3 June 2016

Advanced Global Agricultural Sciences I
IPADS Development Studies

Crop Science and Agriculture in Changing World

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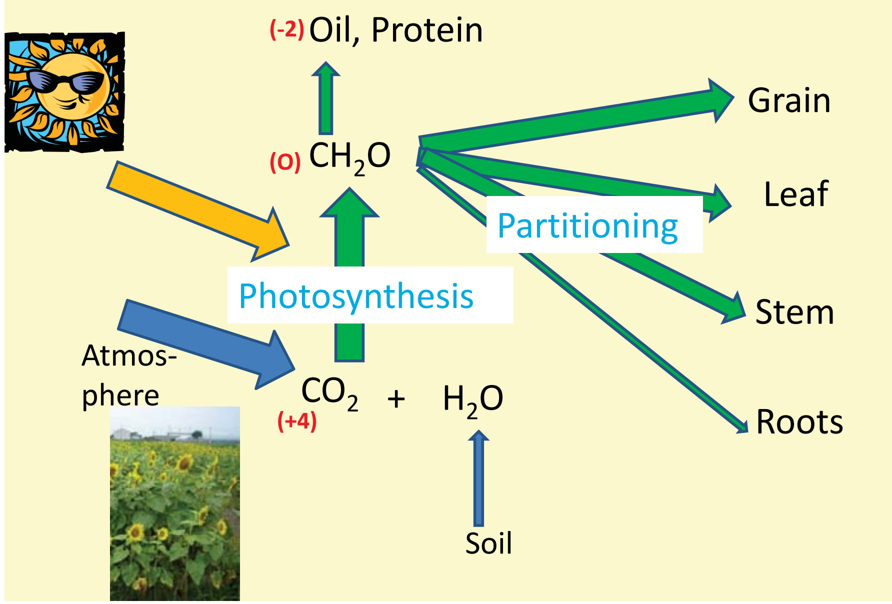
Plant growth and yield = Photosynthesis + Partitioning

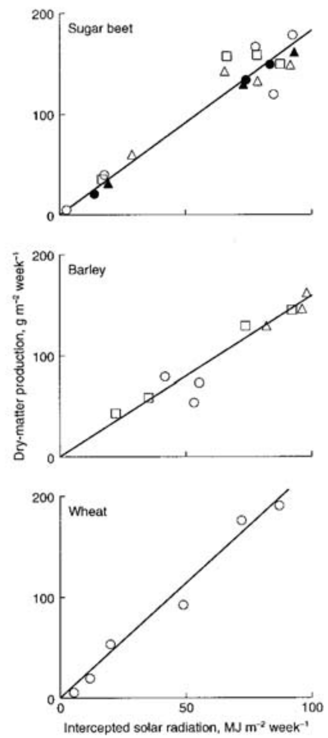


Grain yield

Y=Q × I × ε × H

- Q : total quantity of incident solar radiation received over the period
- I : fraction of Q that is intercepted by the canopy
- ε : **overall photosynthetic efficiency** of the crop (total plant dry matter produced per unit of intercepted radiation
- H : **harvest index (HI)**

Light interception and dry matter production

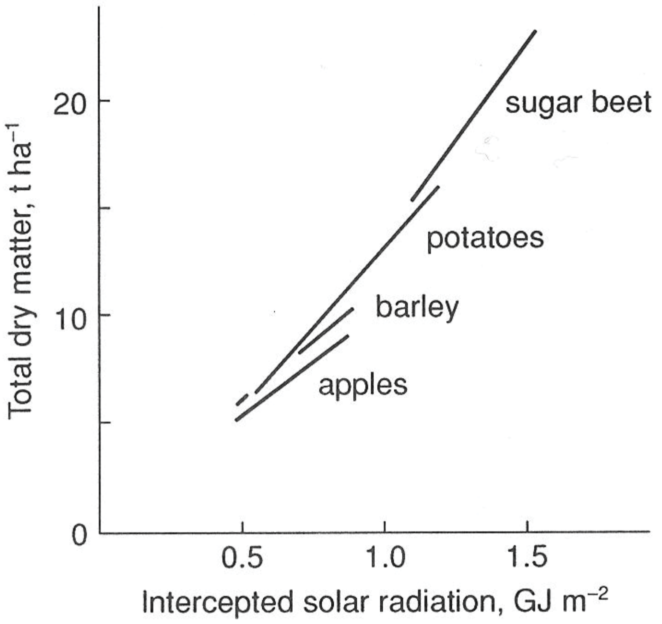


Relationship between dry-matter production and intercepted solar radiation, based on weekly measurements for three crop species grown in the Midlands of England.

(Different symbols indicate different crops)

(Biscoe and Gallagher 1977 cited from Hay & Porter 2006)

Total dry matter at harvest and the amount of solar radiation intercepted throughout a season



(Monteith 1977, Cited from Hay and Porter 2006)

