

Rice Culture and Development of Related Technology in Japan

Dr. Kiyooki MARUYAMA

(Rice breeder, The Former DG of National Agricultural Research Center)

1. Beginning of rice cultivation, current status of rice production
2. Science and technology that supported the high yield production
3. Science and technology that supported the high quality production
4. Rice cultivation technology in the future

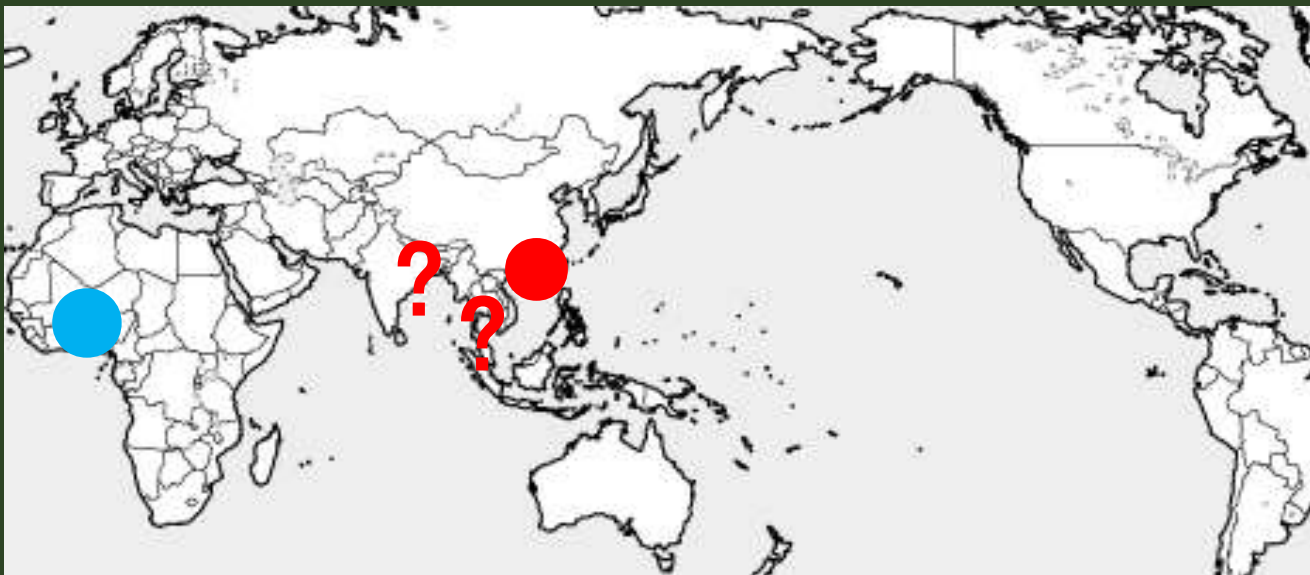
1. Beginning of rice cultivation, current status of rice production



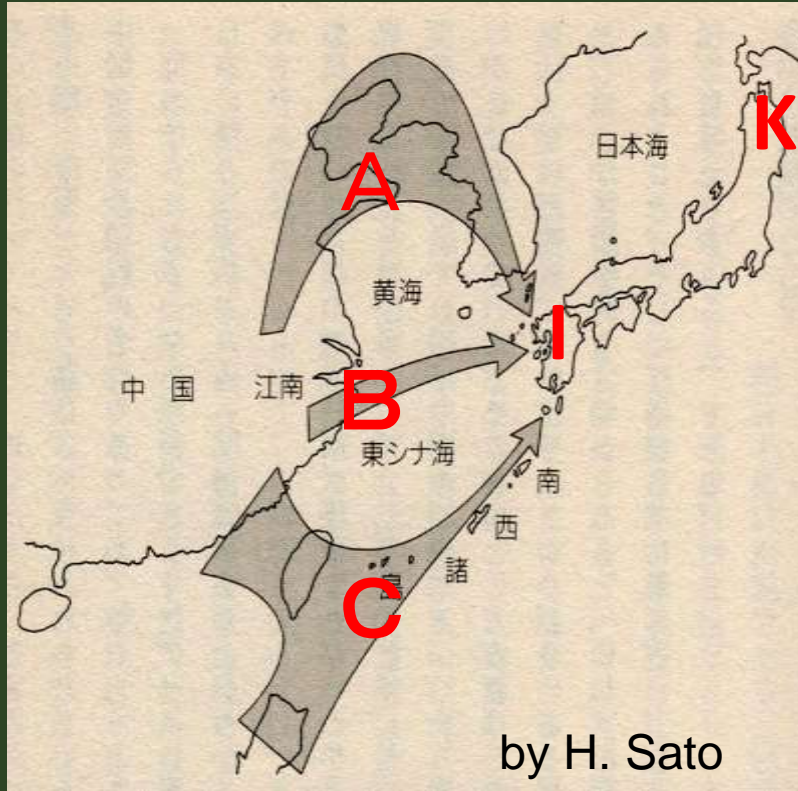
A colony of *Oryza rufipogon* beside a paddy field (Orissa State, India)

Origin of rice domestication

- People in the Yangtze River basin started rice cultivation(11,000 years ago).
- ? East India and South East Asia may be other probable candidate site of rice cultivation in Asia but there are no evidence.
- In West Africa, glaberrima rice was domesticated from *Oryza barthii*(3,000 years ago).



Introduction of rice to Japan



A Via Korean Peninsula and Shandong Peninsula

Immigration of humans from the Korean peninsula because of resemblance of Japanese people with Korean closely in terms of language and appearance.

B Directly from the Jiangnan

Jiangnan (southern part of the Yangtze River) is the origin-site of Asian rice.

Varieties are similar.

People dependent on boat, rice and fish in lifestyle tended to emigrate frequently.

