THE DRYLANDS: GROWING FOOD WHERE WATER IS SCARCE

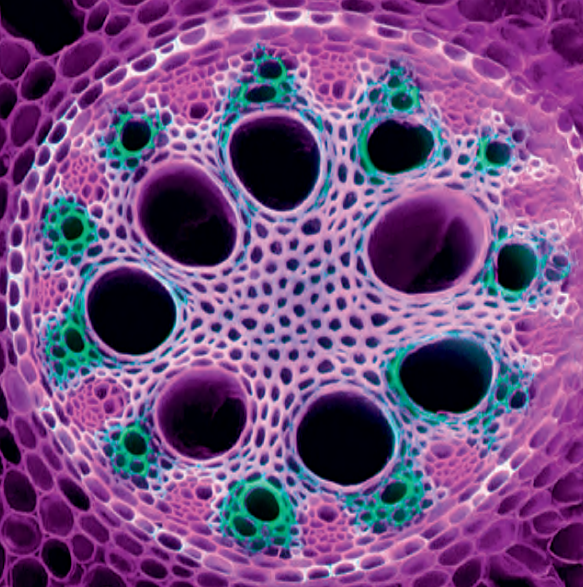
SUPER CEREALS: SEARCHING FOR NEW FORMS OF STAPLE CROPS

NOVEL PROTEIN: CAN INSECTS HELP TO EASE WORLD HUNGER?

HOW TO FEED THE WORLD

IMPACT 2022

AN FII INSTITUTE PUBLICATION



THE RIGHT TO NUTRITION

SUSTAINABLE WAYS TO END HUNGER

FII INSTITUTE
Future Investment Initiative Institute
Impact on Humanity

FOOD FACTS

GLOBAL FOOD ISSUES CHALLENGES OF CLIMATE CHANGE AND SOIL LOSS

Progress made to reduce hunger in recent decades is now going into reverse. Only a concerted effort on many fronts will restore productivity to degraded soil and produce crops that can survive in the hot, dry conditions that are becoming common.

WORLD IN CRISIS

The world is facing its greatest food security crisis since World War II. Indicators show few prospects of the achievement of UN Social Development Goal 2, ending world hunger by 2030. **More than 3 billion people cannot afford a healthy diet.** More than half the world's hungry people are found in Asia and more than one-third in Africa.

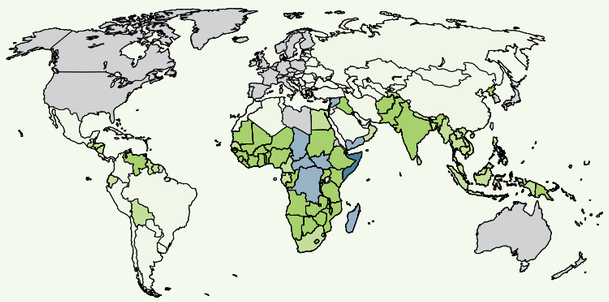
Heavy use of chemically manufactured fertilizers and pesticides pushed up crop yields from the 1960s, but this form of agriculture has led to extreme environmental damage. Now more and more chemical inputs must be applied to achieve the same yields. Mineral fertilizer use is only declining in Europe.

Experts recommend that meat consumption is reduced to make diets healthier and to promote the more efficient use of resources. But meat consumption is increasing globally, with the biggest growth taking place in the developing world.

GLOBAL HUNGER INDEX 2021

The index score is calculated from four key hunger indicators: prevalence of undernourishment; childhood wasting; childhood stunting and child mortality. It is measured on a 100-point scale, where 0 is the best score (no hunger) and 100 the worst.

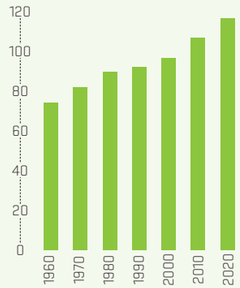
● EXTREMELY ALARMING ● ALARMING ● SERIOUS ● MODERATE ○ LOW ○ NO DATA



SOURCE: CONCERN WORLDWIDE AND WELTHUNGERHILFE

FOOD PRODUCTION PER CAPITA

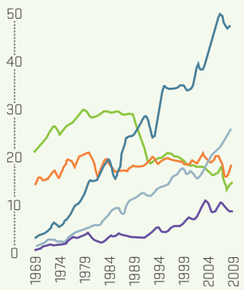
Growth in food production has been greater than population growth. Food per person increased since 1961.

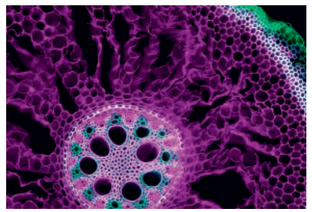


THE INPUT BOOM CONTINUES

Use of mineral fertilizer, million tonnes

● CHINA ● EUROPEAN UNION ● INDIA ● BRAZIL ● USA





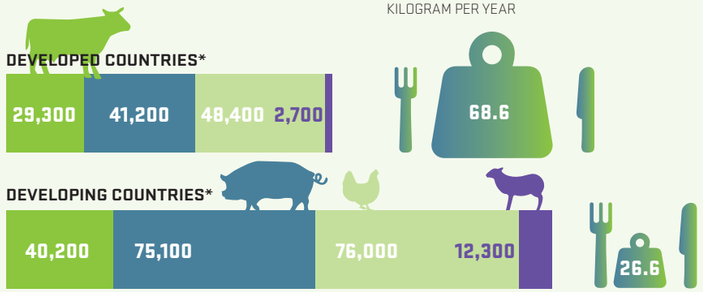
COVER:

Section through a date palm. Scientists at the King Abdullah University of Science and Technology (KAUST) are finding ways to save this iconic tree **(see page 30)**

DEVELOPED WORLD CONSUMES THE MOST MEAT PER CAPITA

Meat consumption in developed and developing countries, by meat type, annual average 2017-19 in 1,000 tonnes.

● BEEF AND VEAL ● PORK ● POULTRY ● SHEEP ● PER CAPITA CONSUMPTION (RETAIL WEIGHT) KILOGRAM PER YEAR



*ACCORDING TO CURRENT FAO CATEGORIES, DEVELOPED: CANADA, USA, EUROPE, CIS, JAPAN, ISRAEL, SOUTH AFRICA, AUSTRALIA, NEW ZEALAND; DEVELOPING: ALL OTHERS

SOURCE: MEATATLAS 2021 / OECD, FAO;

EDITORIAL

FOOD SOLUTIONS MUST BE SUSTAINABLE

ACCORDING TO THE United Nations, food security exists when all people, at all times, have the "physical and economic access to sufficient, safe, nutritious food for a healthy and active life."

Today, it is estimated that at least one in ten of the global population of 8 billion faces daily hunger and that 3 billion are malnourished. Nearly half of all deaths of children under five derive from this cause.

Here, we analyze the scale of the problem, define the right to food, show good practice from around the world and, not least, present a ten-point plan – a menu of practical and, we believe, achievable solutions.

Some solutions, as we show here, are "natural," such as regenerative farming and rediscovering traditional plant species. Some are at the cutting edge of science, such as gene editing and growing meat from animal cells. Others are social and economic.

We believe that having access to enough food to live and raise children healthily is the most basic human right. At the FII Institute we are taking the challenge of food insecurity very seriously and will be prioritizing it under our Sustainability Pillar. With your help, we will take every opportunity tackle this global problem.

COVER: KAUST/CENTER FOR DESERT AGRICULTURE ILLUSTRATION: ANJA JAGER / SOOTHING SHADE

Richard Attias

Richard Attias
CEO, FII Institute

CONTACT US:
info@fii-institute.org
@fiiksa FII Institute
Future Investment Initiative

FII INSTITUTE Future Investment Initiative Institute | Impact on Humanity

TABLE OF CONTENTS

A WHEAT DESERT

The green revolution from the 1950s depended on a dwarf wheat variety and the heavy use of chemical fertilizers and pesticides. Yields were increased. But it has transformed vast areas of land into monocultural deserts and harmed the biodiversity and soil health of the planet on a huge scale.

Breadbasket

This intensively farmed "super field" in Palouse, Washington state, is located in one of the world's most important wheat belts. The primary wheat-exporting countries are Russia, Canada, the United States, France and Ukraine.

PHOTO: GETTY IMAGES/STONE/ART WOLFE

Potato parade

Scientists are rediscovering thousand of varieties of traditional and wild foods.

PHOTO
INTERNATIONAL POTATO CENTER, PERU

PHOTO: INTERNATIONAL POTATO CENTER, NORMAN KURING/COURTESY OF NASA

Dying oceans

Fertilizer run-off causes rivers, lakes and seas to become over-oxygenated dead zones.

PHOTO
THE ARABIAN SEA

Tropical treat

The wild banana is found in tropical rainforest regions of Mexico. Wild species will need to be protected and preserved to ensure disease resistance.

PHOTO

LAS CANADAS, MEXICO

PHOTOS: COOPERATIVA LAS CAÑADAS; GETTY IMAGES/PHOTODISC/GAVRIEL JECAN

A new food

Insects are easy to produce at scale and are a great, underused source of protein, minerals and vitamins for a hungry world.

PHOTO

GRASSHOPPERS ON SALE IN LUANG PRABANG, LAOS

A boy and his mother in a street market in Ganta, Liberia

PHOTO: GETTY IMAGES/UNIVERSAL IMAGES GROUP/VWPICS/EDWIN REMSBERG

CHRONOLOGY OF **FOOD RIGHTS**

- 1945 — **UN Food and Agricultural Office** (FAO) founded
- 1948 — **Universal Declaration of Human Rights (UDHR)** outlines 30 rights and freedoms
- 1949 — **Council of Europe** begins
- 1961 — **World Food Programme**
- 1966 — **UN International Covenant on Economic, Social and Cultural Rights (ICESCR)** reiterates the UDHR and recognises the right to be free from hunger.
- 1974 — UN World Food Conference adopts **Universal Declaration on the Eradication of Hunger and Malnutrition**
- 1990 — **Article 27 of the UN Convention on the Rights of the Child** (CRC) recognizes the rights of children to a "standard of living adequate for their physical development"
- 1992 — First **WHO FAO International Conference on Nutrition (ICN)**
- 1996 — **UN World Food Summit**
- 2000 — UN establishes **post of special rapporteur on the right to food**
- 2002 — **UN World Food Summit**
- 2004 — UN Right to Food guidelines
- 2009 — **UN World Summit on Food Security**
- 2012 — UN WHO Resolution **65.6 set six global nutrition targets**.
- 2014 — Second International Conference on Nutrition (ICN2). **Rome Declaration on Nutrition** commits countries to eradicate hunger and to prevent all forms of malnutrition worldwide
- 2015 — UN Sustainable Development Goals. The 17 goals include SDG 2 – **Zero Hunger by 2030**
- 2016 — UN proclaims 2016 to 2025 as the UN Decade of Action on Nutrition
- 2021 — **UN World Food Summit**

THE RIGHT TO FOOD
REAL WORLD LIMITS OF LEGAL ENTITLEMENT

Despite 50 years of world conferences, declarations, and targets, hunger and malnutrition remain the world's greatest health risk. Can food security be established as a human right?

THE BAR FOR A WELL-FED WORLD has been set very low and a shocking number of people fall beneath it. A healthy diet actually costs more than $1.90 a day, the international poverty threshold. It is possible to achieve an energy-sufficient diet on less than $1 a day but this means merely subsisting on maize, bread, or rice, when these are available, and lacking the vitamins and minerals that are needed for health – in other words, being malnourished. Today, this is the fate of 3 billion of the world's population.

According to the UN Food and Agriculture Organization (FAO), one-third of the world's food is wasted. Although in some parts of the world soil degradation, ecological disasters, or political crises can threaten food security, progress in other places and new agrotechnological solutions pave the way to a world with enough food for everyone. Economically and logistically, humanity could move food to where it is most needed (if wars could be stopped).

Every child who dies of hunger does so unnecessarily and is, effectively, murdered, wrote Jean Ziegler in his book "Betting on Famine" in 2011. It was true when Ziegler served as UN special rapporteur for food security from 2000 to 2008, and it is true today.

The existence of food insecurity for billions of the world's population is a blatant failure of mankind. Food security for everyone should be one of the most pressing concerns of humanity.

The aftermath of World War II began with a mood of optimism. In 1948, the United Nations' Universal Declaration of Human Rights (UDHR) only lacked a specific a right not to be hungry because it was felt to be implied by Article 25, to an "adequate standard of living." The UN was the successor body to the League of Nations, which had been set up after World War I with similar ambitions to create a better world.

GRASS ROOTS SOVEREIGNTY

A radical group called La Via Campesina came to prominence during the World Food Summit in 1996. La Vía Campesina ("the peasants' way") began in Belgium in 1993. Formed by 182 organizations from 81 countries, it described itself as "an international movement which coordinates small and middle-scale producers, agricultural workers, rural women, and indigenous communities." It argues that neoliberal policies have strengthened the industrialization of agriculture. It favors family farm-based sustainable agriculture, and calls for recognition of the rights of peasants.

Poor children at a landfill site on the outskirts of Delhi, India

PHOTO: SHUTTERSTOCK/CLICKSABHI

It was not until 1966 that Article 11 of the UN's International Covenant on Economic, Social and Cultural Rights (ICESCR) recognized the right of everyone in the world to an adequate standard of living, including adequate food, clothing, and housing.

Since then, the ICESCR has been ratified by 169 countries. The right to food was reaffirmed in the Rome Declaration on World Food Security in 1996. The declaration states that everyone has "the right of access to safe and nutritious food, consistent with the right to adequate food and the fundamental right of everyone to be free from hunger."

Article 27 of the Convention on the Rights of the Child (CRC) also contains a right for children to receive adequate nutrition.

The UN, whose 193 full members cover the entire planet, has moral and legal authority. Its treaties, conventions and protocols constitute a body of international human rights law. The UN's Vienna Declaration, adopted by all UN states in 1993, asserts that "all human rights are universal, indivisible and interdependent and interrelated, and they must be treated globally with the same emphasis."

INCORPORATION OF FOOD RIGHTS

In reality, access to universally enforceable international human rights is problematic. Quasi-judicial bodies exist under some UN treaties, but there is no international court to administer international human rights law.

For the ICESCR to have some teeth, countries must also have ratified the convention's Optional Protocol – 160 countries have done so. But this merely allows citizens to present complaints to the UN's Committee on Economic, Social and Cultural Rights – not a court, but a body of experts that "seeks to develop a constructive dialogue with state parties."

The strongest legal right to food that is currently available is incorporating ICESCR principles into a country's legal codes or constitutions. Some states have done this. ICESCR has become part of national legislation in 77 countries, so that its provisions can be cited in a court. In addition, 19 countries have incorporated a right to food in their constitution, of which eight are in South and Central America.

India, which is home to half of the world's hungry people, is recognized as a country with well-established legal food rights. In 2001, a petition was submitted to the Supreme Court by the People's Union for Civil Liberties in Rajasthan, following a famine. The PUCL argued that starvation had occurred despite excess grain being stored and that schemes for food distribution were not functioning.

In 2003, the court ordered grain allocation to be doubled, and that fair price or "ration" shops must provide grain to families below the poverty line at a set price. In 2001, India's Constitutional Court recognized a right to food and, in 2013, a National Food Security Act was passed. It guarantees subsidized food to 50% of the urban population and 75% of the rural population, through public distribution and ration shops.

Today, according to the Global Hunger Index, 213 million people are hungry and malnourished in India. India is placed 101st out of 116 countries in the GHI's 2021 ranking, behind Pakistan, Bangladesh and Nepal and lower than last year – giving it a "serious" status. In the Global Food Security Index (GFSI) for 2021, it is placed 71st out of 113 countries.

A NEW WAY TO END HUNGER

While the UN certainly has legitimacy as a global debating platform, it has failed to establish one of the ideals that is said to motivate it, "food security," in any meaningful sense.

As we can see from India, even an enforceable "right" not to be hungry provides no guarantee that stomachs will be filled. Jean Ziegler, who was a UN insider as its special rapporteur for food security, argues in "Betting on Famine" that the bureaucracies of the UN's FAO and the World Food Programme may in fact be complicit in perpetuating hunger, since it gives them legitimacy.

A less conspiratorial view is that, while the UN has provided famine relief and set multiple targets, it has not meaningfully addressed the causes of hunger – war, extreme weather, and poverty and inequality – or the causes of the causes of hunger. The UN's basic philosophy – international cooperation supporting a rights-based world order – is becoming less achievable in a fragmenting world.

In high-income countries, if you can't afford food or housing, a form of income support paid through taxation provides a minimum level of sustenance and shelter. The international institutions we have don't work that way. Perhaps they should, rather than simply providing disaster assistance or enforcing the rules of international trade and finance.

In November 2021, director of the World Food Programme David Beasley, talking to CNN, suggested that a small group of ultra-wealthy individuals could help solve world hunger using a fraction of their net worth. Citing extreme hunger in Afghanistan, Ethiopia and the "dry corridor" of central America, he called on the world's two richest men, Jeff Bezos and Elon Musk, to donate $6 billion to help 42 million people.

At the time, Musk's net worth was $290 billion, meaning that Beasley was asking for a donation of just 2% of his fortune. Musk tweeted in response, "If WFP can describe on this Twitter thread exactly how $6 billion will solve world hunger, I will sell Tesla stock right now and do it."