Daily and seasonal fluctuation of irradiance

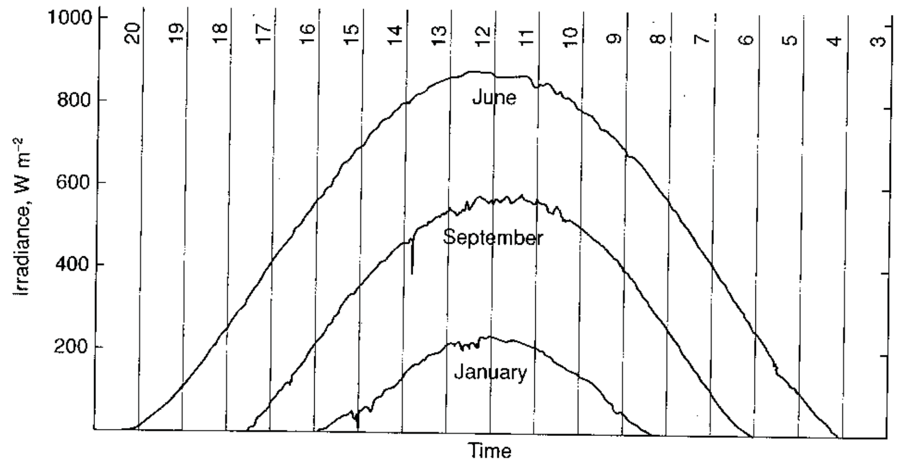
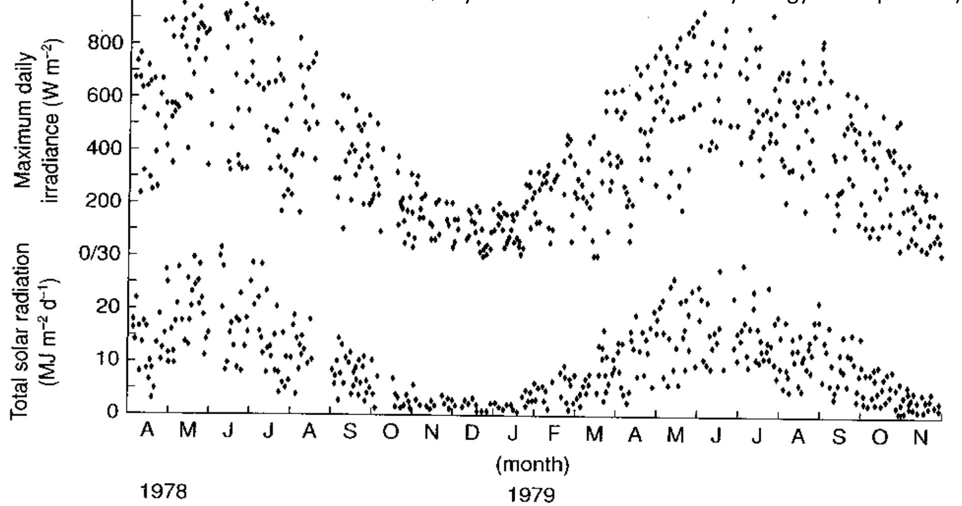


Figure 1.1 Receipts of total solar radiation on three cloudless days at Rothamsted in Central England. The numbers indicate the progression of each day in hours from right to left (from Monteith and Unsworth 1990).

（Hay and Porter 2006 “The Physiology of Crop Yield”)

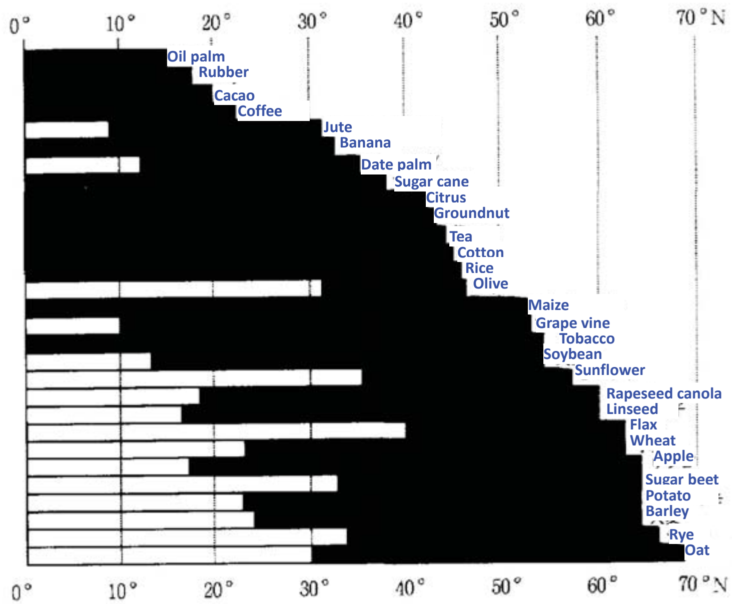
Fluctuation of solar radiation

（Hay and Porter 2006 “The Physiology of Crop Yield”)



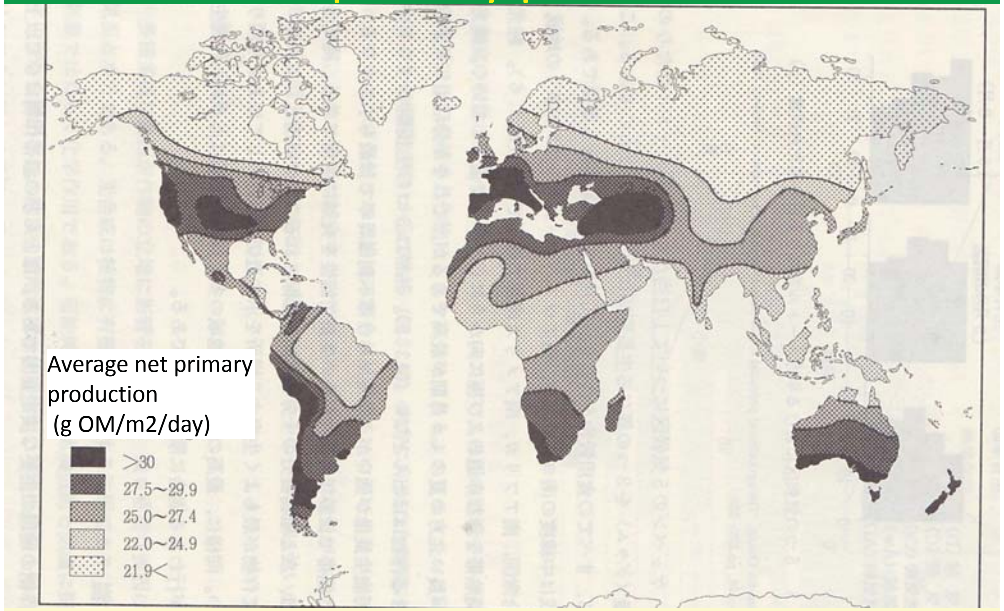
Daily records of maximum irradiance and the total quantity of incident solar radiation (0.35 – 2.5 um) over two growing seasons in the north-west of England (from Hay 1985).

