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The intersection of climate/environment, food, nutrition and health: crisis and opportunity

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Climate/environmental change (C-E-C) is affecting human health and quality of life. Significant attention has been given to the impact of C-E-C on food supply, and food as a vehicle for exposure. However, C-E-C has been superimposed on prevalent malnutrition, infectious and non-communicable diseases. We discuss why nutrition is not synonymous with food and must be viewed as a biological variable that affects and is affected by both C-E-C as well as the current global health challenges. The nexus of C-E-C, food, nutrition and health must be considered in the development of safe and efficacious interventions. A case is presented for how the convergence of C-E-C, food/nutrition and health, presents an opportunity for more integrated approaches to achieve global health goals.

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Introduction

This paper presents two converging trends that are having a significant impact on current and future responses to the global health enterprise. The trends are:

1) The growing evidence of the impact of climate/environmental change (C-E-C) on various aspects of global health; and
2) The recognition of the importance of food for delivery of essential nutrients, and nutrition as a biological variable integral to health promotion and disease prevention.

The opportunity that this convergence presents is to bring divergent communities of expertise together to develop an integrated approach to reverse the trends that are threatening Earth's ability to sustain a growing population, while avoiding, to the extent possible, unintended negative consequences. The goal will be to ensure that efforts to address factors contributing to C-E-C, and that affect our ability to care for and feed a hungry world, include consideration of the complexity, and importance of viewing nutritional status as both an input and an outcome. At the same time, those in the food and nutrition community seeking to address the impact of food insecurity and malnutrition on health need to recognize that the options for safe and efficacious interventions must be considered in the context of C-E-C. For disciplines represented by both trends, the key is to acknowledge that context matters and that adaptation to change is essential and inevitable. The effects of C-E-C and this changing context will continue to be greatest among populations that are already subject to food/nutrition insecurity, pandemic infection and expanding risk of non-communicable diseases (NCDs). These populations include women, young children, the elderly, and those with existing health problems (malnutrition, food insecurity, infectious or NCD) within poor, displaced (political refugees and those displaced by severe climate/weather events), and marginalized communities in particular [1–3].

Core concepts

Paramount among the effects of C-E-C on human health and quality of life is the impact on food systems and production. To date, efforts to address these effects have focused on food production, access and availability, food as a delivery system for nutrients, and food as a vehicle for exposure to pathogens and toxins. Although discussions on the supply side are critical, developing effective responses to global health issues will necessitate inclusion of nutritional status as both a biological input and output of disease/environmental stress.

Nutrition as a biological variable

Nutrition is more than the amount and quality of food consumed. The nutritional status of a person or population is achieved through a series of processes, including ingestion, digestion, absorption, transport, metabolism and utilization. Each of these processes no only affects, but is also affected by nutritional status in health and disease.

Nutritional status is assessed by measuring sensitive and specific nutrient biomarkers that are interpreted relative to accepted standards reflecting states of adequacy/deficiency. Nutritional assessment also involves evaluating the functional impact on biological systems [4•]. With regard to the question of function, it is useful to apply a term borrowed from environmental science, 'bio-indicators', i.e., sentinel signals of perturbations within a system [5•]. When used with sensitive and specific biomarkers of nutritional status, such bio-indicators (e.g., measures of neurological function, hematology, and immune function) can provide a more comprehensive understanding of diet-health interactions.

It is imperative to take an integrated approach to nutritional assessment of individuals and populations when developing and implementing interventions. With specific regard to the intersection with C-E-C, because the processes of nutrition are affected by the supply of food/nutrients, appetite, disease status, exposure to therapeutic drugs or environmental toxins, the value of including nutritional status among existing bio-indicators of the impact of C-E-C should be considered.

In application, these interrelationships have consequences. For example, while public health/population-based food/nutritional interventions are important pieces of the global health response, the need to integrate situation-dependent factors that contribute to the nutritional status of individuals and populations limits the utility of 'one-size-fits-all' approaches to public health nutrition [6••]. Numerous examples have demonstrated the weaknesses of a one-size fits all approach; none more illuminating than the conundrum associated with the assessment, treatment, and prevention of iron deficiency, particularly in settings with high prevalence of infections like malaria [7].