WFP did not respond and Musk hasn't donated the money – yet– but these public statements are worthy of record. Tax-saving donations from the world's wealthiest people would dwarf existing food programs. And global trade tariffs and loans could be structured to allow developing countries to retain more of their wealth. ■

CALL TO IMPACT

1 A legal "right to food" has little meaning if a country does not have the financial means or governance systems to make it a reality.

2 The best way to help poor farmers is through education, so that they can access life and work opportunities.

3 A levy on transnational corporations in the food and agrochemical industries could help to alleviate hunger.

4 Some individuals hold as much wealth as national economies. They too could have a role in funding food programs.

THE SILENT HUNGER: SEEKING SOLUTIONS

Gains made in combating food insecurity are going into reverse, and conflicts and drought bring the prospect of famine to many countries. We talked to former UN Special Rapporteur on the Right to Food Jean Ziegler.

JEAN ZIEGLER

Born in 1934 in Switzerland, Jean Ziegler was professor of sociology at the University of Geneva. He held a seat on the Swiss National Council until 1999. Ziegler was the UN's Special Rapporteur on the Right to Food from 2000 to 2008. An acknowledged expert on development issues and food security, he is the author of "Betting on Famine: Why the World Still Goes Hungry." First published in 2011, the book calls for reform of the UN's Food and Agriculture Organization and opposes the allocation of millions of hectares of land for corn, soy, wheat, and grain to be used for biofuels.

Impact: Despite the Universal Declaration of Human Rights in 1948, the Rome Declaration of 2014, and the UN's Sustainable Development Goals, the number of hungry and malnourished people in the world is increasing.

JZ: It is much worse today than when I was special rapporteur in 2000. There are two types of hunger: structural hunger and situation-specific hunger. Structural hunger is implicit in the underdevelopment of the production forces of third world countries – the hidden, silent hunger. Last year, we know that there were 890 million people who were gravely, permanently undernourished. A child dies of hunger every five seconds.

And situation-specific hunger?

This is the hunger that is connected to natural disasters such as earthquakes or political disasters such as wars. On the 24th of February, the Ukraine war began. This could still produce a terrible famine because Ukraine is the third-biggest exporter of grain in the world. The world knows that, if the ports of the Black Sea are blocked by warships, millions of tonnes of grain can't be exported. On the 23rd of March, António Guterres, Secretary-General of the UN, said that we could be facing a "tsunami of starvation."

When humans are facing a future threat, they often start to think about solutions. So let's try some. Couldn't large-scale land-use change reduce desertification in Africa, for example, and increase food security that way?

It's very difficult, because in Africa climate damage is very strong – one-third of African soil is dry and less than 24 cm of rain is falling. You cannot have agriculture without irrigation.

What about desalination projects, powered by solar energy?

Yes, it's possible but it's very hard to get money for them. You can do all of these things if you have the financial means.

Well, I don't have the financial means – and neither do you. But we as mankind, we should have them.

The UN has two organizations in this area, the Food and Agriculture Organization (FAO) and the World Food Programme. The WFP was set up to provide international aid following humanitarian disasters. Last year, their work saved 91 million people, for example all the refugees in Sudan. They rely on contributions from the industrial world and they have lost one-third of their budget this year, because of Covid and other factors. Is public opinion in the rich countries strong enough to change their governments' policies? We must wait for a change of consciousness.

Couldn't we change global food systems through international cooperation?

Just twelve multinational companies control 85% of all the food in the world – the pricing for stocking, transportation, fertilizers and so on. They make immense profits but they escape any control. They are the masters of the world, when it comes to food. States could impose a right to food, but the states are much weaker than the multinational companies. ■

FOOD WASTE: A TALE OF TWO WORLDS

Each year, one-third of the planet's food is lost or wasted. In poor countries, it may rot before reaching the market. In rich ones, up to 40% of it is thrown away uneaten.

ACCORDING TO THE UN, about 14% of the world's food is lost in production before reaching the retail level. Even more, 17%, is wasted at the retail and consumption stages. This represents almost one-third of the world's food resources, an estimated 1.3 billion tonnes of food.

It's not just a problem in human terms. There are significant environmental impacts. Huge amounts of energy and water are used needlessly and it's estimated that 8–10% of global greenhouse gas emissions are associated with food that is not consumed.

According to the United Nations Environment Programme (UNEP), if food loss and waste were a country, it would be the third-biggest source of greenhouse gas emissions on the planet.

Sustainable Development Goal (SDG) target 12.3 aims to halve per capita global food waste and to reduce food losses by 2030. Food loss is covered by indicator 12.3.1.a and food waste by 12.3.1.b.

The highest levels of food loss are in low-income countries where infrastructure gaps and uneven access to electricity make it difficult to store and transport food, and in which government action is lacking. According to the latest UN Food Loss Index, food loss ranges from 20.7% in Central Asia and Southern Asia to 8.9% and 5.8% in Australia and New Zealand respectively.

UNEP recommends that "strengthening supply chains through the direct support of farmers, investments in infrastructure and transportation and an expansion of the food and packaging industry could help to reduce the problem."

WEALTHY COUNTRIES ARE MOST WASTEFUL

The UN Food Waste Index for 2021, the first conducted, shows a correlation between population size and food waste. China came first with an estimated 91.6 million tonnes discarded annually, followed by India's 68.8 million tonnes.

US households threw away an estimated 19.4 million tonnes of food in a year, while an estimated 5–6 million tonnes was discarded in France and Germany.

Looked at per capita, the statistics tell a different story. Annual average household food waste was 50 kg per capita in India, 59 kg per capita in the United States, and 77 kg per capita in both the United Kingdom and Spain. Australian households, some of the worst, generated 102 kg of food waste per year. By comparison, Russians only produced 33 kg per capita, despite the country's total annual food waste adding up to 4.9 million tonnes.

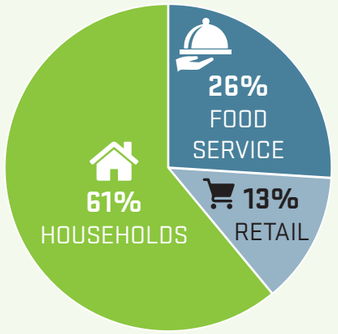
Countries are beginning to target, measure, and act on the problem. Some are adopting legislation, market-based instruments, and voluntary agreements. France, Italy, and the US have adopted all three.

Food banks, taxes and grants, and food donation policies are important mechanisms, encouraging farmers, packers, distributors, processors and shops to redirect wholesome food to people experiencing hunger. Consumer education – for example, on the meaning "sell-by" and "best before" dates and on how to store different kinds of food – is also important. ■

ILLUSTRATION: ULI KNÖRZER

FOOD WASTE BY SECTOR

The majority of food waste is produced by households



SOURCE: UNEP, FOOD WASTE INDEX REPORT 2021

THE ENORMOUS SCALE OF GLOBAL FOOD WASTE

Total annual household food waste produced in selected countries.*

* UNEP ESTIMATES WITH HIGH OR MEDIUM CONFIDENCE

HUNGRY PLANET
FOOD SECURITY VARIES WORLDWIDE

Many countries are facing unprecedented pressure on accessing nutritious food, reversing years of development gains. If effective action is not taken, rising food prices may push millions of additional people into acute food insecurity.

AROUND THE WORLD, MORE THAN enough food is produced to feed the global population, but up to 820 million people are estimated to be hungry, one-tenth of the world's population. Around 118 million more people were facing hunger in 2020 than in the previous year. More than half of the world's hungry people are found in Asia and more than one-third in Africa. More than 3 billion people cannot afford a healthy diet.

Malnutrition ranks as the world's third-largest cause of preventable death, after high blood pressure (which is also food-related) and smoking. Hunger and malnutrition have four main causes – wars, extreme weather, food waste, and poverty. They often occur in combination.

The parching of sub-Saharan Africa as the planet warms up has been a contributory factor to regional wars and major population displacements, which have increased poverty and therefore hunger. A lack of resources in developing countries means that millions of people simply cannot afford to grow or to gain access to nutritious food.

GLOBAL FOOD SECURITY INDEX

- BEST PERFORMANCE
- GOOD PERFORMANCE
- MODERATE PERFROMANCE
- NEEDS IMPROVEMENT
- NO DATA

THE RIGHT TO FOOD

ADOPTED OR EXPLICIT AS A CONSTITUTIONAL RIGHT

BANGLADESH, INDIA, NEPAL, PAKISTAN, SRI LANKA, ETHIOPIA, MALAWI, NIGER, SOUTH AFRICA, UGANDA, IRAN, UKRAINE

NO RIGHT TO FOOD

UNITED STATES
GREENLAND

DATA SOURCES
GLOBAL FOOD SECURITY INDEX (GFSI). SCORES AFFORDABILITY, AVAILABILITY, QUALITY AND SAFETY, AND NATURAL RESILIENCE ACROSS 113 COUNTRIES. THE INDEX IS CONSTRUCTED FROM 58 INDICATORS AND AWARDS SCORES UP TO 100. IN THE 2021 EDITION, AFRICAN NATIONS DOMINATE THE BOTTOM PLACES.

DEFINITIONS

Food security relates to food availability, access, and use. When a person always has access to enough safe and nutritious food to maintain an active and healthy life, they are considered food secure.

Hunger, also known as food deprivation, refers to the distress associated with a lack of sufficient calories to provide the minimum energy required to live a healthy life. The threshold for food deprivation is fewer than 1,800 calories per day.

Undernutrition is the result of an inadequate intake of food in terms of quantity or quality in the form of a shortage of micronutrients. In children, it can take the form of wasting – low weight for age – and stunting – low height for age.

Malnutrition refers to both undernutrition and overnutrition (usually too many calories). Obesity is defined as a "paradoxical state of malnutrition," in which excessive calorific intake is combined with a shortage of micronutrients.

Micronutrients such as vitamins and minerals enable the body to produce enzymes, hormones and other substances essential to health. In low-income countries, deficiencies of Iodine, vitamin A, and iron are a major threat.

PHOTO: GETTY IMAGES/MOMENT/KATSUMI MUROUCHI; ILLUSTRATION: SHUTTERSTOCK/MDV EDWARDS

THE STATE OF GLOBAL FOOD SECURITY

Unprecedented global food inflation, which has surged since January 2020, is having devastating economic and humanitarian consequences, reports Gro Intelligence.

A COMBINATION OF BOTH SUPPLY and demand shocks along with structural changes are causing unprecedented global food inflation, which has surged since January 2020. Skyrocketing prices are leading to devastating economic and humanitarian consequences.

This food inflation (as measured by price changes in corn, wheat, soybeans, rice, and vegetable oils), combined with the impact of the rising US dollar, has led to agricultural price increases in some developing countries of up to 1,914% (Sudan) on a local currency basis since January 2020. The US has experienced a 67% increase in prices in the same time period. More than 150 countries have experienced price increases greater than 50% on a local currency basis. The problem is global.

The global food inflation problem is far worse than what is currently captured in official consumer price index (CPI) statistics around the world, because of the lagged nature of how they are calculated. There is the potential and risk of seeing CPI increase around the world despite an increase in interest rates.

This food price inflation is a result of a combination of supply and demand shocks, which very rarely come together at the same time, alongside structural changes in demand driven by biofuel demand and China becoming a bigger importer of grains.

SUPPLY CHAIN ISSUES

The fragility of the world's food supply chain came into sharp focus with the onset of the Covid-19 pandemic in 2020, when manufacturing and transport industries became overwhelmed trying to get food from where it was available to where it was needed. At the same time, radical shifts in how food was consumed created additional snarls in our global supply chains.

Russia's invasion of Ukraine exacerbated the supply disruptions, blocking exports of key food staples from a region that had previously provided nearly one-third of the world's wheat exports and was among the top five exporters of corn. While the recent resumption of grain exports from Ukraine is a positive development, even an optimistic scenario would mean shipments 36% lower than in 2021.

Such major disruptions to supply chains come as worldwide wheat stocks are projected to be at levels below the last crisis of 2007/08. Corn supplies have suffered due to drought conditions in the US, Argentina, and the EU, three of the biggest corn-exporting regions. In addition, global production of rice, the primary staple for more than half the world's population, will shrink this year for the first time in three years due to a combination of drought in China and India alongside record floods in Pakistan.

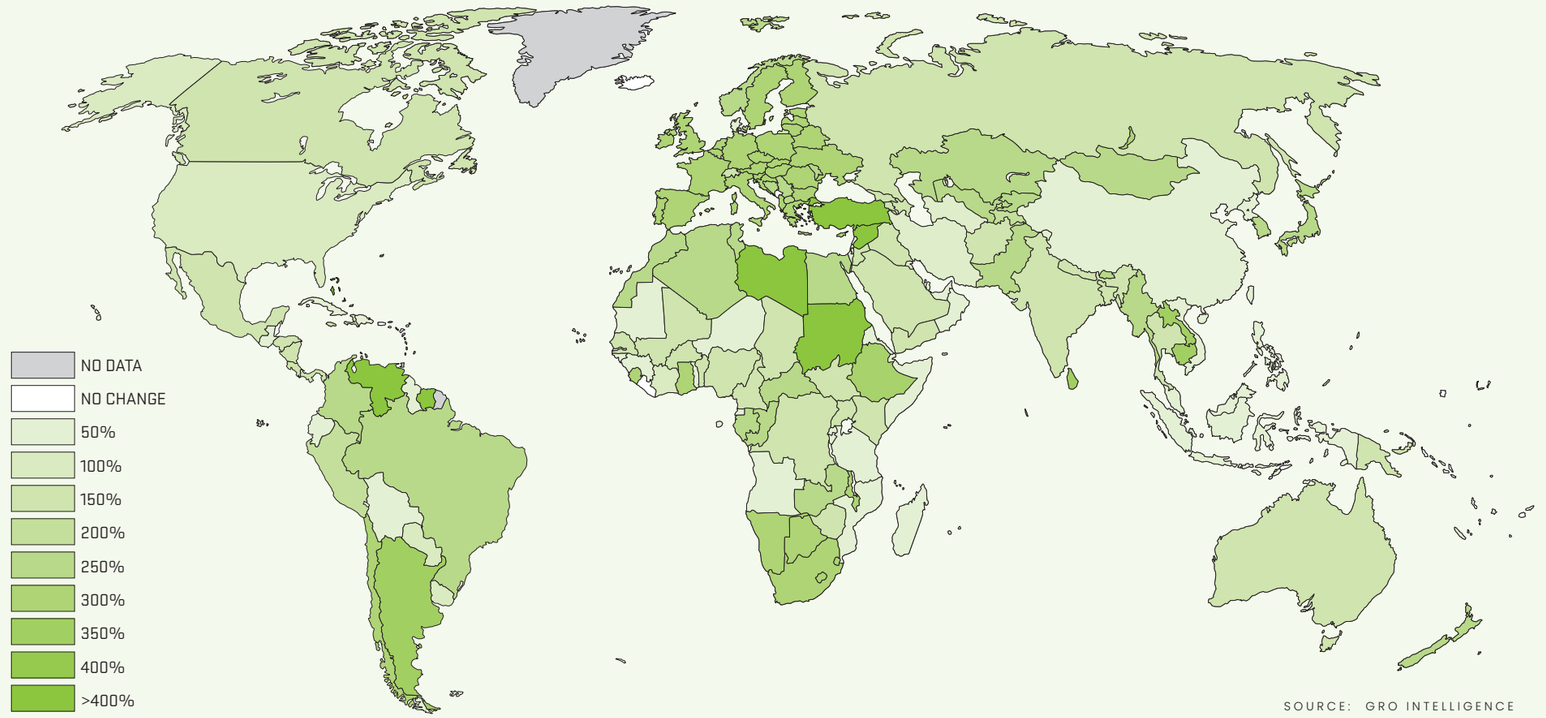
FERTILIZER PRICE INCREASES

Beyond short-term supply constraints, soaring energy prices raise worrying signals on food security for years to come. That's because fertilizers, which are key to achieving reliable crop yields and production, are highly dependent on energy supplies and costs – natural gas accounts for 75%–90% of nitrogen fertilizer production operating costs. That's critical for farmers, for whom fertilizers represent 30%–40% of total planting costs.

Rising fertilizer prices are a years-long trend — for the three main fertilizer types of nitrogen, phosphate, and ↘

AGRICULTURAL PRICE CHANGES IN LOCAL CURRENCY SINCE JANUARY 2020 (%)

Weighted by corn, wheat, soybean, rice and palm oil, soybean oil, sunflower oil and rapeseed oil consumption



SOURCE: GRO INTELLIGENCE

AGRICULTURE AND CLIMATE ANALYTICS

With offices in New York, Nairobi, and Singapore, Gro Intelligence has spent the last eight years building up the world's largest platform dedicated to food security, agriculture, climate, and the economy.

The Gro Platform organizes the world's agriculture and climate data, transforming more than 650 trillion data points into searchable and accessible knowledge. The Gro Platform continually ingests over 50,000 datasets, and new data sources are constantly being added. In addition, Gro has created over 2,000,000 Gro-derived machine-learning and AI-driven models to help predict everything from agricultural yields to the demand for certain commodities and the effects of climate change on our agricultural and financial systems.

Gro's analytics enable agricultural companies, asset managers, financial institutions, and governments to make decisions with confidence.

