MOONSHOT
RESEARCH & DEVELOPMENT PROGRAM

Moonshot International Symposium
December 18, 2019
Working Group 5

Innovation for Future Agriculture
-Satisfying Both Food Production and Environmental Conservation-

Hokkaido University

Research Faculty of Agriculture Fundamental AgriScience
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I. Food and the environment in 2050 and the most urgent issues to address

II. Necessary direction for Moonshot Research work

I-1. Issues that Moonshot must resolve

- With an eye on the future, the Moonshot Research and Development System sets ambitious goals for difficult social issues that can potentially have a serious impact.
- Simultaneous pursuit of sustainable food supply and global environmental conservation is a vital challenge for a sustainable society, and success can contribute to meeting all 17 SDGs.

Issues requiring resolution

○ As the global population grows and the food production environment deteriorates, these are the key issues to resolve to ensure a sustainable food supply.

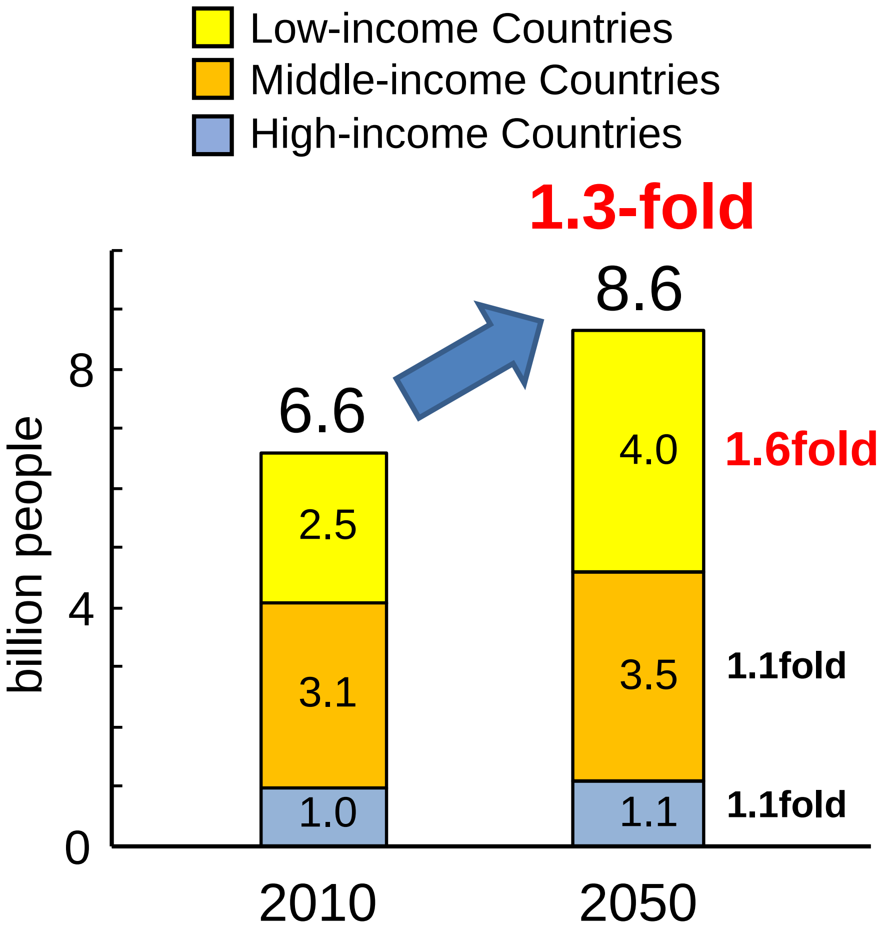
1. Conversion from agriculture requiring a lot of fertilizer, water, etc., to agriculture that contributes to environmental conservation
2. Construction of robust food production systems adapted to climate change and natural disasters associated with global warming
3. Review of food supply systems to eliminate food loss and other economically wasteful food consumption

By resolving social issues through this project, we can contribute to the achievement of all 17 SDGs (goals).

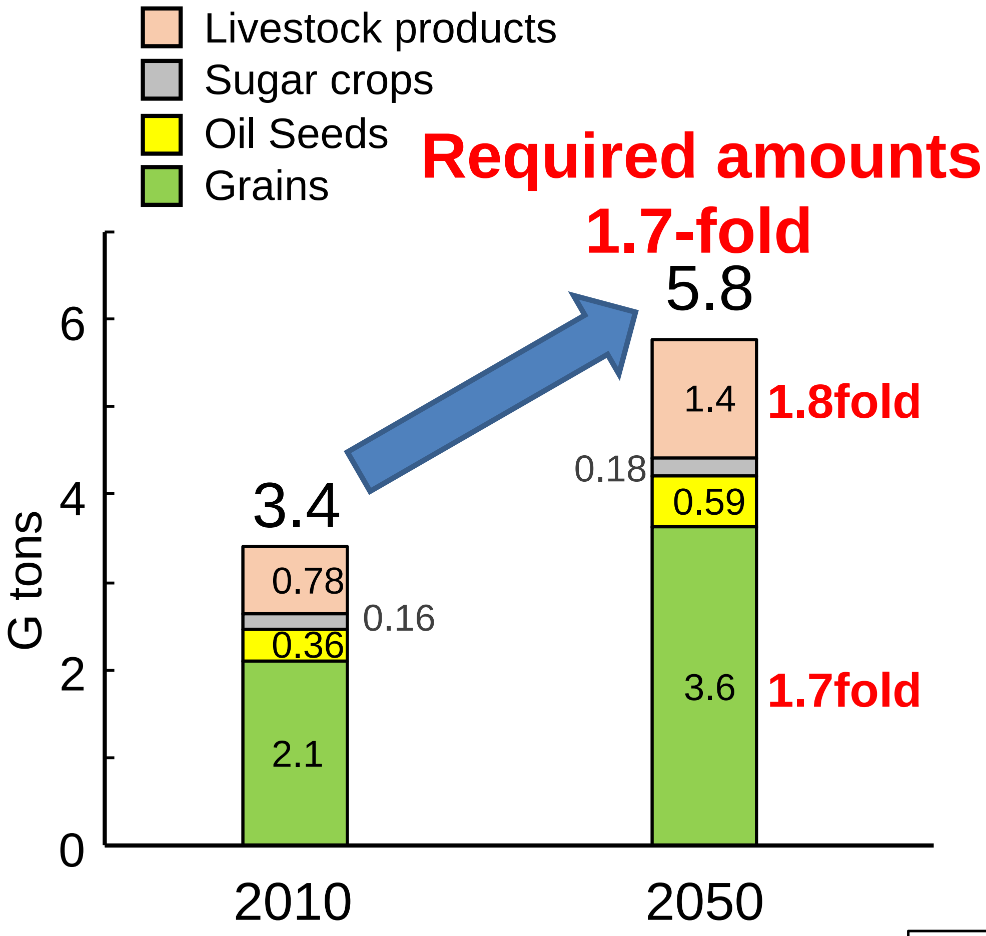
I-2. Outlook on global food demand in 2050

- In 2050, the world's population will be 30% higher than it was in 2010, but due to economic growth in middle-income countries (e.g., higher demand for meat), global food demand is expected to be 70% higher than in 2010.

○ World population outlook



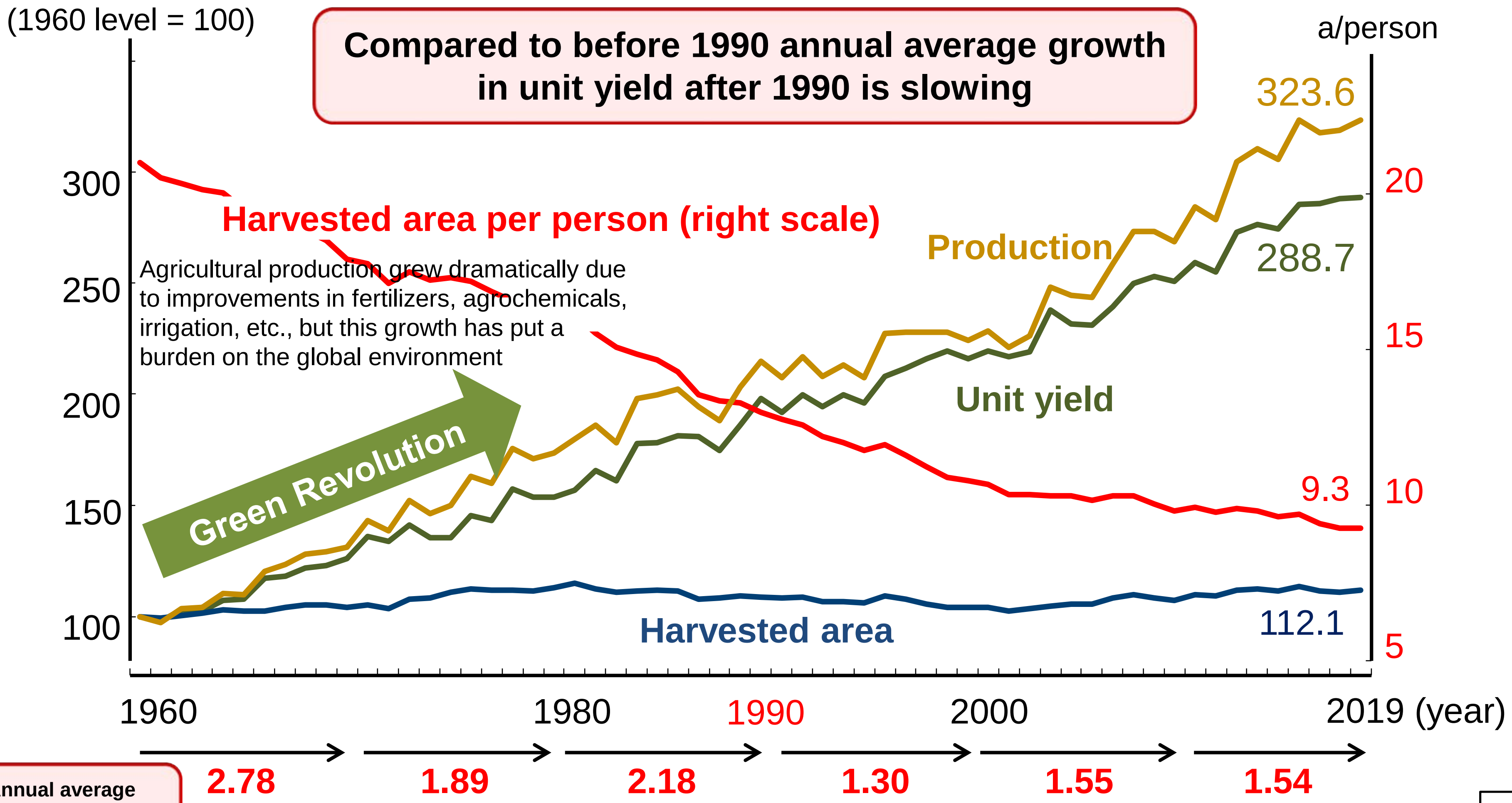
○ Global food demand outlook



Source: Adapted from materials created by Ministry of Agriculture, Forestry and Fisheries

I-3. Grain production trends

➢ As the global population continues to grow steadily, the harvested area of grain remains almost unchanged, meaning the harvested area per person is falling. The spread of irrigation farming and large fertilizer inputs have improved unit yield, but this growth has been slowing in recent years.



