Proceedings of the Nutrition Society (2012), **71**, 222–228 doi:10.1017/S0029665112000213
 First published online 16 March 2012

The Summer Meeting of the Nutrition Society was held at the University of Reading on 4–6 July 2011

70th Anniversary Conference on 'From plough through practice to policy'

Symposium 1: Food chain and health
Linking agriculture and health in low- and middle-income countries: an interdisciplinary research agenda

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Recent global fluctuations in food prices and continuing environmental degradation highlight the future challenge of feeding a growing world population. However, current dialogues rarely address the relationship between agricultural changes and health. This relationship is traditionally associated with the role of food in nutrition and with food safety, and while these are key interactions, we show in this paper that the relationship is far more complex and interesting. Besides the direct effects of agriculture on population nutrition, agriculture also influences health through its impact on household incomes, economies and the environment. These effects are felt particularly in low- and middle-income countries, where dramatic changes are affecting the agriculture–health relationship, in particular the growth of nutrition-related chronic disease and the associated double burden of under- and over-nutrition. Greater understanding of the negative effects of agriculture on health is also needed. While lengthening food value chains make the chain of influence between agricultural policy, food consumption, nutrition and health more complex, there remain opportunities to improve health by changing agricultural systems. The first challenge in doing this, we suggest, is to improve our capacity to measure the impact of agricultural interventions on health outcomes, and vice versa.

Agriculture: Health: Research

There are growing concerns over the ability of current food production systems to keep pace with population growth and expected changes in patterns of food consumption. These concerns are particularly pressing given global competition for land, water and energy, and the multiple effects of climate change on these resources[(1)]. In 2011, the Foresight report on the Future of Food and Farming identified five primary challenges for the global food system[(2)]. First, to balance future demand with supply and to do this in a sustainable manner while ensuring that food remains affordable. Second, to ensure that the global supply of food is stable and thereby protect vulnerable populations from food price volatility. Third, to ensure global food security for all and end hunger. Fourth, to situate the food system as an active partner in a low emission world. Fifth, to maintain biodiversity and ecosystems while meeting the challenge of feeding the world. Much recent international attention on food security such as the Foresight report, has tended to focus on agricultural interventions, but the food system involves much more than just primary production, including complex input industries and even more multi-faceted transport, processing and marketing systems.

Abbreviation: LMIC, low- and middle-income countries.

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The food system as a whole has important consequences for population health, particularly with respect to ensuring the security of supply, nutritional quality and safety of the foods which we consume. But many of the impacts of food systems on health are only recently beginning to be understood. If we are to avoid further setbacks and achieve the ambitious foresight goals of feeding a growing world population healthily and sustainably, we require integrated research, policy and advocacy across the agriculture and health sectors. We discuss the nature of the interaction between agriculture food and health, highlighting areas that require integrated thinking and innovative research, and comment on current research efforts and future opportunities.

Linking agriculture with health

Agriculture is primarily considered an activity to produce food for human consumption, by which it makes a clear contribution to nutrition and health. Other crops such as cotton, silk, wool, rubber, oil and narcotics, and their contingent health impacts are frequently overlooked. However, whatever the crop, agriculture is critically important as a source of employment and income particularly in low-income countries, where agriculture engages 65% of the total work force, provides livelihoods for 85% of the rural population and contributes up to 30% of gross domestic product[3]. This link between agriculture and household livelihoods and national economic growth demonstrates the importance of agriculture for health.

The pathways of action between agriculture and health operate both directly and indirectly and often act within complex chains of influence[4] (Fig. 1). Agriculture influences health directly through the quantity and the nutritional composition of the foods available for consumption in the household and in the market. This is influenced by what we grow. Choices within agriculture between the production of food and cash crops influence competition for land, water and labour resources, and influence food availability. Agricultural practices and policies can therefore have a direct health impact by influencing the price and availability of foods. Another direct effect of agriculture on health is the exposure of human subjects to food-borne diseases[5,6] and to toxicants such as herbicides and pesticides, associated with farming and food chains[7]. In the case of zoonotic diseases that emerge from livestock populations into human populations, such as avian and swine influenzas, these direct agriculture-related health impacts can be truly global in their reach.

Agriculture can also influence health indirectly via its impact on employment, income and national economic prosperity enabling individuals to have healthier lives either through personal decisions on budgetary expenditure on public goods such as health or through national-level structural improvements in the provision and quality of health services. Indirect negative externalities for health are also possible through the effects of agriculture on the environment and ecosystem services through changes in the prevalence of certain diseases, access to water, biodiversity or climate change.