To set the stage for further discussion, it is useful to begin by defining terminology (Panel 1).

Panel 1. Glossary

Nutritional status

- A biological endpoint achieved by ingestion, digestion, absorption, transport, metabolism and functional utilization of macronutrients (protein, fat, carbohydrate) and micronutrients (vitamins and minerals).
- Measurement reflects where an individual/population ranks relative to established standards (i.e., adequate, marginal or deficient) [8].

Malnutrition

- *Overnutrition*: resulting in excess body weight (and overweight/obesity), or potential unsafe levels of micronutrients.
- *Undernutrition*: resulting in marginal and deficient nutrient status and/or poor growth, stunting, wasting/reduced lean body mass.
- *Dual burden of malnutrition*:
  - Populations: co-existing prevalence of overweight and underweight (macro-nutrient and micro-nutrient insufficiency).
  - Individuals: over-nutrition (calories/leading to overweight/obesity) in the context of a poor quality diet leading to concurrent marginal or deficient micronutrient status [9].

Infection

- Interaction of the actions of microbial/viral invasion and the body's inflammatory and immune defense responses.

Inflammation

- Physiological response to infections, tissue injury, psychological stress and other insults.
- Inflammation is not only associated with microbial invasion but is also a concomitant of NCDs — for example, obesity, atherosclerosis, type III hypersensitivity, trauma, and ischemia.
- Pathological situations also occur where microbial invasion does not result in classic inflammatory response — for example, parasitosis and eosinophilia.

Microbiome

- *External*: the microbiological ecosystems that are ubiquitous and essential components of the soil, water and air.
- *Human*: several microbial ecosystems on/within the body; the gut microbiome has greatest relevance to nutrition and health.

Developmental Origins of Health and Disease (DOHaD)

- Impact of conditions early in life on risk of chronic disease later in life.

Environment

- Natural environment
  - Climate and ecosystems: air, water quality, soil (composition and biodiversity)
  - Impact of industrialization: GHGE, exposure to toxins
  - Food systems: indigenous foods, GMF, monocultures, fisheries
- Community
  - Social/cultural factors that influence healthcare delivery/practices
- Home
  - Gender issues — women's empowerment; intra-household nutrition/food insecurity
  - Role of family in development of healthy behaviors
- Economic Development Context (health disparity)
  - Food insecurity and mitigating factors (e.g., climatic disaster, floods, severe drought, or conditions such as HIV/AIDS)
- Biological: prenatal/postnatal
  - Microbiome
  - Xenobiotics including recreational, therapeutic drugs, environmental toxins (natural, or man-made)

The C-E-C context

Climate, the long-term weather patterns of a region (including temperature, precipitation, and wind), is interwoven with Earth's ecological and biophysical systems (atmosphere, water supply: glaciers, oceans, rivers, lakes, and land: arable agricultural land, forests, and wetlands). The Earth's climate has varied over time; however, evidence shows that these patterns of change have become increasingly more varied in recent history. Efforts to support growing populations, including increasing the amount of land under cultivation and reliance on fossil fuels, have increased greenhouse gas emissions (GHGEs)

[1]. Some of these changes (and their relevance to food production and availability) are highlighted in Box 1.

Global health context

Despite significant progress in the last twenty years [17], the global health situation remains an often intractable and expanding challenge, influenced by prevalent and increasing food and water insecurity, and poor sanitation. These factors contribute to malnutrition, pandemic infection and expanding prevalence of non-communicable diseases (NCDs). Box 2 highlights aspects of the current situation.

Figure 1 is a characterization of the current global health context. Ultimately, attention will need to focus on the implications of these interrelationships when considering the impact of C-E-C on health, and for the development and implementation of strategies to address current and emerging health problems.

Impact of global environmental change on food production

C-E-C impacts nutrition in multiple ways; most directly on food productivity, which affects the availability and cost of food, thereby reducing both household and national food security. Figure 2 presents the interdependence of food, nutrition and health as well as the impact of C-E-C on each.