C Via the Ryukyu island arc

Slash-and-burn upland rice is common in Southeast Asia.

Kazahari ruins of Aomori pref.
Carbonized rice grains were found(3000 years ago).

Itazuke ruins of Fukuoka pref.
This is a full-fledged paddy remains(2300 years ago).

Rice production in the World, Africa and Japan

| | 1961 | 1971 | 1981 | 1991 | 2001 | 2011 |
|-------------------------------------|------|------|------|------|------|------|
| Production (million ton) | | | | | | |
| World | 2156 | 3177 | 4100 | 5187 | 5998 | 7228 |
| Africa | 4.3 | 7.4 | 8.6 | 13.7 | 16.7 | 26.7 |
| Japan | 16.2 | 14.1 | 12.8 | 12.0 | 11.3 | 8.4 |
| Area Harvest (million ha) | | | | | | |
| World | 1154 | 1345 | 1450 | 1467 | 1519 | 1641 |
| Africa | 2.8 | 3.9 | 4.8 | 6.6 | 7.6 | 11.2 |
| Japan | 3.3 | 2.7 | 2.3 | 2.0 | 1.7 | 1.6 |
| Yield (ton/ha) | | | | | | |
| World | 1.87 | 2.36 | 2.83 | 3.53 | 3.95 | 4.40 |
| Africa | 1.55 | 1.88 | 1.79 | 2.08 | 2.20 | 2.38 |
| Japan | 4.88 | 5.24 | 5.62 | 5.86 | 6.63 | 5.33 |

Changes in government stock and consumption of rice

| | 1963 | 1970 | 1980 | 1990 | 2000 | 2009 |
|--|-------|-------|------|-------|------|------|
| Consumption (kg/year/capita) | 118.3 | 95.1 | 76.9 | 70.0 | 64.6 | 58.5 |
| Stock (million ton) | 0.2 | 7.20 | 6.66 | 0.95 | 1.62 | 0.86 |
| Production (million ton) | 12.81 | 12.52 | 9.75 | 10.46 | 9.47 | 8.46 |

Consumption = supply amount, the number is all brown rice weight.

Japanese per capita consumption in 1963 was 118kg. However, due to the increase of imported food, and changes in habit of diet the consumption of rice has been reduced.

Governmental rice stock became excessive in the 1970s. The government has paid a great deal of financial cost to its disposal. Since then, production technology development of rice had undergone a shift to focus on a good quality from high yield production.

2. Science and technology that supported the high yield production

Fertilizer(Liebig 's law of minimum, Haber–Bosch process (1908))

Variety(Mendel' s low(1865), rediscovery of Mendel 's law (1900)、crossbreeding of rice plant (1904))

Pesticides(DDT(1938)、parathion(1944), 2,4–D(1944))

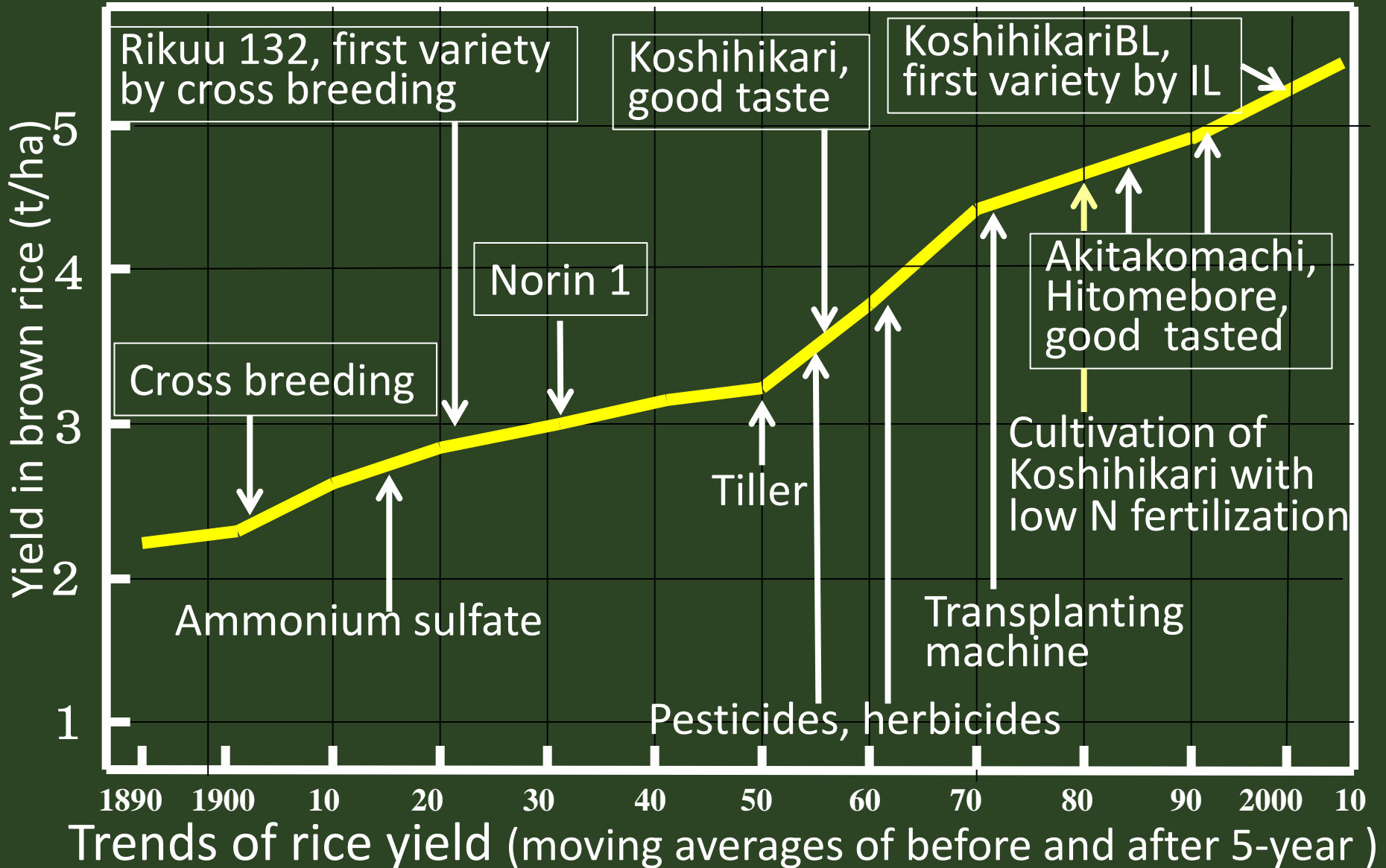
Machines(steam locomotive tractor(1902), tractor with caterpillar)