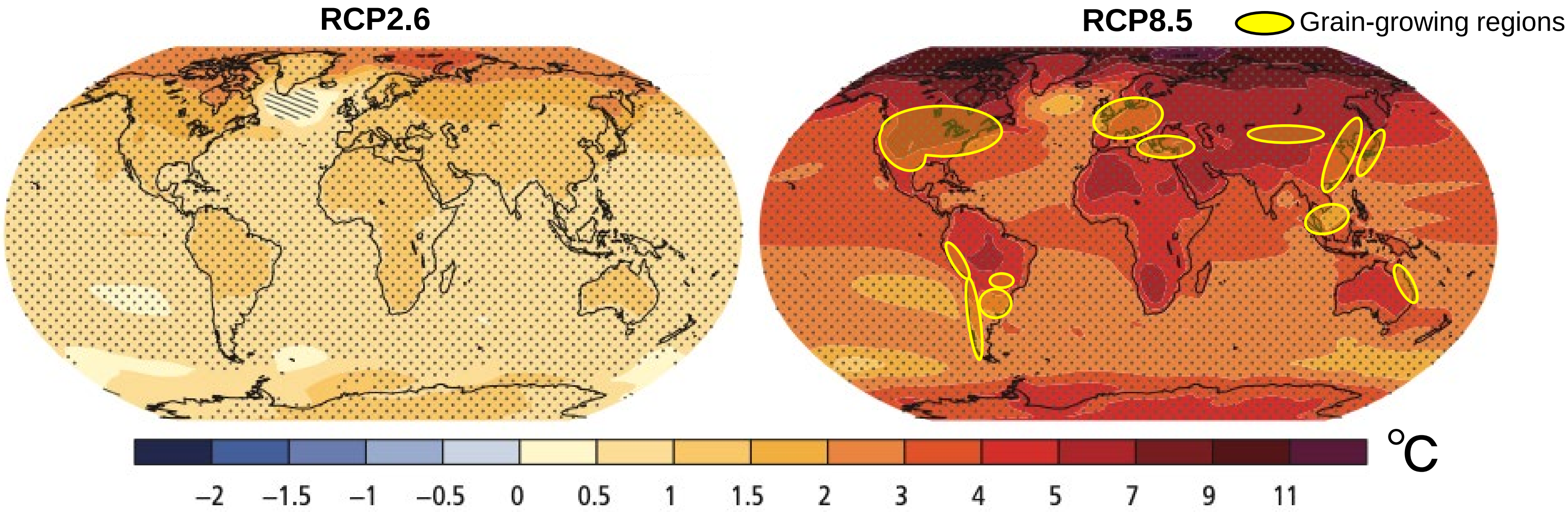
Annual average growth in unit yield (geometric mean)	2.78	1.89	2.18	1.30	1.55	1.54

Source: Adapted from materials created by Ministry of Agriculture, Forestry and Fisheries based on USDA「PS&D」（July 2019）, United Nations「World Population Prospects」

I-4. Climate change risks from continued global warming

➢ Global average surface air temperature to rise by 0.3 to 4.8 ° C by 2100.

◯ Change in annual average surface air temperature (difference between 1986–2005 and 2081–2100)



RCP scenarios of IPCC

GHG emission scenarios

RCP2.6: Emissions are strictly regulated

RCP8.5: Emissions are unregulated

Estimated rise in global average surface air temperature

RCP2.6: 0.3–1.7 ° C, RCP8.5: 2.6–4.8 ° C

Serious concerns about the possible large decline in production yields and stability due to warming and drying of the world's grain-growing regions.

IPCC：Intergovernmental Panel on Climate Change

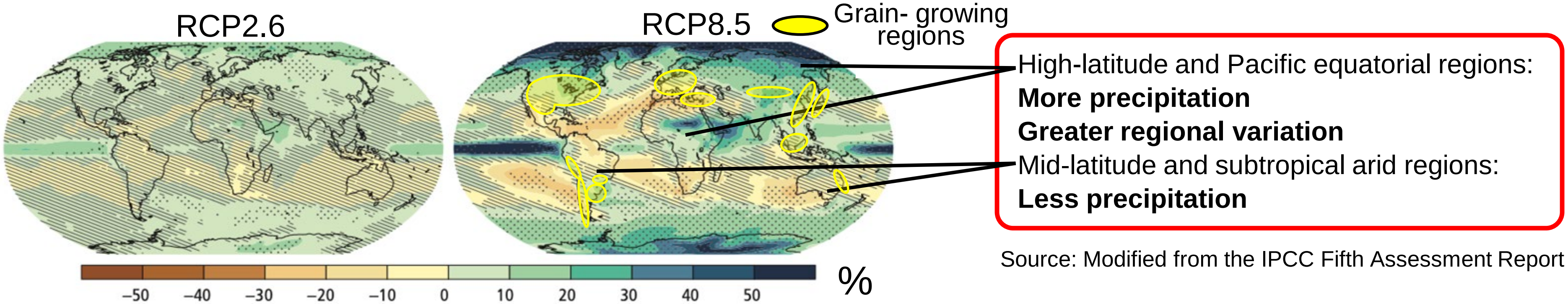
RCP：Representative Concentration Pathways

Source: Adapted from IPCC 5th Assessment Report

I-5. Impact of water resource limits on agricultural production

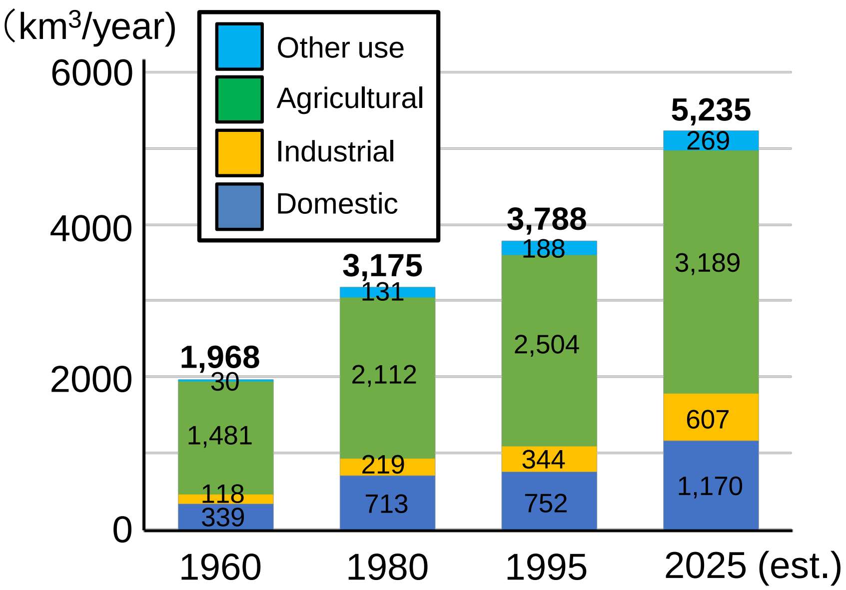
➢ Because of the spread of irrigation farming, demand for water is rapidly rising, leading to water shortages and farmland degradation (higher salinity).

○ Increase in annual average precipitation（1986-2005 to 2081-2100)



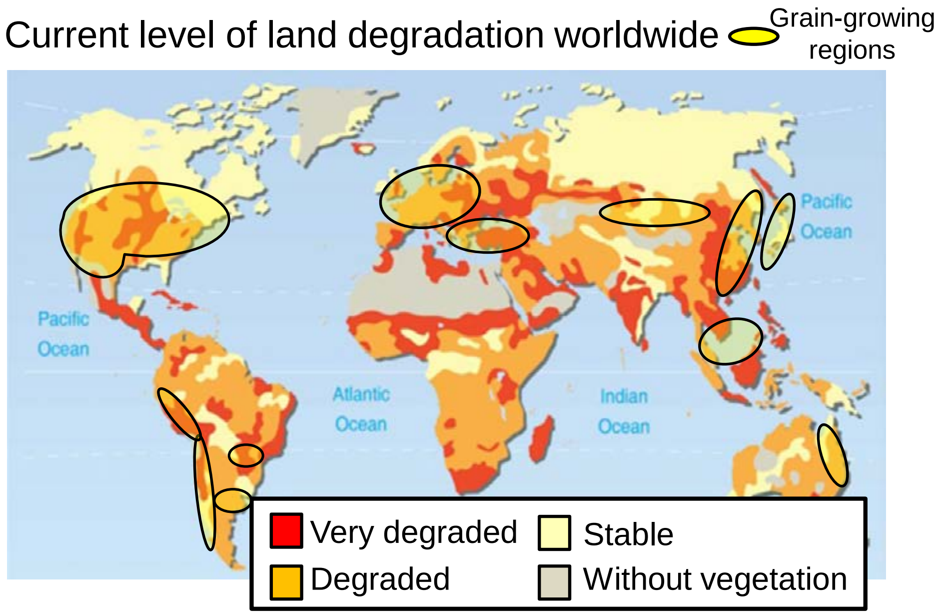
Source: Modified from the IPCC Fifth Assessment Report

○ Change in world water use by purpose



Source: Adapted from UNESCO「World Water Resources Beginning of the 21th Century」(2003）

○ Current level of land degradation worldwide

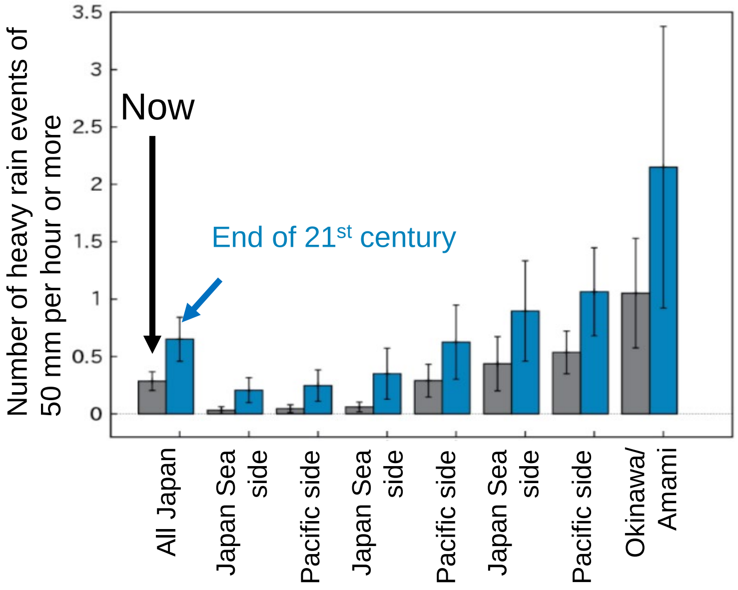


Source: Adapted from Global Soil Degradation. IAASTD-International Assessment of Agricultural Science and Technology for Development. (2008）

I-6. Current and projected damage to farm products due to natural disasters in Japan

➢ Heavy rains will become more frequent in Japan, resulting in increasingly severe damage to farm products.