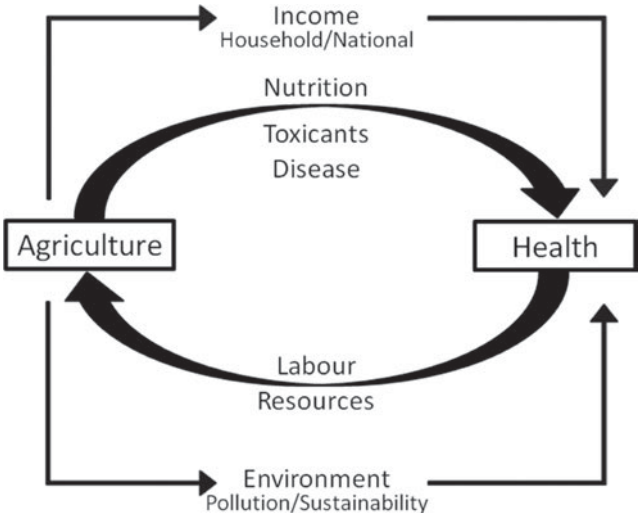

Fig. 1. Framework linking agriculture and health.

There are also important feed-back loops from health into agriculture, since unhealthy rural populations provide less labour and resources for agricultural production, with consequences for productivity and implications for all consumers. Acute ill health at critical times in the agricultural cycle can have dramatic impacts on households, and chronic illnesses such as HIV AIDS can have similar negative impacts on some farming communities[8,9].

With ever greater rural to urban migration, the chains of influence between agriculture and health operate increasingly within global food systems, in which agricultural production is a component of a much bigger system that involves food being processed, stored, transported and marketed by third parties before it is consumed. The health effects generated in these food systems extend well beyond the health effects of food production itself, and the increasingly global nature of food systems means that local health effects may have geographically distant agricultural causes, indicating the need for careful global monitoring of food production and preparation.

Agriculture, health and development

As low- and middle-income countries (LMIC) are particularly challenged in terms of both food security and health provision, it is not surprising that understanding the interactions between agriculture and health has particular significance for international development. Many LMIC have economies strongly dependent on agriculture and hence, both direct and indirect effects may apply to their large rural populations.

Reducing under-nutrition

As a development issue, agricultural investment has been particularly linked to raising household incomes and reducing hunger. Indeed, it was concern about prospects of repeated famines in poorer countries that led the Rockefeller Foundation, the embryonic Consultative Group on International Agricultural Research system and other

organisations in the 1960s to invest in new centres to breed high-yielding cereal varieties which led to the so-called Green Revolution in agriculture[10].

The benefits of this have been considerable. The high-yielding crop varieties of the Green Revolution, generated by the Consultative Group on International Agricultural Research on crop improvement, are estimated between 1960 and 2000 to have reduced food prices in a way that increased energy intake per capita in the developing world by 14%, reducing proportion of undernourished children by approximately 7%[11]. Outside crop production, LMIC have also benefited from advances in the genetics, feeding, management systems and processing of livestock. Transfer of these technologies has led to the wider availability of relatively inexpensive animal proteins.

Despite these advances, undernutrition persists in LMIC. Efforts to address this have focused increasingly on direct, nutrition-specific interventions such as food supplementation or fortification of staple foods with essential micronutrients[12]. These approaches can be targeted directly to reach poor communities, while changes in agriculture, operating in a commercial environment through complex food systems, may not reach the poorest. The greatest potential for specific, local effects of agriculture on nutrition lie with communities where food produced is locally consumed. Here, increased production or diversification of production to provide more nutritious foods may contribute directly to nutrition and health. Recent support for this approach has come from village level projects to improve and diversify agriculture, aimed at improving both diets and incomes[13].

More generally, agricultural biodiversity at the ecosystem, species and within-species varietal levels is an important, albeit underappreciated factor in dietary diversity and nutrition security in LMIC. Agricultural development policy has traditionally promoted particular crops such as starchy cereal staples with comparatively little attention being paid to other crops such as pulses, fruit and vegetables. While the cereal-based approach has played a critical role in fulfilling energy needs and alleviating hunger, attention is now starting to be focused on implications for dietary diversity and dietary quality. There can be large variation even in the nutrient profiles of varieties and cultivars within the same species. Conserving agricultural biodiversity at various scales, boosting investment in neglected but nutritionally important crops and wild species, and nutrient profiling (or even enhancement) as a criterion for varietal development and promotion, are all starting to be seen as important ways to enhance the role that agricultural biodiversity plays in food and nutrition security[14]. Biodiversity is also a potentially important way to help ensure food security by minimising the devastating effects of disease and pest outbreaks on crops and animals.

