Received: 12 October 2015 Revised: 20 November 2015 Accepted article published: 1 December 2015 Published online in Wiley Online Library: 5 January 2016

(wileyonlinelibrary.com) DOI 10.1002/jsfa.7554

Planting seeds for the future of food

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Abstract

The health and wellbeing of future generations will depend on humankind's ability to deliver sufficient nutritious food to a world population in excess of 9 billion. Feeding this many people by 2050 will require science-based solutions that address sustainable agricultural productivity and enable healthful dietary patterns in a more globally equitable way. This topic was the focus of a multi-disciplinary international conference hosted by Nestlé in June 2015, and provides the inspiration for the present article. The conference brought together a diverse range of expertise and organisations from the developing and industrialised world, all with a common interest in safeguarding the future of food. This article provides a snapshot of three of the recurring topics that were discussed during this conference: soil health, plant science and the future of farming practice. Crop plants and their cultivation are the fundamental building blocks for a food secure world. Whether these are grown for food or feed for livestock, they are the foundation of food and nutrient security. Many of the challenges for the future of food will be faced where the crops are grown: on the farm. Farmers need to plant the right crops and create the right conditions to maximise productivity (yield) and quality (e.g. nutritional content), whilst maintaining the environment, and earning a living. New advances in science and technology can provide the tools and know-how that will, together with a more entrepreneurial approach, help farmers to meet the inexorable demand for the sustainable production of nutritious foods for future generations.

Supporting information may be found in the online version of this article.

Keywords: agriculture; soil; plant science; nutrition security; food security; sustainability

INTRODUCTION

Today, over 800 million people live in extreme poverty and experience food insecurity and under-nutrition, while a further 2 billion are overweight or obese. The world population is expected to increase to more than 9 billion by 2050, with a large proportion of this in emerging nations especially in sub-Saharan Africa and South Asia. Nutritional quality, as well as food availability, must be addressed in order to tackle malnutrition (under-nutrition and over-nutrition) and its consequences.[1]

The task of supplying food is dependent on a multitude of factors including socio-economic, ethical, political, environmental and technical challenges. Therefore, a diverse range of expertise and organisations, with a common set of goals, will be needed to address the food agenda. Already, international experts in academia, in governments and non-governmental organisations (NGOs) are together confronting many of the issues, and a wide body of opinion about how to address the challenges has been published.[2–6]

It is clear that scientific and technological advances, especially those that promote sustainable practices in agriculture, will be essential in ensuring a nutritious food supply for future generations.[7] The contribution of science and technology to the future of food in the next 50 years was addressed by an international conference on 'Planting Seeds for the Future of Food: The

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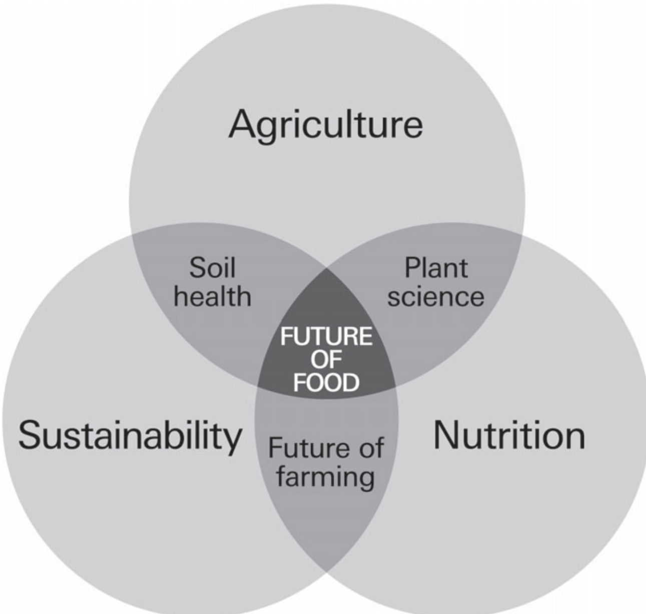

Figure 1. Key aspects of the Agriculture–Nutrition–Sustainability nexus for the future of food.

Agriculture, Nutrition and Sustainability Nexus', hosted by Nestlé in June 2015 (the programme is provided as supporting material). Among the most important observations from the conference were the crucial importance of bringing nutritional quality of the harvested products into agricultural research and food security programmes and the need to focus on areas of the world where subsistence farming is still the norm. The conference also highlighted the need to act at the nexus of Agriculture, Nutrition and Sustainability in order to properly address the multidisciplinary scientific and technical issues and the sociological dimensions involved in establishing a food-secure planet.