Global climate change can increase the risk of food insecurity through reductions in food availability, utilization,

Box 1 Categories of climate change and relevance to food

Increasing mean temperature
- Average land and sea temperatures are rising [10].
- Potential positive effect on crop production in mid to high latitudes.
- Likely detrimental effect in seasonally arid and tropical regions.

Extreme weather events (severe storms, hurricanes, tornadoes, tropical storms cyclone/typhoons)
- An important source of annual rainfall in semi-arid areas.
- Increase in such events will adversely affect agriculture/food production/storage, and health in resource limited settings via loss of life and livelihood, poor sanitation and impact on economic development.

Mean precipitation patterns
- Expected to change, but not predictably, with some areas gaining more and others less.
- Areas dependent on seasonal rainfall, and those highly dependent on rain-fed agriculture will be most affected.
- Anticipated changes could include changes in yields, growing season, arable acreage, types of food that may be grown, vulnerability to plants, animals and humans to disease (vector-borne or other).

Heavy rainfall and flooding
- Causes crop/animal loss, loss of cultivatable acreage, property damage and increased vulnerability to people living in low resource settings.

Rising GHGE/CO_2 and agriculture
- Since the advent of the industrial revolution, GHGEs have climbed causing strain on the natural environment [11].
- Carbon dioxide (CO_2) levels have risen significantly over the last 10 years (from ~380 ppm to ~403 ppm) [12,13].
- The rise in GHGE has led to a range of interrelated changes in the Earth's climate and impacted food systems [14].
  - Experimental evidence indicates that nutrient composition of food crops is negatively impacted by increasing CO_2 concentrations [15••].
  - The impact of increasing CO_2 on other aspects of plant health (e.g., the soil microbiome) particularly as that might impact on plant health and nutritional quality has not been established.

Heat waves
- Extreme temperature events are projected to be hotter. Events that are considered extreme today will be more common in the future and will negatively impact agricultural production particularly if they occur during key stages of crop development.

Drought
- Associated with decreased food production (crops and animal production), water (amount and quality) and increased food insecurity.
- Increasing in intensity, frequency and duration.
- The majority of people suffering from hunger already live in semi-arid and arid zones that are most susceptible to drought [16].

Melting glaciers, arctic sea ice, reduced snow cover/melt
- Historically melting glaciers are associated with increases in water flow in river systems and enhanced seasonal water availability; however the precipitous loss of glaciers due to rising temperature now occurring will significantly impact on this pattern and increase dependence on what is becoming a variable pattern of snow/rainfall.

Sea-level, acidification and temperature changes
- Poses a significant threat to coastal communities via losses of property, agricultural lands and ground water (due to salt contamination).
- Rising sea-level will also increase the damage caused by storm surges.
- Changes in acidity and temperature will significantly impact fisheries, a major source of food globally.

Box 2 The global health context

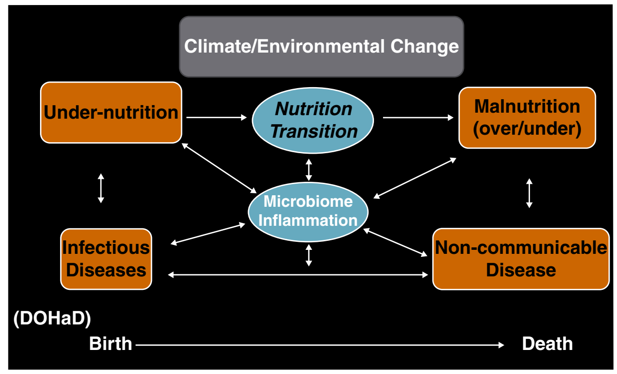
Malnutrition, NCDs and the 'Dual Burden' (overnutrition and undernutrition) [18]

- Childhood underweight remains the 8th highest contributor to overall global disease burden despite significant improvements.
- Among children <5 years, childhood underweight was the leading risk factor worldwide in 2010.
- In most of sub-Saharan Africa (except southern Africa), the share of disease burden attributable to these 3 risk factors has fallen substantially; yet, they remain the leading causes <5 years disease burden.
- High body-mass index (BMI) has increased in the US and globally to become the 6th risk worldwide.
- 2 of 3 overweight/obese people live in developing countries, the vast majority in emerging markets and transition economies.
- The importance of a definition of diet quality within the context of food security has been highlighted by the emphasis on the global risk attributable to poor dietary quality, including excess dietary sodium and insufficient intake of fruit, nuts/seeds, whole grains, vegetables and seafood.
- Diet-related chronic diseases account for more than half of the world's diseases and hundreds of millions of dollars in public expenditure.