Enhancing the nutrient profile of existing crops through methods such as biofortification provides another route to improving the nutrition of poor populations frequently dependent on monotonous staple-food rich diets. The HarvestPlus programme, a recent initiative of the Consultative Group on International Agricultural Research, has successfully modified local cereal and root crop varieties to have high concentrations of important micronutrients such as Fe, Zn and vitamin A. The nutritional impact of biofortified crops such as orange-flesh is beginning to be evaluated[15], and the impacts on livelihoods at the household level of the sale of these enhanced varieties is also under investigation[16].

Addressing overnutrition

Burdened already by undernutrition, LMIC today also face a growing problem of 'overnutrition'. Diets rich in energy and low in micronutrients are contributing, along with reduced activity associated with a shift to urban living, to problems of obesity and associated diseases[17]. Paradoxically, agricultural development has contributed to this by increasing production and reducing the price of energy sources such as cereals and vegetable fats[18], which comprise a high proportion of the diets of the poor.

This emergence of a 'double burden' of both undernutrition and overnutrition in many LMIC has now sparked considerable interest in the widening role of agriculture in development[19]. The dialogue on agriculture and health is shifting today from one related to national food security and the avoidance of food shortages, to the role of agriculture in defining nutrition security, i.e. the provision of appropriate nutrients and energy to maintain population health. This potential for national and regional agricultural policy to play an increasingly important role in relation to non-communicable chronic diseases such as CVD, diabetes and cancer is becoming clear; although evidence on how this might be achieved is limited. Furthermore, the scant existing literature suggests that incentivising the production and consumption of healthy diets while likely to have positive health effects, may also have negative effects on the economic productivity of countries that will require careful evaluation[20].

Economic effects

Agriculture and agricultural development have significant roles beyond the production of food for human consumption. A well-developed agriculture sector can be the engine of overall national economic growth by generating substantial demand for non-farm products and thereby demand from non-farm enterprises. Not surprisingly, stimulation of growth in the agriculture sector is a primary policy tool for development and poverty reduction. Compared to other forms of growth, the benefits from agricultural growth particularly target the poorest sections of society. Cross-country econometric studies have shown that agricultural growth is more important than other forms of growth for the incomes of the poorest[21,22] and that agricultural growth has a larger impact than non-agricultural growth on child undernutrition[23]. It is likely that a more developed agricultural system benefits overall development through a variety of pathways including the stimulation of greater agricultural diversity, with concomitant benefits for food and nutrition security, as well as reducing commodity prices. Improved agricultural systems also have multiple benefits for women who are often major workforce contributors. Developed agricultural systems may increase the time available for taking care of young children, the

nutritional status of women, and their power in agricultural decision making[24].

Negative effects of agriculture on health

In general, agricultural interventions appear to be health-positive. But there are certainly contexts in which they have both direct and indirect negative effects on population health, some of which are quite subtle and easily overlooked.

Toxins and diseases in the food chain

The adverse impact of agriculture on health is most clearly exemplified in the area of food-borne and zoonotic diseases. Aflatoxins (human liver carcinogens) are frequent contaminants of staple foods especially in sub-Saharan Africa and have been linked with growth retardation and immune suppression in human populations[25]. Food-borne bacteria are a significant health concern, and in the US alone it has been estimated that in the year 2000 the health-related cost of five major pathogens (including campylobacter, salmonella, *Escherichia coli* O157 and listeria) was $6·9 billion[26]. Agricultural practices such as changing the scale of crop irrigation also alter the risk for some diseases such as malaria and schistosomiasis[27,28].

Livestock production is a particular area of concern, since the provision of animal protein for a growing global human population has caused major changes in food systems around the world[29]. Apart from an increase in livestock populations and densities, the genetic diversity of animals have been substantially modified with fewer and more productive livestock breeds and lines dominating most livestock populations. While there are still domestic livestock in extensive systems, largely based on grass for ruminants and scavenge-based feed for monogastrics, there has been a dramatic increase of livestock in grain-fed, intensive systems[30,31]. Animals in such production systems are normally housed in relatively controlled environments, delivering benefits through a reduction of losses caused by contagious diseases and reducing feed costs. While these benefits can be large, the changing and intensified livestock systems, modifications in animal genetic profiles and changes in associated global trade patterns may also act to contribute to the emergence and spread of zoonotic disease[32].