Range of longitude for major crops in northern hemisphere



(Yamamoto et al. 1998 “Agricultural geography”)

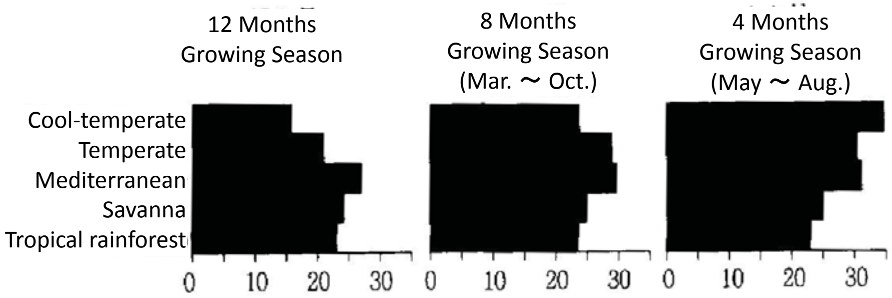
Net primary production



(Grigg, 1995 “An Introduction to Agricultural Geography”)

Question 1
Why is the net primary productivity higher in mid altitude region than the tropical region?

High photosynthesis at cooler climate

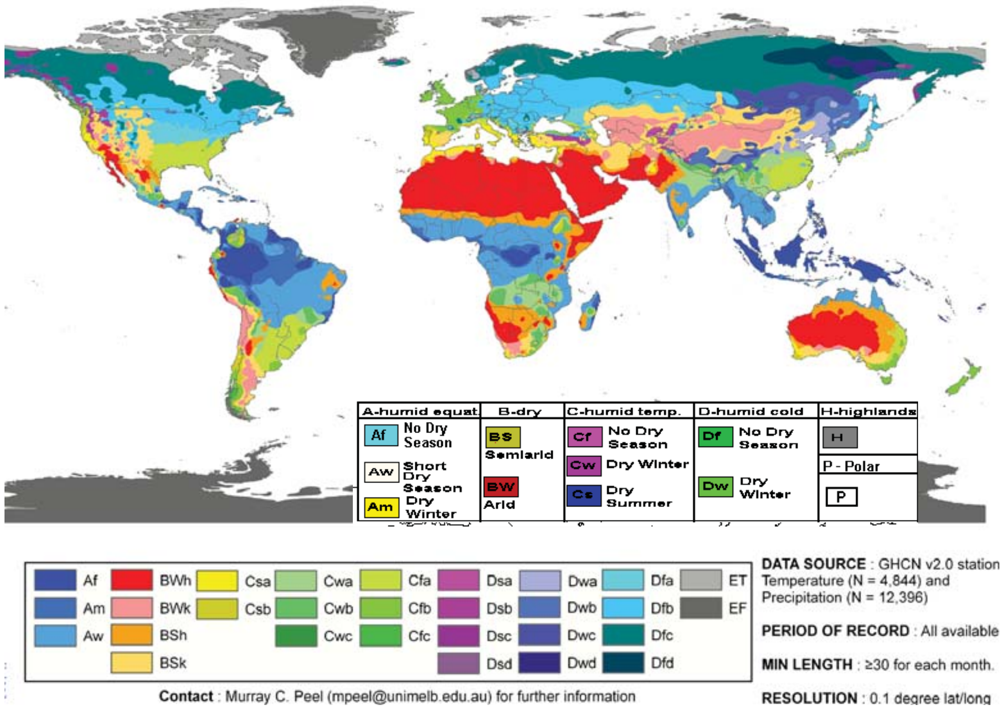


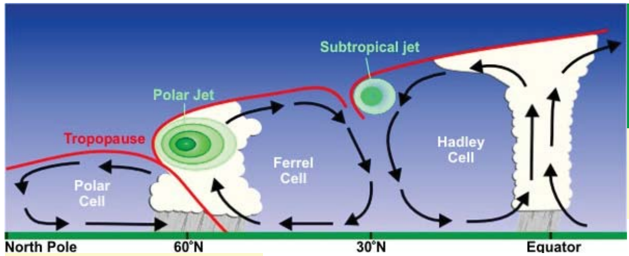
Daily photosynthesis (g/m2/day) at 5 climatic zone

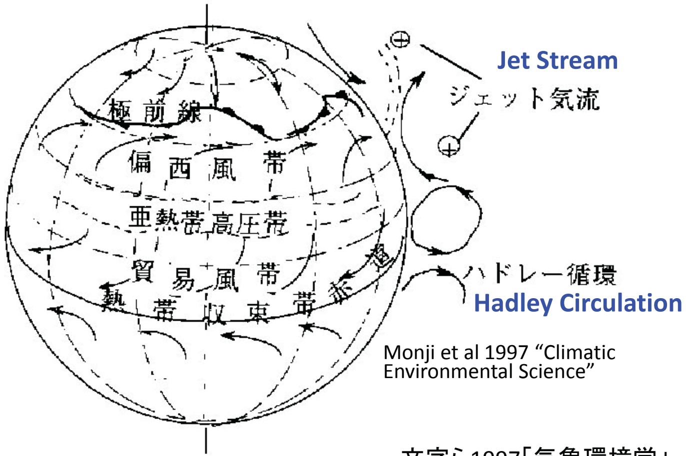
Jen-hu Chang, ‘The agricultural potential of the humid tropics’, *Geographical Review*, 1986, vol.58, pp.333－336.

(Grigg, 1995 “An Introduction to Agricultural Geography”)

Koeppen-Geiger climate map



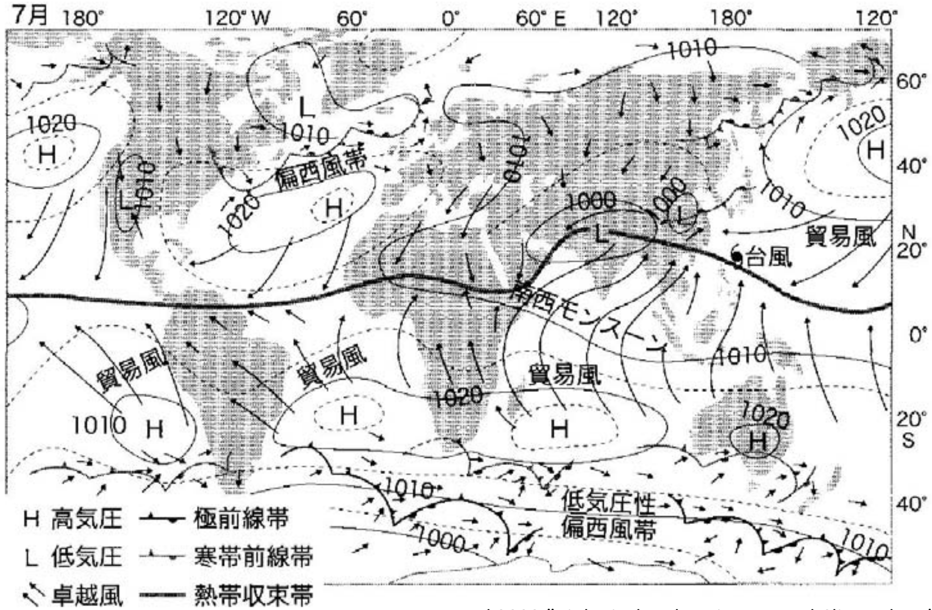




Monji et al 1997 “Climatic Environmental Science”