Infectious diseases (from WHO except where noted)

- *HIV and AIDS*
  - Despite major improvements in survival and prevention (particularly maternal to child transmission) continues to be a significant problem with >34 M people now living with HIV/AIDS; 3.4 M under the age of 15.
  - In 2010, 1.8 M people died from AIDS; 250 000 of them were <15 years.
  - New infections continue to rise (in 2010 — 2.7 M newly infected; 390 000 <15 years).
  - Number of HIV diagnoses in the US: 47 989 (2012), with 6955 deaths.
- *Malaria*
  - In 2010, 219 M cases of malaria with ~80% of cases limited to 17 countries most prominently in Africa.
  - ~660 000 deaths, mostly among African children.
- *TB*
  - While TB death rates dropped 41% from the 1990 level, in 2011 there were still ~8.7 M new cases and 1.4 M deaths and increasing antimicrobial resistance.
  - 95% of TB deaths occur in low-income and middle-income countries, and it is among the top three causes of death for women 15–44 years.
  - New cases in the US: 9945 (2012).
- *Diarrheal disease*
  - Kills 2195 children each day — more than AIDS, malaria, and measles combined.
  - Diarrheal diseases account for 1 in 9 child deaths worldwide, making diarrhea the second leading cause of death among children <5 years [19].

Figure 1



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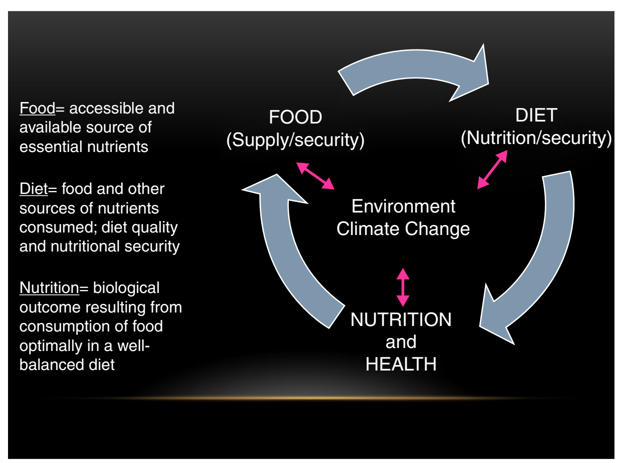
Arrows depict the bi-directional nature of the relationships within the nutrition-disease cycle, i.e. nutrition affects the susceptibility to (and outcomes of) disease; and disease affects nutritional status and related function (e.g. immunity, neurological function). These interconnecting relationships therefore create a vicious cycle of malnutrition, disease and poor health. This figure also highlights the emerging understanding that health risks have both short-term and long-term implications throughout the life cycle; and acknowledges a growing appreciation of the importance of both inflammation and the microbiome as mediators of the response to human health and disease factors.
Adapted from [6••].

Figure 2



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The intersection of diet, food production, health and the environment/climate. The impact of putative food, nutrition and health outcomes on the environment and climate are manifested by the direct impact of attempts to enhance and repair food systems, and the indirect effect of diminished work capacity of malnourished/sick and displaced populations; necessitating further efforts to increase production with concomitant pressure on the environment via increased use of fertilizer/pesticides, which increases GHGE and the accompanying 'carbon-footprint'.

Box 3 The interface of biodiversity and health

Macro-ecology

- The loss of biodiversity limits the production, pollination, and pest control integral to health food systems [23•].
- The loss of diversity of both animal and plant food sources is linked to human health by changes in dietary intake and quality.
- Reductions at a macro-level due to:
  - Degradation of natural habitats,
  - Overexploitation of biological resources,
  - Pollution,
  - Introduction of invasive species, and
  - The acidification of oceans.