In the case of RCP8.5, the annual occurrence of heavy rain is expected to more than double on national average.



Source: Created based on 2017 global warming forecast data by the Japan Meteorological Agency

Damage caused by heavy rains in July 2018

Type of damage	Main damage	Damage extent	Damage value (¥100 million)
Farm products	Farm products	21,168 ha	94.3
	Greenhouses	8,901events	63.6
	Subtotal for farm products, including livestock		300.2
Farmland and agricultural facilities	Damage to farmland	26,821 ha	565.1
	Agricultural facilities	23,371 places	854.5
Total damage including forests and fisheries			**3,409.1**

Source: Ministry of Agriculture, Forestry and Fisheries website

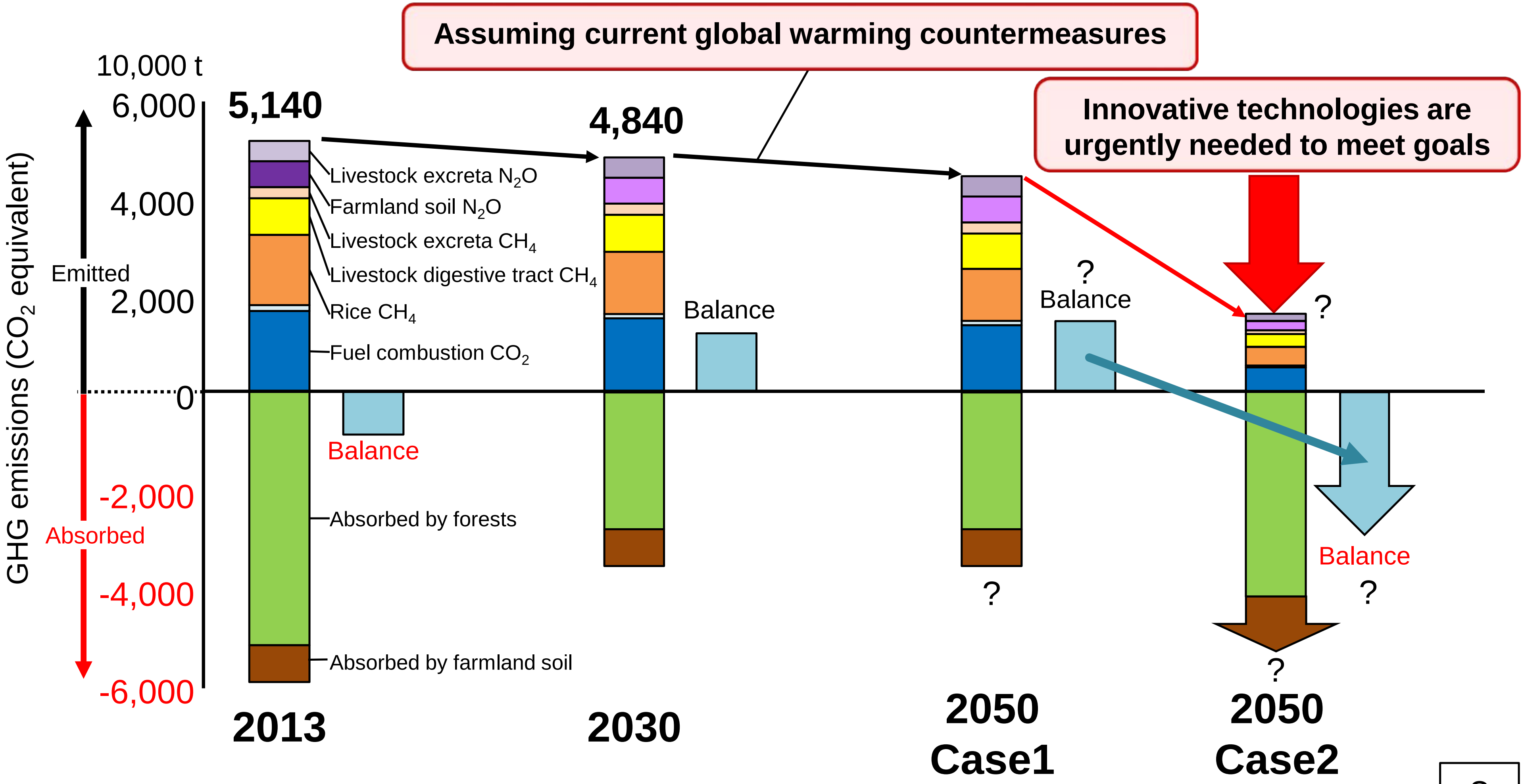

Flooding of a soybean field


Flooding of a greenhouse


Collapse of a reservoir

I-7. Trends in GHG emissions from agriculture, forestry, and fisheries in Japan

- For the "Long-term Strategy under the Paris Agreement," a bold commitment to reducing greenhouse gas (GHG) emissions by 80% by 2050 is required.
- Agriculture, forestry, and other land use accounts for one quarter of the world's total GHG emissions. There is an urgent need to cut these by developing innovative technology.



Source: Adapted from materials created by Ministry of Agriculture, Forestry and Fisheries

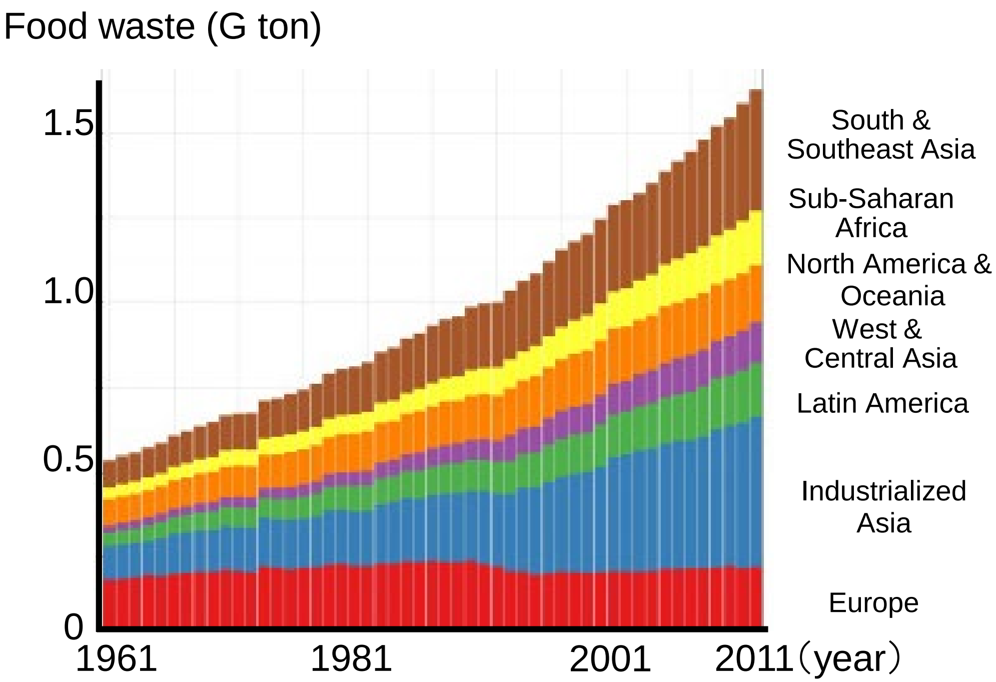
I-8. Current state of food consumption (food loss and waste)

➢ More than one-third of edible food parts gets lost or wasted, mostly in developed countries.

○ Change in total food loss and waste globally

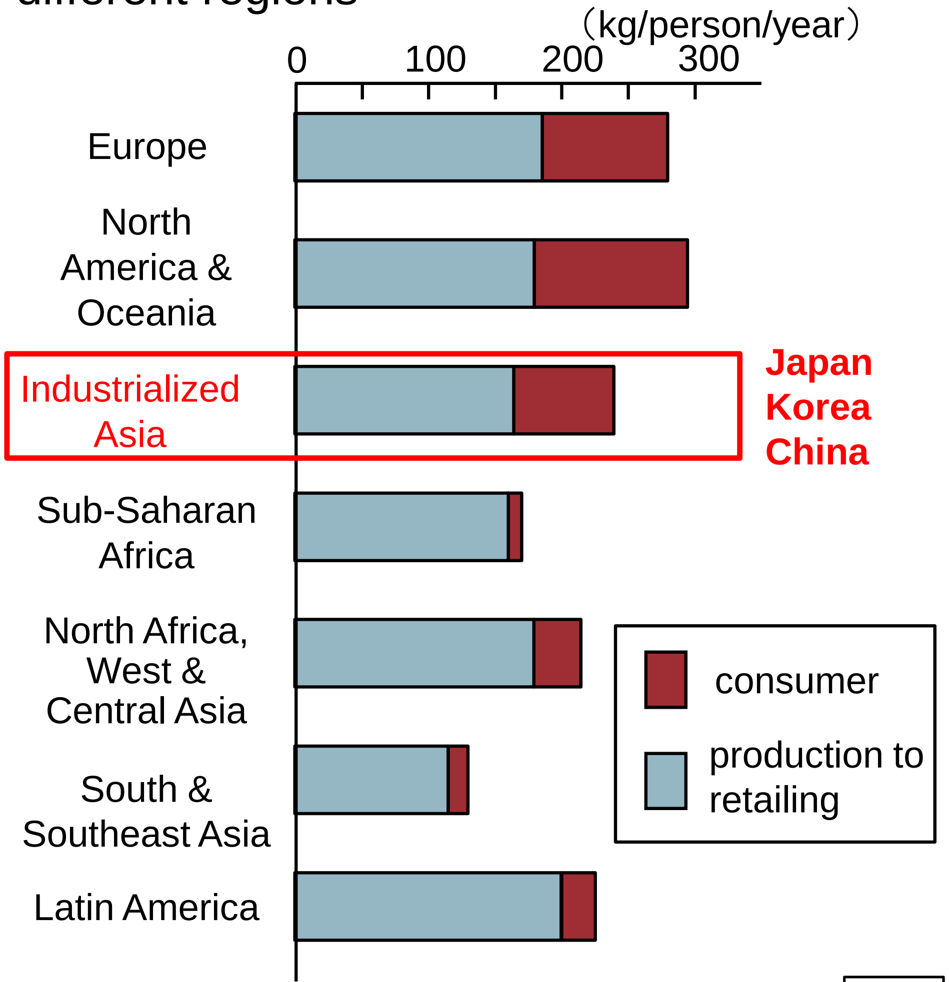
Total in FY2011 was 1.6 billion tons

cf. Total rice production in Japan: 8.6 million tons



Source: Adapted from *Science of The Total Environment* (Porter , S.D. et al. 2016)