Water(Introduction of pump, dam & water channel)

Agricultural plastic film(Polyvinyl chloride film(1951))

Agricultural technology supported by **chemistry** and **engineering**

Rice cultivation technology boosted yields



History of chemical fertilizer

Mineral nutrition theory of Liebig (1840's)

Plants can grow only through input of mineral nutrition. For high yielding, inorganic nutrients which are apt to be short is a nitrogen, phosphate, potassium.

Superphosphate production patent by J.B.Lawes (1842)

Harbor process (1908)

Ammonia can be synthesized from hydrogen gas and nitrogen gas under high temperature and pressure with iron oxide catalyst.

In case of potassium and phosphorus fertilizer, resources are localized. However, sufficient potassium and phosphorus exist in the soil. However, function of microorganisms and root in the soil are not fully elucidated.



History of pesticide



Because of insect 'plant hoppers', big damage to rice was subjected in western Japan in 1732. As per the record around 970,000 people starved to death.

Traditional pesticides: pyrethrum, derris root, Bordeaux mixture (circa 1890)

Active ingredient of pyrethrum: pyrethrins (H. Staudinger 1924)

Chemical pesticides: DDT(P. H. Muller 1938), BHC (1941) parathion(1944) ,2,4-D(1944) mercurial (1944)

The pesticide regulation in Japan

1946: Law of pesticide legislation

1971: (Strengthening of pesticide residue standards)

2002: (Strengthening of unregistered pesticide regulation)

2006: Law of Food Control (added the positive list system)

Suspicious is guilty

History of machinery for rice cultivation

Motorized machines replaced the human power and animal power.

Threshing machine: In Japan, since 1930s, threshing machine with electric motor began to spread.

Tiller: H.C. Howard of Australia patented in 1920. In Japan, the tiller was introduced and subsequently improved in 1950s. The adopted 80000 units were in 1955, 3.38 million units in 1974. The tillers were gradually replaced with tractors.

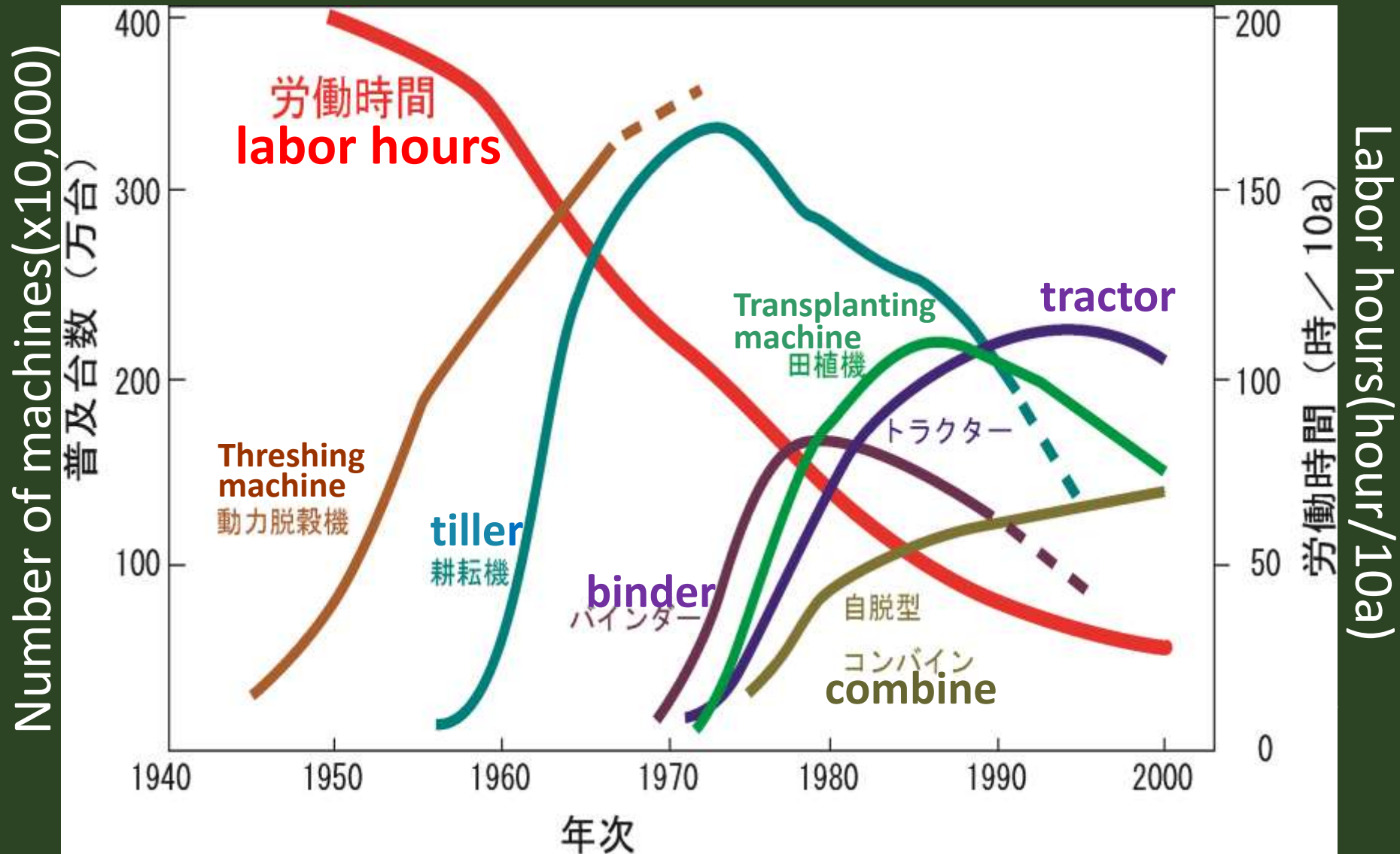
Tractor: Production of domestic tractor was started in 1960.