Micro-ecology

- Soil biodiversity is a critical component of food system health and productivity.
- Biological diversity is also involved in the regulation of infectious diseases, for example through the transfer of pathogens from animals to humans.
- A reduction in the diversity of animal or human gut microbiome can cause immune dysfunction and increase susceptibility to both infection and in humans NCDs [23•].
- Shifts in the gut microbiome may be due to:
  - Shifting dietary patterns due to changes in ration, dietary quality or nutrition transitions [24].
  - Increased exposure to antibiotics either directly via medical treatment or indirectly via use in animal production practices.
  - Reduced food and water safety (e.g. increasing the risk of diarrheal disease and intestinal inflammation).
  - Interactions between microbial diversity, health and nutritional status [25••]. For example, the provision of supplemental iron to young children through point-of-use fortification with micronutrient powders has been observed to adversely affect the gut microbiome, leading to increased pathogen abundance and intestinal inflammation [26].

and food system stability [20]. For example,

↑ extreme weather pattern/events ↓ crop yields + increased demand ↑ pressures on food prices

This scenario further exacerbates the risk of food insecurity and malnutrition, particularly in developing regions such as sub-Saharan Africa and south Asia [21•].

Paradoxically, as economic development expands, markets change from traditional food/diets toward commercially produced food. This 'nutrition transition' puts additional stress on public health through rising rates of obesity and related NCDs [22]. This latter trend will also be driven by diminished availability of staple crops due to climate change, thereby pushing consumers more toward processed commercial foods and away from fresh produce.

Biological diversity

The variety of life within an ecosystem (biodiversity) is influenced by factors related to C-E-C, such as the loss, degradation, and fragmentation of natural habitats, overexploitation of biological resources (e.g. overfishing), build-up of environmental pollutants such as nitrogen and phosphorus, introduction of invasive alien species, and acidification of oceans [23•]. Some of the impacts of biodiversity loss at a macro-ecosystems and micro-ecosystems level are highlighted in Box 3.

Fisheries

In the aquatic biome, over-fishing, ocean warming and acidification, and marine habitat degradation have led to a disruption in fish supplies through large-scale distribution shifts and loss of species diversity [27•]. Fish is a critical source of protein and income for over 2.9 billion people worldwide [28], and thus a reduction in fish stocks increases the risk of food insecurity, malnutrition and poverty. Paradoxically, due to biomagnification of toxins (e.g., mercury), fish can also be a bio-indicator of environmental degradation as well as a source of dietary toxin exposure. Depleted fish populations also exacerbates terrestrial biodiversity loss, as alternative sources of protein are sought through hunting and trapping by indigenous population.

Bio-indicators reflecting impact on food systems

Of the numerous available bio-indicators that reflect perturbations in the ecological system, two serve as exemplars of the impact of C-E-C on food crop production:

- Disruptions in soil ecology
  - Soil degradation (including loss of physical, chemical and biological integrity) and erosion, due to intensive farming methods, urban development, industrialization and extreme weather [29] results in:
    - Reduced agricultural productivity,
    - Desertification from soil erosion, loss of organic matter and structure,
    - Increased risk of flooding,
    - Loss of soil microbial diversity, and
    - Reduced carbon fixing capacity.
  - Negative impact of GHGE on soil biodiversity/ microbiome, which are essential to plant health and nutritional quality [30•].
- Reduced domesticated and wild pollinator populations [31].
  - Results from increased exposures to parasites and agrochemicals, and losses in genetic diversity of food crops.
  - Insect-assisted pollination is required by at least 87 food crop species, thus the loss of pollinators directly affects agricultural productivity [32•].

Box 4 Research gaps

- Utilization of systems approaches to understand the interrelationships between climate, soil, and crop systems.
- New approaches to land use/capacity.
- Role of biotechnology including the use of genomics and other new technologies to create crops resistant to:
  - Temperature extremes
  - Pest resistance
  - Impact of GHGE
- Understand factors that impact on:
  - Soil structure
  - Soil quality (nutrient composition, transport)
  - Soil biodiversity and impact on plant health and nutritional quality of crops
- Plant Pollinators: better understanding of
  - Factors that affect plant pollinators
  - How to protect/improve pollinator health and sustainability
- 'Low-carbon diets' (reduced 'carbon footprint')
  - Nutritional quality/viability
  - Sustainability

Summary

Box 4 contains some suggested research gaps regarding C-E-C and food/crop production interactions.