○ Per capita food losses and waste in different regions

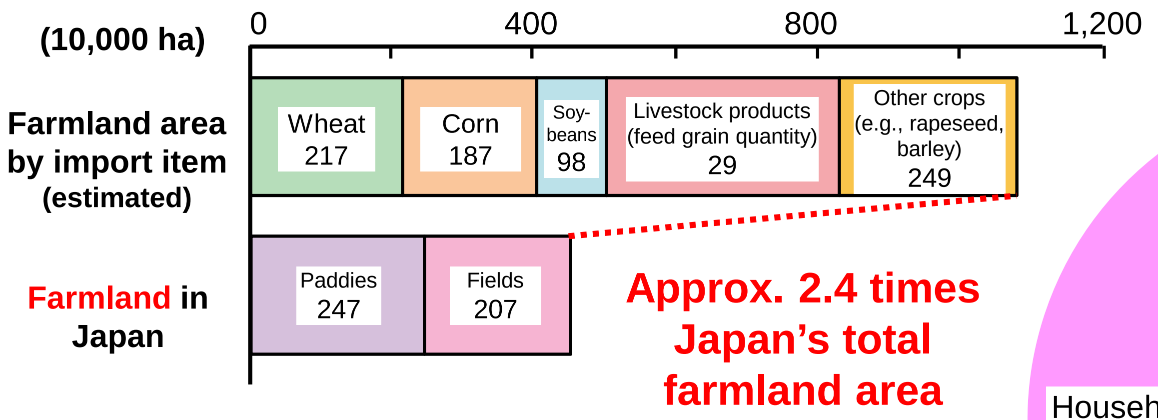


Source: Adapted from FAO(2011)

I-9. Current state of food consumption, loss & waste, and overseas reliance in Japan

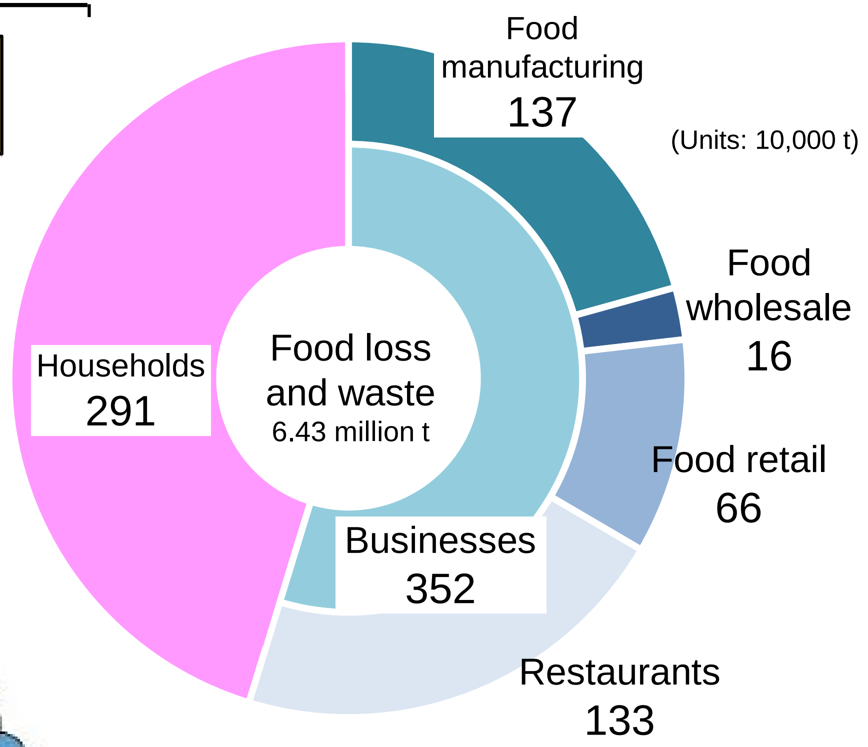
➢ Japan has a low level of food self-sufficiency. In addition to its total farmland, Japan relies on 2.4 times as much overseas farmland to feed itself. Thus, a rise in global food demand could significantly impact Japanese dining tables.

○ Reliance on overseas farmland



Source: Cited and modified estimation materials by the Ministry of Agriculture, Forestry and Fisheries based on "Food Balance Sheet," "Statistics on Cultivated Land and Planted Area"

○ State of food loss in Japan



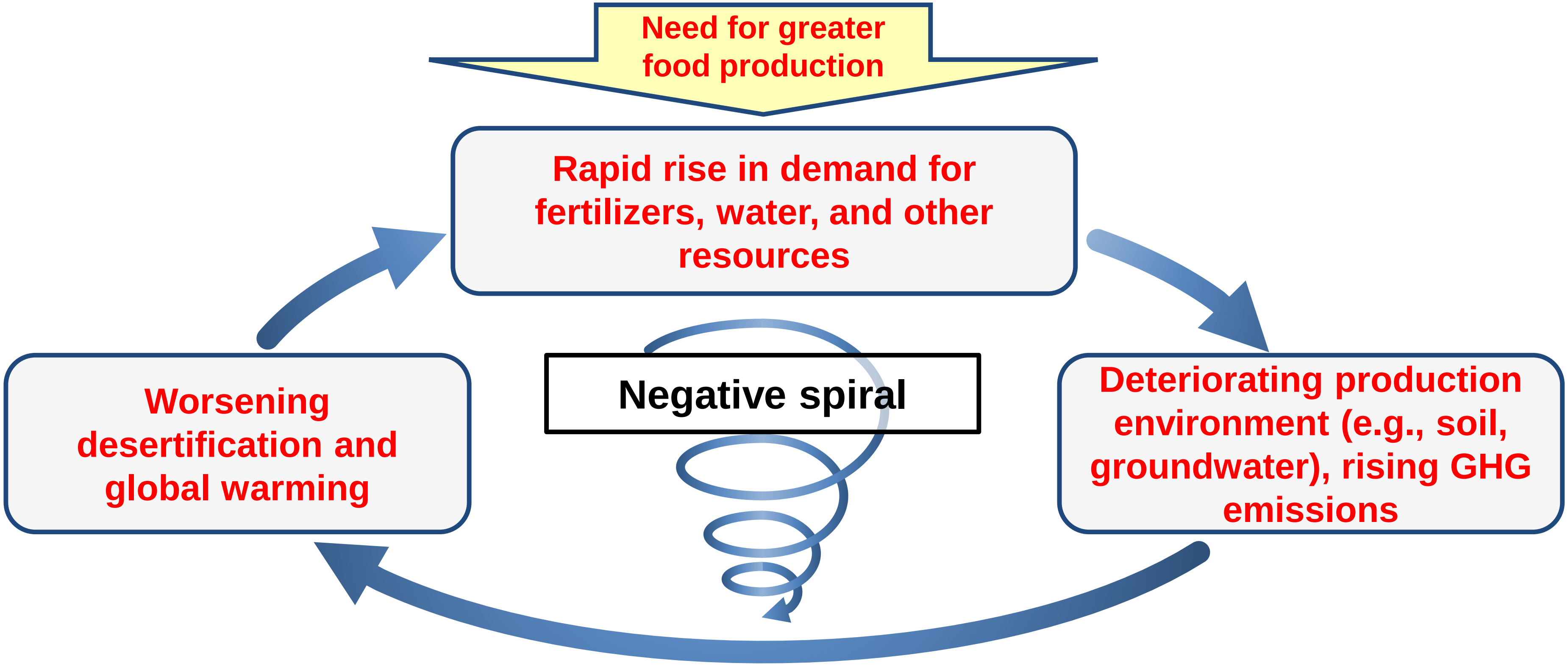
Amount of food loss and waste per capita: Approx. 139 g per day (about 1 bowl of rice)

Source: FY2016 figures by Ministry of Agriculture, Forestry and Fisheries)

I-10. Anticipated social issues in 2050

- Conventional production methods based on large inputs of chemical fertilizers and water are limited, so invention and innovation are essential for achieving a sustainable food supply while ensuring environmental conservation on a global scale.
- It is also necessary to review food delivery systems and consumption behavior to minimize food loss.

Rise in food demand due to population growth and economically wasteful food consumption (e.g., food loss, obesity problems)



If things continue the same way...

It will be **difficult to ensure a sustainable food supply** on a global scale.

I. Food and the environment in 2050 and the most urgent issues to address

II. Necessary direction for Moonshot Research work

II. Necessary direction for Moonshot Research work

- With global population growth and a deteriorating food production environment, ensuring a sustainable food supply is a common challenge for all mankind.
- Moonshot Research uses cutting-edge technologies, such as AI, robotics, and biotechnology, to maximize the biological function of nature. We will create innovative solutions that both expand global food supply and conserve the global environment, and promote challenging R&D initiatives with the following **three goals**:

II-1. Establish robust agricultural, forestry, and fisheries systems that can adapt to rapid climate change (full automation)

II-2. Overcome constraints to water, fertilizers, and other resources by fully utilizing the biological functions of nature

II-3. Develop solutions for eliminating food waste and promoting more rational food consumption, taking into account the environment and human health

II-1. Establishment of fully automated system for robust Agriculture, Forestry, and Fisheries in response to sudden weather changes

Mission goal example (1)
Realization of fully automated system for Agriculture, Forestry, and Fisheries by 2040

II-1-1. Exceed the five senses of “Takumi” (highly skilled farmers)
: Development of innovative sensing technology for super-precision farming

II-1-2. Expand the accurate assessments of “Takumi”
: Development of an AI analysis system

II-1-3. Exceed the skill of “Takumi”
: Creation of intelligent farming with uninterrupted operation

II-1. Establishment of fully automated system for robust Agriculture, Forestry, and Fisheries in response to sudden weather changes

- Remarkable improvement in prediction of crop growth by innovative sensing technology and AI
- Creation of intelligent farms where a group of robots operates through a distributed autonomous and collaborative system
- Establishment of immediate response system to sudden weather changes through uninterrupted operation

Current situation and issues

■ Stable food production cannot be ensured under frequent bouts of extreme weather, even with many years of farming experience.