The conference highlighted how healthy soils, productive crops, combined with sustainable farming practices are needed to provide a solid foundation for the future of food. Therefore, this article considers the future of food, from the perspectives of soil health, plant science and the future of farming practice (Fig. 1).

This article provides some specific examples of promising avenues of research and development as well as some concrete outcomes to achieve the goals of productivity, quality and sustainability, which were described for the first time at this conference.

SOIL HEALTH

A healthy soil is a prerequisite for the sustained production of nutritious raw materials for food. Indeed, by declaring 2015 as the International Year of Soils, the UN General Assembly has drawn attention to the importance of healthy soils for food security as well as for maintaining a sustainable ecosystem.

Field trials, such as the long-running Broadbalk Winter Wheat Experiment at Rothamsted Research (UK) (www.rothamsted.ac.uk/long-term-experiments-national-capability/classical-experiments), provide a wealth of data on how soil characteristics and different types of fertilisation and crop management can optimise yield and crop resilience in changing environments. Soil as a growth medium and its chemical, physical and biological fertility are critical for better nutrient acquisition by plants.[8,9] Therefore, agronomic interventions involving mineral fertilisation and soil nutrient management can help to improve the nutrient concentration of food crops, and micronutrients in particular.

The concentrations of a number of micronutrients in the edible part of different plants can be increased by using nutrient-enriched fertilisers or foliar sprays for single nutrients. These minerals include zinc, iodine, copper, molybdenum and selenium.[10,11] Care has to be given to the concurrent levels of N and P fertilisation, as they may promote or inhibit the accumulation of micronutrients in the consumed parts of the plant.[12–15] The HarvestZinc Fertilizer Project (www.harvestzinc.org) is exploring the use of different fertiliser formulations to increase the zinc and iodine content of cereals in different parts of the world. Field trials conducted on wheat and rice have shown that foliar application results in substantial increases in the Zn content of the grains The application of micronutrients can also improve crop yield as it addresses soil deficiencies that can be detrimental to the development of the crop.[16,17]

The link between the micronutrient content of plants and human health can be illustrated well by data from Finland and Turkey. Due to low national selenium intakes, sodium selenite has been added to multi-nutrient fertilisers since 1984. This has increased the concentration of selenium in cereals, milk, beef and pork, and led to an improvement in the selenium status of the Finnish population.[18] In Turkey, the application of Zn formulations has dramatically increased to nearly 500 000 tonnes today, following a NATO-funded project demonstrating the benefits on wheat productivity and grain Zn content. This has resulted in significant productivity gains for the farmers and health benefits for local populations.[19,20] These outcomes, which show the potential of crop fortification through micronutrient applications, are motivating further studies around the world (www.fertilizer.org/AwardBorlaug).

A better understanding of the different ways by which plants acquire and accumulate nutrients would provide the scientific basis for producing nutrient-enriched plants that could benefit consumers. One promising area of research concerns symbiotic associations with fungal organisms and bacteria on the roots of crop plants. In this regard, it is increasingly recognised that the rhizosphere microbiome is an important determinant of plant health.[21] Advances in molecular biology and microbiology are increasing our knowledge of the soil microbiome,[22] and will enable us to identify soil microbial genotypes that assist in increasing crop yield as well as nutrient content. Ultimately, therefore, optimising or improving plant–microbe interactions could have major implications for both food production and food security.[23,24] Potentially, for example, soil microbes could be used as 'probiotic supplements' to improve plant nutrient uptake from the soil.[22]

Challenges in developing countries

Insufficient fertilisation can be a problem in developing countries, where poor smallholder farmers lack access to financial credit and where fertiliser distribution and cost can be beyond reach.[25] Poor soil fertility also limits the ability of plants to efficiently use water. This is compounded by loss of soil through erosion and loss of soil structure, which can be countered through better agricultural practices especially by the inclusion of more organic matter and stimulation of rhizosphere microorganisms.

On the other hand, in many developing countries, over-fertilisation causes major problems of water contamination,[26] soil acidification[27] and greenhouse gas emissions[28] as well as high costs. Furthermore, the use of the correct type and amount of fertiliser can reduce the amount of water needed per tonne of crop yield. Data from field trials in Bangladesh indicate that there is an optimum level of nitrogen fertiliser application in combination with the right irrigation regime to optimally support crop yield.[29]

One of the solutions and future challenges is to deliver the optimal level of nutrients and water when and where they are needed. Precision farming is an innovative way of optimising and targeting fertilisation and irrigation more effectively.[30] This is already being implemented on large farms in more developed economies, but it is currently too complex and costly for smallholder farmers. However, the developments in 'connected agriculture' through mobile technology already provide significant future opportunities even for smallholder farmers.