Impact of C-E-C on food quality

In addition to reduced food production and increased food insecurity, C-E-C will also affect food quality and nutrition security. Increased atmospheric CO_2 has been associated with specific reductions in essential nutrients. Moreover, food quality and safety are also compromised through the adverse effects of C-E-C and unintended consequences of efforts to improve food production. Some examples of these effects are highlighted in Box 5.

Box 5 Adverse effects of C-E-C on food production

Impact of C-E-C on food quality

- Reduced levels of iron, zinc, and protein in such crops as rice and wheat.
- Lower zinc and iron content in legumes (e.g., peas and soy beans) [33].
  - Using predictive modeling, it has been estimated that by 2050, 138 M people could be at risk of zinc deficiency if CO_2 emissions continue rise at their current rate [34•].

Unintended consequences of efforts to improve food production

- Unsustainable use of fertilizers for food production has led to excess nitrogen and phosphorous in terrestrial ecosystems and wetlands.
- Increased exposure (via food, water, air, through the skin, in utero and via breastmilk) to pesticides, heavy metals, and industrial waste.
- Bioconcentration of toxins in the food chain (terrestrial and marine) [35].
- Loss of plant/animal species/biodiversity.
- Changes in land use patterns due to chemical pollution, or increased mobilization of organic pollutants [36].
- C-E-C has been linked to increased production of mycotoxin from mold/fungi and most prominently aflatoxin, a hepatotoxin associated with maize and peanuts [37].

Strategies to mitigate the impact of C-E-C on food systems

As the impact of GHGE becomes more evident, efforts to reduce the 'carbon footprint' (i.e. the amount of CO_2 and related GHGE produced as a result of fossil fuel use) of food production through dietary/lifestyle choices have gained recent interest. The success of these approaches will demand that they are: first, compatible with an expanding global food demand; and second, can result in diets of sufficient quality to meet nutritional needs [38••].

Advances in biotechnology have mitigated the impact of C-E-C on food production through the generation of new cultivars that are more resistant to warmer, wetter, or dryer environments. Despite these advances, however, several factors can overcome the adaptive advantages of these cultivars, including:

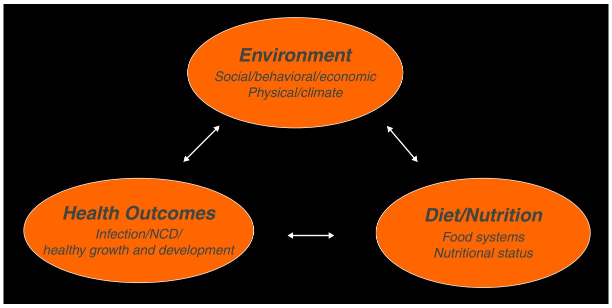
- The increased frequency of extreme weather events;
- Increasing concentrations of ground-level ozone (a plant toxin) due to methane emissions [39];
- Reduced availability of water for irrigation [40];
- Heat stress, which increases plant susceptibility to diseases caused by fungi, bacteria, viruses and molds [41].

Clearly, while the benefits provided by new biotechnology will need to continue to be exploited, there will come a point beyond which those benefits can overcome the damage of unchecked increases in GHGE.

Impact of C-E-C on disease risk

C-E-C can exacerbate the nutrition-disease cycle by increasing the risk of disease transmission and further challenging abilities to assess nutritional status under diseased conditions. For example, air pollution (particularly at the household level) can increase the risk of acute respiratory infection in children or obstructive pulmonary disease in adults [42]. Increased temperature, humidity, and rainfall variability can amplify the spread of water-borne pathogens and increase the risk of diarrheal disease [43]. Schistosoma infection risk can also increase due to the effect of river disruption (flow, water level), overfishing, eutrophication, and biodiversity loss in wetlands on the populations of common vectors such as freshwater snails. Like other parasitic infections, schistosomiasis can lead to malnutrition, stunting, and anemia,

Figure 3



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Interdependent relationships between ecological systems and human health.

which are also associated with reduced worker productivity and school performance [44••].