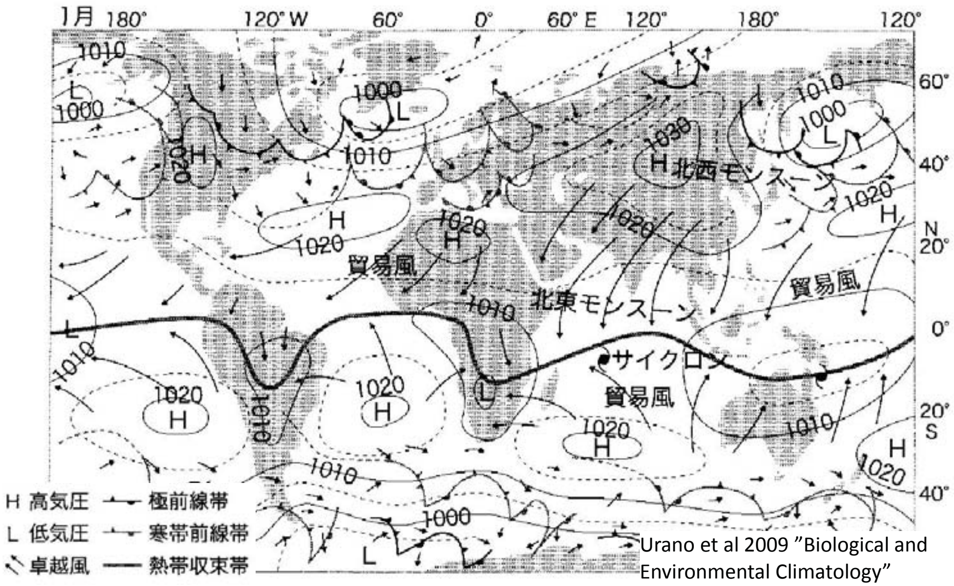
文字ら1997「気象環境学」

High and low pressure area (July)



Urano et al 2009 ”Biological and Environmental Climatology”

High and low pressure area (January)



Urano et al 2009 ”Biological and Environmental Climatology”

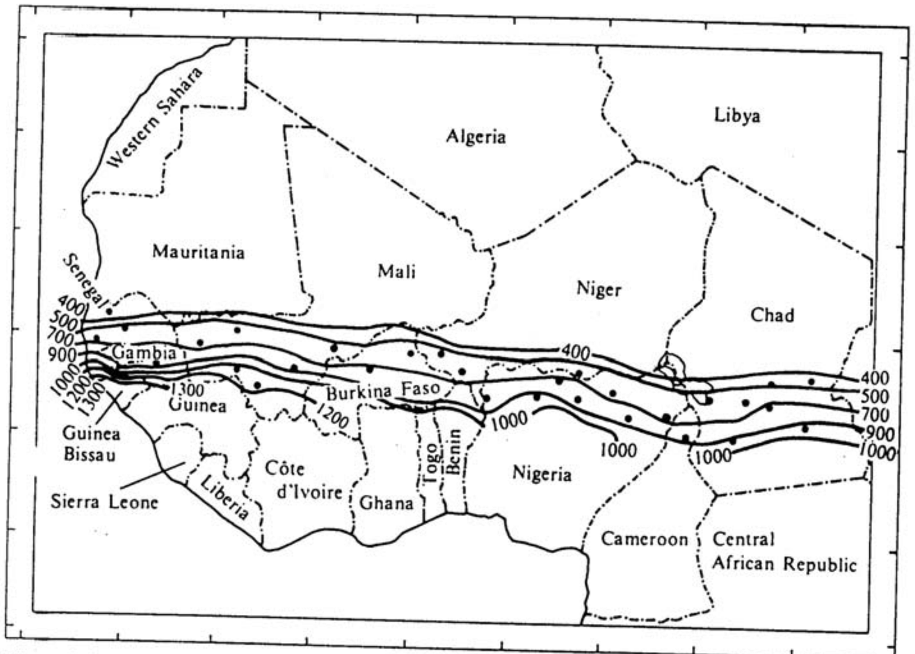


Figure 2. Mean annual rainfall (mm) in the Sudano-Sahelian zone.

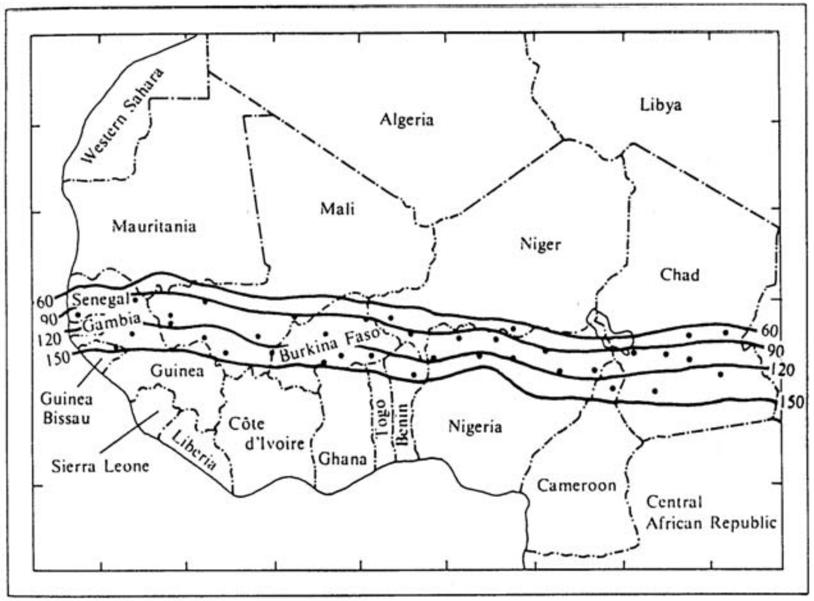


Figure 13. Mean length of the growing season (days) in the Sudano-Sahelian zone.

