of productivity growth in agriculture



(Source: IFPRI, 2013, based on Fuglie)

Not only the essential productivity growth has changed toward more sustainability. Other changes we can point out as historical and current examples, e.g.

- the cooperative formations initially in the 1860s by Raiffeisen in Germany – then spreading to many countries around the world, which facilitated collective actions to deal with market malfunctioning in output, input, and credit markets and social innovation;
- the “Green Revolution” combining improved seeds of staple crops with irrigation and fertilizers pioneered by Norman Borlaug in South Asia and others in China prevented a food emergency threatening the lives of millions; its dependence on growing input and water intensity has been much reduced in the meantime (compare inputs and water shares 1960s and 70s with the 2000s in Figure2).
- the Chinese economic policy reforms of 1979 and thereafter, giving farmers access to markets and management freedoms on their farms, which gave a boost to economic growth of the Chinese economy, drastically reduced hunger, and actually led into a changed world;
- the Vietnamese rice market policy reform of the 1990s, which led the powerful incentives to reach the farm gates of small farmers, who responded strongly and made Vietnam a major rice exporter improving the world food situation;

- the innovation of microfinance by Mohammed Yunus in the 1980s that facilitated access to finance for women's groups improving their livelihoods;
- the innovation of conditional cash transfer schemes to improve nutrition and health, initially tested and scaled up in Mexico in the 1990s and spread thereafter around the world.

All these big innovation examples have two things in common: one, they focused on policy and institutional innovations, and two, they entailed years of research and experimentation before they were implemented and scaled up. An important lesson is that not only technological innovations but also institutional and policy innovations are quite research-intensive. Moreover, researchers' and policy makers' interaction in implementation- oriented research can be very effective for overcoming hunger. However, there is an additional lesson learned from each of these very successful examples: despite their great contributions to the reduction of hunger and food insecurity, none of them alone is a panacea to end hunger in every context.

Public policy has two possibilities: either they introduce policies that change behavior of farmers, food processors, and in the end consumers or they implement nutrition-specific interventions which compensate for nutritional damages that are partly a consequence of food system failures (Pinstrup-Andersen 2013). A broad set of public policies is required to address hunger and nutrition risks, including policies and programs directly targeted at the undernourished with social transfers and nutrition programs. Most of these actions are carried out by national governments, but international support for these investments is also needed, especially in the least developed countries. Policy actions in three priority areas are called for: (1) expand social protection and child nutrition action to protect the basic nutrition of the most vulnerable, (2) take protective actions to mitigate short-term risks (such actions would include cash transfers, pension systems and employment programs), and (3) adopt preventive health and nutrition interventions to avoid long-term negative consequences. Social safety nets not only ease poverty in the short term, but also enable growth by allowing poor households to create assets, protect their assets, and allocate resources to more risky but highly remunerative production activities.

Since good nutrition is crucial for children's physical and cognitive development as well as their productivity and earnings as adults (Hoddinott et al. 2008), early childhood nutrition and school feeding programs should be strengthened and expanded to ensure universal coverage. Of relevance are also employment-related transfer programs, such as the Indian rural employment scheme, scaled up to the national level in the past decade. Cash transfer programs are increasingly common. When well implemented, these programs—which transfer cash to households partly on the condition that they meet certain requirements such as sending children to school and using preventive health services—have proven successful in reducing poverty. In the short run, these programs have improved nutrition and increased household income. In the long run, cash transfer programs can have a beneficial impact by helping to build human capital. Still, these programs also have deficits, as shown after many years of experience in Latin America, including potentially undermining the formation of formal labor markets and corrupting political processes at regional levels (Birner, von Braun 2015).