Rice transplanter: Young seedling rice transplanter has spread rapidly from 1970. As a result, machine transplanting covered 90% area of paddy field in 1975.

Self-threshing-type combine: Sale has been started in 1966.

By mechanization the laboring time reduced to 1/7, and release from hard labor was realized. However, It is not sufficient in terms of cost.

Changes in labor hours due to the progress of mechanization in rice cultivation



By MAFF

Transplanting Machine



By YANMAR

A small irrigation pond at Aichi pref.



Irrigation water

Japan is rich in precipitation, but because of requirement of lot of water for puddling and transplanting, development of irrigation water was required.

Since the start of rice cultivation, about 200 000 irrigation ponds have been accumulated in Japan.

The total length of the waterway to irrigate paddy fields, reaches to 400 000 km. This is the length of the 10 laps of the earth.

In addition, over the past 50 years, huge dams were built in mountainous areas. They are used for irrigation water, industrial water, domestic water, and power generation.

In recent years, pipeline canals are embedded beside the paddy field. By opening the valve, farmers can pour water into their paddy field.

Genetics is a base for breeding

- | | |
|------|---|
| 1865 | G. J. Mendel published the Mendel's law. |
| 1900 | H. M. De Vries, K. H. Correns, E. Tschermak rediscovered it. |
| 1901 | De Vries advocated mutation theory. |
| 1903 | J. L. Johansen published pure line theory. |
| 1911 | T. H. Morgan <i>et al</i> constructed a chromosome map of <i>Drosophila</i> . |
| 1927 | H. J. Muller induced mutation by X-ray in <i>Drosophila</i> . |
| 1930 | R. A. Fisher <i>et al</i> established statistical genetics(1930s). |
| 1937 | A. F. Blakeslee <i>et al</i> found chromosome doubling by colchicine. |
| 1953 | J. D. Watson, F. H. C. Crick elucidated double helix of DNA. |
| 1961 | M. W. Nirenberg <i>et al</i> elucidated genetic code. |
| 1970 | D. Nathans, H. O. Smith discovered restriction enzymes. |
| 1973 | S. H. Cohen, H. W. Boyer built the first GMO in <i>Escherichia coli</i> . |
| 1982 | The first genetically modified plant was produced in tobacco. |
| 2004 | Entire nucleotide sequence of the rice genome was deciphered. |
-

Start of rice breeding based on genetics

Based on the pure line theory by J. L. Johansen, pure line selection was applied to the native varieties.

In 1904, knowing the rediscovery of Mendel's laws, S. Kato in MAFF succeeded in the artificial crossing of rice plants for the first time in Japan. Since then, cross breeding became a mainstream method for rice breeding.

In 1961, MAFF has established Institute of Radiation Breeding (IRB). Mutation breeding became the second important breeding method.

Gamma field of IRB is a circular field of 100m radius with 88.8TBq Co-60 source at the center.



High yielding

Many agronomic traits are contributing to high yield.

Main traits are;

1. Active root system,
2. Long and wide leaves,
3. Many panicles,
4. Heavy panicles,
5. Long upright flag leaves,
6. Short culms to prevent lodging under high N application.



Takanari



Gene for high yielding

The most apparent gene for high yield is a semi-dwarfing genes. Interestingly, many high yielding varieties possess a semi-dwarfing gene on a same *sd1(d-47)* locus.

Jikkoku(Japanese native variety, genetic resources of Reiho)

Shirosenbon(Japanese native variety, genetic resources of Kinmaze)

Reimei(mutant of Fujiminori, high yielding variety)

Hokuriku100(mutant of Koshihikari, genetic resources of Kinuhikari)

Dee-geo-woo-gen(semi-dwarf gene sources of IR 8)

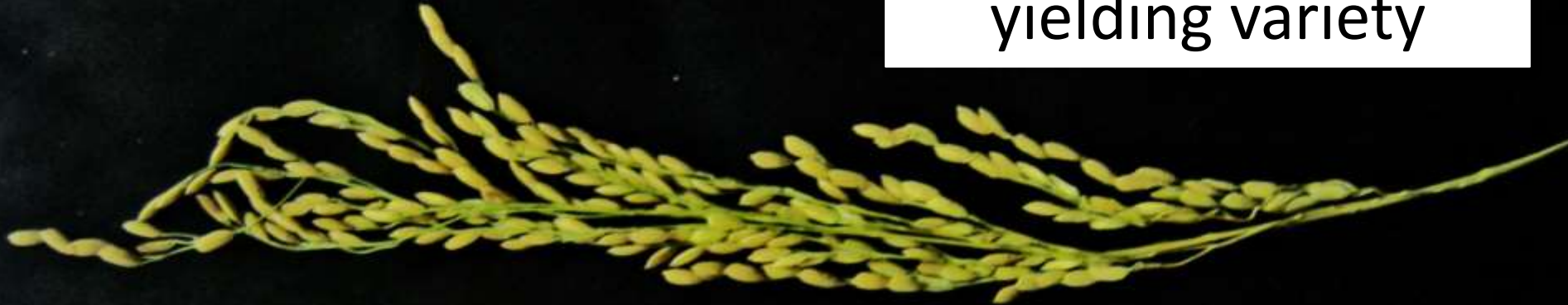
Aizizhan(semi-dwarf gene sources of Chinese variety)

Calrose76(mutant of Calrose, USA)

Farmers and modern rice breeders selected the gene on the same locus, *sd1*!