Gro Intelligence was founded in 2014 by Sara Menker. Menker was born in Ethiopia, and prior to founding Gro was in Morgan Stanley's commodities group, where she managed a multi-billion dollar energy options trading portfolio.

↘ potassium (NPK), prices nearly tripled from last year and were up fourfold over the past two years. This trend was made worse by the Russia-Ukraine war, which drove up energy prices and limited supplies, especially to Europe. That has prompted fertilizer plants to shut down. More than 70% of European fertilizer capacity is estimated to be offline today due to costs.

This reduction in supply is turning an affordability problem into one of availability – for the first time ever, there is the risk that there simply won't be enough nitrogen-based fertilizer available to produce the crops needed to feed the world. While some regions like North America will be well supplied, others such as Europe, Asia (excluding China), and sub-Saharan Africa face significant risks.

While fertilizer prices have come down from the peaks reached in spring 2022, they are still close to all-time highs. And continuing upward pressure on energy costs threatens to maintain high fertilizer price levels well into next year and possibly beyond.

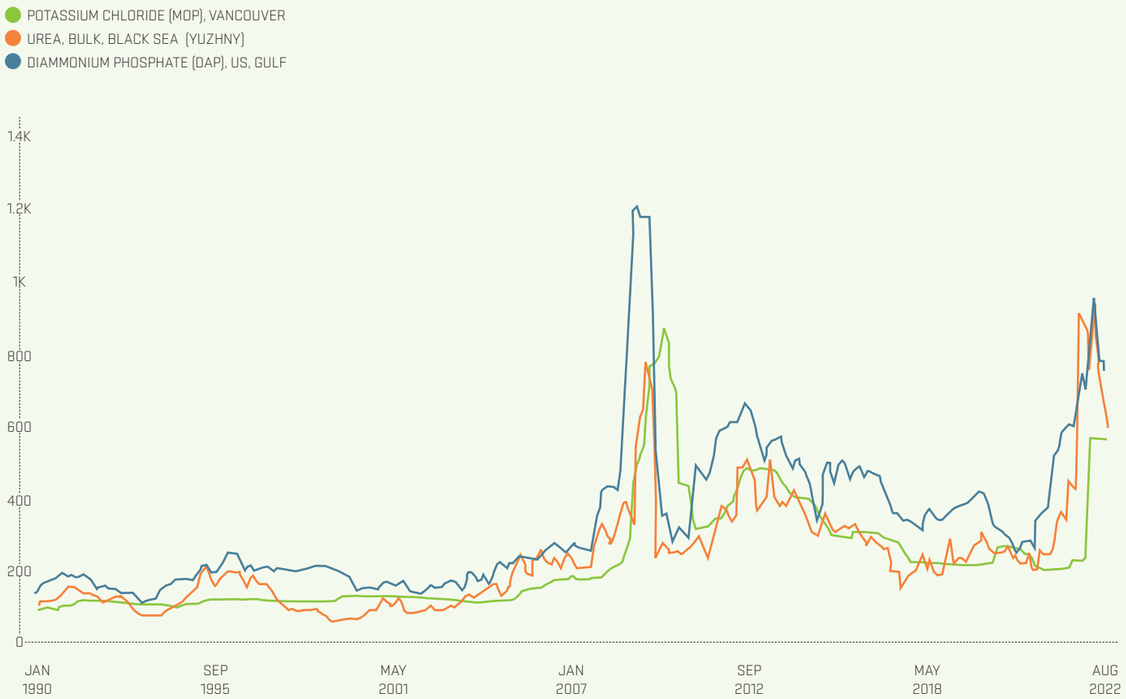
CLIMATE SHOCKS

On top of already historically high commodity prices, persistently negative environmental conditions are likely to significantly increase food insecurity. Extreme weather events underlie the world's currently tight inventories of many agricultural commodities.

China struggled this year under one of the most severe heat waves to hit the country in six decades, damaging wheat, rice, and other crops. Record heat and drought also pummeled crops across the EU and reduced yields in the US. The Horn of Africa is seeing its longest drought in some 40 years, raising concerns about smaller harvests of principal grain crops, shortages of forage, and depleted water supplies.

Meanwhile in Pakistan, deadly flooding from monsoon rains and Himalayan ice melt washed away entire rice fields. And Thailand and Vietnam, two of the world's biggest exporters of rice, were hit in September by a tropical cyclone.

WORLD FERTILIZER PRICES
in USD per tonne



SOURCE: GRO INTELLIGENCE

Sara Menker at the FII Institute Priority Summit in New York

PHOTO: ADAM SCHNEBERG

Much of deteriorating crop conditions can be blamed on the La Niña climate pattern, which brought abnormally dry conditions two years in a row to corn and soybean crops in major producers Brazil and Argentina.

Now, La Niña is forecast to make a rare return appearance for a third year, raising concerns about South America's upcoming growing season and increasing the likelihood that tight worldwide grain and oilseed stocks will continue at least for another year.

STRUCTURAL CHANGES IN DEMAND

In addition to the issues facing supply, demand patterns have shifted sharply. Import demand has surged as drought has led to production declines in many net food-importing regions, including North and East Africa and across the Middle East.

In the past few years, China has exploded as the world's leading grain importer, and despite Covid restrictions and a slowing economy, imports are keeping up the record pace. China's grain imports more than doubled in 2020/21 from the levels of preceding years, and have since hovered at close to those record levels.

These changes are here to stay, and as lockdowns end and the economic pace picks up, they will put increasing pressure on global agricultural markets.

INVESTING IN FOOD SECURITY

Without action, the devastating effects of this crisis will continue for the foreseeable future - with increasing mass famines, and a rise in the number of people facing food insecurity. There will also be devastating global economic consequences.

There are a number of global levers that need to be addressed. First, we need to rapidly increase production and availability of fertilizer to avoid a significant calorie deficit in 2023 and beyond. In certain parts of the world, such as sub-Saharan Africa, we also need to address the issue of affordability, given that a majority of farmers are small-scale producers.

Second, the world's multilateral institutions must seriously explore a new round of emergency relief from official debt to enable vulnerable countries to respond to hunger. The food inflation crisis is impacting some developing countries by more than 5% of their GDP, and the strong dollar is making this worse. Debt relief can be a temporary solution and provide some relief to national balance sheets.

Lastly, ensuring that humanitarian organizations such as the World Food Programme are fully funded is absolutely critical. The numbers of people in poverty and at severe risk of catastrophic levels of hunger are dramatically increasing, and humanitarian action is critical for preventing starvation, death, and social and geopolitical unrest.

The food security crisis is not going away, and we cannot let this fade from the agenda – both short-term emergency actions and structural changes are needed to avoid the current crisis from getting worse, and to prevent future crises. ■

CALL TO IMPACT

1 Rapidly increase the production and availability of nitrogen, phosphate, and potassium fertilizers.

2 Speed up debt relief talks with at-risk countries to help provide some relief to national balance sheets.

3 Fully fund humanitarian and relief organizations, such as the World Food Programme.

FII: FEED THE WORLD IMPACT REPORT 2022

RISE OF THE GLOBAL STANDARD DIET

Semi-dwarf wheat now accounts for about 99% of global wheat production by area. See page 44.

PHOTO: GETTY IMAGES/WESTEND61

What people eat has become homogenized worldwide – more starchy carbohydrates and calories from meat, fat, and dairy produce, fewer nutrients from fresh fruit and vegetables. Experts say that more varied and localized diets are essential to food security.

THE VARIETY ON DISPLAY IN YOUR local supermarket, if you live in one of the world's wealthiest countries, is extraordinary. On its shelves you will find gluten and lactose-free staples, including vegetable-based milks, the ingredients of various world cuisines, and, of course, the latest "superfoods," such as quinoa, chia seed, and kale.

For thousands of years, people ate locally produced food. Steamships, refrigeration, powered farm machinery, and chemical fertilizers increased productivity to an astonishing degree and opened up international markets.

The food economy has never been as global as it is now, and yet an extraordinary rationalization has taken place in what we eat. It is believed that, since farming began in the Neolithic period, up to 7,000 plant species have been cultivated for food. But today, three-quarters of the global food supply comes from just 12 plant and five animal species. Three crops – rice, maize and wheat – make up nearly 60% of plant calories in the human diet.

PHOTOS: GETTY IMAGES/E+/KUPICOO . GETTY IMAGES/MOMENT/ ALEXANDER SPATARI; ICONS: FLATICON.COM

Wheat is a major staple in 98% of countries and rice in 91%. Traditional cereals including sorghum, millets, and rye and root crops such as sweet potato, cassava, and yam have lost ground, even in the countries where they once dominated diets.

A 2014 report from the Colombia-based International Centre for Tropical Agriculture (CIAT) drew attention to the negative effects of increasing homogeneity in food production. The study was based on 50 years of data from the Food and Agriculture Organization (FAO), covering more than 50 crops eaten in 150 countries between 1961 and 2009.

CIAT scientist Colin Khoury, one of the report's researchers, explains that a "global standard diet" has emerged. It is energy dense but lacks micronutrients. "More people are consuming more calories, protein, and fat," he says, "and they rely increasingly on a short list of major food crops, like wheat, maize and soybean, along with meat and dairy products, for most of their food. A global diet of such limited diversity obligates us to bolster the nutritional quality of the major crops, as consumption of other nutritious grains and vegetables declines."

GLOBAL STANDARD AGRICULTURE

Over the 20th century, ever-increasing yields of wheat, maize and rice were achieved through the heavy use of industrially manufactured nitrogen, phosphorous and potassium fertilizers and chemical pesticides. It was called the "green revolution." Without it, and the efforts of the United Nations' World Food Programme, which was created in 1961, many more people would have starved. But the gains produced by "global standard agriculture" are leading to diminishing returns.

George Monbiot, ecologist and food and soil expert notes: "Farmers worldwide are converging on identical techniques, using the same machinery, the same chemicals, the same varieties of the major crop varieties. As crops approach their plateaus, returns on effort diminish. Fertlizers have a massive impact on production when yields are low, but every new increment is less effective."

The application of what are called N-fertilizers causes acidification that breaks down the microorganisms in soils, the bacteria of the "rhizosphere," that make nutrients naturally available. As soil becomes poorer in structure and nutritive value, more and more chemical fertiliser must be applied to maintain yields. Ultimately, what was once soil becomes dust that simply blows away.

Rainfall in cereal-growing areas causes mineral fertilizers to run off the surface on a large scale. Resulting high nutrient levels in watercourses lead to excessive algal growth and oxygen starvation, known as eutrophication. This kills fish and invertebrates and the animals that depend upon them for food.

The CIAT study also warns that dependence on small number of cereals restricts genetic diversity, making crops more vulnerable to pests and diseases. Globally, tens of thousands of wild or rarely cultivated plants could provide varied and nutritious foods, resistant to disease and tolerant of the changing environment. But in Thailand, 16,000 varieties of rice once cultivated have fallen to just 37 in the past century. The US is estimated to have lost 80% of its cabbage, pea, and tomato varieties.

To rely on so few food crop species and heavy application of chemical pesticides that kill naturally pollinating insects invites disaster. Luigi Guarino, senior scientist at the Global Crop Diversity Trust, explains: "As the global population rises and pressure increases on our global food system, so does our dependence on the global crops and production systems that feed us. The price of failure of any of these crops will become very high."

DIET-RELATED DISEASES

Traditionally, horticultural production of fruits and vegetables supplemented diets when crops failed. But land is increasingly being used for other purposes. It is estimated that the supply of fruit and vegetables, nuts and seeds falls about 22% short of population requirements, according to nutritional recommendations.

Favouring the mass production of starchy crops for calories for primary food production has made the world less healthy overall. More than 2 billion people lack vital micronutrients (vitamins and minerals) and 2 billion are overweight or obese. Diet-related heart disease and type 2 diabetes, associated with obesity, are now the leading causes of death in all regions except Africa.

Climate change, the rise of super viruses, urbanization, the scourge of starchy diets, and the diminishing effectiveness of the stock solutions of agribusiness, add up to gigantic and escalating problem.

The connected nature of these problems points to the solution. There is a strong school of thought that the only way to increase the supply and distribution of food in line with population growth is to adopt sustainable methods that will also help to slow down climate change. Our primary food supply, from hundreds of millions of farmers, remains diverse, and demand can drive significant change in how food is produced and where it comes from.

High-tech solutions will help: protein grown in vats, cell-grown meat that tastes like the real thing. We can use desalinated seawater to green drylands and create gene-modified crops that will grow in arid and saline environments. Happily, solutions are not mutually exclusive. We'll need elements of these and many other approaches in the years leading to the deadline for global net zero that has been set, following the 2015 Paris Agreement, at 2050. ■

FAST FACTS

Agriculture covers up to **38%** of the earth's surface. Some **75%** of the world's agricultural land is devoted to raising animals.

Cereals account for more than half of the world's harvested area. Cereals are grain-producing grasses, such as wheat, rice, maize, and millet. Of the **2.3 billion tonnes** of cereal produced, about a billion tonnes is destined for food use, 750 million tonnes for animal feed, and the remaining 500 million tonnes is processed for industrial use, used as seed, or wasted.

Rice is the primary crop and food staple of more than half the world's population. Asia is the world's largest rice-producing and consuming region. Rice is also increasingly becoming a food staple throughout Africa.

CALL TO IMPACT

1. The application of fertilizers should not only target maximum yield, but also consider soil preservation.
2. A greater diversity of crop and animal species in agriculture would reduce vulnerability to disease.
3. The adoption of more varied diets, produced sustainably, would be healthier for people and planet.

PLANET CLOSE TO THE EDGE

The environmental crisis is not just about global warming. Agronomics expert Mark Tester argues that the world is now exceeding planetary limits on water use, soil fertility and the nitrogen cycle. But human ingenuity can provide solutions.

TALKING TO PROFESSOR Mark Tester is a chastening experience. It's challenging because he makes one aware of the sheer scale of the mismatch between the world's food resources and its growing population. It's also hopeful because Tester, who describes himself as a "techno-optimist," believes that the planet is tougher than we think and that human ingenuity may be able to crack the problem.

Born in Tasmania in 1963, Tester studied botany and plant sciences at the Universities of Adelaide and Cambridge, where he earned his PhD in 1988. He has made his name as a science popularizer, and especially as a defender of genetic modification against criticism from environmentalists that it's a form of "tampering with nature" whose dangers could outweigh its benefits. An outspoken defender of the scientific method, he gives short shrift to such views.

He decided to move from pure academic research to helping to develop practical solutions to hunger and poor nutrition, and in 2013 took the position of professor of plant science at King Abdullah University of Science and Technology (KAUST). He is also associate director of KAUST's Center for Desert Agriculture (CDA), which is conducting research to develop sustainable agriculture in extreme conditions.

He says, "It's really good to see cross-disciplinary work in action, bringing together engineering, material science, and plant science to develop systems for reducing the water and energy footprints of agriculture."

Tester does not underestimate the huge challenges that the planet is facing. He argues that the looming catastrophe of famine caused by the Ukraine crisis may merely be a tragic episode in a larger and even more ominous story: "There are a lot of children who go to bed hungry every night and the Ukrainian issue is going to cause massive hardship. But the suffering that's ahead of us could potentially be even greater because it could be long-term."

He does not solely attribute the problem to excessive carbon emissions causing global warming, but to a nexus of issues that he refers to as global environmental change. Drawing on the writings of US ecologist David Tilman, he says that, because of unsustainable overconsumption of resources, including fresh water, and intensive agriculture, ↘

PHOTOS: NASA/ROBERT SIMMON/LANDSAT/UMD GLOBAL LAND COVER FACILITY, PICTURE-ALLIANCE/AP PHOTO/PATRICK SEMANSKY

Satellite view of the Gulf of Mexico dead zone
Inset: fish killed by algae on the Louisiana coast

FII: FEED THE WORLD IMPACT REPORT 2022

“If you stick to truthfulness and scientific accuracy for long enough, you finally get some traction .”

PROFESSOR MARK TESTER

Professor of plant science at KAUST

Sheep killed by a prolonged drought on overgrazed land in Wajir County, Kenya

PHOTOS: GETTY IMAGES/ED RAM, HELMY H. ALSAGAFF

humans are now exceeding global planetary limits.

Many factors play their part, but he argues that the role of water stress and the planet’s damaged nitrogen cycle have received insufficient attention from environmentalists, many of whom focus purely on climate change. “It’s not just about CO_2 emissions, methane and so on,” he explains. “It’s also to do with the nitrogen cycle. The unsustainability of our current food production system makes me extremely worried. We just keep pumping huge amounts of nitrogen into systems and, in addition, using unsustainably vast volumes of groundwater. We know that we’re depleting the water because areas of the planet have a smaller gravitational pull than they did a decade ago and that can only be due to loss of water.”

THE NITROGEN CYCLE

So what is the nitrogen cycle and why is it so important? In the natural process of biological nitrogen fixation (BNF), microorganisms known as diazotrophs found in soils reduce molecular nitrogen N2 into ammonia NH3 and related nitrogenous compounds, known as reactive nitrogen Nr. The process is vital because these compounds are required for the creation of amino acids and proteins that are essential to life. Chemical processes invented in the late 19th and early 20th centuries fixed nitrogen artificially in order to produce nitrogen fertilizer, greatly increasing soil fertility. The human production of reactive nitrogen has increased more than tenfold in the past century due to the overuse of chemical fertilizers and industrial and automotive emissions.