4 Innovations in Markets and Trade for Reduction of Hunger

Innovations for improved functioning of markets and trade are important for food security. Poor consumers and farmers' lack of access to markets as well as excessive volatility of prices remain problems for many of the hungry. Risk and uncertainty are quintessential features of agriculture and food markets. In extreme cases, they can cause severe food crises as experienced multiple times in several parts of the world throughout history. Food shortages that have occurred in the 20th and 21st centuries, most notably the global food crises in the 1970s and more recently in 2008, 2011/12, have affected millions of poor people in food-importing regions. Before the crisis in 2007/08, it was widely propagated that only market-based approaches should be used to stabilize agricultural markets. However, this view has been revised in the aftermath of the crisis. Several important factors were found to have been underestimated, such as the level of price instability, the exposure of producers and consumers, and potential social unrest. Consequently, surging food prices and the associated extreme food price volatility have caused panic and protest in developing countries resulting in major challenges for policy makers. Yet, little protection against price shocks exists currently and the most vulnerable people remain with a limited capacity to quickly adjust to abrupt price changes. Thus, the need to improve the resilience of agricultural markets remains as high as ever. The international community and many governments have yet to develop an effective risk management strategy to be well prepared for future crises (Kalkuhl et al. 2016).

Innovations to deal with volatility aim to promote the integration of different markets for improved risk-sharing among them. This does not only apply to an international context but also within countries. Furthermore, integrating markets also helps to cope with seasonality as distant markets have different seasonal patterns. Integration also comprises connecting processes along the value chain, and eliminating non-tariff and political barriers to trade. Value chain analyses can help explain why in some cases low income producers do not profit from market integration, e.g., because product standards exceed their capabilities. Thus, while promoting market integration it is necessary to equip farmers with the necessary tools and training to enable them to participate and compete in markets. In addition, measures for prevention of excessive volatility include national and regional grain reserves and regulations that restrict excessive speculative engagement in food commodity markets (Tadesse et al. 2014). Food markets will remain volatile to a certain extent and therefore improved early warning and information sharing is needed at regional and global levels.

5 Innovations to Address Hunger in Complex Emergencies and Wars

Abrupt and strong food price increases, as was the case in the 2007/08 and 2011/12 crises, can lead to social unrest, violent conflicts, political instability, and reduced economic growth (Bellemare 2015). Because governments are held responsible to ensure that people have an acceptable level of food security, their legitimacy is challenged when the poor lack access to food following food price rises and spikes. From the beginning of 2007 to mid-2008, food-related protests including strikes, demonstrations, and riots occurred in more than 40 countries, with some countries experiencing multiple occurrences and a high degree of violence. Social unrest does not only harm human and physical capital, which ultimately affects the country's economy, but it also hinders domestic and international trade that is crucial for accessing food. Furthermore, there is a strong correlation of food riots with the international food price development (Kalkuhl et al. 2016).

Of increasing relevance at an international scale is hunger in complex emergencies, i.e., when political conflicts, war, terrorism and environmental emergencies interact. The list of countries and regions within countries having to deal with hunger in complex emergency situations is getting longer, including for instance Syria, Yemen, Afghanistan, parts of Nigeria, South-Sudan, Burundi, and others. The human right to food is often violated in some of these settings, and hunger is implicitly a weapon, when cities or localities are encircled, preventing food and other aid from entering. In these settings hunger reduction depends on innovative cooperation between security policy, diplomacy, and development policy. Even in these sometimes almost hopeless and depressing situations, innovations in emergency relief operations can make a difference. Good examples would be innovations such as cash cards for local purchases facilitating positive leakages of essential goods across borders or cell phone based money transfers that can be locally used to buy food.

Protecting nutrition as much as possible during crises and rebuilding thereafter must consider inequalities and discriminations that determine resilience or the lack thereof. Typically, communities and groups of individuals that are marginalized and excluded lack such resilience and need special attention in emergency operations. Resilience is the capacity to withstand shocks and to recover quickly after a shock (Figure 3).

Nevertheless, taking a combined short- and long-run view is needed to overcome these protracted hunger problems by peace building and development. In terms of the proportions of hunger worldwide, it must be kept in mind that structural, mostly poverty and marginality related causes of hunger dominate and must be addressed by income and employment opportunities, as well as increased productivity on small farms.