Distribution of dry zone in the world

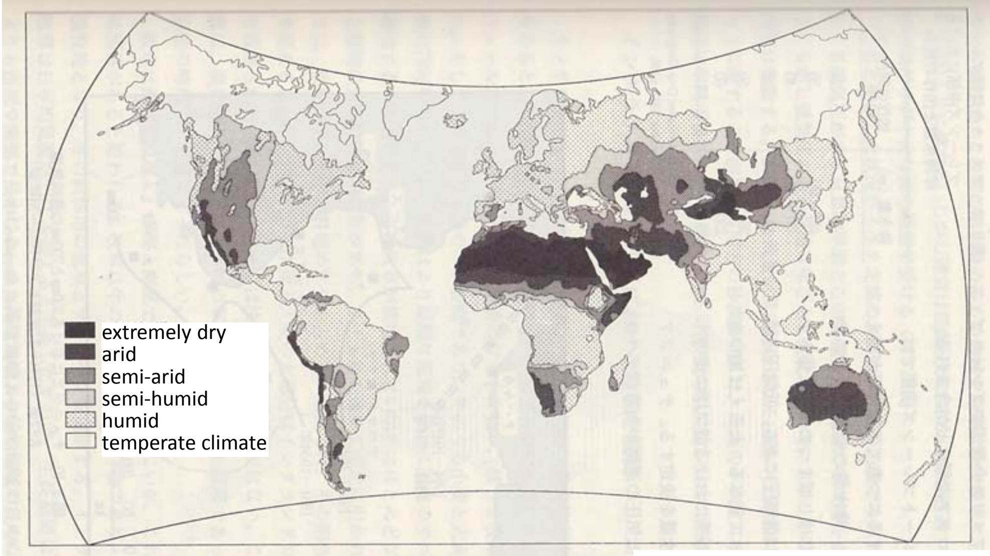
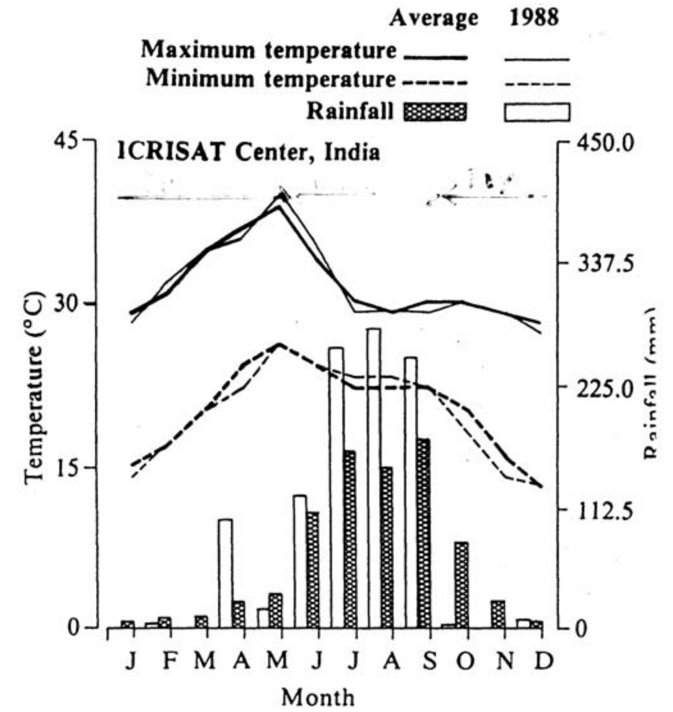


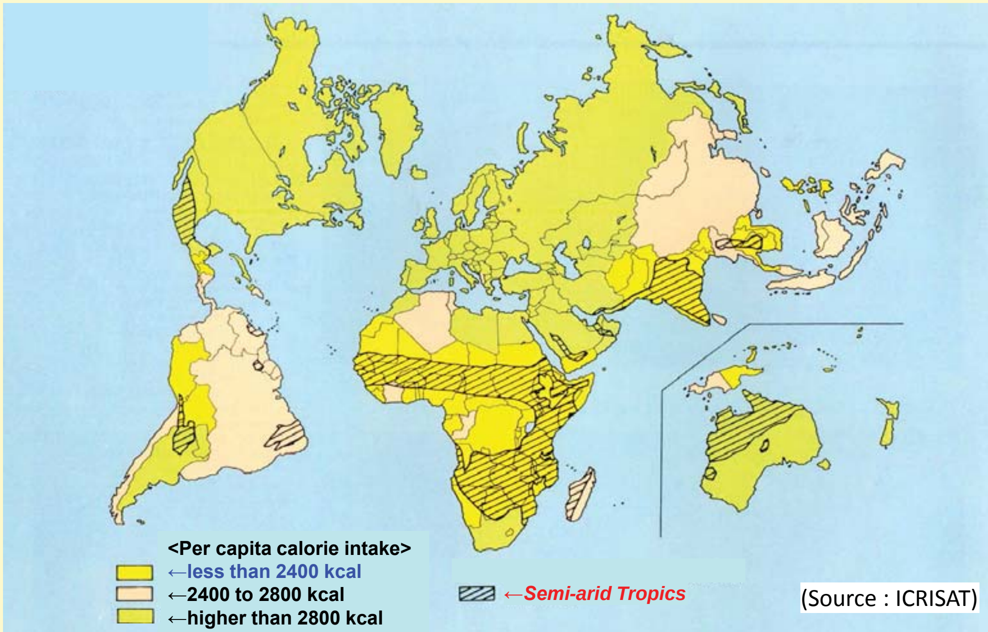
図3.9 世界の乾燥度分布

資料：N.J. Middleton and D.S.G. Thomas, *World Atlas of Desertification*, United Nations Environment

(Grigg, 1995 "An Introduction to Agricultural Geography")