An estimated 80% of nitrogen is lost from agriculture through leaching and run-off and gaseous emissions to air. Both nitrogen and phosphorous escape into waterways, leading to the excessive algal growth of eutrophication. This starves both fresh water and seawater of life-sustaining oxygen, in extreme cases causing temporary or permanent “dead zones” hostile to aquatic life. Accelerated by global warming, dead zones have occurred in parts of the Gulf of Mexico; in the Baltic, Arabian, and Black Seas; and off the coasts of South America, China, Japan and New Zealand. Experts have identified more than 400 worldwide.

Atmospheric nitrous oxide, N2O, from car emissions and agriculture, is toxic to humans, a greenhouse gas, and the third-largest contributor to global warming after CO_2 and methane. Altered levels of acidity in soil caused by nitrogen fertilizers also jeopardize the health of the bacteria that naturally regulate the soil’s nitrogen balance and adversely affects soil texture, so that it may blow or wash away.

Human alterations to the nitrogen cycle are most intense where vehicle emissions and intensive agriculture are highest. Global Land Outlook reports, produced by the United Nations Convention to Combat Desertification (UNCCD), estimate that one-third of the planet’s soil is severely degraded.

TECHNO-OPTIMISM

In view of the apocalyptic scenario that Tester has outlined, of planetary environmental limits having been breached, is it too late? “It’s a perfectly valid question. I’m sure that the planet is a lot tougher than as portrayed by many environmentalists. But that doesn’t give us license to keep trashing the place. Yes, I think it’s too late for those kids who are growing up with underdeveloped brains because they haven’t had enough iron nutrition or vitamin A. It’s too late for the species that are going to become extinct. It’s too late for a lot of communities whose cultures and histories have been completely eliminated. But for the planet itself, as a lump of rock spinning around the sun, I’m not sure.”

He adds: “I have a tendency to be a techno-optimist. We can say that humans are fabulously inventive. And also that humans will devise and adopt technologies when they have to.” A menu of options, described in this report, includes large-scale desalination of seawater to bring fertility to the world’s arid areas; reduced use of agrochemicals, as advocated by the UNCCD, to help slow down the nitrogen cycle; the adoption of regenerative agriculture, including ranching; gene editing to increase crop yields and pest resistance in unfavourable conditions; the “growing” of new proteins through cell culture or microbial fermentation; global cooperation to decrease food waste and increase the efficiency of food distribution; and the disaggregation of food and chemical corporations, or appropriating their vast financial resources to a global battle against food insecurity.

The more options, the better, says Tester: “The truth is that there is no single solution. Desalination by reverse osmosis, for example, requires huge amounts of energy and is extremely expensive. We would need to imagine a scenario in which the price of desalination goes down by at least a factor of ten. In practice, we’ll require lots of solutions. Some of them will work and some won’t.”

SCIENTIFIC INTEGRITY

High on his list of priorities is scientific integrity. “Call me a boring, stuffy academic,” he says, “but I believe that following the truth is the core business – discovering the truth and being absolutely honest with what we do in research. I talk to my students about the mirror test. You have to be able to look yourself in the mirror in the morning and say that you are genuinely trying to make a contribution towards improving knowledge and improving the lot of humans and the planet. For me, that is incredibly important. If you stick to truthfulness and scientific accuracy for long enough, you finally get some traction.” ■

CALL TO IMPACT

1. Increasing food production by depleting water reservoirs is not sustainable. As long as desalination is too expensive, water-saving technologies are needed.
2. The planet’s nitrogen cycle is severely damaged. Repairing it will require a reduced use of agrochemicals.
3. Collaborations are needed between the engineering, material and plant sciences and water and energy technologies.
4. There is no single answer to hunger. The more compatible solutions we apply the better.

GREENING THE DRY LANDS

The Saudi-based Center for Desert Agriculture is developing practical ways of growing nutritious food in heat- and water-stressed environments. Impact talked to center director Rod A. Wing.

Above: the Sahel, Chad
Below: (left) a well in Matam Senegal, (right) dried up soil, Mali

PHOTOS: GETTY IMAGES/IMAGEBROKER/MICHAEL RUNKEL. GETTY IMAGES/AFP/JOHN WESSELS. GETTY IMAGES/LIGHTROCKET/KONTRIBUTOR/WOLFGANG KAEHLER, PR

> **“Our job as academics is to do the basic research, but getting new technologies to scale needs commercial investment.”**

PROFESSOR ROD A. WING

Professor for Plant Science, Director, Center for Desert Agriculture

IT'S NO EXAGGERATION TO SAY that the world is running out of water – or rather, that population growth and human activities are stressing ground water resources to a point at which they may no longer be able to sustainably support the global population.

Deserts make up one-third of the earth's land surface. But forget sand dunes and the French Foreign Legion. Deserts are found on every continent and they are not all covered with sand. Many include mountain terrain, and the polar deserts qualify, as areas receiving less than 25 cm of rainfall a year, as “cold deserts.”

Because the planet is warming up, the landmasses of world's hottest and driest subtropical deserts, of which the Sahara is the largest, are expanding. In addition, the drylands fringing them, which can be savannahs, grasslands, shrublands, or steppes, are being degraded by a process known as “desertification” and losing their ability to sustain agriculture.

Recognising this issue, The UN Convention to Combat Desertification (UNCCD) was adopted relatively recently, in 1994. The convention produced Global Land Outlook (GLO) reports in 1997 and 2022. They make frightening reading.

From 1998 to 2013, one-fifth of the earth's vegetated land surface showed persistent declining trends in productivity. The worst affected area is sub-Saharan Africa, but poor land management in Europe also accounts for an estimated 970m tonnes of soil loss every year.

Soil health may be one of the least recognized environmental issues, but it should deeply concern us all. An estimated one-third of the planet's soil is severely degraded. In an alarming feedback loop, the attendant loss of carbon sequestration is speeding up global warming. If this trend continues, 95% of the earth's land areas could become degraded by 2050.

At the launch of GLO2 in Abidjan, Ivory Coast, in 2022, UNCCD Executive Secretary Ibrahim Thiaw, said: “We cannot stop the climate crisis today, biodiversity loss tomorrow, and land degradation the day after. We need to tackle all these issues together.”

CENTER OF WORLD EXCELLENCE

So is anyone doing anything about it? Saudi Arabia's King Abdullah University of Science and Technology (KAUST) located on the Red Sea Coast at Thuwal, and founded in 2009, provides a world-leading example of good practice.

KAUST's Center for Desert Agriculture (CDA) opened three years ago to examine a simple idea: “How can we feed the world without destroying our planet?” While its solutions are being designed for Saudi Arabia – a country with a 34 million population that has no rivers and is 70% desert – they could be applied in many other hot countries with limited water.

The CDA has 200 teaching and research staff members, straddling ↘

FII: FEED THE WORLD IMPACT REPORT 2022

Above: KAUST university campus
Below: Research at KAUST's Center for Desert Agriculture

PHOTOS: KAUST/CENTER FOR DESERT AGRICULTURE/ ANASTASIA KHRENOVA

↘ disciplines including plant biology, genetics, microbiology, soil nutrition, disease resistance, pest and parasites, plant breeding and salt resistance. Engaged in basic and applied research, the faculty supports more than 70 post-graduate students. Well-funded and focused, it has attracted some of the world's brightest minds.

Some of the CDA's work is attached to the Saudi Green Initiative. For example, its "fast fit palms" research program is seeking to ensure the survival of the kingdom's iconic and nutritionally important tree, the date palm, which is threatened by water stress. Another ambitious research program, "native genome," is seeking to genetically sequence all of Saudi Arabia's aquatic and terrestrial life forms by 2030.

The 350 ha Wadi Kadid nearby is to form part of a network of 300 new Saudi Arabian national parks, in which date palms will thrive. One-fifth of the site will be used for CDA field research.

GENE-EDITING PIONEER

Heading the center since 2019 and holding degrees from UC Berkeley and Davis, as well as research positions at Berkeley, Cornell and Arizona universities, Professor Rod A. Wing is a world authority on plant genomics. In Arizona in 2005, he was part of the first team to sequence the genome of a cereal crop. It was rice, Oryza sativa. The $200m project involved researchers from ten countries.

"It turns out that all cereals shared a common ancestor 50 million years ago," he says, "and that their genomes can be aligned. We sequenced rice first because it was the Rosetta Stone for all the other cereals. It unlocked the genetics and biology on the others."

Genome sequencing has now been carried out for all cereals. It has been a daunting task – wheat's genome is five times larger than that of humans, and it has six sets of chromosomes compared to humans' two. KAUST researchers, with colleagues from South Africa, France and the US produced, this year, the highest quality genome to date for bread wheat.

Wing believes that genetic research will prove vital to how we how can feed the world without destroying the planet. Controversial GMO technologies in the 2000s sought to combine genes from plant and animal species. More modern methods use gene editing techniques, such as CRISPR (see page 54) to bring about a form of directed mutagenesis within a single organism, enhancing characteristics such as ripening rate, micronutrient content, fruit size or salt water tolerance.

One of the CDA's research programs, "neo-domestication" led by Simon Krattinger, takes Fonio millet, a wild species native to Africa, and seeks to improve its natural properties to be fast-growing and nutritious. In two other projects, salt-tolerant species Salicornia bigelovii or dwarf saltwort, an oilseed plant, and Oryza coarctata, a wild rice relative, are being adapted to grow in salt water. Oryza coarctata could be grown on the beach margins of the coastal deserts of Asia, Africa and South America.

There could be both commercial and world-feeding potential in such projects – rice is the staple food of about half the world's population – but it's hard to predict which will take off beyond the lab. For Wing, the value of university-led research, unlike that conducted directly by agro-tech companies, is that its findings are almost always open-source, shared with other researchers and not geared to profit. "Our job as academics," he says, "is to do the basic research. But getting new technologies to scale needs commercial investment."

The center has already generated three spin-off companies – Red Sea Farms (see page 30), Edama Organic Solutions, which provides organic waste recycling solutions for desert environments, and GrowBioM, which produces soil microbes to enhance plant growth.

The hype around chemical fertilizers and pesticides may persist, but the emphasis of agronomy has changed. A new consensus is emerging, Wing says. "Globally, we know that there is enough food to go round. The focus is now shifting to nutritional quality and sustainability."

It may never be viable, he argues, to "green" the entire Sahara desert – the challenges are too great. But CDA is pioneering a new model of feeding the world. In the dry areas of the tropics, controlled environment agriculture would produce nutritious crops, using sustainably desalinated water and genetically adapted seeds and rootstock, with cereals brought in as required.

The world's cereal-growing areas would be increased by introducing new strains – such as rice that can grow in salt water, wheat that can tolerate drought, and perennial crops. In this model, we would no longer worship the god of producing higher and higher crop yields at whatever cost – the concept that dominated post-war food policy.

The goals would be sustainable agriculture, genetic variety, and production as close as possible to where produce is consumed. It turns out that the goals of feeding the planet and slowing down global warming are entwined. The only question Wing asks is, with the world's population set to reach 10 billion by 2050, will we get there on time? ■

CALL TO IMPACT

1 We need to develop sustainable desalination at scale, using renewable energy, in water-challenged regions.

2 We need more varied crop and animal species. "Genetic diversity is the most important thing in the world."

3 High, short-term crop yield is not as important as nutritional content and sustainability.

4 The best way to help poor farmers is through economic development. Educate their children, to lift them out of poverty.

SOLUTIONS FOR HOT CLIMATES

Saudi-based Red Sea Farms is developing practical new technologies that allow food to be grown in water-stressed and saline environments. We talked to co-founder and CEO Ryan Lefers.

How did Red Sea Farms begin?
My co-founder Mark Tester and I started the company at the beginning of 2018. We were both academics, working at the King Abdullah University of Science and Technology (KAUST) in Saudi Arabia. I was working in the water desalination and reuse center. Mark was working on plant science. We later added a third partner: Derya Baran, a material scientist and energy expert. Red Sea Farms is a venture capital-funded spin-off company that grew out of our research interests. To date, we have raised about $35 million from nine main investors in the US and Middle East, including the FII Institute.

And why did you begin that venture?
We want to help to feed the world sustainably. Our specific focus is to develop technologies serving areas of the world where the temperature is more than 90 degrees Fahrenheit or 32 degrees Celsius. That might be in the UK or Canada for a certain part of the year, but it could equally be somewhere like the Caribbean for all of the year. As well as heat, these areas tend to face additional challenges around water security, and issues around salt and salt water. Initially, we weren't focusing on how we could support the world in a climate transition. But, as it turns out, we're well-positioned to support a planet that's transitioning to warmer temperatures.

Coming from North America to Saudi Arabia, you have also transitioned to warmer temperatures.
Indeed, in South Dakota, where I come from, 90 degrees Fahrenheit is about the maximum temperature in summer. I grew up in a farming family in South Dakota on the fringes of the corn and wheat belts. My father is a farmer. I studied agricultural engineering at South Dakota State University and worked in consulting as a professional engineer for a number of years. To do my PhD, I moved to Saudi Arabia, focusing on water and food security. That's when I met Mark and how Red Sea Farms came about. It's our hope and prayer that we can help to feed people and reduce the negative impact of agriculture on the planet.

> "We're well positioned to support a planet that's transitioning to warmer temperatures."

How many staff do you have and where?
We currently have about 50 staff members. Our head office is in Saudi Arabia, but we now have additional offices in the UAE, the US, Portugal, and the UK, where we have a partnership with Total Produce in Kent. In Saudi, we grow produce under our own brand on a seven-hectare site. We are selling tomatoes, lettuce, cucumbers, and capsicum. Later this year, we're looking at adding berries. It's nutritious, locally grown food, sold at highly competitive prices.

What's your business model?
As well as selling produce, our business is to sell the technologies we have created that enable crop production in hot climates. We're looking at partnerships in the southern part of the US and Mexico, and also in Southern Europe, so Spain, Portugal, and Italy. We are also looking at expanding into Southeast Asia and Australia.

What technologies do you use?
We have two main pillars. One is technologies to support controlled environment agriculture. These controlled environments can be anything from a shade house or a polytunnel to a glasshouse. We make these environments more energy- and water-efficient and cost-effective, for example, using solar energy and optics technology and advanced sensor and analytics systems. In hot regions, heat from solar radiation is a negative. We have patented a heat-blocking polymer film, which produces what we call passive cooling.

And the other pillar?
Is genetics. Our genetic work is around developing rootstocks for plants that have high heat and salt tolerance. We are not producing genetically modified organisms (GMOs) or using CRISPR gene-editing, but we do take advantage of modern biotechnology techniques for predictive breeding. For example we have developed tomatoes to be more salt-tolerant. In one project, we are growing them in the Nile Delta, which is very affected by salt and heat. The tomatoes can be grown using 90% seawater for cooling, while only 10% needs to be fresh water for irrigation, and their yield is much higher than normally available commercial varieties.

Salads aren't going to feed the world are they?
That's a fair point. But a big trend now is nutritional security. We've done a fair job as a planet over the last 50 years of increasing people's access to carbohydrates. But we've done a much poorer job of increasing and encouraging nutritional security. The work we're doing with tomatoes could help to support food security from a nutritional perspective. That's not to say that carbohydrate security isn't still important in some areas of the world.

> "We are focused right now on getting our products to the places that need them most. That's our goal."

What happens next?
We're quite a young company. We are focused on getting our products to the places that need them most. That's our goal. Farmers might buy our heat-blocking polymer, or our tomato or cucumber seedlings. There's more work to do in terms of how we get our products to market in emerging economies. There's obviously potential for support from charitable organizations or international institutions. That's something that we haven't yet devoted a lot of time to. ■

ILLUSTRATION: ULI KNÖRZER

RYAN LEFERS
CEO and co-founder of Red Sea Farms

CIRCULAR FOOD SYSTEMS

Regenerative agriculture focuses on preserving soil health and making the most of local conditions to produce food sustainably. Examples from Mexico, Rwanda, Niger, and Kenya demonstrate the benefits.

The Las Cañadas Farm Cooperative in Veracruz, Mexico, uses regenerative forest farming for crops and animals.

HIGH ABOVE SEA LEVEL, in the cloud forest region of Veracruz in Mexico, Ricardo Romero farms land that used to be his father's cattle ranch. This fertile tropical highland ecosystem, so beautiful that it attracts international tourism, naturally has a canopy of oaks, macadamias and hickories, abundant ferns, orchids, passion fruits and flowering succulents. But human activity has had a major impact. Between 70% and 90% of the region has been deforested. Cattle and coffee are the main agricultural products and intensive grazing has severely degraded soil.

When Romero took over the cattle ranch in the late 1980s, its soil was impoverished and biodiversity had been severely reduced. He decided to do things differently than his father. In 1995, he sold his cows and planted 50,000 native trees on 60 ha of land, while allowing another 40 ha to regenerate naturally. On a further 22 ha, he reintroduced silvopasture, or agro-forestry, a system in which animals are grazed beneath trees. He adopted perennial food crops similar to annual staples such as maize and beans, including varieties that grow on trees, vines, and palms, in a system that could be called an "edible forest." He also started a plant nursery and seed company.