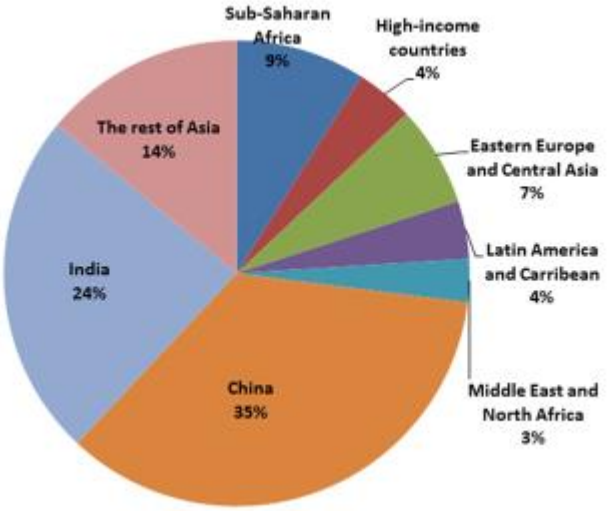
Figure 3: Resiliance of more vulnerable and less vulnerable groups

(Source: von Braun and Thorat, 2014)

6 Innovations to Cope with the Fast Farm Transformations

The small farm economies are in structural change. In the cases of Asia and Africa, both continents are sooner or later approaching a turning point from a farm size decrease to increase, and demand for labor-saving mechanization will rise. This structural change will impact the labor market, thus spilling over into other economic sectors. Yet, this transition towards larger farms, especially in regions where small farms are dominant, will take a long time. The world has about 570 million mostly small farms (Figure 4).

Figure 4: Where the World´s Farms are (about 570 holdings)



(Data sources: Lowder et al., 2014, FAO datasets)

These small farms are impacted by a rapidly changing context that affects the food situation – some positive, some increase risk. Some examples are

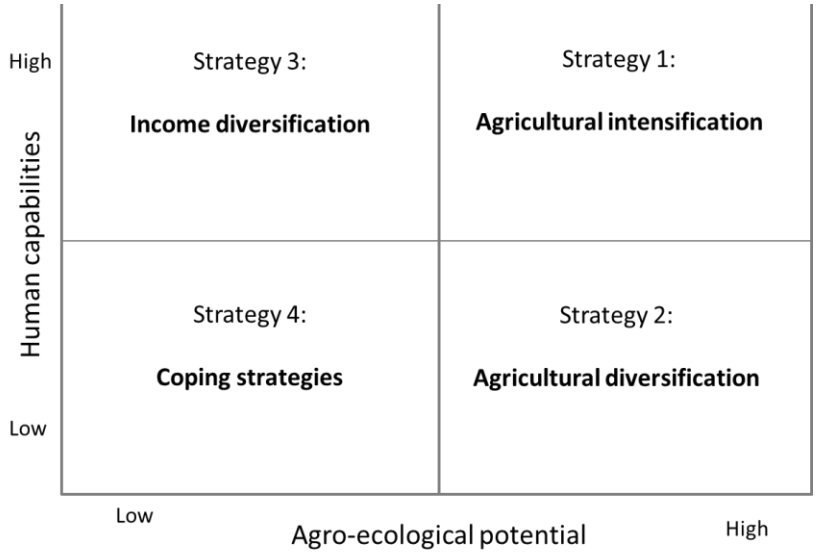
- opportunities are increasingly seen outside agriculture labor markets; youth in many countries are leaving farming;
- the market value of land is rising because of agricultural price changes and the increasing influence of non-agricultural demand for land use, and land speculation;
- international dynamics resulting from consumption shifts as fundamental drivers;
- the scale and pattern of investments in infrastructure and social policy change in the socio-economic context of farming.

It should be considered that a farm being small is not only a matter of land size, but a matter of assets and income (von Braun 2005). For example, one hectare of irrigated fertile land planted with high value vegetables and fruits and located close to major urban markets could generate much higher total income than, say, 20 hectares of rain-fed area under subsistence crops in remote areas. The factors that put small farms at an advantage or disadvantage compared to large farms have been debated by economists for years (Schultz 1964; von Braun and Kennedy 1994; Hazell et al. 2010). Hired labor is the main reason for the lower land productivity of larger farms (Binswanger and Rosenzweig 1986). This is because family workers are more efficient than hired workers. Since family members receive a share of the farm's