This necessitates the following:

① Technology that can facilitate the rapid evaluation and prediction of crop conditions in response to sudden weather changes

② Analysis to determine the best cultivation and management strategies based on predictions from the pattern of crop growth and historical data

③ Following this analysis, rapid automatic management and harvesting is available at all times.

Necessary aims of R&D

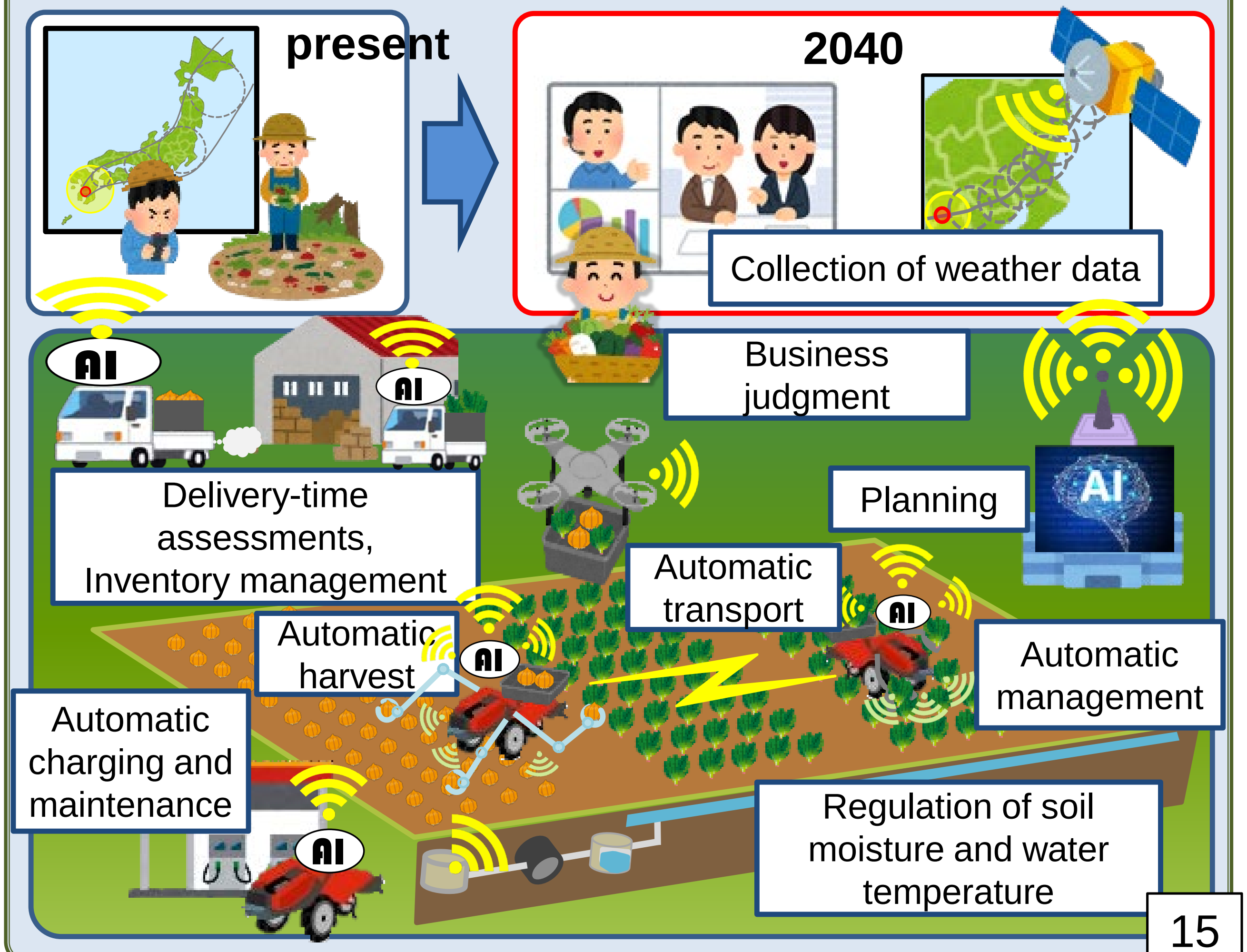
■Sensing technology that exceeds the five senses of “Takumi”

■AI that expands accurate assessments of “Takumi”

■Robot technology that exceeds the skills of “Takumi”

■Intelligent farming that operates without interruption

Vision to aim at for 2040



II-1-1. Exceed the five senses of "Takumi" Development of innovative sensing technology for super-precise farming

- Detection of subtle signs undetectable by humans by sensing odors, ultrasound, and invisible light
- Very early detection of pests, individual crop management, and optimally timed harvesting

Rapid and precise sensing of proximal objects

Nondestructive measurement by harvest robot

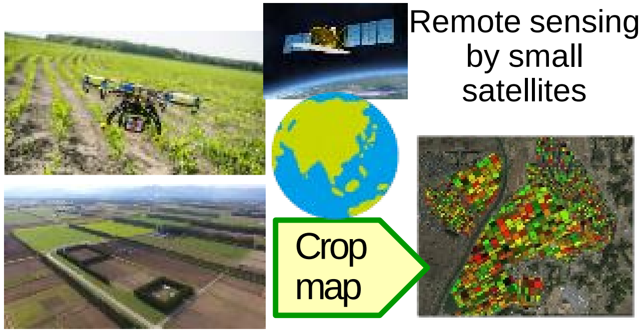
- Rapid nondestructive measurement of sugar content in fruit
  → Selection and optimally timed harvest
- Measurement of UV-induced visible fluorescence → Detection of stress and improvement of pollination rate

Immediate disaster response (automatic water management and transportation)

Upgrading of individual sensing

- Individual management and harvesting by a group of robots with high-performance sensors that exceed the perception levels of "Takumi"

Immediate and precise sensing over a wide area



- Automatic and precise evaluation of individual crop growth
- High-resolution assessments of field conditions at night and during rainfall
- Precise detection of subtle signs before natural disasters

Maximization of quality and yield with minimization of damage due to natural disasters through individual detection of crop conditions

[Utilization of technologies in different fields, such as ImPACT results]

Artificial odor detection system (ImPACT: Tokou PL, Prof. of Kyusyu University)
: Detection of odors from plants and soil for early discovery of pests, evaluation of crop maturity, and monitoring of soil conditions
MSS sense of odor IoT sensor (NIMS: Yoshikawa GL) : Detection of strain in sensitive membrane due to gas molecule adsorption

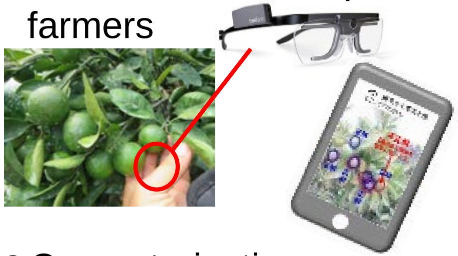
II-1-2. Expand the accurate assessments of "Takumi" Development of AI analysis system

- Development of AI that achieves the assessment level of "Takumi" with many years of experience, such as creating a cropping plan based on three-month weather forecasting data and planning early harvesting based on one-week typhoon forecasting.
- Upgrading of AI by real-time gathering of information about weather, soil moisture, soil nutrients, pests, crop growth, and the climate around the field and employment of deep learning

Cropping plan and emergency response by AI

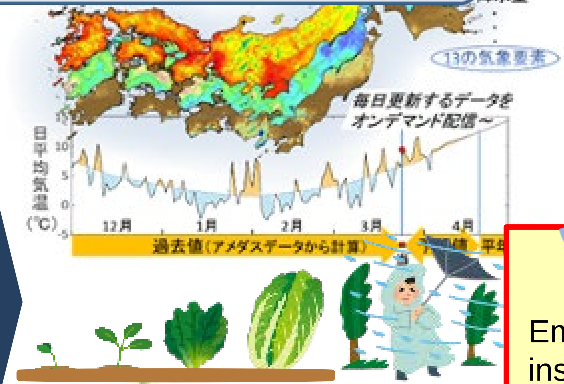
2019
Transformation of "Takumi skills"

- "Takumi skills" of top farmers



- Computerization of "Takumi skills"
- Use of "Takumi skills" by unskilled farmers
- Improvement of quality and yield

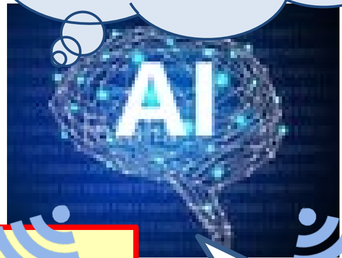
System for meshing agricultural & climate data

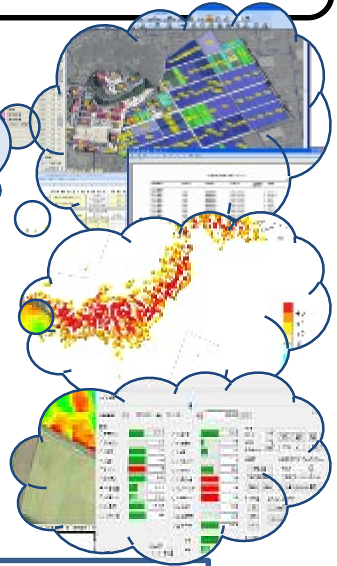


Advancing harvest

Automatic drainage

Learning about farm land, agricultural equipment, weather, crop growth, pests, soil and 3D geography





Emergency instructions before typhoon

Harvesting instructions

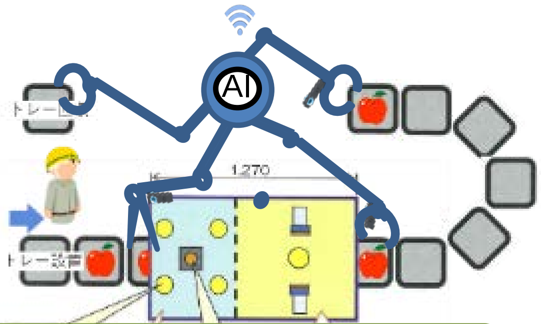
Degree of maturity: early ↔ late

2040
Transformation of "Takumi skills" and creation of AI that exceeds the abilities of "Takumi"

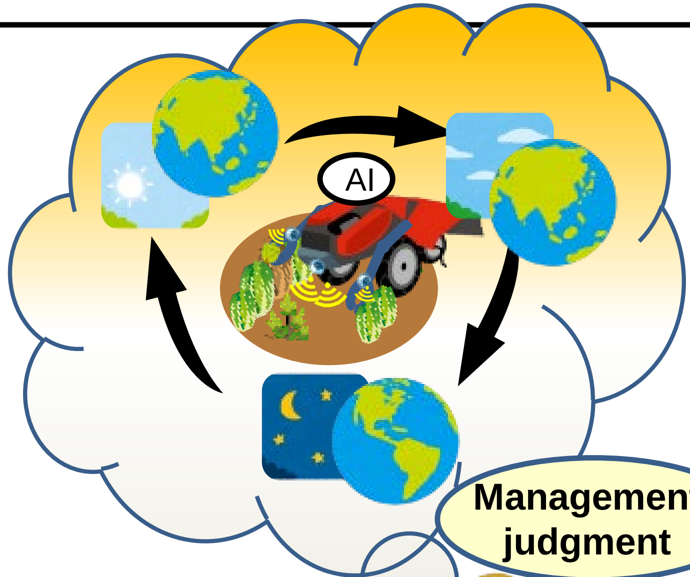
Securing profitability in the case of severe cold damage and large typhoons