The Las Cañadas Farm Cooperative shows regenerative agriculture in practice. It illustrates bio-intensive organic growing methods that produce crops with high yields in small spaces, while also capturing more carbon in the soil than traditional annual crop planting. This makes it an example of "carbon farming."

Romero's aim is to develop food production systems that provide a complete diet, while incorporating as much of the ecosystem function of the cloud forest as possible. Such systems, if repeated on a large scale, could create corridors that could reconnect remaining fragments of intact forest.

PERENNIAL CROPS

Eric Toensmeier, lecturer at Yale, a senior biosequestration fellow with climate NGO Project Drawdown, included Las Cañadas in his book, "The Carbon Farming Solution." He argues that perennial crops offer the highest potential of any food production system to sequester carbon, especially when grown in diverse, multilayered systems, as at Las Cañadas .

He says; "Many of the agro-forestry techniques with the highest sequestration rates are largely confined to the tropics, and most of the best perennial crops available today are also native to, or grown best in, the tropics. The head start the tropics have on carbon farming provides an excellent opportunity for wealthy countries to repay climate debt by bankrolling mitigation, adaptation, and development projects in the Global South."

PHOTOS: COOPERATIVA LAS CAÑADAS (2), ROB DEZA

> "Many of the agro-forestry techniques with the highest sequestratation rates are found in the tropics."

ERIC TOENSMEIER

Lecturer at Yale University

A hectare of trees can sequester or store up to 10 tons of carbon dioxide per year and it is estimated that the woody biomass of trees could contain as much carbon dioxide (CO_2) as is currently present in the earth's atmosphere.

Toensmeier believes that removing carbon from the atmosphere and storing it in trees, soils, and perennial vegetation, combined with a massive reduction in fossil fuel emissions, could play a significant role in reducing global warming. This in turn would increase agricultural production in areas that are becoming too hot and dry to grow crops.

According to researchers at Ohio State University, if farmers worldwide adopted Romero's carbon farming methods, they could take up to 1.2 billion tons of carbon out of the atmosphere annually, which in 100 years would bring carbon levels back down to where they were in pre-industrial times.

Regenerative agriculture has been defined as a form of farming that has positive rather than negative impacts. It is context-specific in that what works in one environment may not work in another. Processes that increase agricultural yields without negative environmental impact are known as sustainable intensification.

Above: baobab trees in Zinder, Niger. Below: Adouna valley and Zabon Mousso, also in Niger

PHOTOS: SVEN TORFINN/PANOS PICTURES (2), DAVID ROSE/PANOS PICTURES

↘ Nearly all regenerative agriculture focuses on improving soil health. Common practices include no-till planting (sometimes called no-dig) to reduce soil disturbance, limiting pesticide and fertilizer use, introducing cover crops, mixing forage species and perennial grasses into monoculture crops, and incorporating adaptive multi-paddock grazing (AMP).

Forage rotation allows pasture to rest and regenerate. Water and air quality are important and ecological principles apply. Regenerative agriculture recognizes the interconnected ecosystem of water and nutrient cycles, energy flows and community dynamics.

TRANSFORMING RWANDA

In Africa, the World Resources Institute (WRI) is at the start of a three-year Circular Food Systems Project for Rwanda. It believes that circular economies for food will be crucial to support the growing global population, expected to be 10 billion by 2050, in ways that operate within planetary limits.

The WRI believes that Rwanda, a landlocked country in the Great Lakes region of East Africa, has great potential to transform its food systems. The agriculture sector engages more than 70% of the population. It includes more than 6 million small-scale producers and accounts for one-third of GDP.

The country is a founding member of the African Circular Economy Alliance (ACEA) and the EU-funded Global Alliance on Circular Economy and Resource Efficiency (GACERE).

Eric Ruzigamanzi, project manager, notes that the industrial or "green revolution" model of agriculture contributed to greenhouse gases and depleted soil carbon. It has also been disastrous for biodiversity, devastating pollinators critical for sustainable food systems.

He says: "Our project aims to promote circular practices in the food chain, reducing loss and waste, encouraging recycling, and using renewable energy. By working with SMEs, innovators in this sector, we are building an ecosystem of young entrepreneurs creating sustainable jobs for themselves and society."

GREENING NIGER

Another excellent example of regenerative agriculture can be found in Niger. Northern Niger is in the Sahara. The southern half of the country lies in the semi-arid Sahel region. This belt of land, crossing the African continent from the Atlantic to the Red Sea, is primarily covered by grassland and savannah. It is becoming increasingly infertile because of drought, deforestation, and intensive agriculture.

The importance of trees in providing shade in a country as hot as Niger, as well as shelter from winds, fertilization, moisture, and branches for firewood would appear obvious, but the traditional practice was to remove trees from farmland, for fear they would compete with crops for nutrients and water.

But since the mid-1980s, thousands of farmers have turned 5 million hectares of barren land green. Realizing the benefits of agro-forestry, they have allowed up to 200 million new trees to grow back naturally. As result, says Chris Reij, senior fellow at the WRI, soils are more fertile and moist, and crop yields are up. He describes the process as the "the biggest positive environmental transformation in Africa."

The WRI estimates that increased tree cover has sequestered up to 30 million tonnes of carbon over 30 years.

While the practice has not turned around Niger's problem of hunger, ranked "severe" by the Global Hunger Index, agro-forestry has increased agricultural production. Reij says that, in the Zinder and Tahoua regions, increased wind and drought protection has facilitated the annual production of 500,000 additional tonnes of cereals. Before agro-forestry was adopted, winds would destroy crop cover, so that three or four crops a year would be planted. Now crops are planted only once.

The practice is spreading to Mali, Ethiopia, Senegal, Burkina Faso, and Malawi. According to global food partnership CGIAR, 40% of developing countries cite agro-forestry as a method of mitigation in their national climate strategies. Interest is particularly high in Africa.

CROP AND LIVESTOCK SYSTEMS

The use of perennial grass-related crops is also common in regenerative agriculture. Remaining in the ground each year, they protect and help stabilize the soil, add organic material, and assist carbon sequestration.

It is a solution that farmers in Kenya and other east African countries are turning to in the form of Brachiaria grasses, cultivated as forage. Brachiaria, a genus of grasses common to tropical and subtropical regions, is being used as part of mixed crop and livestock systems, improving soil fertility and increasing production.

Napier grass, which was traditionally used, has been attacked by pests and stressed by climate change. Brachiaria grasses are attractive to cattle and higher in protein. They are nitrogen-efficient and can withstand low soil fertility. Projects are underway to assess the impact of Brachiaria on farming in neighbouring Rwanda, where trials have shown up to 78% increases in milk production.

In some ways, regenerative agriculture reverts to forms of farming that were commonly used before the green revolution. But it has been informed by our knowledge of global warming and the complex processes involved in the carbon and nitrogen cycles, and is being complemented by the latest discoveries genomics and plant biology. These can now be used to create plant adaptations that would take hundred of years to occur in nature. ■

CALL TO IMPACT

1 Regenerative agriculture has been defined as a form of farming that puts more into the environment than it takes out.

2 It recognises the interconnected ecosystem of water and nutrient cycles, energy flows, and community dynamics.

3 Preserving soil health and correcting the damage done by intensive agro-chemical agriculture is key.

4 Features include restricting digging or tilling, limiting the use of chemical pesticides and fertilizers, forest farming techniques such as grazing beneath trees, and the cultivation of perennial crop species.

BEEF DEBATE: THE CASE FOR HOLISTIC GRAZING

"Meat is bad" is a mantra of environmentalists. Supporters of holistic grazing say that it can allow us to eat beef without worsening soil degradation or global warming. We consider the arguments.

MANY STUDIES CLAIM TO SHOW that the greater adoption of vegetarian and vegan diets will reduce the environmental impacts of agriculture, whether it be mitigating climate change, reducing water use, or tackling dwindling biodiversity. All this at the same time as making us healthier. This message has almost become a mantra.

Vegetarianism and veganism are growing worldwide. The Vegan Society reports that registrations for "Veganuary" – a month dedicated to the diet – increased from 3,300 in 2014 to more than half a million in 2022, with 228 countries and territories taking part.

Beef production has seen vast areas of forests, which are carbon sinks that sequester about twice as much carbon dioxide as they emit, cleared to make way for cattle farming and to grow feedstock such as soy.

Ranchers use fire to clear these areas, which also releases greenhouse gases. Grazing animals produce methane, and although this gas doesn't last as long as carbon dioxide in the atmosphere, over the first 20 years its warming effect is 80 times greater.

An Oxford University study into the global ecological footprint of meat found that while it consumed up to 83% of farmland, it provided less than 18% of calories and 37% of protein.

Lead researcher Joseph Poore was widely quoted as saying that switching to a vegan diet is "probably the single biggest way to reduce your impact on planet earth" and far outweighed cutting down on flights or switching to electric cars. The Oxford study claimed that that if we globally adopted a vegan diet – a very tall order – it would still be possible to feed the world and worldwide farmland use could be reduced by more than 75%.

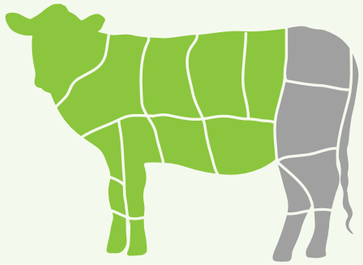
Meat-rich diets are also implicated in health problems such as heart disease and diabetes. Researchers at the Global Burden of Disease Project estimate that 34,000 cancer deaths each year internationally are attributable to diets with high amounts of processed meat. In comparison, there are 600,000 deaths a year attributable to alcohol consumption, and a million cancer deaths worldwide due to smoking.

Some of the world's healthiest diets include meat. The Mediterranean diet, for example, is characterized by high volumes of fruit and vegetables, legumes, wholegrains, nuts, spices, and healthy fats like olive oil. It includes some fish and seafood, limited amounts of animal products such as eggs, chicken, and cheese, and small, infrequent amounts of red meat.

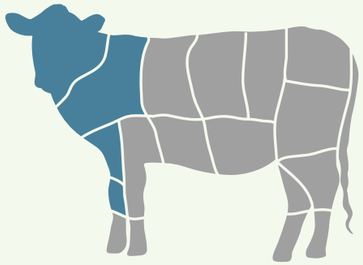
Studies of the Mediterranean diet have shown that it reduces the risks of heart disease, depression, and dementia, and ↘

PHOTOS: GETTY IMAGES/MOMENT/AKEMAZING; ILLUSTRATION: GETTY IMAGES / A-DIGIT

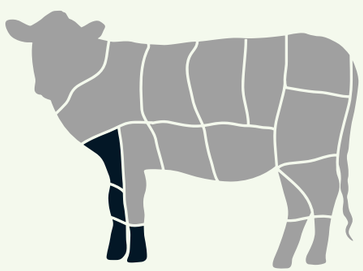
FARMLAND IN RELATION TO ITS NUTRITIONAL VALUE



83% of farmland worldwide is being used for meat production



37% of protein is provided by meat production



18% of calories are provided by meat production

Above: Savory Institute's US White Oak Pastures
Below: grazing projects in Kenya and Uruguay

↘ it has been promoted by dieticians and public health experts.

Another diet recommended by experts as extremely good for our health is that eaten by the inhabitants of Okinawa, a Japanese island, who enjoy high levels of longevity. This diet is low in fats and high in carbohydrates, with moderate protein. Staples are root vegetables such as sweet potatoes, soybean-based foods, spices, low-fat meats, and fish.

Both these diet are heavily plant-based, with moderate red meat consumption, and avoid ultra-processed foods. They can be termed "flexitarian."

The Eat Lancet Commission convened 37 leading scientists from 16 countries and various disciplines. Its brief was to find out, "Can we feed a future population of 10 billion people a healthy diet within planetary boundaries?"

Its report, which was launched in 2019, concluded that we could, but said that a transformation to healthy diets by 2050 would require doubling the consumption of fruits, vegetables, nuts and legumes, and halving consumption of foods such as red meat and sugar. It argued that "food is the single strongest lever to optimize human health and environmental sustainability on earth."

THE CASE FOR HOLISTIC GRAZING

The way beef is currently produced is carbon-intensive, but does it have to be? A growing school of thought is promoting holistic management of cattle, saying that this can improve and enrich the environment.

"There's this very reductionist viewpoint that to solve our environmental crisis we just need to plant trees everywhere and eat plant-based diets," says Bobby Gill, director of development and communications at the Savory Institute, based in Boulder, Colorado. The institute's mission is to "facilitate the large-scale regeneration of the world's grasslands and the livelihoods of their inhabitants, through holistic management."

> "We already produce a surplus of calories around the world – enough to feed almost eight billion of us."

BOBBY GILL

Director of development and communications, Savory Institute

Founded by Zimbabwean scientist and livestock farmer Allan Savory in 2009, the institute has 46 hubs in the Americas, Europe, the Middle East, Africa, Asia and Australia. They are located in some of the world's most challenged countries, such as Senegal, Bolivia, Myanmar and Mongolia. The institute claims to have trained 8,000 people and influenced the use of 25 million hectares of land.

Gill says that to argue all livestock is bad is wrong, and "vilifies" animal agriculture and grazing. Around one-third of the earth's surface is made up of grassland, which co-evolved with ruminants that grazed on the grasses, cycling nutrients back into the soil in their urine and dung.

The institute's work is based on the premise that herbivores are a vital component of grassland and rangeland ecosystems. Their methods mimic the traditional migratory movements of people and animals. Cattle would be moved around in migratory corridors, arriving at new pastures as necessary.

They wouldn't return until the original grasses and their deep perennial roots had regrown. They were kept in tightly bunched herds to offer protection against predators.

Savory, whose influential TED talk in 2013 has garnered 11 million views, has said: "Only livestock can reverse desertification. There is no other known tool available to humans with which to address desertification that is contributing not only to climate change but also to much of the poverty, emigration, and violence in the seriously affected regions of the world."

It's a controversial view. UK-based environmentalist George Monbiot believes that the arguments for holistic grazing are overstated.

CALORIES VERSUS NUTRIENTS

Monbiot aruges that the methane emissions of cattle, sheep, and goats and their dung would more than counteract, in global warming terms, the carbon absorption of grazing or ranching land, if increased land area was devoted to this. He argues that livestock should be kept away from the world's drylands rather than introduced to them.

There are environmental arguments both for and against holistic grazing. They center mainly on how much carbon we need to sequester from soil and vegetation to counteract anthropogenic greenhouse gas emissions (estimated at some 680 billon tonnes since 1750) and the role that holistic grazing could play in this.

Another set of arguments focuses on food security. Holistic grazing may be less environmentally damaging than keeping cattle in pens or sheds and only occasionally letting them graze on real grass, but what about its productive food output per hectare in a world whose population is becoming hungrier?

Gill describes this as a "straw man" argument that positions the conversation in a way that prioritizes calories. According to him, "We already produce a surplus of calories across the globe – enough to feed almost all 8 billion of us, as around 40% of food is waste.

"If we want to talk about calories, the discussion should be around how we reduce food waste. If we want to have, I think, a more honest conversation, it's about how we get adequate nutrition for all those 8 billion people, because calories do not necessarily equal nutrition." ■

Sheep at the Savory Institute's Pampa Oriental Hub, Uruguay

PHOTOS: SAVORY INSTITUTE (5)

CALL TO IMPACT

1. The greater adoption of vegetarian and vegan diets will reduce the negative environmental impacts of agriculture.
2. The healthiest diets have high volumes of fruit and vegetables, legumes, wholegrains and nuts, and small amounts of meat.
3. Regenerative or holistic grazing is better for soil health and retaining carbon than conventional ranching or factory beef farming.
4. Not all land is needed for cereals. There is a surplus of calories – enough to feed almost all 8 billion of us – and around 40% of food is wasted.

Eshtykel plateau, Russia. Part of the Siberian tundra that could disappear by mid-century

BREAKING THE ICE

The thawing of the world's permafrost is widely acknowledged as symptom of global warming. With more and more traditional farming land now degraded, could it provide the potential to tap a mostly unexploited agricultural resource?

PERMAFROST IS DEFINED as a permanently frozen layer on or under the earth's surface. It is made up of soil, sand, and gravel, bound together by ice. It usually remains at or below 0°C for at least two years. It is estimated that just under one-quarter of land in the Northern Hemisphere is permafrost – some 15 million km².

Temperatures are rising faster closer to the poles than on the planet as a whole, and as permafrost thaws it releases methane, which further speeds up the thawing rate, creating a feedback loop.

The Arctic holds more than a trillion tonnes of carbon locked in the permafrost, more than twice as much as there is in the atmosphere, according to the National Academy of Sciences. A recent international study led by the University of Leeds warned that the vast permafrost peatlands of Siberia and Europe could be closer to a climatic tipping point than previously thought.

However, climate warming is also extending the region's growing season, making it easier for people to produce crops in these areas.

With more and more of today's arable land becoming degraded through intensive farming and overuse of fertilizers, some scientists predict that the northern high latitude areas are set to become a valuable resource.

NORTHERN FRONTIERS

Could the world's permafrost regions actually be part of a solution to help alleviate world hunger? Two recent reports provide some valuable data. Both reveal that the world's agricultural footprint is alrady shifting northwards.

A 2020 study published by US, Canadian and UK institutions, including University of California Davis and Kings College London, terms areas that may become newly suitable for one or more crops as "climate-driven agricultural frontiers." They cover, it notes, an area equivalent to more than 30% of the current agricultural land on the whole planet.