From a feed perspective, the greater number and proportion of livestock dependent on feed grains has lengthened value chains and created issues in terms of processing and mixing of feeds. For example, the UK-wide BSE (bovine spongiform encephalopathy) epidemic in cattle linked to the use of prion-contaminated meat and bone meal in feed led to the banning of its use and increased the requirement for other protein sources such as soya meal. The greater demand for soya meals has increased the land area needed for livestock feeding[33], and there is evidence that if contaminated these meals are implicated in the global spread of pathogens such as salmonella[34].

To date, most research regarding zoonotic and food-borne disease risk has focused on specific diseases in particular environments and has been based on epidemiological research largely focused on pathogen–host relationships. It is rare that research takes into account the context in which a pathogen circulates, specifically the global livestock systems and their associated value chains. The changing demands for foods constantly modify the resource costs in producing, transporting and processing food, and dynamic approaches at the system level are therefore needed[35,36]. In order to create a food system that at best eliminates and at worst minimises disease, a holistic research endeavour is required that incorporates biology, epidemiology and economics through an understanding of how human behaviour modifies the environment, host and pathogen, and the interactions between these three fundamental aspects of disease[37].

Effects on climate change

An indirect, but potentially significant impact of agriculture on health relates to the role it plays in climate change. Climate change is predicted to affect health in several ways, including increasing the frequency and severity of extreme climatic events[38]. Agriculture, in turn, is a significant contributor to climate change, and this contribution is very much influenced by the kinds of food produced. The agricultural sector is estimated to contribute 10–12% of total global anthropogenic greenhouse gas emissions[39] without taking into account the significant effect of agriculture-associated changes in land-use. The major contributor to greenhouse gas emissions in the agriculture sector is the rearing of livestock and in 2006, the UN FAO estimated that livestock-related emissions accounted for 18% of total global greenhouse gas emissions which equates to approximately 80% of emissions from agriculture[33].

While these estimates are currently being reviewed, it is clear that increasing demand for livestock products will have a tremendous impact on greenhouse gas emissions, and it has therefore been widely suggested that changes in lifestyle factors such as reduction in the demand for animal source foods would be important for global climate change mitigation efforts[40]. A recent modelling exercise identified that mitigating greenhouse gas emissions via reduction in livestock production would also contribute substantially to health by reducing CVD associated with the consumption of saturated fats from animal sources[41].

Effects on dietary quality

Finally it is clear that diets that are low in nutritional quality contribute to poor health, and are perhaps the most significant negative effect of changing agricultural and food systems. While diets are linked to the availability and price of different kinds of agricultural products, this link is not always strong; in food secure situations, our diets depend on our food culture. There is long experience with interventions in the nutrition and health sectors to improve diet quality, such as healthy eating guidelines to change population food consumption patterns. In high-income countries, there have been some successful campaigns such as the Five-A-Day and salt reduction strategies[42].

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However, achieving desired outcomes is not always straightforward and can confront problems such as replicability in different settings, strategies for scaling up and relative cost-effectiveness.

There are a range of policy measures that arguably could be applied in the upstream agricultural and food production sectors that have the capacity to contribute to population-level nutritional and health outcomes in a cost-effective manner, although this is still a largely unexplored area. Moreover, as food chains lengthen and grow more complex, information on food ingredients and their quality becomes more inaccessible, posing risks to consumers and challenges to regulators entrusted with their dietary well being.

The influence of agricultural policies, climate change and other external factors[43] on food price volatility also identifies an important area for research across agriculture and nutrition. What happens when the price of a particular food commodity rises relative to others? Of greater importance in the complex food systems; how do commodity price changes influence the content of processed foods? Are consumers willing to pay more for particular foods or will they substitute more expensive foods for cheaper foods? And importantly, what are the direct nutritional and indirect financial consequences of food substitutions? International comparison of food price elasticities (which quantify the relationship between food price and food purchase) suggest that the response to price changes is larger in lower-income countries than in higher-income countries[44]. Recent data from the US suggests that the highest elasticities (i.e. the largest effect on purchase of changing food prices) are for foods consumed away from home and for soft drinks[45]. In an era of rising and fluctuating food prices, much more evidence is needed on the food and non-food purchasing choices of populations, and the consequences these choices will have on nutrition and health especially of vulnerable sub-groups in LMIC.

Assessing the impact of agriculture on nutrition and health

The earlier sections identify many specific research opportunities for improving health through changing agricultural and food systems, including breeding more nutritious foods, diversifying local diets, changing patterns of production and reducing disease risk in food value chains. We focus this section, however, not on specific potential interventions, but on the broader research challenge of how we measure impacts of agriculture on health, as a basis for evaluating these interventions.