The *sd1* locus encodes the enzyme of gibberellin synthesis.

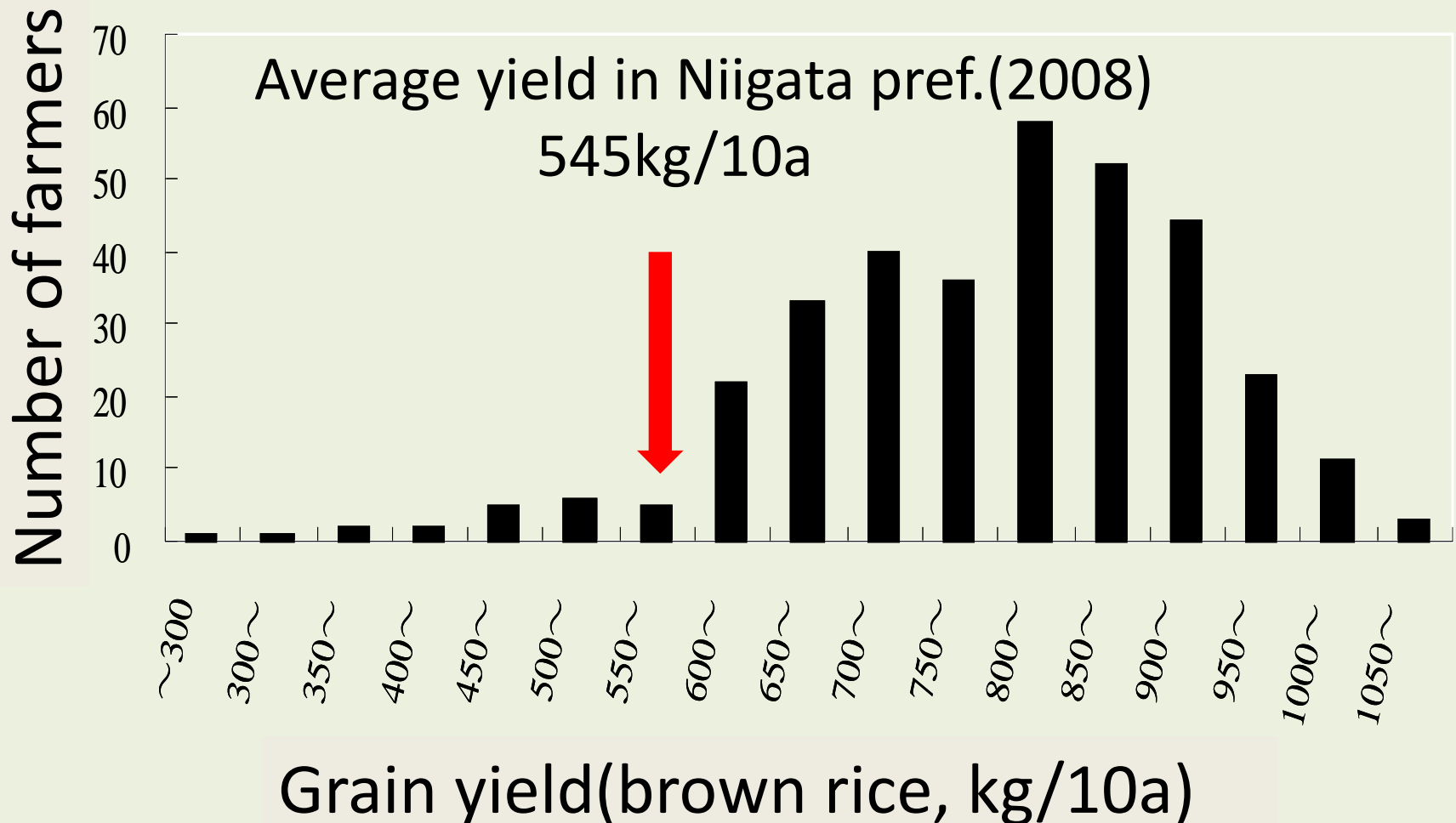
Hokuriku193, high yielding variety



Nipponbare, typical Japanese variety



Performance of Hokuriku193



Yield of 344 farmers in Niigata prefecture
(National Agricultural Research Center, 2008)



Takanari
high
yielding
variety

Tachisugata
variety for fodder

Resistance to diseases

Blast(BL) is the most serious disease in temperate zone. After the degradation of resistance of Kusabue in which *pik* gene from Lai-Zhi-Jiang(Chinese variety) was introduced, rice breeders tended to use field resistance. But some breeders built up a multiline of blast resistance. SasanishikiBL was put into practical use in 1994. KoshihikariBL was planted in 90,000ha in 2010.

Bacterial leaf blight(BLB) was the second important disease. However, actual damage reduced drastically as *Leercia*, the intermediate host of this bacteria, disappeared by the improvement of water channel. BLB is still very serious disease in tropical area.

Rice streak(RS) is caused by virus intermediated by small brown planthopper. A resistance gene was successfully introduced from a native variety in South India.

Cold resistance

Rice production has been repeatedly damaged by the cold weather in the northern Japan. The pollen of rice loses its function when it encounters with low temperature (below 17°C) at booting stage (about 10 days before heading).