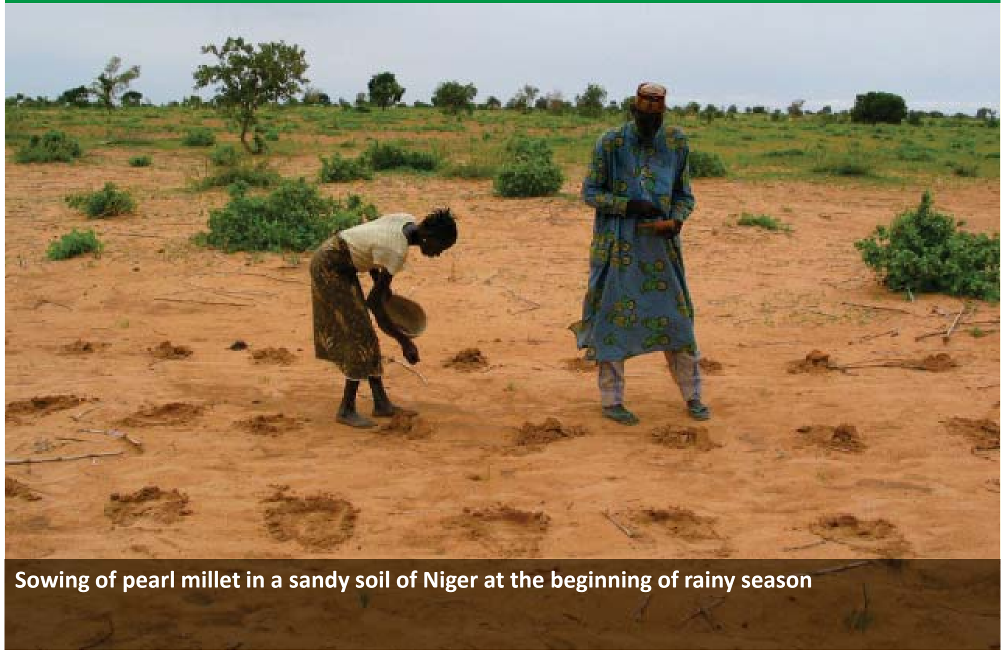


Semi-Arid Tropics

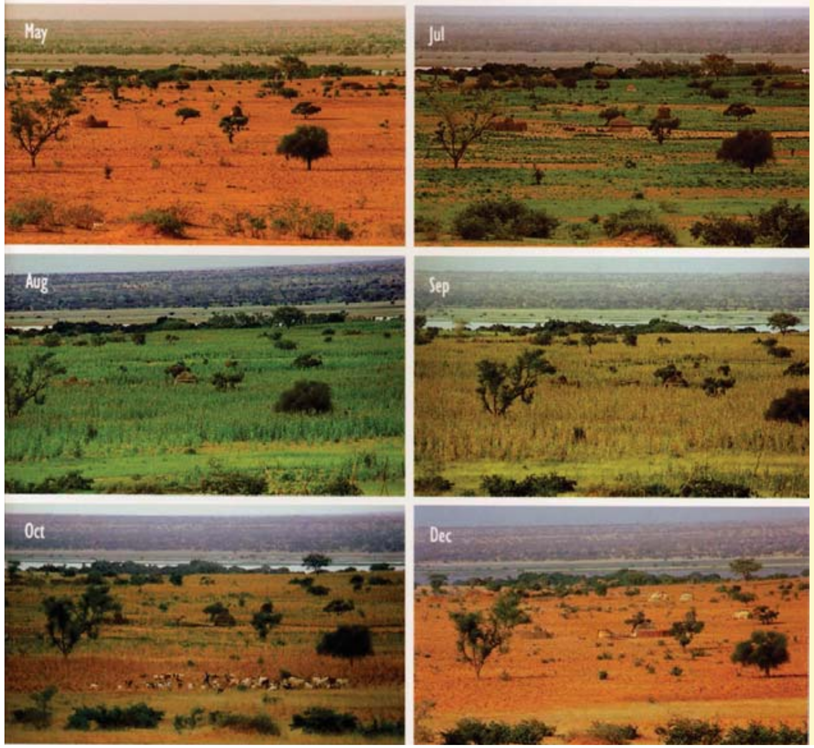


(Source : ICRISAT)

An example of subsistence agriculture in Africa. Niger, a country of the lowest GDP per capita



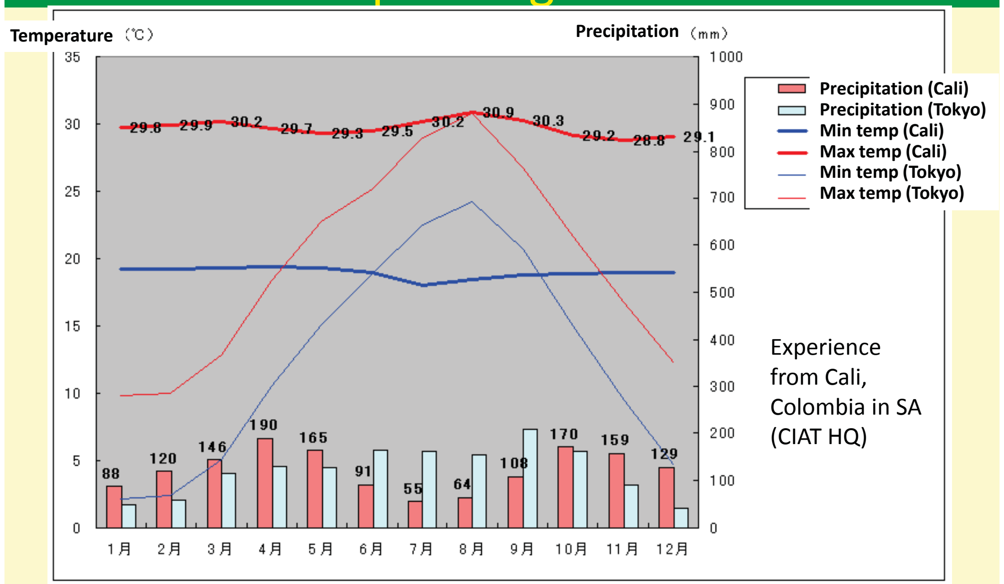
Sowing of pearl millet in a sandy soil of Niger at the beginning of rainy season



Seasonal changes of vegetation in the Sahel

(Niger)