profit, they pay greater attention to the quality of their work compared to hired labor. Several studies corroborate these findings by showing that small farms have a higher land productivity than bigger farms due to higher incentives and productivity of family labor (Eastwood et al. 2010), especially in Asia where labor is more abundant than land (Hazell et al. 2010). Fan and Chan-Kang (2005) indicate that, in certain cases, once the varying degrees of soil fertility and land potential (irrigated vs. rain fed) are taken into account, the diseconomies of scale in land productivity between small and large farms may disappear. Wiggins et al. (2010) conclude that the distinct advantages of small farms are present in cases when the main agricultural input is family labor and there is very little use of external inputs, the production being chiefly for home consumption with whatever surpluses exist being sold to small-scale traders. Since most of the poor in the world reside on small farms what happens on these small farms will be decisive to reduce poverty and hunger. Therefore, if these farmers were better off, hunger and the sticky problem of child malnutrition would diminish. Hence, an appropriate focus on small farms' prosperity is called for, but that priority should not be a dogma in view of urban–rural change and rural landlessness, as well as the need to provide low-cost, safe, and healthy food for the rural and urban poor in the markets.

In view of the different characteristics of farms and people, different segments of marginalized smallholders must be kept in mind when considering innovation strategies. Strategies must match economic and human capability as well as agro-ecological potential (Figure 2). Four broad people-and-land related segments within those two dimensions can be identified: 1) Areas where rural populations have relatively high capabilities and land with relatively high agro-ecological potential (AEP). 2) Areas where the level of human capabilities is relatively high but AEP is low. 3) Areas where human capabilities are relatively low and AEP is high. And 4) where capabilities and AEP are both low. For each segment of the rural poor, strategic options can be identified: Intensification, diversification, and coping strategies. Innovations to improve land productivity will be favored in segments 1 and 2, where agro-ecological potentials are relatively high. Innovations to improve labor productivity will be favored in segments 1 and 3, where human capabilities are relatively high. In segment 4, intensified efforts for improving both types of productivity need to be made. This segment is typically the domain of development aid organizations and needs to be embraced by national development and social safety net programs. Value-chain-focused approaches are suitable for segments 1 and 2.

Figure 5: Potential strategies, technological and institutional innovations considering



(Source: Gatzweiler and von Braun, 2016)

A strategy of sustainable agricultural intensification could involve improved access to production means, e.g., high yielding varieties, fertilizer, pesticides, and seeds to enhance productivity through intensification (The Montpellier Panel 2013). In this segment, technological and institutional innovations need to support the aim of increasing yields per area of land. Depending on the specific context in which innovations are sought, strategies towards sustainable intensification will need to be more people and/or area-focused. These strategies include:

1. Intensifying crop production and minimizing environmental impact by making use of improved varieties and technologies adjusted to changing environmental and climatic environments.
2. Diversifying agricultural crop production and production techniques to reduce external inputs and risks of failure and maintain agro-biodiversity.
3. Diversifying income opportunities and facilitating exit strategies, as well as enabling private business opportunities.
4. Providing basic educational, food, and health services for the most deprived, including them in social safety net, and connecting them to communication and transport infrastructure.

By investing more in farms, and by increasing efficiency of farming, a large portion of poverty and malnutrition could be reduced. Small farms play multifunctional roles in development, such as food and non-food production, contributing labor to local ecosystems services (soils and waters), and providing local social capita (HLPE 2013). Policy support should be aimed at promoting the dynamism within the family farm sector itself, but also enhancing the dynamic interactions and integration of the family farm sector into the rest of the economy. All three options for small farm transformation need public policy attention not just a smallholder growth strategy. At the same time, land rights of small farmers must be protected by recording and by enforcing ownership against powerful international and domestic investors. Digitally supported ownership records can help with that, but rule of law is essential.

7 Innovations from the Bottom up with Farmers

We can distinguish between two interrelated components of innovation, i.e., institutional and technical innovations. They are driven by common forces, especially scarcity of resources and related prices of resources, mainly land, water, and labor (Hayami and Ruttan 1984). When resources become scarce, opportunities for innovation arise. For instance, measures that enhance the land productivity are taken when land is the scarce factor. In contexts of water shortage, the efficiency of water use in irrigation may be increased or labor saving technologies are implied when wages rise. Moreover, we need to include all actors of innovative change into the system, i.e., farmers themselves, the research communities, businesses along value chains, and policy makers.