Among the commercial varieties, Koshihikari and Hitomebore derived from Aikoku are strongest in resistance.

The number of cold resistance genes is estimated to 5-7. Accumulation of these genes, therefore, is not so difficult. Somewake in northern Japan, Silewah in Indonesia, Lijiang-xintuanheigu in Yunnan province of China were used as genetic resources. As a result, some breeding lines such as FukeiPL1 or TohokuPL1 were developed. The cold resistance of these lines is very high.



Test field of cold resistance
in Furukawa Agri. Ex. Sta.

Rice genome project

1991 Rice genome project by MAFF started.

1994 High density genome map with 3,000 markers

1998 Start of whole genome sequencing by international consortium.

Japan (1,2,6,7,8,9), USA (3,10,11), Korea (1,9),
France (11,12), UK (2), India (11), Thailand (9),
China (4), Taiwan (5), Brazil (9)

2004 Completion of whole genome sequence analysis.
(389million base pairs, about 30,000 genes)

Output of rice genome project will contribute much.

1. Deeper understanding of the rice plant
2. Easier identifying of useful genes
3. Enhancing the efficiency of cross breeding using DNA markers. For example, breeders can estimate taste of rice without cooking by analyzing the leaf of a seedling.

Recombinant DNA technology

Breeding has been developed along with the advances made in genetics. Naturally, breeding methods based on the most advanced molecular genetics is the most powerful method of breeding. GMO has been cultivated in 160 million ha. which is equivalent to 11.4% of the world's arable land area in 2011. Further, half of them are cultivated in developing countries.

In Japan, disease resistance lines, a line which can mitigate pollinosis, were already developed. But they are not commercialized yet, as anti-GMO movement is still strong.

3. Science and technology that supported the high quality production

Unpalatable rice! I do not need it!

High quality rice in the world

| | |
|----------|--|
| China | Shaochan-mi (Tianjin area, japonica varieties), Ruan-mi(low-amylase varieties), Siang-mi(long-grain scented rice varieties) |
| Korea | Akibare(Japanese variety), Ipum(japonica) |
| India | Basmati(long-grain scented rice varieties), Samba (small grain, low-amylase varieties) |
| Thailand | Khao do mali(long-grain scented rice variety) |
| Egypt | Nahda(japonica variety) |

common : soft rice (medium to low amylose content)

Difference : fragrance, fluffiness rather than stickiness

Cooking quality

Sticky and soft rice is preferable in Japan because we take plain rice with chopsticks.

Koshihikari, the leading variety, possesses such traits. Stickiness is controlled by amylose content of starch. High amylose(above 25%) rice like indica rice is not so sticky. Japonica rice with medium amylose(around 20%) content is sticky. Glutinous rice without amylose is too much sticky and soft.

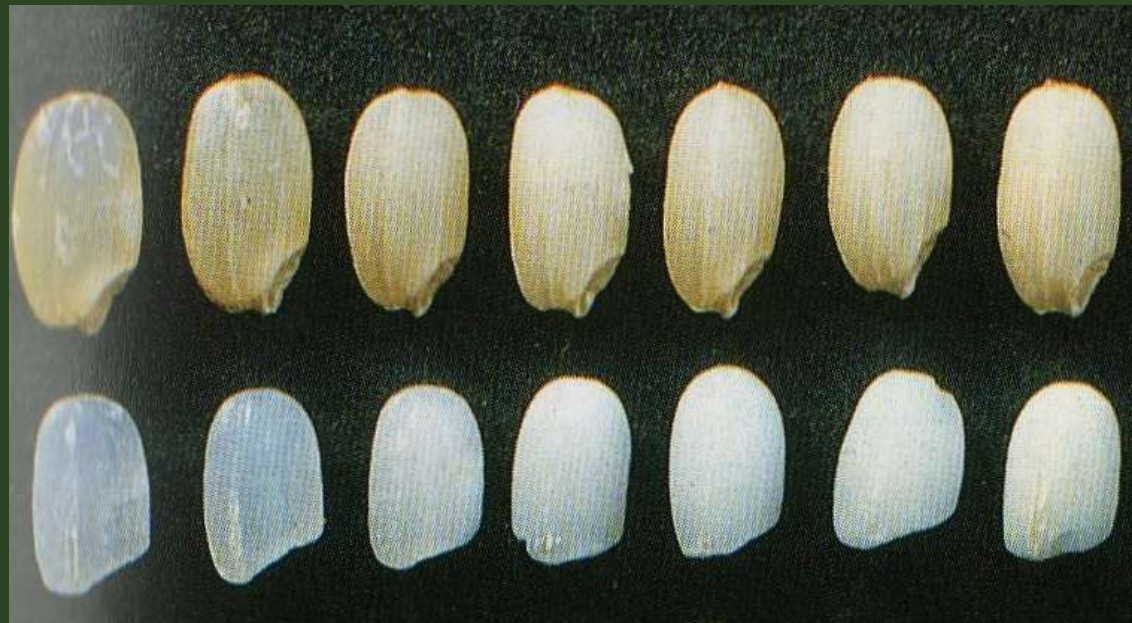


Discovery of low amylose genes

K. Okuno found many intermediate amylose-content varieties in the genetic resources in South East Asia and in artificial mutants. He also identified the genes lowering amylose content. His research triggered the development of good taste varieties.

Nowadays, many varieties with better taste than Koshihikari are developed.

Brown rice and milled rice with various amylose contents
(by K.Okuno)



Medium-amylose

low-amylose

glutinous

Variation of amylose content in rice

Starch is composed of amylose and amylopectin (both are polymerized glucose with different characters). Amylose is linear polymerized glucose and amylopectin is polymerized glucose with branches.