PLANT SCIENCE

Plant science offers additional tools for developing crops that are healthier, more nutritious and more productive in the field. These tools include conventional breeding as well as genome-supported biotechnological approaches, such as Marker Assisted Selection (MAS), genetic modification (GM), genome sequencing, Targeting Induced Local Lesions in Genomes (TILLING) and gene silencing by RNA interference (RNAi). It was beyond the scope of the conference, as well as this paper, to review all the new advances in plant science research.

A key enabler of conventional breeding is the understanding and exploitation of genetic diversity. Natural variation, including that in wild relatives, has been successfully used in breeding to enhance the nutritional value of crops, while maintaining or increasing their productivity.[31] Similar approaches have been targeted at important field traits: breakthrough work in rice breeding at the International Rice Research Institute (IRRI) has led to flood tolerant varieties that reduce yield variability and raises expected yield.[32] Breeding work is also on going at IRRI on resistance to drought, salinity and heat. With the increased incidence of flooding, flood tolerant traits will become relevant for more food crops. Conventional breeding techniques, have enabled major increases in productivity in all major crops[33] and have been the foundation of the green revolution.[34] However, the breeding process is complex and time-consuming as new germplasm needs to be tested for qualitative and quantitative traits in multiple environments. This process may take up to 10 years or more before varieties with the desired traits can be released.

Biotechnology has allowed major progress in plant science during the last decades. The term 'biotechnology' encompasses a wide range of disciplines that aim at accelerating and enhancing the breeding process. The use of biotechnology can increase the precision of breeding and its cost-effectiveness. In particular, biotechnology can lead to crops with nutritional qualities that could not be achieved, or not as fast, through conventional genetic or agronomic approaches.[35,36] Several biofortification projects relying on biotechnology are underway, for example to biofortify rice, maize, cassava, and wheat.[35]

Molecular approaches such as marker-assisted breeding,[37] now enhanced by whole-genome selection as well as genetic engineering,[38] allow plant breeders to more efficiently target and introduce specific genetic traits. For example, molecular genetics has been used to identify the genes that determine the content of the β-carotene, a precursor of vitamin A, in maize. Interestingly, natural variation in only two genes can increase the levels by 16-fold. Although the best alleles for these genes were not found in the same breeding pools, the application of molecular techniques enabled researchers to bring these genes together to generate maize plants that are richer in this essential micronutrient.[39]

Studies have shown that iron, zinc and vitamin A status in human populations can all be improved using biofortification strategies that involve genome-assisted conventional plant breeding.[10,40,41] Moreover, the Expert Panel at Copenhagen Consensus (2008) ranked biofortification among the top five most cost-effective investments for addressing malnutrition in developing countries.[42]

In certain cases, traits that are not accessible through conventional breeding can be introduced through genetic engineering, to influence nutritional quality of the crops and/or their field performance. Golden rice is an example of what can be achieved through the introduction of genes from wild plant species when natural diversity is not available for breeding in the crop.[43] Similarly, the genetic engineering route was chosen in the African Biofortified Sorghum project to simultaneously enhance pro-vitamin A content and other nutritional traits in this important cereal crop.[44]

The introduction of traits such as the expression of the *Bacillus thuringiensis* (Bt) insecticidal protein or herbicide tolerance has already markedly improved yields in emerging countries.[35] Such crops, commonly designated 'genetically modified' or GM, have been adopted rapidly since their commercial introduction almost 20 years ago. In 2014, GM crops were grown in 28 countries, 20 of which were emerging countries, on just over 181.5 million hectares by 18 million farmers, 90% of whom were resource-poor small-holder farmers.[45] Globally, GM crops have boosted yields by roughly 22%, decreased pesticide use by 37%, and increased farmers' yields by 68%.[46] GM crops have an impeccable safety record and multiple environmental benefits.[45,47] Despite anecdotal reports, no allergies, illnesses or deaths have been reproducibly linked to the consumption of GM food or feed.[48–50]

Nonetheless, GM approaches continue to face both political and consumer resistance[51] and can be expensive to implement. Hence most biofortification projects are built on conventional or marker-assisted breeding strategies, and not on genetic engineering.