Farmer innovation is as old as farming when sedentary farming evolved and hunter-gatherers began to build permanent houses of stone and wood, and accelerated with inventions of agronomic, plant and animal breeding. Already then, human development interacted with climate change: climate warmed suddenly at the time which facilitated the planting of steppe fields with wild wheat and barley and with vegetables in other parts of the world, including in forests. It is an irony that human development was triggered by climate change while today food security is threatened by climate change. Nowadays, climate change puts pressure on agricultural production systems and food security, especially in regions where the population is already vulnerable to undernutrition (Wheeler and von Braun 2013). Adapting agricultural systems to these new challenges is the aim of innovations fostering climate-smart food systems. Weather index-based crop and livestock insurance systems are an innovative approach gaining increased attention.

Long before formal science institutions were established, innovation was changing and improving productivity of farming and food systems. It must not be forgotten that this type of bottom-up initiatives is still an important force of innovation in which farmers are investing. Gupta (2016), who pioneered the “Honey Bee Network” including thousands of farmers in India that makes grass roots innovations visible and accessible through sharing, points out, that “minds on the margin are not marginal minds”. Wünscher and Tambo (2016) studied farmer innovations in Ghana. Farmer innovations include technologies or practices which can be applied along the value chain, are different from common or traditional practices, and are developed by a farmer or a group of farmers without external assistance. They stem from modifying existing technologies, inventing new practices or experimenting with new ideas. By means of a farmer innovation contest among smallholder farmers in Ghana high-potential innovations were identified and encouraged. The researchers show that farmers can be a promising source for locally adapted, site-appropriate innovations which may be suitable for rapid and cost-effective dissemination. They point to the fact that, despite poverty, a farmer’s innovative capacity remains part of their capabilities, which can be made use of by changing incentive systems for innovation. The provision of incentives in the form of a contest is a way to stimulate the farmers’ innovative behavior and to facilitate the dissemination of successful technologies on the regional level. Farmers become creative, share their knowledge with institutions and other farmers, and engage in experimentation. Thereby, partnerships between farmers, extension officers, and scientists are strengthened, and the appreciation for farmer innovations among the involved stakeholders is increased. Furthermore, encouraging the innovativeness of farmers is a means of building resilience since their ability to

autonomously adapt to changing conditions can be increased. Reducing a farmer's dependence on external inputs facilitates the application of this human resource of creativity and innovation. The approach of farmer innovation contests and farmer group formations is being rolled out in several more African countries.

Agriculture may be even responsible for shaping the mindsets of people. Talhelm et al. (2014) showed that there may be a two-way relationship between people's behavior and agriculture. Looking at China, they found that rice farming makes societies more interdependent whereas farming wheat has the opposite effect making societies more independently thinking. They found in rice producing regions of China a comparatively higher degree of holistic thought; also, group goals were given a higher priority than individual goals (Cross et al. 2011). In wheat producing regions, people tended to be more analytic and individualism was given a higher priority than the overall welfare of the group. Other new research points at the important role aspirations or lack thereof play for innovation and technology adoption in agriculture. Mekonnen and Gerber (2016) find in Ethiopia that farmers with less aspiration adopt innovative practices less often, such as improved seeds and fertilizer. The upshot of this research is that innovation is endogenous to fundamental drivers, and not just a matter of transfer of knowledge and technology. Yet, transfer of innovation also plays important roles today. Relying just on bottom-up innovations would neglect opportunities offered by new research and applied scientific insights.

8 Research and Innovations serving Farmers and reducing Hunger

During the past 200 years, several major inventions for the agricultural sector could be observed that had a great influence on shaping societies (Fogel 1999). This accumulation of innovations took place simultaneously with the exponential population growth, actually facilitating population growth. Early scientific communities focused on agronomy and emerged in the late 1700s. Major contributors to the agricultural economics included Johan von Thuenen (1810s) and Robert Malthus with his studies on population and hunger in the 1830s. Plant nutrition was dramatically changed by Justus von Liebig's discovery of essential plant nutrients in the 1840s. The animal sciences already saw innovation in the 1800s regarding selective breeding. The increase in food safety measures was much improved by Louis Pasteur, who treated milk to stop bacterial contamination in the 1860s. Increasing awareness of food safety led to an amelioration of public health. It was Gregor Mendel in the 1850s who revolutionized plant breeding through genetic considerations. His innovative statistical studies had great influence on breeding. Norman Borlaug's work on plant breeding in the 1970s had a huge impact on the food security situation in Latin America and Asia, increasing wheat and rice yields by planting high-yielding crop varieties (Gillis 2009). Since the 1990s, advanced biology has become important in agricultural science. Scientific innovations have made significant contributions to hunger reduction and the Centers of the Consultative Group for International Agricultural Research (CGIAR) have played important roles in that respect together with national research systems of emerging economies. Still, a big gap exists between potential agricultural productivity and yields of crop and livestock between low and high income countries. This gap must be further addressed by new ways of cooperation, and farmers' vocational training and extension services must be strengthened.