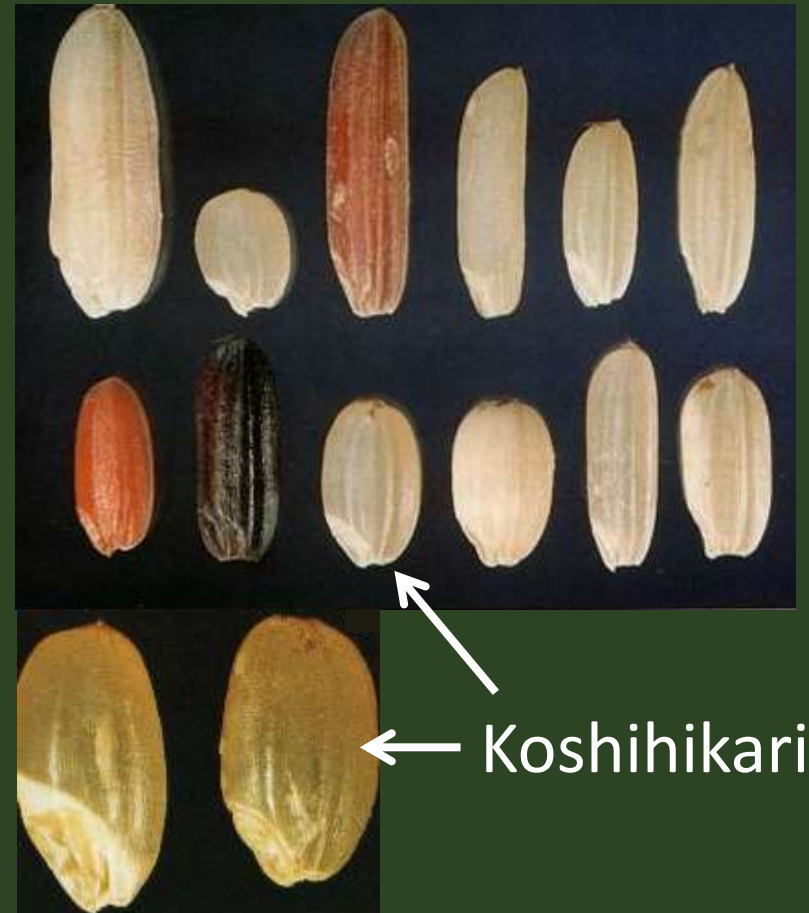
Most indica varieties contains high amylose and thus the cooked rice is hard. The amylose content of japonica rice is medium and it is preferred as cooked rice. Starch of glutinous rice contains amylopectin only.

| | amylose content | existence | gene for starch synthesis |
|----------------|-----------------|---------------------------|---------------------------|
| high-amylose | > 25% | most indica variety | <i>Wx-a</i> |
| medium-amylose | 25 ~ 18% | all japonica variety | <i>Wx-b</i> |
| low-amylose | 17 ~ 5% | Southeast Asia | <i>du 1 ~ 5, wx-mq</i> |
| Glutinous | 0% | mainly japonica varieties | <i>wx</i> |

Various utilization of rice

The rice in Japan consist of 95% of no-glutinous rice, 3% of glutinous rice, 1% for brewery and 1% for livestock feed. In order to enlarge rice utilization, a research project started in 1989 using world rice genetic resources. Super high yielding varieties are being utilized for live stock feed.

| | |
|---|--|
| Starch low amylose high amylose | Varieties developed Milkyqueen(10%) Hoshiyutaka(28%) |
| Protein low glutelin low allergen | LGC-1, Shunyou LA-1 |
| Fat | Haiminori |
| Grain size | Oochikara(36mg) Kanto152(13mg) |
| Pigments | Asamurasaki |
| Flavor | Sariqueen |



4. Rice cultivation technology in the future

High yield in rice production is realized. We can eat various varieties all year round. But, we had forgotten the nature.

- Various kinds and number of vermin/ creatures around paddy field reduced.
- Water of the river and the became dirty.
- In addition, the safety of food is also suspected.



Is the present food production system really sustainable?

In the 21st century, we create agricultural technology by the use of **information science** and **biology**.

High yielding technology equipped with food shortages

No one cannot deny that worldwide famine will come.

Varieties that can harvested 12t/ha have already been developed in Japan. Currently, it is being used for domestic animals because of poor cooking quality. Hence, to make it eatables for Japanese it is necessary to improve cooking quality of such rice. Fortunately, isogenic lines(IL) with low-amylose gene can be developed using DNA markers in next few years.

High yield is controlled by a number of traits. We must study the traits of high yield deeply from the point of view of ecology and physiology, and isolate genes responsible for high yield.

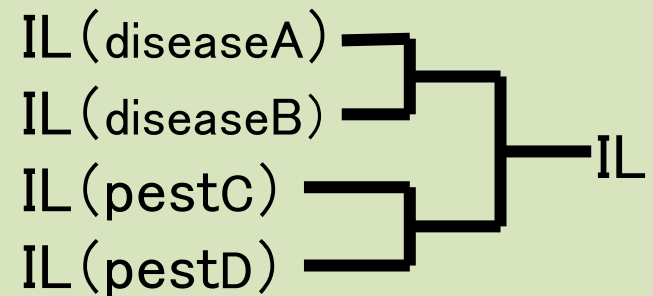
Further, it is also necessary to built up the cultivation method to pull out enough the characteristics of varieties developed.

Reduction of chemical pesticide

Safety of pesticide has improved, but suspicion of citizens has not been erased yet.

If a resistance gene is found in rice genetic resources, agricultural chemicals is not required. Therefore, we should speed up the accumulation of several kind of pest and disease resistance genes into the core varieties.

To reduce the pesticides, in addition to the use of resistant varieties, we must exercise biological control and ecological control by adoption of new cultivation method.