PHOTO: PICTURE ALLIANCE/ZOONAR.COM/SERGEY PISTYAZHNYUK

The report predicts that frontiers will be most extensive in the permafrost regions of the northern hemisphere and in mountainous areas, and says that northern agriculture has potential to increase the local supply of food and contribute to the global food system.

It predicts that cold-resistant crops, such as potatoes, wheat, maize, and soya will be the first to be grown. Precision agriculture and genetically modified crops, including quick maturing soybeans, are giving farmers the ability to plant in environments that once would have been considered extreme.

The government of the Northwest Territories in Canada has created a strategy to promote development of northern lands. Russia has policies promoting homesteading in Siberia, and China and Korea have both leased land in Siberia for agriculture.

The report says that the Northern agricultural frontier is "at a moment in history similar to just before Brazil started investing in soy production."

POTENTIAL OF SIBERIA

An article published last year in the journal *Frontiers in Sustainable Food Systems* comes to similar conclusions. Climate change, it says, is expected to lead to an expansion of agriculturally feasible climate over an area of up to 5 million square kilometers by the end of the 21st century, with linear northward shifts of up to 1,200 km, potentially affecting 0.2 billion people.

Under the exceptionally rapid warming of northern regions, temperate crops and cold-adapted varieties of crops such as maize will be grown further north. In Alberta, Canada, increased droughts will induce northward shift of barley, while agricultural expansion into northern Russia will compensate for drought-related declines in cereal productivity in southern regions. The article states that Siberia, described as a "dormant breadbasket," is currently at less than half of its estimated production potential.

Alaska's extensive permafrost region is one of the world's last agricultural frontiers.

Dr. Melissa Ward Jones harvests Kohlrabi at an Alaskan farm with ice-rich permafrost.

POLAR PERMACULTURE

An organic farm has been created on Norway's Svalbard archipelago by expat US chef Benjamin Vidmar. Here, the solution is to focus on crops like onions and tomatoes in the summer season and micro-greens in the dark winter months. The project, which features an arctic dome greenhouse and an indoor hydroponic garden, supplies local homes and restaurants with a source of fresh produce.

↘ Legislation in Canada, Alaska, Greenland, Iceland, Mongolia and Russia is financially supporting northward agricultural expansion. In Finland, the national objectives are founded on food self-sufficiency. Norway prioritizes sustainable intensification and Sweden is considering permafrost farming.

The article recommends that new crops be developed, resistant to climatic extremes. It calls for cultivar evaluation trials, concluding: "Converting 10% to 20% of the northern areas potentially suitable for agriculture by 2100 might feed 0.25 to 1 billion people, compensating for estimated reductions of food output in the earth's most productive regions, thus, northern agriculture could become a net contributor to global food security."

CAUTION NEEDED

The article comes with warnings. Historically, expansion of intensive agriculture into northern communities led to a loss of traditional food supplies, environmental degradation, and reliance on costly imported food.

The clearing of undisturbed land for agriculture removes the protective vegetative buffer layer. Permafrost degradation can create subsidence and sinkholes from melting ground ice, making farming difficult. Fertilizers and pesticides, typically required for intensive agriculture, may have serious consequences on ecosystem resilience.

Negative effects could be global. Environmentalists warn that northern forests store 32% of the world's carbon. Intensive agriculture could turn them into net greenhouse gas emitters. Only an estimated 2% of Northern peatlands are currently drained and farmed as croplands. Peatlands store most of northern soil's carbon and their capacity to sequester atmospheric CO_2 is partly due to cold and poor drainage conditions.

> "Different types of permafrost have different responses to thaw. Ground-ice content is key."

DR. MELISSA WARD JONES

Post-doctoral fellow
University of Alaska Fairbanks

PERMAFROST GROWN PROJECT

Melissa Ward Jones, postdoctoral fellow at the University of Alaska Fairbanks (UAF) Water and Environmental Research Center, is an expert at the sharp end of research on an area of agronomy of growing importance. The US National Science Foundation has recently awarded a team at the university $3m for a five-year project to study permafrost agriculture.

Previous fieldwork has taken Ward Jones to the Canadian Arctic, Svalbard in Norway, and throughout Alaska. The aim of the Permafrost Grown project, she explains, is to fill knowledge gaps using a combination of field data collection, remote sensing techniques, crop trials, interviews with farmers, and socioeconomic risk modeling.

Before the invasion of Ukraine, the team had planned to collaborate with Siberian farmers to better understand permafrost agroecosystems and collaborate on best practice guidance.

The project is seeking to pair crops to permafrost types, in terms of thermal dynamics, moisture, and hydrology.

Ward Jones says: "It's important to know that different types of permafrost have different responses to thaw. The ground-ice content is key – with high ground-ice content you'll get subsidence on the surface, which is obviously bad if you're trying to grow things. If you have low ground-ice content, the ground will benefit. We have farms with all ranges of ground-ice content in our study."

She continues: "If you look at the models, they say that climate suitability will increase and we'll be able to grow food on all these large tracts of permafrost land. But it's not just a question of the climate being more suitable. It's also a question of infrastructure, markets, and storage. These are very, very rural areas, so all of these things need to be in place before they can enter the global food system.

"I caution that farm techniques in southern latitudes won't necessarily translate up here. There will be on-the-ground practicalities that will need to be focused on. We're right at the beginning of all this, so now's the time to get ahead of these potentially big changes and get that knowledge. We're going to need," she says, "really smart farms."

She stresses that, while modeling studies show that climate warming in the permafrost zone is likely to substantially increase the areas suitable for crops, making sure that any northern expansion of agriculture is successful and supports adaptable, resilient, and sustainable permafrost agroecosystems will require a better understanding of the feedbacks and interactions between permafrost and food production. ■

PHOTOS: GETTY IMAGES/MOMENT/NOPPAWAT TOM CHAROENSINPHON; MELISSA WARD JONES (2); L-P LORENTZEN

CALL TO IMPACT

1 Global warming is thawing the world's permafroist. But the northward shift of agricultural frontiers can at least partly substitute reduced food production in southern areas affected by drought.

2 Farming in former permafrost regions is happening already. Legislation in Canada, Alaska, Greenland, Iceland, Mongolia and Russia supports northward agricultural expansion.

3 Cold-resistant crops, such as potatoes, wheat, maize and soya, will be the first to be grown on newly released land.

IN SEARCH OF 'SUPER CEREALS'

Climate change and rising sea levels are having dire consequences for cereals. Scientists worldwide are developing new strains designed to preserve yields in harshening environmental conditions.

THANKS TO THE EFFECTS of climate change, wheat and other essential cereals are expected to become increasingly difficult to grow and harvest. Without action, the impact will be profound.

Maize was first domesticated in present-day Mexico around 10,000 years ago, about the same time as wheat in the fertile crescent of the Middle East. Both were derived from wild grasses. Sorghum was first cultivated along the Egyptian-Sudanese border and rye around the Black Sea. It is believed that rice, also a grass seed, was first domesticated in China's Yangtze River basin up to 14,000 years ago. Today, it is normally grown commercially in flooded paddies.

The origins of these crops are as different as the optimal conditions for their cultivation, but they have one thing in common: Their dominant position in global food systems is endangered by climate change. Wheat, used to make bread, chapatis, pasta, couscous, noodles, and pastry, is a rain-dependent winter crop, sown in autumn and harvested in spring or summer. It grows best in temperate climates, which are now being compromised by changing weather patterns. Global warming, sea-level rise, and increasing salinity also mean that rice yields and growing areas are decreasing. Together, wheat and rice account for over 40% of the calories and plant proteins consumed by humans.

While climate change might increase the amount of land available for wheat fields, by pushing permafrost towards the poles (see page 40), other factors will more than erase this effect, according to NASA scientists.

Carbon dioxide in the atmosphere promotes photosynthesis, so it should improve the conditions for plant growth. But the growth acceleration gives the plants less time to lock in nutrition. Add to this, increased drought frequency and higher temperatures, and farmers end up with less grain.

"You can think of plants as collecting sunlight over the course of the growing season," said Alex Ruane, co-director of NASA's GISS Climate Impacts Group on the publication of a 2019 paper about climate impact on wheat. "They're collecting that energy and putting it into the plant and the grain. So, if you rush through your growth stages, by the end of the season, you just haven't collected as much energy. By growing faster, your yield actually goes down."

A separate study published in the journal *Science Advances* concludes that up to 60% of the world's wheat-growing area will soon face concurrent severe water scarcity events, up from 15% today. Even if the climate stabilized in line with the Paris Agreement target of 2°C above pre-industrial levels – which doesn't look likely – droughts would still double in the next 20–50 years.

This isn't a future problem, it's happening now. Researchers in Western Australia found that the area's wheat yields would have dropped 27% between 1990 and 2015 without the adoption of advanced technology and management systems. On a global level, we'll need a lot of research and innovation just keep yields where they are right now.

> "If you rush through your growth stages, by the end of the season, you haven't collected as much energy."
>
> **ALEX RUANE**
> Co-director of NASA's GISS Climate Impacts Group

With projections for lower rainfall in the territory, particularly in winter and spring, median yields will fall between 26% and 38% by 2090 under a central scenario. Three-quarters of the impact will come from less water, with a quarter resulting from higher temperatures.

GOING AGAINST THE GRAIN

Since the wheat genome is five times larger than the human one, identifying which genes in wheat are responsible for different characteristics is difficult.

A team led by Dr Rudy Dolferus at CSIRO Agriculture and Food in Canberra believes that it has developed a durable line of wheat that maintains yield, including the number and size of grains, under drought conditions.

Trials at the International Maize and Wheat Improvement Center, Obregon, Mexico

PHOTOS: JOSH HANER/THE NEW YORK TIMES/REDUX/LAIF (2); THE LAND INSTITUTE; PICTURE-ALLIANCE/AP PHOTO/MARCO UGARTE

In a study funded by Australia's Grains Research and Development Corporation (GRDC), the group set up to help safeguard Australia's wheat industry, Dolferus looked at different biological responses to impacts from abiotic stress.

During photosynthesis, a process required for pollen manufacture, wheat leaves must open their stomata – pores in the plant tissue – to take in carbon dioxide by photosynthesis. This makes them lose water through evaporation.

Hormones present in wheat control the opening and closing of stomata in response to ambient conditions. Dolferus' team focused on getting the balance right between photosynthesis and water retention.

"We now have lines that can serve as parents to transfer drought tolerance into breeding programs, but also as controls when screening additional genetic diversity for stronger forms of tolerance," Dolferus told *Ground Cover*.

He said that DNA markers are available to select for the genetics that maintain grain number during severe drought, but more work is needed to identify markers for the genetics that help maintain grain size. The research, which deals with very cold conditions, as well as hot ones, has been made available to commercial growers of wheat and pulses.

VARIETY IS THE SPICE OF LIFE

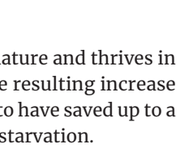
The definition of a sustainable crop is not set in stone, and what saved the world yesterday might not be up to the job today. The almost total lack of diversity in modern crops means science must keep assessing whether high-yield crops are living up to their name.

Semi-dwarf wheat proliferated as a "miracle crop" during the so-called "green revolution" in the second half of the 20th century, and is now so dominant in modern farming that it accounts for about 99% of global wheat by acreage. It was developed in Mexico halfway through the 20th century to make crops more robust.

While "normal" wheat is tall, frail, and prone to collapse in the wind, the semi-dwarf variety is shorter and stockier, takes less time to mature and thrives in heavy fertilizer. The resulting increase in yields is thought to have saved up to a billion people from starvation.

The problem is that semi-dwarf wheat is susceptible to high temperatures because of its relatively late life cycle flowering and grain growth. It needs water from rain just as drought conditions are becoming more likely.

A study published in March by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) suggests wheat strains with novel genotypes – gibberellic-acid-sensitive dwarfing genes to be specific – could be sown earlier and deeper, drawing from stored soil water and emerging bang on time.

> "There's enough diversity to cope with climate events. We just need to find and exploit it."
>
> 
>
> **MATTHEW REYNOLDS**
>
> Head of physiology at CIMMYT's wheat program

"We predict that these genotypes, coupled with deep sowing, can increase national wheat yields by 18%-20% under historical climate trends, without increased yield variability, with benefits also projected under future warming," says the study.

"These benefits are likely to extend to other dryland wheat production regions globally. Our results highlight the impact of synergy between new genetics and management systems to adapt food production to future climates."

Kernza heads are harvested by hand at a Land Institute research plot.

PHOTOS: THE LAND INSTITUTE (2); THOMAS LUMPKIN/CIMMYT

In general, diversity is a critical factor in breeding resilience, so experts are always on the lookout for wheat varieties with natural defences against extreme weather.

"There's enough diversity to cope with unpredictable climate events – we just need to find and exploit it," says Matthew Reynolds, head of physiology at CIMMYT's wheat program based in Sonora, Mexico. His organization investigates new wheat and maize varieties and tests 5,000 lines each year for physical stress in controlled environments, as well as for common diseases.

The best performers become parents to the next generation and the process is repeated until gold standard varieties are sent to be approved and used in agriculture. CIMMYT estimates wheat demand will spiral 50% by 2050. Its breeding lines are found in varieties sown on more than 60 million of the total 240 million hectares worldwide.

SEARCH FOR PERENNIAL CROPS

Cultivation over thousands of years has improved yields and other characteristics, but the grains we have today are annual, unlike wild grasses, which are perennial. Perennial plants tend to produce smaller grains and to grow more slowly, as they have a few years' time.

Once annual crops die, they leave bare ground and their root systems no longer stabilize the soil. These crops grow shallow and fast, need a lot of fertilizer and water, and only form temporary ecosystems.

Perennial crops grow more slowly, with lower yields, but they have extensive root systems that help stabilize the soil and allow them to reach water and nutrients deeper down, meaning that they need less fertilizer than annuals do, and are able to withstand more extreme conditions.

In the face of skepticism, the Kansas-based Land Institute in the US has set out to develop new perennial crop types. Its work has been bearing fruit. Kernza, its brand name for a perennial intermediate wheatgrass (Thinopyrum intermedium) is now an emerging, though still niche crop growing in 10 countries and 15 US states. Kernza can be used in baked goods, beer, or as a whole grain. It is described as having a sweet, nutty flavour. While the grain is 25%-50% the size of that from conventional wheat, breeding programs are expected to increase its size.

Kernza's roots can reach up to a depth of 3 meters. The grain can prevent 95% of nitrogen from leaching out of the soil, removes atmospheric carbon and stores it in the earth, and creates soil stability, preventing runoff.

The institute's long-term idea is to grow Kernza alongside a range of other long-lived plants to create a self-sustaining ecosystem that retains nutrients, soil, and water – the same way that nature works. It is breeding new varieties by domesticating wild perennials, including rice, legumes, oilseeds, sorghum, and wheat.

The mission statement of the Land Institute sums up the principles of sustainable farming: "When people, land, and community are as one, all three prosper; when they relate as competing interests, all three are exploited." ■

CALL TO IMPACT

1. Semi-dwarf wheat accounts for about 99% of global wheat by acreage – a high-risk dependence on just one species.
2. Up to 60% of wheat-growing areas will soon face severe water scarcity, making conventional crop growing difficult.
3. Wheat strains with novel genotypes could be sown earlier, drawing water from deeper and cropping more reliably.
4. Perennial cereal strains, which can be adapted from wild varieties, are beneficial to soil health.

BIRTH PAINS OF CULTURED MEAT

The energy, water, and feed costs needed to rear animals for food make this a costly and input-intensive form of protein. Is it time to give serious consideration to meat that never lived?

Cell-cultured chicken made by California-based Upside Foods

BY MASS, CHICKENS ACCOUNT for about 70% of the global stock of birds. There is roughly one sheep for every seven humans and nearly as many cows. The UK-based vegan charity Viva! says that 75 billion land animals die every year for the dinner table, including an eye-watering 66 billion chickens.

The morality of ending so many lives in the name of food is one thing. But another issue, from a world hunger point of view, is that they ever lived in the first place: fattening up such a colossal number of bodies for slaughter drains trillions of calories each year from food sources that could otherwise feed people. The problem is that people like meat.

In short, there is a pressing need for a Plan B. Cultured meat, or animal protein not grown on farm, but by technicians in a laboratory, is known as cultivated meat, or slaughter-free meat, or clean meat. The technology borrows from regenerative medicine, using tissue engineering to develop animal cells into muscle tissue that forms a steak, bacon rasher, or chicken breast.

The market sparked into life in 2013, when food critics Hanni Ruetzler and Josh Schonwald tasted the first lab-grown beef burger at a London press event. Their reviews were mixed. Ruetzler commented: "It's close to meat, but it's not that juicy. The consistency is perfect, but I miss salt and pepper." Schonwald added, "I miss the fat, there's a leanness to it, but the general bite feels like a hamburger."

The patty, funded by Google co-founder Sergey Brin, cost more than $300,000 to develop. But in the intervening period, prices have come down while quality has improved.

Californian start-up Eat Just began in 2011 with a mission to create a natural egg substitute using vegetable proteins. It raised $120 million in venture capital and became a unicorn in 2016, surpassing a $1 billion valuation.