While genome-based marker-assisted breeding continues to flourish,[52] approaches that are more targeted and less intrusive than genetic engineering, such as genome editing, may allow a more acceptable use of genome information to improve nutritional traits in the future.[53] The success of plant science-based approaches to improve the nutritional value of crops will ultimately depend on the acceptance of consumers and farmers and how this is acted on by policy makers. The benefits of the crops need to be considered from farm to end-user, in the value they add in the field, the suitability and sustainability of supply chains, as well as the cost, public health benefits and attractiveness to the consumer.[54,55]

FUTURE OF FARMING

Knowledge transfer

There is an urgent need to improve agricultural practices in order to address global challenges of reducing poverty and hunger, improving human health and rural livelihoods, as well as ensuring sustainability.[56] The use of science and technology to improve farming practices hinges on knowledge transfer and exchange with the farmer. This is not a new challenge. For example, it was

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addressed 25 years ago by the Farmer First[57] initiative, which was based on the principle that farmer participation, and not just top-down advice, is more effective in helping farmers to gain access to advances in science and technology. Although Farmer First focused on farmers in developing countries, the principles are also relevant for farmers in developed countries.

Indeed, a recent study of New Zealand pastoral farmers[58] shows that interpersonal networks play a key role in knowledge transfer. In other words, agricultural science is transferred through well-organised networks of farmers, who share their knowledge and experience with one another. The success of this approach lies partly in the fact that the farmers gain knowledge that relates to their specific needs and circumstances. This model could work well in those sub-Saharan African countries where public extension has collapsed.

Agribusiness

Agribusinesses, from local to global enterprises, play significant roles in the agriculture and food system – from delivering seeds to farmers to the enterprises that bring food to the market.[59] As the average age of farmers is increasing globally, a new generation of farmers and agribusinesses is needed for the future. This is particularly critical in many developing countries where there are significant levels of migration of young people from rural to urban areas. Even where they stay in rural areas young people often do not have interest in agriculture as it is practised today.

The Youth Agripreneurs programme of the International Institute for Tropical Agriculture (IITA) in Nigeria addresses this issue in a very innovative way by providing support and training for young graduates. The work of the IITA illustrates that focusing on agricultural concepts as core business plans, and involving the young people themselves, can be a successful strategy to mobilise the young workforce, increase incomes, and meet the food requirements of the local population. The Youth Agripreneurs programme aims to educate young graduates with a range of backgrounds, and attract them to agriculture as a business opportunity. Beginning with intensive training in agricultural techniques and business, the IITA facilitates partnerships between students and other parties including the private sector, local government and international organisations. The results from this programme have a positive domino effect. The core businesses created by the students not only provide a long-term source of income, but also the agricultural activities they are implementing are an important step forward in raising food and nutrition for the local population. Promising results have been achieved in a short period of time. One example of this is the Aflasafe Project (www.aflasafe.com), which is developing and commercialising a biological control technology for aflatoxin (a dangerous mycotoxin in corn and oilseeds stored in sub-tropical environments).

THE NEXUS OF AGRICULTURE, NUTRITION AND SUSTAINABILITY

An overarching challenge across these three perspectives is how to bring new science and technologies to farmers and enable them to adopt good agricultural practices and seeds to produce high yielding, high quality plants, now and in the future. To resolve this, an integrated approach is necessary at the nexus of Agriculture, Nutrition and Sustainability.

With the global challenge of addressing health and well-being, the issue of food has to be viewed through a nutritional lens as well as through the lens of yield at the farm gate, while at the same time respecting natural resources. Although there is a wealth of scientific data linking food and health, we must take a step back to the source: plants. We will need to employ a variety of strategies in order to improve the nutritional quality of the foods that we eat, and this includes breakthrough science and technologies to improve the health of soils and plants.

From the perspective that plants are at the centre of agriculture, food and health, the farmer will remain pivotal to sustaining a healthy population. Farmers, particularly small-holders in the developing world, represent a large reservoir of producers who hold the unique position as custodians of the world's land and natural resources.

Moreover, tackling food, nutrition and health, while also facing the combined challenge of climate change and the global population explosion, will require innovative and sustainable agricultural practices. Feeding in excess of 9 billion people in the future will require more than another green revolution; it will require a metamorphosis of classical agriculture into a system that integrates a range of scientific tools with sustainable agricultural practices to provide the optimal nutrition to foster human and environmental health now and in the future.

Marshalling the vast resources of the local and international private sectors will be critical but it is neither a panacea nor automatic, and will only work in tandem with increased investment and actions by governments themselves. Furthermore, to be successful in addressing the challenges laid out in the Future of Food (and in a post-2015 world), all investments must be inclusive. Here the quality of inclusion matters and putting *people* at the centre of development is essential.

ACKNOWLEDGEMENTS

This article draws on the presentations and discussions during a multi-disciplinary international conference on 'The Agriculture, Nutrition and Sustainability' nexus, hosted by Nestlé in June 2015. The conference was attended by 165 experts from the public and private sector. The agenda of this conference, which includes the names and affiliations of speakers, is provided as supporting material.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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