II-1-3. Exceed the skill of “Takumi”
Creation of intelligent farming with uninterrupted operation

- Operation of a robot group by a distributed, autonomous, and collaborative system through deep learning that enables the optimization of cultivation management with immediate response to sudden weather changes and that exceeds “Takumi skills”
- Creation of an intelligent farm operation system that operates without interruption by constructing an error-recovery system



Automatic attachment and removal of robot components according to type of crop and operation



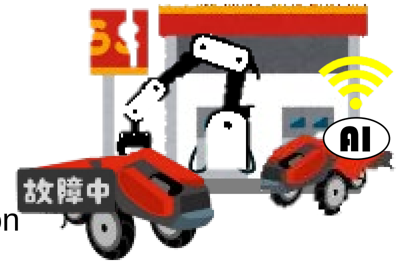
2040: Uninterrupted operation of robot groups on intelligent farms that respond immediately to sudden weather changes.

Management judgment

Automatic maintenance pit on the farm

Cooperative operation through multidirectional communication of many automated agricultural machines

- Equipment for error recovery system
- Regular automated maintenance
- Automatic malfunction reports



Improvement of operability, profitability, and self-repair of agricultural equipment with multiple functions and AI.
Contribution of Japanese intelligent farm model to global agricultural productivity

II-2. Overcome constraints to water, fertilizers, and other resources by fully utilizing the biological functions of nature

Mission goal example (16)
Establish a global-scale agriculture that increases biodiversity by 2050

II-2-1. Development of super-crops ("AI design breeding")

II-2-2. Total control of soil microbial environments (zero chemical fertilizers)

II-2-3. Total control of pests (zero agrochemicals)

II-2. Overcome constraints to water, fertilizers, and other resources by fully utilizing the biological functions of nature

- "AI design breeding" makes it possible to incorporate the "strength" of wild species in cultivated species within a short period of time, thereby greatly enhancing the environmental adaptability of crops and biomass plants.
- With the aim of developing new solutions for "zero chemical fertilizer" and "zero agrochemical" agriculture, we will achieve sustainability, biodiversity, conservation, and growth in agriculture, forestry, and fisheries.

Current situation and issues

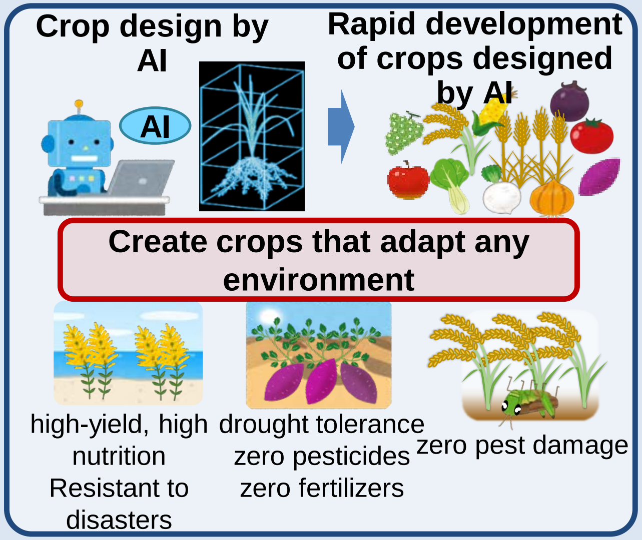
- Need to incorporate the environmentally adaptive genes of wild species (e.g., for drought resistance) into cultivated species.
- Need to control use of methane, nitrogen, and phosphorus to overcome constraints on the use of fertilizers and other resources, and to cut GHG emissions by maximizing use of breeding, microbial functions, and mechanisms of interaction between crops and microorganisms.
- Need to eliminate reliance on agrochemicals for pest and weed control and achieve both sustainable agricultural production and biodiversity conservation and growth.

Necessary aims of R&D

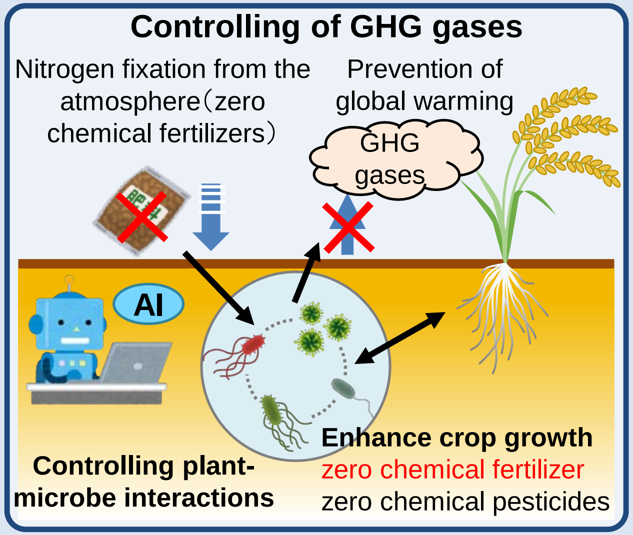
- Construct a breeding system that enables crops adapted to future environments to be designed in cyberspace.
- Achieve total control of symbiotic microorganisms and soil microorganisms.
- Develop new pest, vermin, and weed control technologies to enable zero agrochemical use.

Vision to look toward for 2050

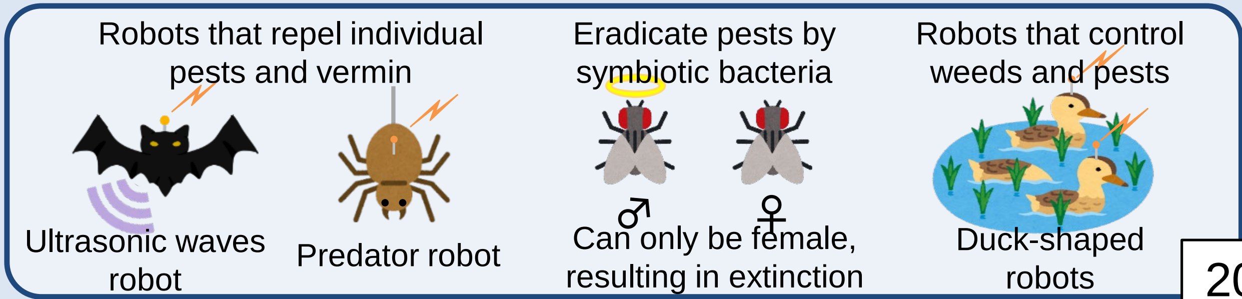
AI design breeding



Total control of soil microbial environment



New pest control technologies for zero chemical pesticides



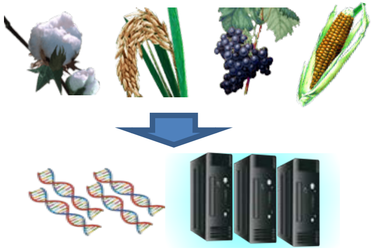
II-2-1. Develop super-crops: "AI design breeding"

- We will fully elucidate the genetic function of agricultural, forestry, and fishery products and construct a "AI design breeding" system for designing crops in cyberspace. We will rapidly create super-crops by making maximum use of unused genetic resources and freely conferring environmentally adaptive genes according to environmental conditions.

Build a phenome base

Standardized phenotype measurement

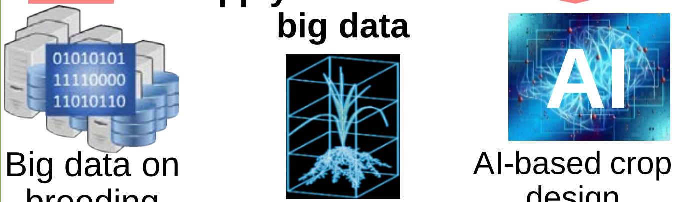
Accumulate big data on traits and genetics of crops



Big data

"AI design breeding"

Supply standardized big data



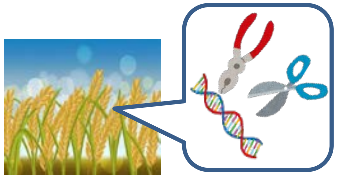
Big data on breeding

AI-based crop design

Model validation and demonstration

Super-crop design
Breeding and growing simulations

Rapid crop creation technology

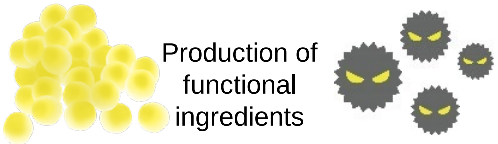


Genome editing to insert various mutations into useful genes

Create super-crops and plants

Develop high-CO_2 fixing crops that can be grown in barren or unused areas such as deserts and sea water.

Develop crops able to produce functional ingredients and absorb harmful soil components



Production of functional ingredients

Absorption/ elimination of hazardous substances

Make maximum use of unused genetic resources

Achieve evolution that took 10,000 years in the wild within a decade

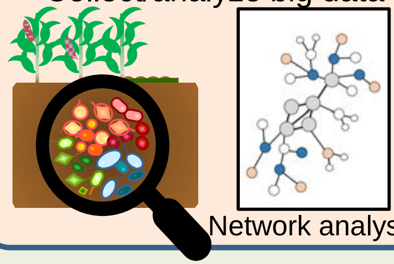
Ⅱ-2-2. Total control of soil microbial environments: zero chemical fertilizers

➢ We will completely elucidate the microbial environment of soils. By maximizing the use of symbiotic and useful microorganisms in soils, we aim to create optimal soil environments for crop production to enable zero use of chemical fertilizers.