In 2017, the company developed a cultivated meat product to make chicken nuggets. The government of Singapore approved cultivated meat in 2020, and the nuggets went on sale at the Singapore private members restaurant 1880, where they cost $17 for a set meal.

Figures from the Good Food Institute show that 21 companies entered the cultured meat market in 2021, a 24% increase on the previous year. Organizations including Future Meat, Wildtype and Upside Foods all opened manufacturing facilities, while JBS, the world's second-largest food producer, invested $100 million with a pledge to sell slaughter-free meat by 2024.

But the biggest endorsement comes in the perhaps surprising guise of the Chinese Communist Party, which in January of 2022 added cultured meat to its five-year plan for agriculture for the first time.

Eat Just CEO Josh Tetrick called it one of the most important policy decisions in the history of alternative proteins. "This nationwide strategic initiative could accelerate the country's regulatory timeline for cultivated meat, drive more research and investment into the alternative protein industry, and fuel broader consumer acceptance of these products."

That's the good news, but there's bad news too. In the same month as the CCP's announcement, a survey published by the UK Food Standards Agency revealed that just one-third of consumers in Britain were willing to try lab-grown meat.

This perhaps reflects a technology in its infancy. According to the Good Food Institute, more research is needed to find which cell types are most suited to mass production techniques, which is important given that products are currently grown in sheets only one cell thick.

This, combined with only a modest increase in funding for academic research and the customary sluggishness of regulatory change, means cultured meat is very much a technology for the future from a consumer point of view.

But if one-third of the planet is prepared to make the switch from once-living meat, then slaughter-free products are a trillion-dollar market in the making. Combined with growing consumption of plant-based meat alternatives and good old-fashioned vegetarianism, they could also take the strain from a planet that is creaking under the weight of animal carcasses.

PHOTOS: UPSIDE FOODS; GOOD MEAT

THE GROWING POTENTIAL OF LAB-PRODUCED FOOD

The twin challenges of population growth and soaring meat demand necessitates innovative, rapidly implemented solutions. Paul Shapiro, CEO of the Better Meat Co., thinks he has an answer.

Impact: What is Better Meat?
PS: It' a four-year-old start-up that takes microscopic fungi and subjects them to a special kind of fermentation that, within hours, converts them into a whole-food mycoprotein with a meat-like texture, more protein than eggs, more iron than beef, and naturally occurring vitamin B12. We sell that mycoprotein to food companies as an ingredient, either for them to hybridize meat for a lower carbon footprint or to create animal-free meat-like products.

How quickly has it grown?
Four years ago, it was basically an idea held by me and two other people and we were just looking for funding. Today, the business has 20 full-time employees and we have patent protection on our core process. We have built North America's largest mycoprotein biomass fermentation facility and we are partnered with major companies such as Hormel Foods to bring mycoprotein to the mass market.

What is the problem you're addressing?
The planet isn't getting any bigger, but humanity's footprint is constantly growing. One of the primary ways in which we leave that footprint is through the food we eat. It takes enormous amounts of land, water, and climate-changing emissions to raise and slaughter billions upon billions of animals for food.

I'd be thrilled if people would just eat rice burritos, lentil soup, and hummus, but most people want to eat meat, so we have to create meat that doesn't involve animals. There are numerous ways to do that, for example by taking soy or peas or wheat, and creating plant-based meat.

Or lab-based meat.
You can cultivate animal cells to grow in a lab, but we have taken a third way – fermenting microscopic fungi to create food, delivering the sensory experience people are accustomed to when they eat meat.

It's like the evolution of cars. It'd be great if people walked and cycled more, but they want to drive, so technicians are creating cars that don't run on fossil fuels, but electricity generated through wind, solar, and geothermal technologies.

What is the process?
We inoculate and harvest our fermenter within a 20-hour period, which is pretty quick compared to feeding a cow, when a year and a half passes before you get your steak.

How much we harvest depends on the size of the fermenter. Whether it's 1 liter or 100,000 liters, the timeframe is always the same, so we have a pretty quick cow. We're currently at a scale where we are producing hundreds of liters at a time. We have built a pilot-scale facility, now we need a full-scale facility with commercial-scale fermentation assets, which will produce a lot more of our product in the same timescale.

Cell-cultured chicken nuggets shown in Singapore, the first country to approve lab-grown meat

PHOTO: GETTY IMAGES/AFP/NICHOLAS YEO; ILLUSTRATION: ULI KNÖRZER

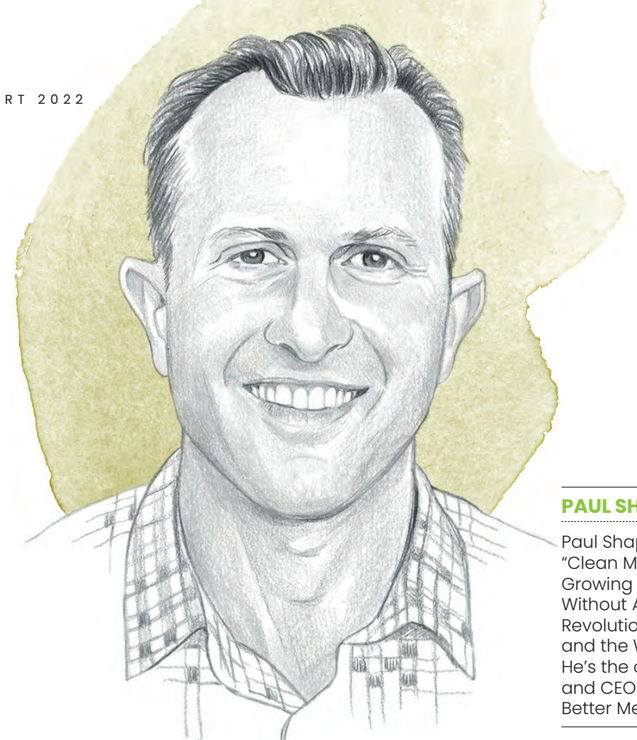
In what ways does it have the edge on animal cell culture?
I am very bullish on animal cell culture, so much so I wrote a book on the subject, called "Clean Meat," but it's still a technology for the future and it can't solve the problem in the near term because, although it's on sale in some parts of the world, it will take a long time to scale up to even 1% of the market. Plants are already doing very well, for example in milk alternatives – soy, almond, and oat – which are about 15% of the US market. Cultivated meat is at least a decade away from that sort of impact.

One is not better than the other, but we have a very efficient way to produce that meat experience, and it can be scaled today.

What is the flavor and consistency like?
Neither is easy to replicate, but we think it's hard to tell the difference when it comes to flavor. Consistency is harder, because meat has a unique texture. The benefit of mycoprotein is that it has very long filament fibers, the longer the fiber, the more meat-like it becomes, so we're pretty close.

Is this something that could satisfy the growing demand for meat?
The developing world is already eating increasing amounts of meat. Chinese demand has quadrupled in the last 50 years, India's appetite is soaring, and even in places like the US it's still going up. There are few places on Earth where demand is falling. Combined with numbers of people growing, you have a very serious global problem. The only way we can sustainably feed humanity, particularly with the kind of food it seems to want to eat, is by decoupling the meat experience from animal rearing and slaughter. To put it into perspective, a 20% decrease in cattle farming would translate to a 50% reduction in deforestation. Whether you care about the welfare of animals or the welfare of humans, it's clear we have to cut down the number of animals we are raising for food.

What are your plans for the future?
The potential scale is enormous, so my main concern is how quickly we can get there. The key will be to make alternative protein no longer "alternative." I think about other human innovations that changed fast, like analog to digital photography. We can make these transformations if there is the energy to do it. Investor interest is there, especially now that valuations are coming down, which I think will only serve to increase demand. ■



PAUL SHAPIRO

Paul Shapiro wrote "Clean Meat: How Growing Meat Without Animals Will Revolutionize Dinner and the World." He's the co-founder and CEO of The Better Meat Co.

CALL TO IMPACT

1. Animal production massively overuses scarce resources of land, water, food, and energy.
2. Tissue engineering can be used to develop animal cells into cultured steak, bacon rasher, or chicken breast.
3. Lab-grown meat will only be a niche market in the beginning – for example, the UK's Food Standards Agency found that just one-third of UK consumers were willing to try it.
4. If one-third of the world is prepared to switch from once-living meat, slaughter-free products promise a trillion-dollar market

CAN WE REALLY FEED THE WORLD WITH INSECTS?

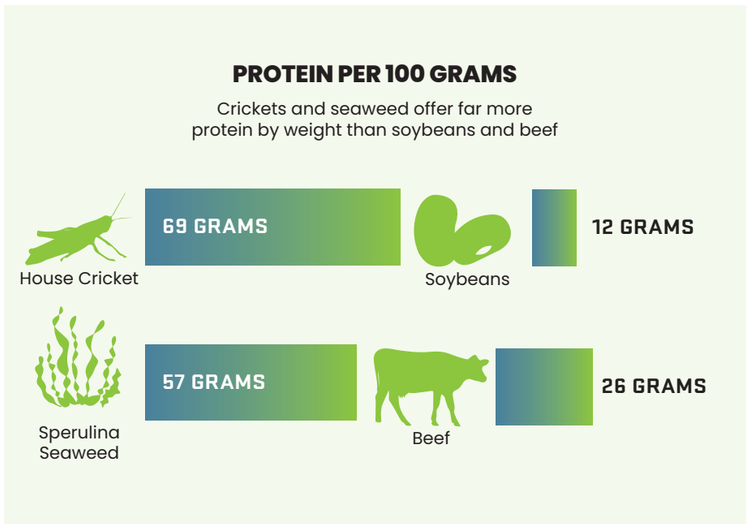
Novel proteins, such as those derived from insects, algae, and fungi, could be the answer to world hunger, but a long list of questions must be answered – not least, whether populations in the West will eat them.

THE WORLD HAS A PROTEIN PROBLEM. While the nutrient is essential to the growth and maintenance of healthy humans, billions of people get theirs via the regular consumption of mammalian and avian meat, which from a conservation perspective is inefficient and resource-intensive.

It's a problem for several reasons, one of which is the growing appetite for chicken, pork and beef worldwide. Between 1998 and 2018, meat consumption in developed countries broadly stabilized, but in the developing world it rocketed, causing a global increase of 58% to a total 360 million tonnes annually. Adding to this soaring demand is global population growth. It took the whole of human history to get to 6 billion people, then just 25 years to add a further 2 billion. The UN expects the figure to reach 11.2 billion by 2100 and, if that feels too far off, it projects 10 billion humans shortly after 2050.

If nothing changes, there will be a major and ongoing need to farm vast numbers of livestock and birds to feed everyone, which, as population grows, will become more and more difficult. Cattle and sheep, in particular, but also pigs, chicken and other large animals drain resources, produce carbon, and degrade land and rivers.

According to EIT Food, an EU-funded body promoting innovations in food production, a single kilogram of beef mass takes 8 kg of cattle feed, making it an extremely inefficient foodstuff to create and a poor solution to the problem of world hunger.



> "Insects could play an important role in tackling global hunger."
>
> **ALEXANDRA RUTISHAUSER-PERERA**
> Head of Nutrition at Action Against Hunger UK

Added to the pressure on production is the fact that most protein produced globally goes into farmed animal feed, with only 34% directly consumed by people in plant or animal form.

SIX LEGS BETTER THAN FOUR?

There are alternatives; ones that are high in protein, low in environmental impact and, according to the roughly 2 billion people who already eat them, bursting with flavor. Insect protein from mealworms, crickets, and locusts is consumed as a delicacy in many countries, and also used in the preparation of ingredients such as flour.

Cricket flour contains essential amino acids, calcium, iron, potassium, vitamins, and fatty acids. It can be used to make pasta, bread, burgers, and smoothies. One hundred grams of mealworms yields 45 grams of protein; for buffalo worms it's 56 g, while the humble house cricket delivers 69 g. Beef cannot compete with these numbers; on average it offers roughly 26 g per 100 g of produce.


Fried insects on sale in Khao San Road in Bangkok, Thailand

PHOTO: SHUTTERSTOCK/SHANTI HESSE; ILLUSTRATIONS: GETTY IMAGES / LINEARCURVES; GETTY IMAGES / VREEMOUS; GETTY IMAGES / FILO; GETTY IMAGES / JOBALOU;

Arnold van Huis, Professor of Tropical Entomology at Wageningen University, says that insect farms require less land and water, emit fewer greenhouse gases, convert protein more efficiently. Insects can be fed on organic by-products such as food waste, while some species can be used as animal and aqua feed, replacing inputs such as fish meal.

Combined with vegan diets that incorporate protein-rich plant alternatives, switching to insects "could have 80% less environmental impact than the average current European omnivore diet," says doctoral researcher Rachel Mazac from the Faculty of Agriculture and Forestry, University of Helsinki.

Reducing intensive farming of livestock for Europeans, as well as wealthy populations elsewhere, frees up resources to dedicate to feeding hungry people around the world with cheap, low-impact, nourishing food.

As Alexandra Rutishauser-Perera, Head of Nutrition at Action Against Hunger UK, says: "Consumption of insects could play an important role in tackling global hunger. Insects are more capable of weathering the increasing climate shocks we are witnessing and deliver more calories, protein, and nutrients than traditional staples."

As well as insects, other sustainable sources include seaweed and microalgae, which have a higher protein yield per hectare per year than soybean, pulses, legumes, and wheat. Plus, sea plants remove the need for added water, a huge bonus given that 75% of the world's consumption of fresh water is taken up by agriculture.

WORK TO BE DONE

Insect and plant protein has great potential, but more work is needed to realize the benefits, including a major PR campaign to convince large numbers to switch. As this is a novel food, global production is comparatively low with a lack of processing facilities, meaning prices are high in some parts of the world.

According to Rutishauser-Perera, another problem is the seasonality of many insect species, meaning their availability is limited during a calendar year. This is exacerbated in the developing world by inadequate means to preserve insects for consumption out of season. "There is a need to explore solutions that preserve them all year round," she says.

In the West in particular, red tape can be a roadblock on the development of insect foodstuffs, because of the risk of allergies. Progress has been slow. The EU, for example, only passed safety assessments on species of cricket, locust, and mealworm as recently as 2021. In the UK, meanwhile, marketing edible insects is permitted only after authorization by the Foods Standards Agency.

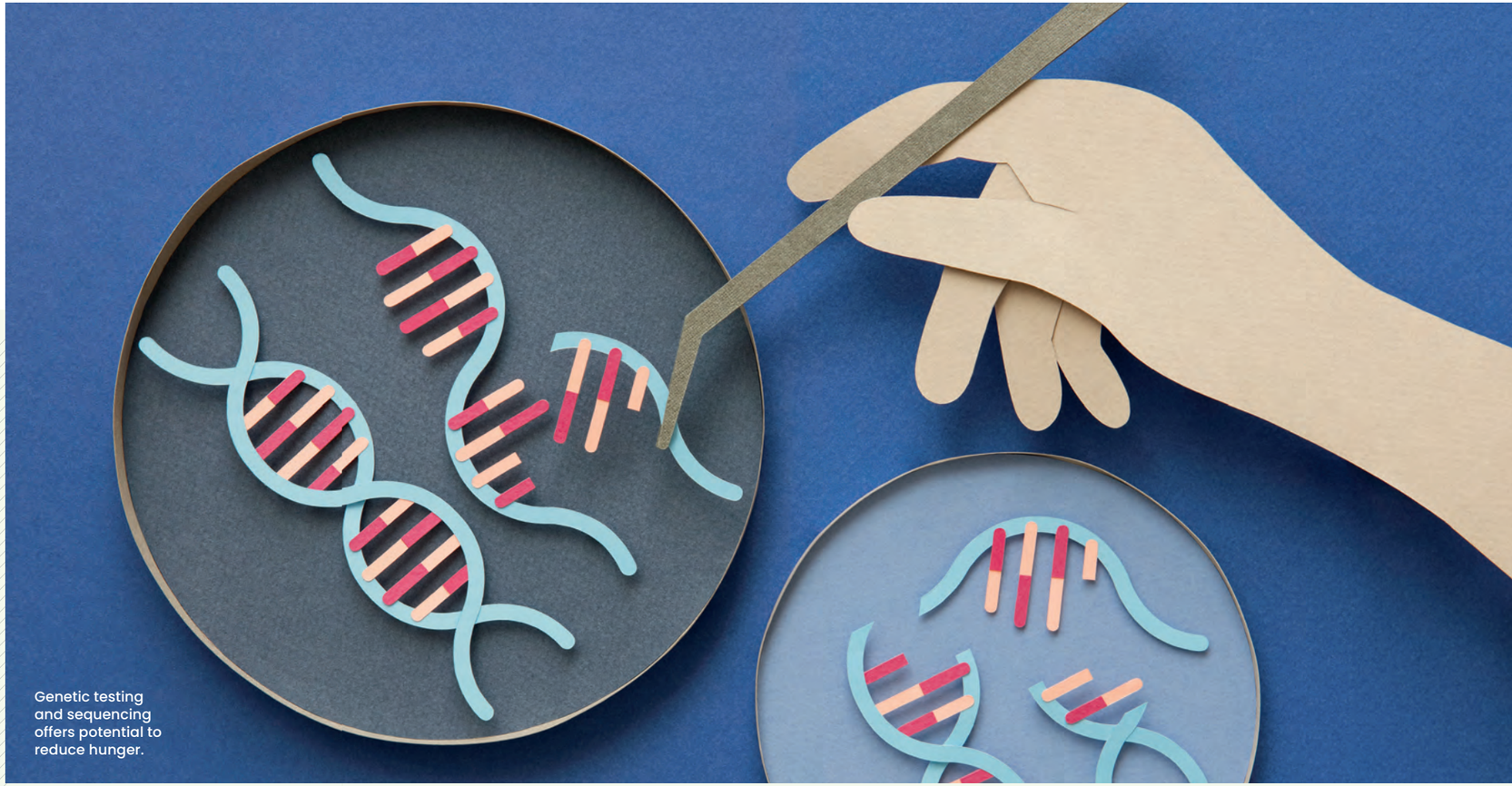
With sufficient backing, novel proteins have incredible potential in beating world hunger, particularly if combined with a general lowering of animal meat consumption and growth in new sources of plant-based protein. In short, where there is a will there is a way. ■

CALL TO IMPACT

1. Novel proteins, such as those derived from insects, algae, and fungi, could greatly help to reduce world hunger if invested in and more widely adopted.
2. Cricket flour contains amino acids, calcium, iron, potassium, vitamins, and fatty acids. It can be used to make pasta, bread, burgers, smoothies, and many other foods.
4. Seaweed and microalgae achieve a higher protein yield per hectare per year in commercial production than those associated with soybean, pulses, and wheat.
5. Regulatory progress has been slow. The European Union only passed its safety assessments on the human consumption of species of cricket, locust, and mealworm in 2021.