Ecological alterations resulting from C-E-C (including biodiversity loss) have led to increased rates of other emerging and re-emerging infectious diseases such as malaria, Hantavirus, Ebola [21•,45] and Zika virus [46]. Vector-borne diseases like malaria and Zika are especially affected by C-E-C leading to increased abundance, survival, and distribution of mosquito populations [47,48]. The potential for C-E-C to overcome recent advances in the reduction of infectious disease rates was recently demonstrated using the IPCC A1B scenario, which projected that an additional 200 M people may be at risk of malaria due to C-E-C in the year 2050 [49].

Of particular interest to this discussion is whether the prevalence of infection, NDCs, and malnutrition are in fact bio-indicators of C-E-C. In 2006, the World Health Organization estimated that 25% of the global disease burden was attributable to modifiable environmental factors (http://www.who.int/quantifying_ehimpacts/publications/preventingdisease.pdf). In a more recent report [42], environmental factors were identified as leading contributors to global disability adjusted life years (DALYs). Although 'environment' in this case can be broadly defined, the evidence clearly indicates that the intersection of C-E-C, food, nutrition and health is in need of closer scrutiny. These assessments also highlight the need to develop a deeper understanding of the complex and synergistic relationship between ecological systems and all aspects of human health [2,50•]. The interdependent nature of these interrelationships are characterized in Figure 3.

The challenges

We have highlighted the importance of two converging tracks: the impact of C-E-C and the role of nutrition in all aspects of human health. The need for an integrated approach connecting these two tracks must be informed by the relevant disciplines in order to exploit the promise of advancing knowledge in biotechnology, genomics, other emerging technologies, and social-behavioral science. This interface will be essential to the development of interventions that ensure a safe, sustainable and high quality food supply needed to ensure nutritional adequacy and health. These interventions must be developed in the context of the immediate and long-term needs of the people and populations in need. Box 6 presents several scenarios that exemplify these challenges.

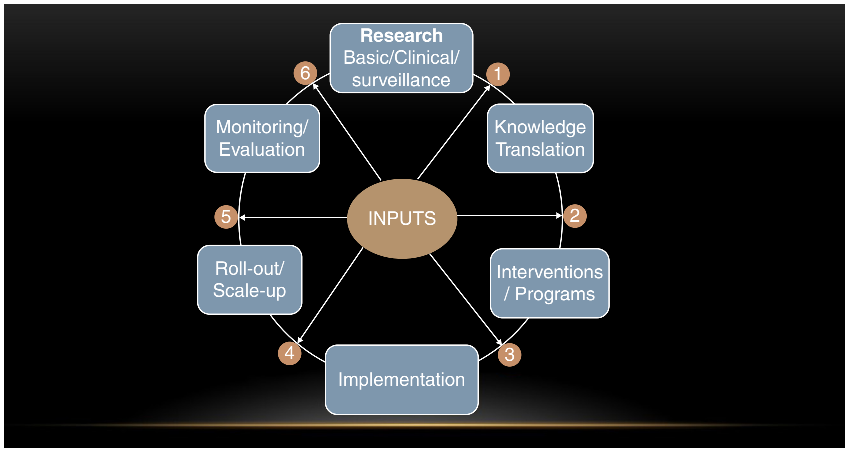
Box 6 Possible scenarios and importance of the health context

- Ameliorating food insecurity in areas where obesity/NCDs are on the rise (the role staple crops and dietary diversity).
- Addressing micronutrient malnutrition/nutritional security in areas with reduced arable land for sustainable production and in the context of the impact of $C0_2$ on plant nutrient quality.
- Safety and effectiveness of interventions in the context of infection, e.g. the iron conundrum.
- The paradox of improving economic development, the 'nutrition transition' (movement away from 'traditional diets' and increased consumption of commercially 'processed' foods) and risk of NCDs.
- Potential differences in quality of 'low carbon diets.'
- Challenges of meeting dietary guidance in the face of limited/sustainable agricultural production potential.
- Understanding and accounting for impact of social/behavioral/economic factors that affect successful implementation of interventions in individuals and at scale.
- Impact of climate change refugees on food, social, economic and health systems