Understanding diets

Consensual evidence is available on the constituents of healthy diets[46], and many countries have adopted dietary recommendations to encourage healthy consumption patterns[47]. However, our ability to assess whether national agricultural and food systems are providing the correct balance of foods, or whether populations are consuming recommended dietary patterns is extremely limited[4].

The most comprehensive data on the global and national availability of foods are compiled as Food Balance Sheets by the FAO, and are widely used to inform agricultural and food policy. While extremely useful, these data have been criticised and are particularly problematic in terms of their accuracy and completeness for many LMIC[48,49]. Food Balance Sheets food availability data provide no information on the availability of foods by sex, age, socio-economic status or geographic region and importantly provide no information on actual dietary intake.

Unfortunately, we also have very little good quality nationally representative information on food consumption from dietary surveys for most LMIC. This lamentable evidence gap means that we are currently unable accurately to assess the impact of changing agricultural practices or policies on dietary intake patterns or on national health profiles and this remains a major obstacle to research and policy in many parts of the world. There are some countries that have nationally representative micro data on all aspects important for detailed cross-sectoral analysis such as socio-demographics, dietary intakes, health and nutrition outcomes, household income sources, including agriculture and expenditures. However, the information generated is typically split across data collection efforts, and such fragmentation limits possibilities for integrated cross-sectoral research.

For example, detailed information on health and nutrition outcomes for many countries is available via the Demographic and Health Surveys. Many countries also have national household budget surveys or Living Standards Measurement Surveys collected by the World Bank. Some countries have national dietary intake and nutrition surveys. However, there are almost no cases where all these aspects are available for the same households or individuals, as part of a common data collection effort. The China Health and Nutrition Survey[50] is a notable example and a good model in this regard for the research community; it is no coincidence that the available cross-sectoral research evidence base is richest for China[51,52].

The India Human Development Survey[53] launched in 2004 in India is another example of a multi-purpose data collection effort that expands cross-sectoral research possibilities. Both the China Health and Nutrition Survey and the India Human Development Survey are collaborative efforts between local public or research agencies and overseas research institutions, and involve a mix of local and international funding. Micro data availability has improved enormously in the last two decades, but is still bedevilled by fragmentation. There are other promising efforts underway towards more comprehensive and integrated data collection. For example, the Living Standards Measurement Surveys Integrated Surveys on Agriculture, funded by the Bill & Melinda Gates Foundation that builds in much more detail regarding agriculture into Living Standards Measurement Surveys surveys, but far more needs to be done.

Reconciling health and agricultural methods and metrics

A significant current constraint in interdisciplinary research encompassing agriculture and health is the lack

of experience with metrics bridging the sectors and disciplines. There are also very few examples of shared research study designs across agriculture and health[54]. A complicating factor is the fact that the evaluation of health outcomes is often associated with controlled, public sector interventions to produce measures such as Disability Adjusted Life Years and Quality Adjusted Life Years, while outcomes for the agriculture sector are generally market driven and produce outcome indicators such as consumer and producer surplus measures. Interdisciplinary researchers must urgently work to improve research methods and integrate measures of outcome to truly assess the impact of agriculture on health.

Conclusions

In this paper, we have surveyed the breadth of agriculture and health interactions. As these are so poorly understood, much of our survey has been descriptive, even anecdotal. However, what we do know highlights a need to move away from the simplistic view that increasing agricultural production improves health by providing better nutrition, to build a more useful understanding of the way in which production affects prices, income, food availability and consumption through complex food value chains. However, in order to do this, two important advances are required. First, we must improve the quality of the research undertaken in agriculture and health using quantitative and qualitative methods, and robust study designs such as randomised controlled trials and quasi-experimental studies. This will require the integration of epidemiologists and trialists into agriculture and health research groups to increase expertise in the design and interpretation of studies. Second, there is an urgent need to define better how to measure and evaluate trade-offs between agricultural change and population health in an integrated manner. The current metrics are inadequate for measuring these outcomes and trade-offs, and new metrics must be designed that integrate existing tools from the distinct disciplines. Only through the provision of robust and appropriately measured evidence will policy makers be able to prioritise the most effective way of ensuring that agricultural interventions and policies really do lead to improvements in health into the future.

Acknowledgements

The authors gratefully acknowledge a grant from The Leverhulme Trust, which supported in part the preparation of the manuscript. All authors declare no conflicts of interest. A. D. D., R. G., B. H., J. R., B. S. and J. W. defined the scope of the review, contributed to all drafts and approved the final version of the paper.

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