Examples of special environment（2） Tropical highlands



Experience from Cali, Colombia in SA (CIAT HQ)

http://www2m.biglobe.ne.jp/%257EZenTech/world/kion/Colombia/Colombia_Cali.htm

Tropical highlands in the world and its characteristics

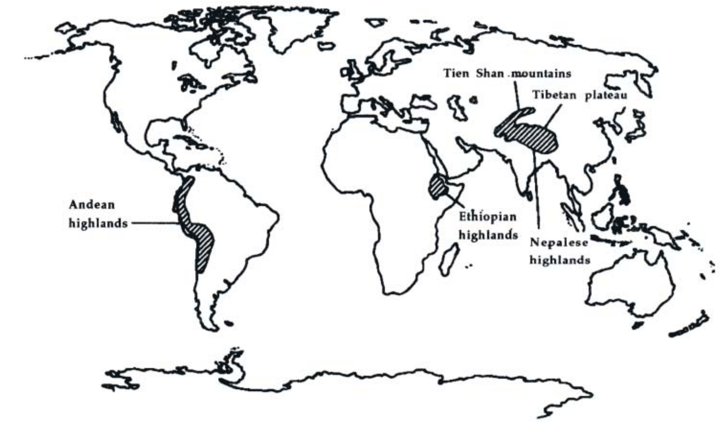


図 8．世界の 3 大高地（標高 2500以上の高地で，大きな人口を擁している山岳地域)。
[Fig 8. Areas of the world above 2,500m(Pawson & Jest, 1978).]

- Andean region
- East Africa (Ethiopia, Kenya)
- Papua New Guinea,
- Candy, Sri Lanka

(Grigg, 1995 “An Introduction to Agricultural Geography”)

Question 2
What are the differences between tropical high land and temperate area?

ABNORMAL CLIMATE

Interaction between atmosphere and oceans

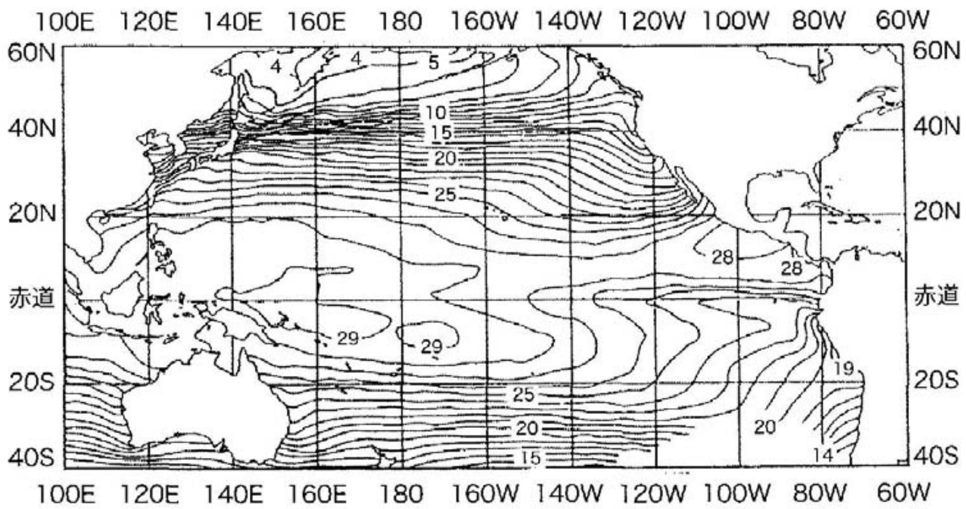
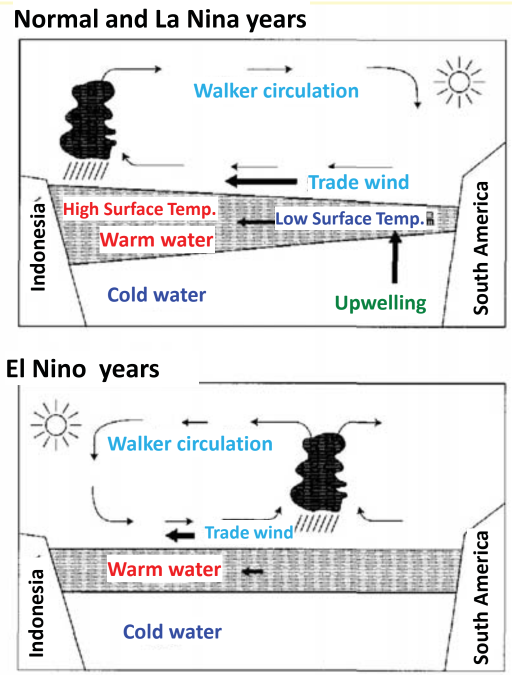


図6-3 太平洋の年平均海面水温分布
（気象庁：異常気象レポート'89, 1989）（浦野

Urano et al 2009 "Biological and Environmental Climatology"