Technical innovation

- Next-generation sequencing
- AI/big data analysis
- Microbial culturing technology

Search/identify useful microorganisms
Collect/analyze big data

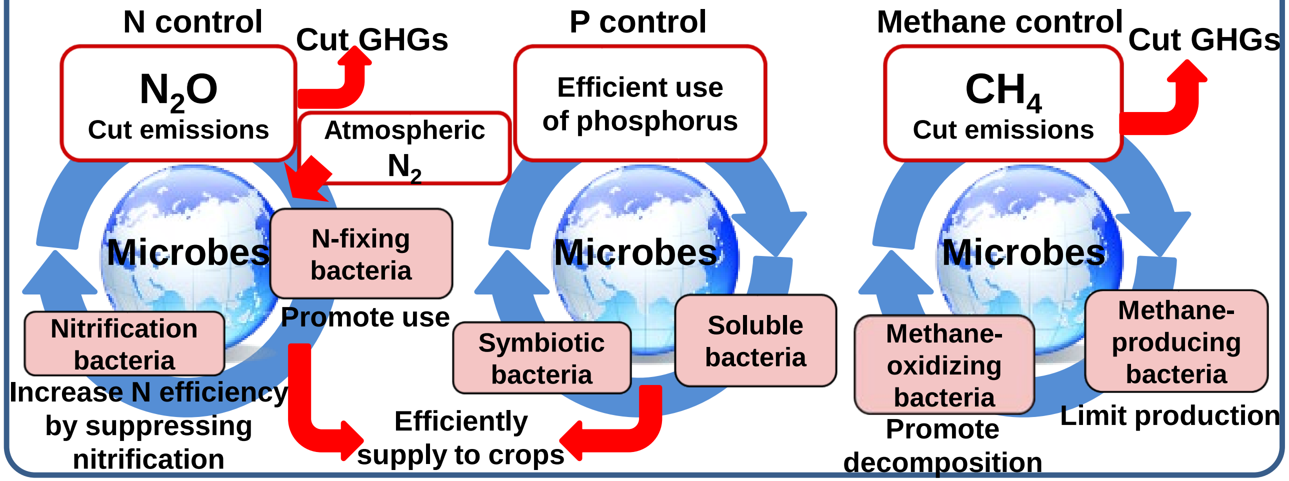


Network analysis

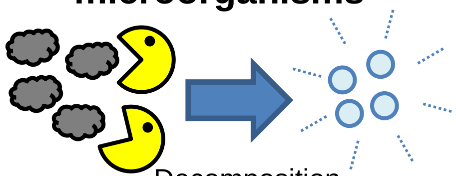
Development of AI-based microbial design and control methods

Synthetic biology

Make full use of microorganisms to maximize fertilizer efficiency and help prevent global warming

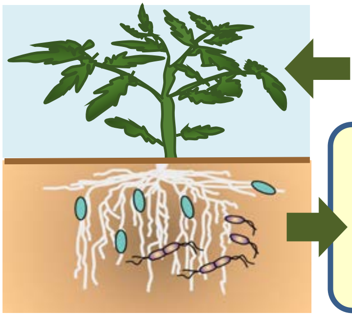


Create super microorganisms



- Promote use of K in soil
- Remove/decompose plastics and hazardous substances from soil

Create robust crops



Crop breeding with high level of microbial symbiosis

- ◎ Zero chemical fertilizers
- ◎ Zero agrochemicals
- ◎ Zero pests
- ◎ Grow in poor environments

Robustness by means of microbial symbiosis

Achieve “zero chemical fertilizer” agriculture

II-2-3. Total control of pests : zero agrochemicals

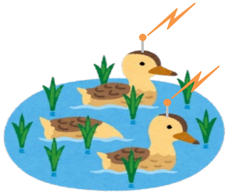
- Making full use of Japan's strength in robotics and biotechnology, we will establish new pest control technologies with the aim of achieving "zero agrochemical" agriculture and simultaneously conserving biodiversity.

Control methods that make full use of AI and robotics

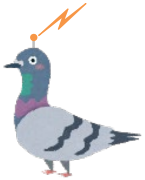
Robots that use remote signaling to repel pests and prevent infestation

Prevent all pests from entering plant factories and fields using ultrasonic waves, repellent sounds, or other such methods

Robots that control weeds and pests in the field

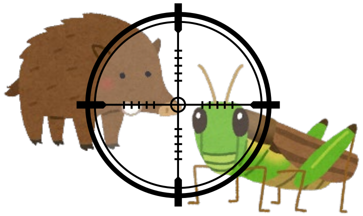


Duck-shaped robots for wet rice fields

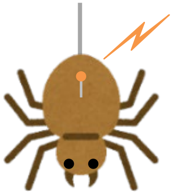


Dove-shaped robot for dry fields

Robots that recognize and repel individual pests and vermin



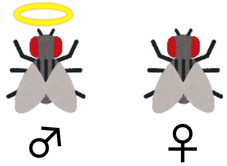
Robots that can find and prey on any pest



Ambush spider robot working 24 hours a day

Control methods that make full use of biological functions

Eradicate pests by hereditary manipulation using symbiotic bacteria



Can only be female, resulting in extinction

Using microorganisms that live inside insect bodies

Mass-produce and release infertile insects (genetic sterilization)

Melon fly

Release bugs to kill bugs

Breed natural enemies for various environments and pests

A natural enemy resistant to heat

Achieve "zero agrochemical" agriculture using technology that integrates investigation and control of pests and vermin

II-3. Develop solutions for eliminating food waste and promoting more rational food consumption, taking into account the environment and human health

Mission goal example (13)
Eliminate food loss by 2050 to efficiently deliver enough food for everyone

II-3-1. Foods personalized according to health and taste preferences (Reuse)

II-3-2. Establish AI supply chains driven by logistics, quality, and personal information (Reduce)

II-3-3. New “zero food waste” solutions (Recycle)

II-3. Develop solutions for eliminating food loss and waste and promoting more rational food consumption for sustainable and healthy societies

- We will develop "zero food loss and waste" solutions by establishing personalized food manufacturing technology and AI-based supply–demand adjustment systems.
- Using these, we will promote "local production–local consumption" and "semi-self-sufficient" consumer behavior globally.

Current situation and issues

- Much of the loss and waste in agricultural products and foods at production and distribution stages is caused by supply–demand mismatches due to a quality degradation.

→Need a system for real-time supply–demand matching (commercial flow) and a logistics system to ensure rapid delivery.

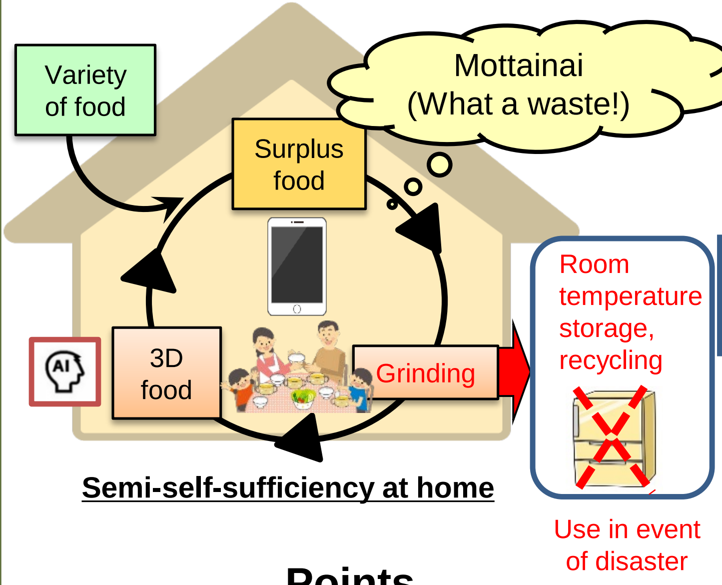
- Half of food loss and waste occurs in the home.

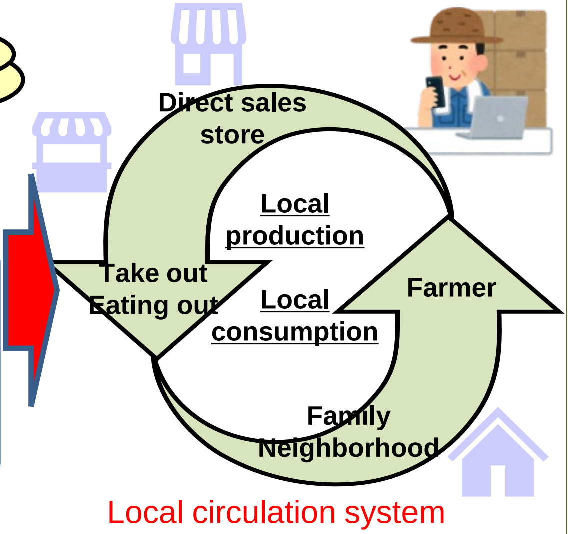
→Need a new solution that enables long-term storage and reprocessing of surplus food at home.

Necessary aims of R&D

- Technology for processing personalized foods according to health and taste preferences in the home. (Reuse)
- Establish a backcasting-type supply chain with AI-based supply and demand forecasting. (Reduce)
- Innovative recycling technology for food loss and waste. (Recycle)

Vision to aim at for 2050





Points

(1) Reduce volume and grind surplus food
(2) Digitize food quality data
(3) Reconstitute 3D foods by automatic AI-chef machine
(4) Develop big data on health and taste preferences

Personalized food, semi-self-sufficiency at home, and fully circulating society for food

Implement all over the world

A "zero food loss and waste" sustainable society

II-3-1. Foods personalized according to health and taste preferences: Reuse

- We will establish technology to enable surplus household food to be freely reprocessed according to personal health and taste preferences and promote rational consumption behavior for sustainable and healthy societies.