Meeting these challenges will require multi-sectoral approaches (Figure 4) including:

- Basic biomedical/clinical/plant/animal science research to understand the nature and mechanism of problems related to environment/climate, disease, toxicology, and all aspect of human growth and development.
- Application of that knowledge to devise best practices in clinical assessment and surveillance to identify problems as they occur in individuals and populations.
- Development of nutrition specific and nutrition sensitive interventions (including sustainable food production practices for crops, fisheries etc.) and programs to address those problems in a sustainable (environmentally/economically), culturally and biologically relevant/efficacious manner.
- Implementation (roll-out/scale-up) involving the range of stakeholders at local/community, national (Ministries of Health/Economics and Agriculture) and global levels.
- Monitoring and evaluation of programs/policies and standards of care that allow for timely and appropriate change as needed. Data collected in these exercises

Figure 4



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1. **Basic research and knowledge translation: 'What's happening?'**

   Examples of inputs: nutrition biology/assessment/relevant bio-indicators of function/effect; Genomics/Metabolomics/exposome; Toxicology/pharmacology; Microbiome; Systems biology (human/plant/soil/food)

   Examples of collaborating disciplines:

   Nutrition science; Medicine (clinical/research); Food, animal science, agronomy, horticultural science; Plant biology, breeding; Soil science; Marine biology; Biotechnology; Microbiology; Agricultural engineering

   Physical/Environmental Sciences: Climatology; Geology/land use science; Soil science; Geo-spatial science

2. **Intervention/program development:**

   Examples of inputs: Nutritional assessment (Nutrient biomarkers; bio-indicators; Diagnostic platforms; food science including fortification options/ bioavailability; Biotechnology options; Land use patterns/trends; Food/resource assessment, feasibility/acceptability studies)

   Examples of collaborating disciplines:

   Clinical Care: Nutrition science; Medicine; Microbiology; Dietetics; Public health. Food science, biotechnology, agronomy, plant breeding, animal science, marketing, social/behavioral science, population dynamics

3. **Intervention/program efficacy and implementation:**

   Examples of inputs: Social/behavioral public health context input from the implementation chain; community/country/regional; Environmental assessment

   Examples of collaborating disciplines: *Population Based Sciences*: Epidemiology; Implementation science; Agricultural economics

   Enabling Communities: Policy makers; Public and private sector

4. and 5. Scaling up effective interventions/programs and monitoring/evaluation:

Examples of inputs: Improved surveillance; GPS/spatial technology; Global health indicators

Examples of collaborating disciplines:

Enabling Communities: Policy makers; Public and private sector engagement

Understanding the implications of change: Social/behavioral sciences; Systems science

6. **Research agenda development and progression:**

   Examples of inputs: All: data and feedback from 1–5

   Examples of collaborating disciplines: All

must be used to give feedback and thereby creating a critical interconnecting and continuous loop to enable responsiveness to changes anywhere along the chain.

As depicted in Figure 4, these steps are not unidirectional but represent the continuum of effort by the many participants in the global environment-agriculture-food-nutrition-health enterprise. In proceeding from one step to the other, each area must inform and be informed by the others. Only in this way will rolling-out, scaling-up and evaluating programs/interventions lead to the identification of knowledge gaps and research needs. Importantly, the evidence that evolves from this process reflecting what we can do now must be translated into new technologies and effective programs and policies that are accessible (in terms of cost, capacity and support for implement) in low-income settings. These evidence-informed practices must be sensitive to social, behavioral and developmental (human and economic) implications.

Responding to the direct, indirect, and bi-directional effects of C-E-C on agriculture, food, nutrition and health demands both improved resilience and efficiency in food production. The goals of improved food systems must be integrated with interventions that meet nutritional requirements through ecological approaches that harness the promise and power of technology. This calls for open communication connecting all stakeholders regarding how best to meet the needs of the global community while avoiding unintended consequences in an already complicated world. This will require an unprecedented level of interdisciplinary discourse. The challenge, in the words of that great explorer of the future, Jean-Luc Piccard, is to 'Make it so!'

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