Research increasingly focuses on the goal of achieving higher and more stable yields as well as on the plant-microbial relations, and advances in molecular and cellular processes. New forms of water saving irrigation systems will become more important. Innovations in pest and disease resistance in a post-antibiotics age, such as chemical control, biological control, sterile insects breeding, and breeding for resistance. In addition, meat substitutes made from pulses or algae have become prominent on research agendas to bridge protein gaps. Demand-side innovations will focus on consumption and behavior change to overcome food related health problems. Consumer preferences and the willingness of consumers to alter these will be one of the major determinants of the actually adopted change of agricultural products in the next decades, as well as reducing waste and losses.

Agriculture-related nutrition linkages influence farm families directly and indirectly through availability of foods in the markets. Nutrition-sensitive agriculture aims at making nutritious foods available and accessible, thus focusing on an important cause of malnutrition (Jaenicke and Virchow 2013, Balz et al. 2015). An important evolution in the past 10 years is the increase of the nutrient content of staple foods, such as wheat, maize, rice, beans, and sweet potatoes through plant breeding – an approach called biofortification (Bouis et al. 2013). Biofortification is seen as one major contributor to eliminating micronutrient deficiencies. At the same time food fortification through mixing micronutrients into staple foods such as flour or cooking oil has become more widespread and more effective, too. These approaches need to be applied in optimal combinations rather than separately.

The bottom-up innovations discussed above and the science based top-down innovations from research systems should be connected in new and more effective ways. A means for that are innovation platforms or innovation centers in which researchers and farming practitioners meet and jointly identify opportunities. The “Green Innovation Centers” initiated by the German Government in several African countries can be a basis for such synergy between bottom-up and top-down among farm actors and research communities on local or international levels (Husmann et.al 2015).

9 Digital Technologies for Food Security

The mobile phone has not only become the most important communication technology globally, but also offers numerous additional functions such as access to the internet, audio-visual recordings or financial transactions. Digital technology is a game changer for food and nutrition security. It potentially makes monitoring hunger risks more effective. Farmers can be better informed about market opportunities and become strong users of innovations that fit their circumstances. On the consumer side digital technologies can facilitate the provision and dissemination of information related to malnutrition. Furthermore, costs for nutrition program experts to reach their target groups, especially mothers and children in need, decrease. Many of these opportunities are yet to materialize, but the potentials are large. In particular, the advent of smartphones has opened up a whole new range of services to their users. At the same time, the nature of the internet is changing towards a network of diverse mobile devices which can collect, share, and analyse huge amounts of data and connect users around the globe, including in Africa, through social networks. Several services are already being offered to farmers with the help of mobile technologies (referred to as m-services, Baumüller 2016). Using information and communications technologies (ICT) such as global positioning and information systems, remote sensing or sensors to monitor climatic conditions, soils, or yield, farmers can detect temporal and spatial variability across their fields. They can then selectively treat their crop, either manually or through technologies that adjust their behavior in response to the gathered data. Much of the focus has been on variable rate application of inputs based on yield and soil monitoring (McBratney et al. 2005).