Agricultural products and surplus food

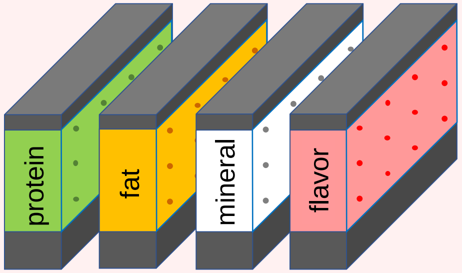

High-protein rice


Dietary fiber, residual polyphenols


Surplus food

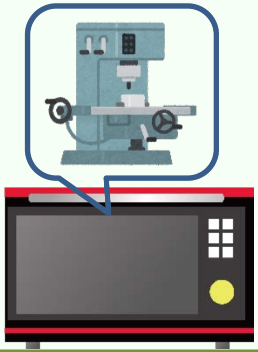
Grinding and separation

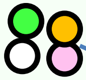
Grinding technology



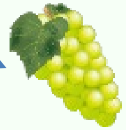
The AI 3D chef app will provide on-demand individual meals for personal health requirements

Development of AI chef machine



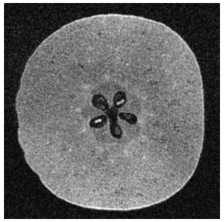


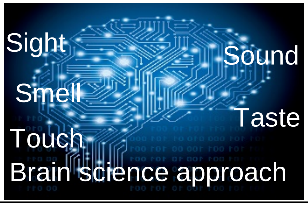

Plant protein-based steaks


Raw fruit


Baked eel made from plant protein

Analysis of eating quality/palatability using advanced technology


Quality data



Taste preference data

Blood pressure
Blood sugar

Health data


VR data

Food for the elderly, recreate the taste of home cooking

Apply to various types of emergency food


Recipe data

Points

(1) Reduce volume and pulverize ingredients using drying and grinding technology
(2) Use advanced technology to precisely measure health requirements, palatability, and foodstuff, and conduct AI-based big data analysis
(3) Develop 3D reconstitution and cooking technology based on powdered ingredients

Improve quality of natural disaster foods

Reprocess surplus food freely according to personal health and taste preferences

II-3-2. Establish AI supply chains driven by logistics, quality, and personal information: Reduce

- Through real-time integration and optimization of cyberspace (commercial flow) and physical space (logistics), we will completely eliminate supply–demand mismatches and eliminate food loss and waste at the production and distribution stages.

Cyberspace (commercial flow)

- Deciding prices dynamically according to supply and demand
- Leasing and buying/selling among individuals (sharing economy)

Production volume, sales performance, demand trends, market conditions, weather, traffic level, etc.

Harvest forecasts, taste, quality degradation, transport conditions (temperature, packaging materials), nutrition and function, eating season, etc.

Health, taste, ease of eating (e.g., swallowing, etc.), social media, appetite, mood on the day, etc.

Logistics information → Reduce loss and waste

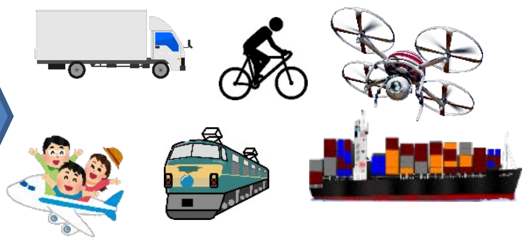
Quality information → Increase value

Personal information → Increase QOL

Blood pressure
Blood sugar

Physical space (logistics)

Agricultural, forestry, and fishery products are living during transport



Ambient temperature without packaging, Local distribution

Low temperature with packaging, Wide-area distribution

Points

(1) Match supply and demand in real-time in cyberspace
(2) Determine optimal transport method and route using logistics information to reduce food loss and waste
(3) Determine optimal transport conditions (temperature, packaging) according to quality information to deliver "just harvested" freshness
(4) Provide optimal ingredients according to personal information on health, taste preference, and age to improve quality of life

Apply to natural disaster food for the sick

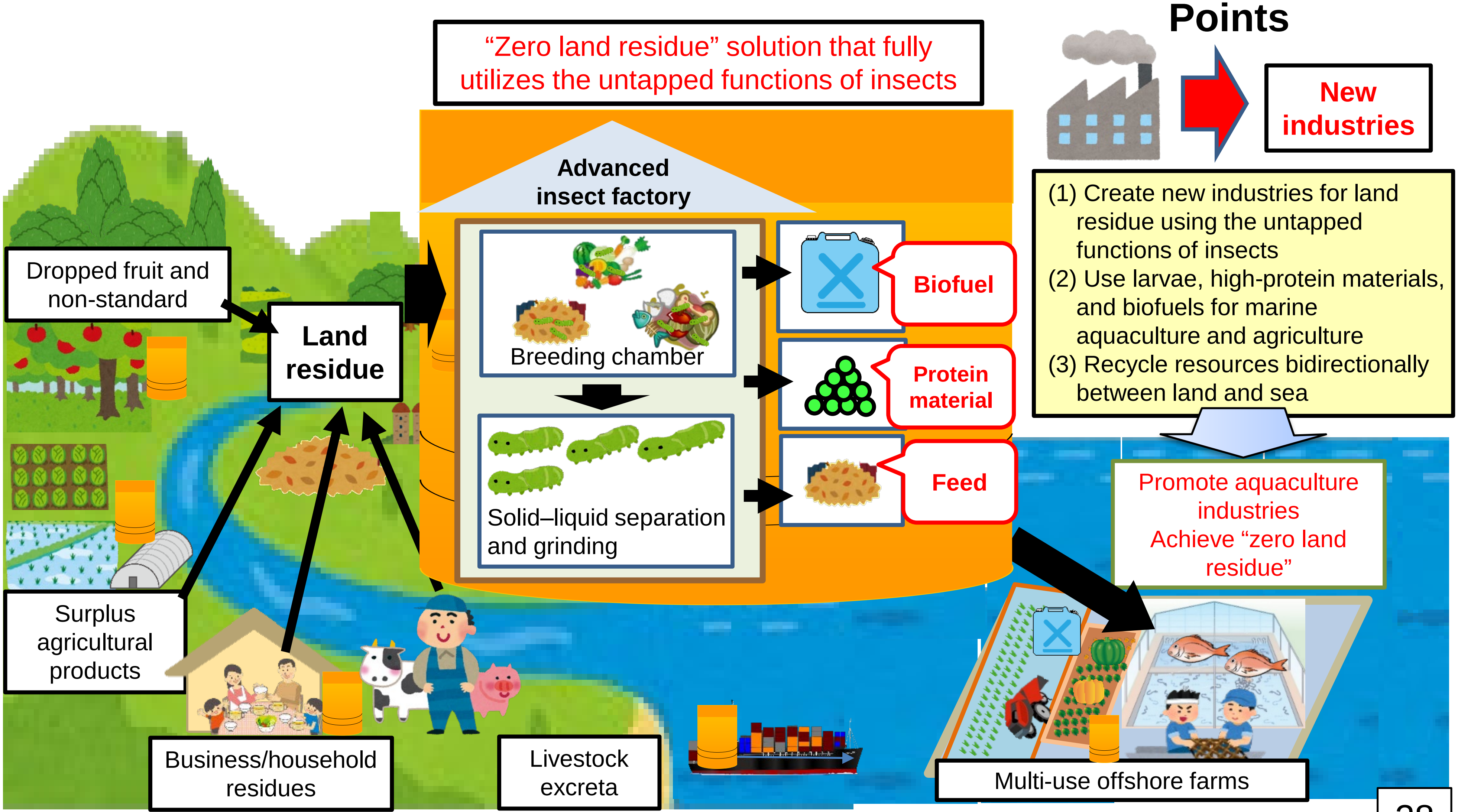
Use cyberspace data to achieve "zero food loss and waste", increase value, and improve quality of life

[Utilization of technologies in different fields, such as ImPACT results]

- Develop big data processing system for optimization of matching from huge volumes of commercial flow and logistics data (ImPACT, PM Hiroshi Harada)

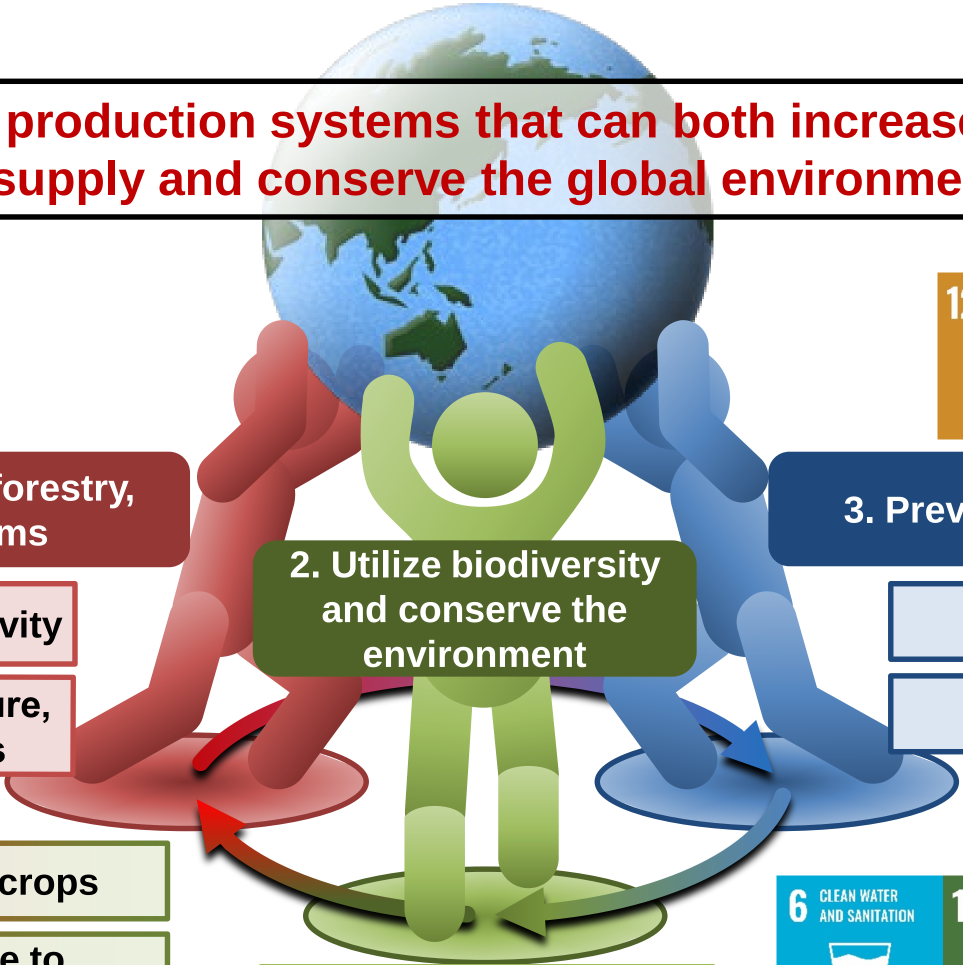
II-3-3. New “zero food waste” solutions: Recycle

➢ Utilizing the outstanding protein synthesis capabilities of insects, we will create new industries for converting food into biofuels and aquaculture resources, and also promote aquaculture using vast ocean spaces.



Summary: Necessary direction for Moonshot Research work

Create food production systems that can both increase human food supply and conserve the global environment



1. Strong agriculture, forestry, and fishery systems

- Sharply increase productivity
- Fully automate agriculture, forestry, and fisheries

2. Utilize biodiversity and conserve the environment

3. Prevent food loss

- Personalized foods
- Total waste recycling

- Create super-crops
- Minimize damage due to natural disasters
- Prevent global warming
- Fully sustainable “zero fertilizer” and “zero agrochemical” farming methods

Current problems: Growing world population | Rising food demand | Food loss | Global warming | Decreasing biodiversity | More frequent natural disasters