Pyramiding of resistance genes

N fertilizer producing methods other than Haber–Bosch process

HB process is consuming 1% of the crude oil of the world. There is an ammonia-producing plant of 2.5 million tons per day in Russia, and that of 1.5 million tons in USA. And, it is said that 2 billion people will starve to death if there is no HB process (T. Hager).

Rhizobium: Symbiotic bacteria that fix N by forming root nodules in the roots of legumes

Endophyte: Symbiotic bacteria that live in the plant body including stem and leaf and fix N

Azolla: Cyanobacteria living inside azolla (aquatic ferns) fix N. Azolla has been used since 500 years ago in northern Vietnam and southern China as green manure.

N-fixing crops: Researches for introducing the genes of N-fixing bacteria to crops are practiced.

Robot transplanting machine assisted by GPS



To enter itself from footpath/road to paddy fields, and revert back after the rice planting. Faster and accurate than normal transplanter.

It works by using GPS with error of only few centimeters, it can also work at night.

Robot Grand Prize (2008) by METI, Japan

Utilization of information technology to agriculture

Agricultural technology of the 20th century has been supported by engineering and chemistry. Information technology will play an important role to modify and improve it.

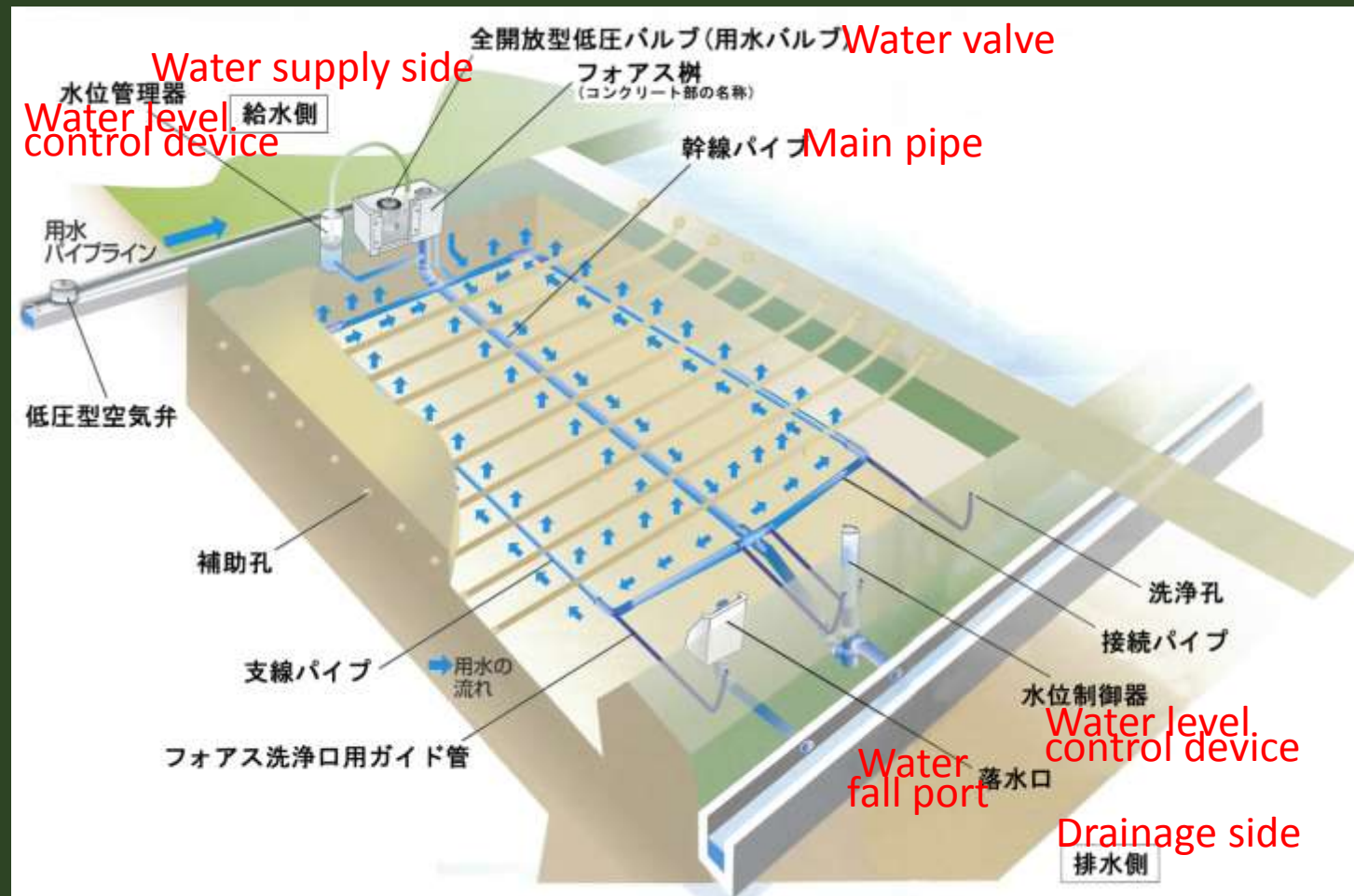
Field server is a network computer. It is equipped with a web camera and sensors, for measurement of various factors such as temperature, humidity, solar radiation, wind speed, precipitation, counter of pest, etc., the data is sent to the host computer, and is used for growth diagnosis or growth projections, etc..



field server, by NARC

Underground water level control system "FOEAS"

Precipitation is large amount Japan, crops suffer from moisture damage. In particular, if crops other than rice are grown in paddy field, they receive moisture damage. FOEAS which is developed by Rural Engineering Institute can adjust the groundwater level with a simple valve and piping buried in the field. It can perform intermittent irrigation freely in rice cultivation as well.



Soybean cultivation in paddy where FOEAS is installed



Control plot
2.4t/ha

FOEAS+Irrigation
4.7t/ha

Thank You