Many of the high-tech agricultural applications used in industrialized and a few developing countries are unlikely to be appropriate in development contexts given low levels of literacy, limited access to equipment, and small landholdings. However, the rapid spread of mobile phones and networks as well as advances in the Internet of Things (IoT) could lead to applications that are better adapted to the needs and capacities of small-scale producers. Farmers can use IoT services to assist with site-specific management of their fields, monitor the development of their crops, adjust their agricultural practices in response to the data, and track the sales of the produce. The information they gather is complemented by other information to help with planning, such as weather forecasts or price information for inputs and outputs. Baumüller (2016) reports that in Kenya, Virtual City's Agrimanagr and Distributor systems use mobile phones to collect data when farmers deliver the produce, e.g., weight and location (through GPS) and track the produce throughout the chain to the processing plant. In Ghana, SAP uses barcodes linked to a famer's profile to record deliveries of shea and cashew and upload the information to a central system via mobile phones. IoT technologies are also being used to track the movement of cattle, for instance in Kenya with GPS tracking devices attached to one cow in the herd (The Cattle Site, 2012). Insurance companies are deploying M2M technologies to manage micro-insurance schemes for crop and livestock producers. The company ACRE (formerly Kilimo Salama*)*, for instance, uses data from weather stations to trigger insurance pay-outs in case of severe weather events via mobile phones. The inclusion of the next generation of millions of small farmers in ICT opportunities could also contribute to a reduced urban–rural divide.

10 Conclusions for Innovations to End Hunger and Improve Nutrition

At the outset of this paper we emphasized that hunger has become ever more complex. To conclude, efforts to sustainably eradicate hunger and malnutrition depend on policies and programs that match these complexities of causes and features. Innovations are critical for progress. However, they require increased public and private investments as well. Key elements of inclusive policies and partnerships are:

- Agricultural development in the hunger-affected rural areas and communities to improve productivity will remain a major part of solutions. Therefore, innovations are key to increasing productivity sustainably and ensuring food security while maintaining environmental quality and resources. The German "One World no Hunger" initiative with its innovation centers serves this purpose. It needs to be sustained for the long run, because agricultural development needs time.

- Farmers' own innovation capacities need strengthening. Bottom-up innovativeness of smallholder farmers and appreciation of their problem-solving potential is an opportunity. Vocational training can support that. Stimulation of farmers' innovative behavior by providing appropriate incentives and incorporation of local knowledge into more institutionalized research frameworks and extension services is called for. A strong focus of such actions on women farmers is fair and efficient.

- Investment in food and agricultural research and development (R&D) is an important tool for broad-based innovation, for instance, related to improved seeds. In Sub-Saharan African agriculture more investment in R&D is needed to raise production per head and total factor productivity (TFP). Although agriculture and food security have become clear priorities on the political agenda of many low-income regions, investments in R&D have not increased sufficiently. Stronger international food and agriculture science partnerships between science-rich countries and emerging economies can make important contributions.

- Digital technology is a game changer for food and nutrition security. Many of the promising opportunities of the new digital technologies are yet to materialize, especially in contexts of developing countries, but the potentials are large and need international engagement and support. It can enhance farmer productivity and market access as well as nutrition actions, even in emergency relief.

- Innovations for improved market functioning and avoidance of price shocks require information and early warning systems, as well as better preparedness with improved trade and food reserves policies.

- The environmental and climate change aspects of agricultural and land and water use change need attention for sustainable hunger reduction. An essential component of

resilient agriculture is an end of land and soil degradation. The end hunger goal is not separable from related environmental sustainability goals.

- More attention to innovative social protection and direct nutrition intervention programs is needed, including addressing the micronutrient deficiencies in rural and urban areas. A focus on young children and mothers is required in these programs. Fortification and biofortification of foods and nutrition sensitive agriculture should be scaled up for overcoming the micronutrient deficiencies soon.

- Hunger in complex emergencies needs to bring together development policy with diplomacy and security policy. Development and humanitarian actions can build on innovative emergency relief experiences. A combined short- and long-run view is needed to overcome these protracted hunger problems by peacebuilding and development. The structural and marginality-related causes of hunger caused by exclusion must be addressed by rights- based approaches, income and employment opportunities, as well as increased productivity on small farms.

- Innovation initiatives like any development investments must follow principles of good governance, achieving investment at low transaction costs, sound financial practices, and avoidance of diversions of funds. Partnership principles and strict monitoring and evaluation systems must be established which measure the progress with regard to the mutually set goals. Strong alliances among the private and public sectors and nongovernmental organizations are needed to end hunger and undernutrition.

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