GENE SCIENCE AND SUSTAINABLE FOOD

A front-runner in new genomic techniques is making waves. Advocates say that Crispr could lead to life-saving genetic vaccines and help create "super crops" that will contribute to feeding the world.



Genetic testing and sequencing offers potential to reduce hunger.

ILLUSTRATION: GETTY IMAGES/MOMENT/ EUGENE MYMRIN

WHEN IT COMES TO CLIMATE change and scarcity, agriculture is both a cause and a casualty. Mainstream techniques, barely adapted over generations, can be intensive, wasteful, polluting, and incapable of meeting global demand for food in the long term.

Arguably, the best, most realistic course of action is to improve what farmers do already. The question is, how? From a global hunger point of view, one way is to ensure more of the seeds that go into the ground come out again in the form of healthy wheat, rice, maize, tubers, vegetables, pulses and sugar.

CABI, the inter-governmental group charged with improving agriculture through science, says that between 20% and 40% of cereal and potato crop yield is lost to pests and diseases each year. Julien Godwin, head of project operations at the organization, says that this "directly impacts food security and nutrition, while losses in key commodity crops, such as banana and coffee, have major impacts on both household livelihoods and national economies."

The problem could get worse before it gets better. Climate change is in some cases causing more instances of disease and more pest infestations, as well as the increased physical stress resulting from extreme weather.

The world needs scalable, impactful solutions, and "gene scissoring" might be one of them. Clustered Regularly Interspaced Short Palindromic Repeats, or CRISPR for short, is the name given to a genetic engineering technique by which the genomes of living organisms can be modified. The bacterial CRISPR/Cas9 enzyme-based antiviral defence system allows genes to be removed or added precisely and cheaply to living organisms. That's what has earned CRISPR/Cas9 the more common name "gene scissor."

In the animal kingdom, CRISPR technology has been used to enhance meat quality, disease resistance, organs for human transplantation, and even virility. In flora, genome mutations could be implanted to increase quality, yield, and tolerance to unfavorable growing conditions, as well as to domesticate particular plant types.

Since its introduction as a gene-editing tool in 2012, CRISPR has made some significant strides forward, not to mention earning its discoverers, Jennifer Doudna and Emmanuelle Charpentier, a Nobel prize in chemistry.

Doudna is an American research biochemist based at UC Berkeley. Charpentier is French and director of the Max Planck Institute for Infection Biology (MPIIB), in Berlin. They met in 2011 and began a collaboration on using Cas9 to make cuts in DNA sequences, using guide RNA molecules. Both women are co-founders of medical biotech companies – Doudna of Scribe Therapeutics, and Charpentier of CRISPR Therapeutics.

CRISPR, which has regulatory approval in the US but not in the EU, has already had practical applications, including diagnostic testing for Covid-19. It may form the basis of a new generation of genetic vaccines that could be used to treat conditions including malaria and cell therapy treatments for cancer. Experts predict that crops modified using this technique could be mainstream within the next decade.

"CRISPR has given researchers the ability to make changes to the genome with surgical precision," says Dr. Sadie Hayta, senior scientist at The John Innes Centre. "They have used it to create wheat plants with larger grains, design novel tomato plant architectures, generate resistance to fungal infection and engineer other traits in new plant varieties."

In May 2021, Sanatech Seed, a start-up partnering with the University of Tsukuba in Japan, began selling a gene-edited variety of tomato seed it calls the Sicilian Rouge High GABA. In September, it began offering the tomatoes themselves, and soon afterwards a puree, though only to customers in its native Japan.

From a scientific point of view, it's full steam ahead, but regulators in some parts of the world are urging caution. A month before Sanatech's tomato seeds hit the market, the European Commission published a report admitting "limitations as to the capacity of [existing] legislation to keep pace with scientific developments."

A release published with the report added: "There are strong indications that the legislation is not fit for purpose for some new genomic techniques (NGTs) and their products, and that it needs to be adapted to scientific and technological progress." It added that NGTs "have the potential to contribute to sustainable agri-food systems."

China, so often a technological first-mover, approved gene-edited crops in February 2022, paving the way for a national biosafety certificate within two years.

There is no shortage of enthusiasm or financial backing for the technique, especially now the world's second-biggest economy has given CRISPR the green light. One way or another, we'll be able to gauge the efficacy of agricultural gene-scissoring soon. ■

CALL TO IMPACT

1. CRISPR technology is mainly associated wih health contexts, but has a far wider potential.
2. In crops, CRISPR can be used to increase quality, yield, and tolerance to unfavorable growing conditions, and to domesticate wild plant types.
3. CRISPR has regulatory approval in the US but not in the EU, which has traditionally blocked the adoption for farming of genetically modified organisms (GMOs).
4. China, a technological first-mover, approved gene-edited crops in February 2022, paving the way for a national biosafety certificate within two years.

TIME FOR A REAL RIGHT TO FOOD

The global community still hasn't solved the problems of hunger and poor nutrition. It should be our foremost duty as humanity to fulfil the most basic of all basic needs for all human beings. Here's how.

BY SAFIYE KUCUKKARACA, HEAD OF THINK, FII INSTITUTE

WE COULD REALLY FEED THE WORLD. And, in theory, we already do. We produce enough food to secure every person on earth a sufficient and nutritious diet. And we could do it even for some more billions of people than actually live on this planet. But in practice, 800 million of us are still undernourished, and millions die of starvation each year.

Clearly, our international institutions have not risen to that challenge. Yes, the UN World Food Programme, set up in 1961, has often provided lifesaving food aid and disaster relief. But there's no institution to cover the "normal" disaster of starving. Yes, we have the UN's Universal Declaration on the Eradication of Hunger and Malnutrition from 1974, but it has mostly stayed a declaration on paper. And paper has no nutritional value.

The people now living on this planet are wealthier and better educated than any previous generation – and still haven't solved the problems of hunger and poor nutrition. Also, the UN's emphasis on a theoretical right to food has not succeeded. It has not fed the hungry, nor has it addressed the causes of hunger: poverty, war, extreme climate and waste; nor, just as importantly, has it addressed the causes of the causes.

In a fairer world, adults in every country would have enough income to buy food for themselves and their families. This is the situation in almost all industrialized countries and also in some emerging countries. It should be the case everywhere. The means are there, theoretically. Let's use them in practice.

On the international level, this could be done by declaring the right to food as a material human right – a right that can be claimed and enforced. This may need new institutions and it will definitely need considerable resources. But we as humanity have these resources; we just use them for other purposes. On the individual level, there are lots of actions we can take to make the world a hunger-free place. Some of them are described on the opposite page among our "Ten ways to reduce hunger."

We don't have to wait for the great global consensus to take these actions. The world needs a new paradigm to end hunger, and it needs to come from us. ■

PHOTOS: GETTY IMAGES/WESTEND61, FII

TEN WAYS TO REDUCE HUNGER
A CHARTER FOR CONSUMERS, POLICY SHAPERS, SCIENTISTS, AND GOVERNMENT

1 REDUCE WASTE
A third of the world's food is lost or wasted. In developing countries, economic development will lead to better infrastructure, improving transportation and storage. In the Global North, cultural change is needed. We should not fixate on cosmetic perfection or buy food we don't need. The land and resources devoted to food that is never eaten are vast.

2 ADOPT A WIDER FOOD PALETTE
The world relies on too few cereal crops and animal species. Thousands more wheat, maize, rice, and fruit and vegetable varieties, including many developed from wild species, could be eaten. Taking more of our nutrients from insects, fermented microbial cultures, and cultured cells will also mean that current farm land can be rewilded.

3 CONSUME LESS MEAT
Rearing meat for human consumption is an inefficient use of land, water, and energy. The UN's FAO and the EAT-Lancet Commission have called for the world to become "flexitarian," to both protect the environment and improve health. The Mediterranean, Okinawa, African Heritage, and Red Sea diets, which include only small amounts of red meat, are the healthiest.

4 EMBRACE SCIENCE
Genome-sequencing and gene-editing techniques, such as CRISPR, have vast potential. We can take DNA sequences from wild plants to make new ones that will grow in hot places. Genetically adapted varieties can make the world's drylands productive and allow cereals to grow without destroying soil. Technologies should be open-source and not tied to specific fertilizers or pesticides. Robots can now pick weeds.

5 END CALORIE FIXATION
Calorie-rich diets, high in overprocessed starchy cereals, have failed the Global North, where cardiac diseases and diet-linked cancers and diabetes are health blights. They have also failed the Global South. Relying on feeding the undernourished with grain sourced from Canada, the US, Russia, and Ukraine is not a long-term solution.

6 FOCUS ON QUALITY NOT YIELD
Intensive agrochemical-based farming is killing the planet. And if the planet dies, we all do. Consequently, farming practices should shift from their post-World War II focus on ensuring crop yields and fattening animals quickly at all costs, to producing crops and animals that are rich in micronutrients and uncontaminated by harmful chemicals.

7 FARM MORE SUSTAINABLY
Regenerative agriculture, applied to plants and livestock, recognises the interconnected ecosystems of water and nutrient cycles, focuses on soil health, and puts more into the environment than it takes out. Carbon sequestration is increased, nitrogen and phosphorous release are reduced. It's a longer-term answer to food insecurity than applying more and more mineral fertilizer to ever-degrading soils.

8 INTRODUCE VARIED FARM TYPES
Assisted by the latest energy, sensor, water, and gene technologies, controlled environment farming has huge potential to produce food in water-stressed areas. In hot, dry countries, desalinated water can be used for irrigation and cooling. Under a new food model, locally produced nutritious vegetables would be supplemented by varied imported cereals grown in the Global South.

9 FOOD AS MATERIAL HUMAN RIGHT
As we produce far more food than is necessary to feed every human being, hunger is not just a problem of distribution, but a failure of mankind. The global community should move from a written right to food to a material right to food. It would require considerable resources to facilitate that right – and robust mechanisms to enforce it.

10 ESTABLISH A HUNGER FUND
As Elon Musk has shown, there is a willingness among the global rich to contribute to ending global hunger. Governments, corporations, NGOs and individuals could donate resources to a Feed the World Fund exclusively dedicated to eradicating hunger. And if voluntary action is not enough, we can still talk about a hunger tax.

PUTTING BREAD ON THE TABLE IS A CHALLENGE FOR HUMANITY

FII-I has three pillars to deliver its mission: THINK, ACT and XCHANGE

1 FII-I THINK
Identify societal challenges and current inhibitors. Curate the brightest ideas to address societal issues

2 FII-I ACT
Catalyze innovation and initiatives by mobilizing partners and resources

3 FII-I XCHANGE
Create platforms for live discussions on the future of humanity. Share knowledge, stories, and publications with different stakeholders

OPTIMISM is the most sustainable resource we have. It is the force by which we can create a new reality, and it is more in demand than ever before, as we face the challenges of climate change, biodiversity loss and rising food insecurity at the same time. In this report we have looked at sustainable and equitable ways to end hunger.

Feeding the world is a moral imperative for humanity, and putting bread (or rice) on the table is a daily challenge for hundreds of millions. Climate change and political and economic disruption are threatening food security in the short term, and this threat will stay with us in the long term. In this Impact Report we have set the goal of food security as a human right, and offer solutions for how technology, innovation and human effort can contribute to reaching that goal.

Publishing solutions alone can solve no problem. Something needs to be done – only action can have an Impact on Humanity. That's why we have placed a Call to Action box at the end of each article, and included a ten-point plan to reduce hunger, addressing consumers, policy shapers, scientists and governments.

ABOUT THE FII INSTITUTE

THE FUTURE INVESTMENT INITIATIVE (FII) INSTITUTE is a new global nonprofit foundation with an investment arm and one agenda: Impact on Humanity. Global, inclusive and committed to Environmental, Social and Governance (ESG) principles, we foster great minds from around the world and turn ideas into real-world solutions in five critical areas: Artificial Intelligence (AI) and Robotics, Education, Healthcare and Sustainability.

THE FII INSTITUTE

is guided in all it does by a strong purpose, vision and mission.

PURPOSE
"Enabling a brighter future for humanity"

VISION
"Empowering the world's brightest minds to shape a brighter future for ALL, and with ALL"

MISSION
"Curating and enabling ideas to impact humanity sustainably"

PHOTO: ADOBE STOCK, FII INSTITUTE

We are in the right place at the right time: when decision-makers, investors and an engaged generation of youth come together in aspiration, energized and ready for change.

We harness that energy into three pillars: THINK, XCHANGE, ACT.

- Our THINK pillar empowers the world's brightest minds to identify technological solutions to the most pressing issues facing humanity.

- Our XCHANGE pillar builds inclusive platforms for international dialogue, knowledge-sharing and partnership.

- Our ACT pillar curates and invests directly in the technologies of the future to secure sustainable real-world solutions.

Join us to own, co-create and actualize a brighter, more sustainable future for humanity. ■

SOURCES

Overview of key sources used for this report

PROBLEMS AND SOLUTIONS

United Nations Food and Agriculture Organisation (UNFAO)
https://www.fao.org/home/en

UN World Food Programme (WFP)
https://www.wfp.org/

World Health Organization (WHO)
https://www.who.int/

International Fund for Agricultural Development (IFAD)
https://www.ifad.org/en/

State of Food Security and Nutrition in the World (SOFI) 2022
https://www.fao.org/publications/sofi/2022/en/

Global Hunger Index (GHI)
https://www.globalhungerindex.org/

Global Food Security Index (GFSI)
https://impact.economist.com/sustainability/project/food-security-index/

Our World in Data
https://ourworldindata.org/

NEW LANDSCAPES

World Resources Institute (WR)
https://www.wri.org/

Noble Research Institute
https://www.noble.org/

Savory Institute
https://savory.global/

The Land Institute
https://landinstitute.org/

Red Sea Farms
https://redseafarms.com/

King Abdullah University of Science and Technology (KAUST)
https://www.kaust.edu.sa/en

Rainforest Alliance
https://www.rainforest-alliance.org/

University of Alaska Fairbanks
https://www.uaf.edu/uaf/

NEW IDEAS

EIT Food
https://www.eitfood.eu/

Consultative Group for International Agricultural Research (CGIAR)
https://www.cgiar.org/

International Center for Tropical Agriculture (CIAT)
https://ciat.cgiar.org/

International Maize and Wheat Improvement Center (CIMMYT)
https://www.cimmyt.org/

IMPRINT

FUTURE INVESTMENT INITIATIVE INSTITUTE

PUBLISHER
Future Investment Initiative Institute
3884 Alakheel
District Unit 9
Riyadh 12382 - 6613
Kingdom of Saudi Arabia

CONTACT
For clarifications and inquiries, kindly email:
info@fii-institute.org

EDITOR
William Hatchett

“THE PLANET IS A LOT TOUGHER THAN AS PORTRAYED BY ENVIRONMENTALISTS. BUT THAT DOESN’T GIVE US LICENSE TO KEEP TRASHING THE PLACE.”

MARK TESTER, PROFESSOR OF PLANT SCIENCE AT KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY (KAUST)

FII INSTITUTE
Future Investment Initiative Institute
Impact on Humanity

Founding Partner

Public Investment Fund

Vision Partner

وزارة الاستثمار
Ministry of Investment

Strategic Partners

aramco · BNY MELLON · الصندوق الثقافي · DIRIYAH · EMAAR · HSBC SABB · MA'ADEN معادن · مسار MASAR · Reliance Industries Limited · ROSHN · الهيئة الملكية لمحافظة العلا Royal Commission for AlUla · الهيئة الملكية لمدينة الرياض ROYAL COMMISSION FOR RIYADH CITY · سابك sabic · سنابل للاستثمار SANABIL INVESTMENTS · SNB · stc · SoftBank Vision Fund · standard chartered · The Red Sea Development Company · TONOMUS. NEOM · صندوق التنمية السياحي Tourism Development Fund