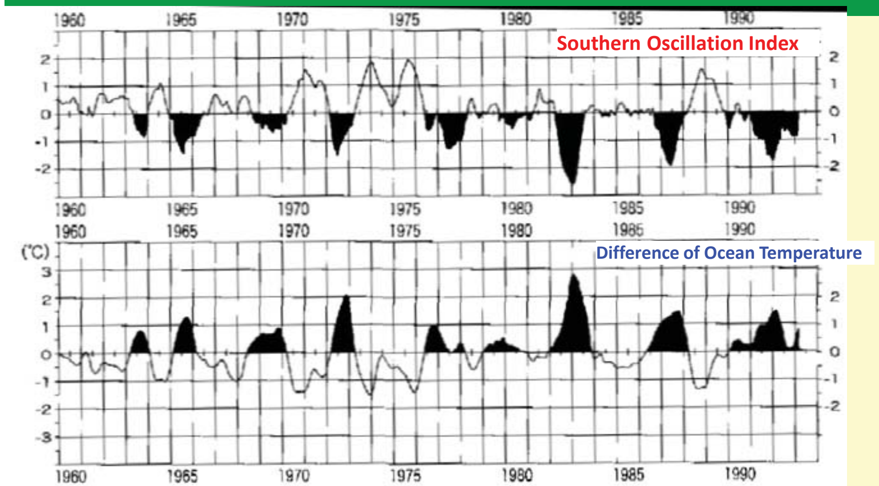
El Nino and La Nina



Distribution of ocean temperature and atmospheric circulation

（Urano et al. 2009）

Southern Oscillation Index

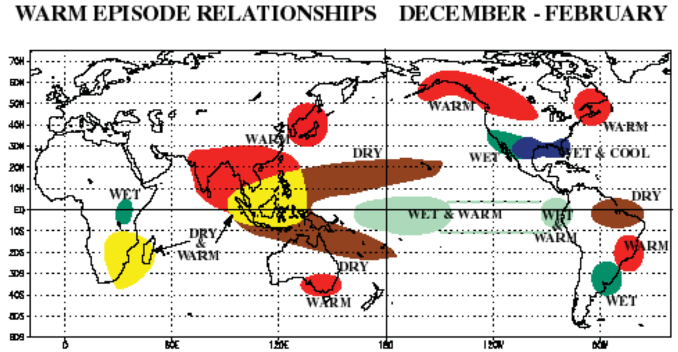


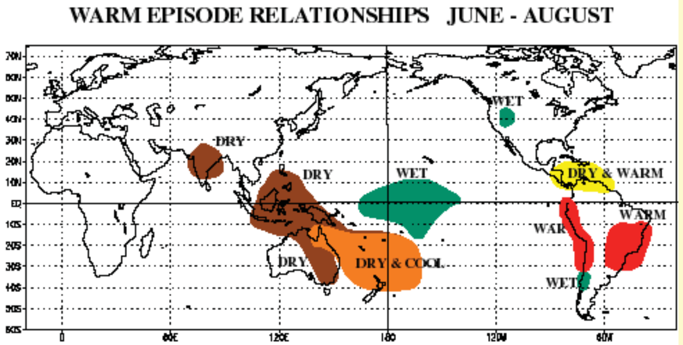
SOI =(BP at Tahichi (East)) - (BP at Darwin, Australia (West))

BP : Barometric Pressure

Negative SOI = El Nino = Less rainfall in Indonesia, etc.

Urano et al 2009 "Biological and Environmental Climatology"





Abnormal Weather in El Nino year

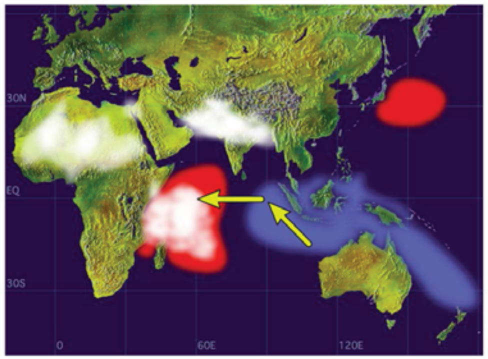
Maximu El Nino (1997-1998)

・Drought at Tropical Rain forest in Indonesia and Brasil, large forest fire

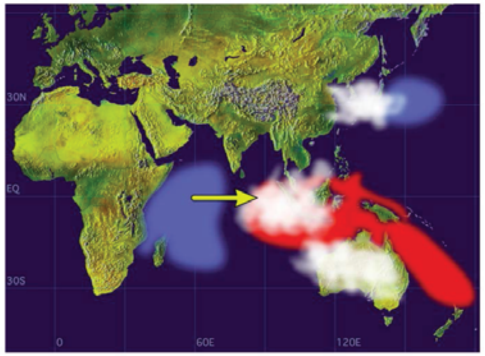
・Flood in the dry area in Peru and East Africa. Extraordinary warm winter in Japan.

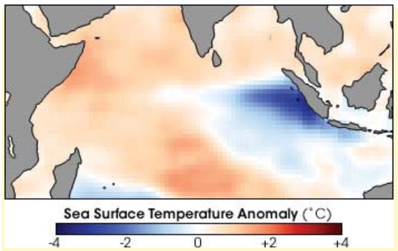
Indian Ocean Dipole

Positive Dipole Mode



Negative Dipole Mode





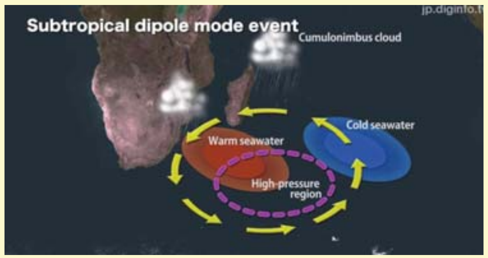
When the Trade Wind of the South-East direction is strengthened, warm water volume at the east part of Indian Ocean shifts to west. And then the upwell from the deeper sea and the evaporation at the surface is strengthened.

This is the positive dipole mode. As the result, the rainfall at the Eastern Africa is increased, but that In Indonesia decreased.

（海洋研究開発機構JAMSTEC）

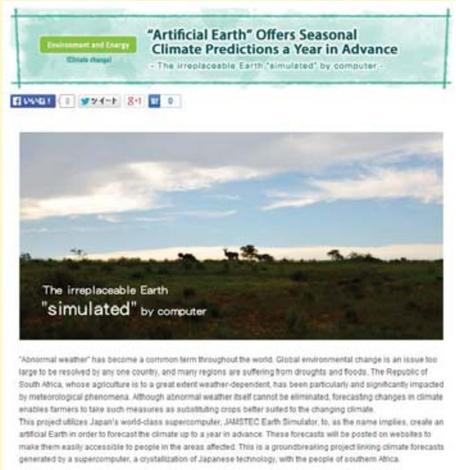
→South Atlantic Ocean Dipole

Application of climate predictions to agriculture



Southern Indian Ocean diploe affects the weather pattern for South Africa

http://www.diginfo.tv/v/12-0010-a-en.php#.U1nuATzAs0M.mailto


"Artificial Earth" Offers Seasonal Climate Predictions a Year in Advance

- The irreplaceable Earth "simulated" by computer -

The irreplaceable Earth "simulated" by computer

Knowing when the rainy season starts for the next yearnning period of the rainy season

Question 3

Confirm how the climate will be affected by el Nino and la Nina in your country.

Agricultural Technologies

1. **First, second, and third Generation Agriculture**
2. **Selected topics related to the third-age agriculture**
   - 3-1 Conservation agriculture
   - 3-2 Plant's ability to acquire nutrients
   - 3-3 Microbe's ability to acquire nutrients
3. **Future direction**

1. Development of agriculture
1-1. Beginning of agriculture

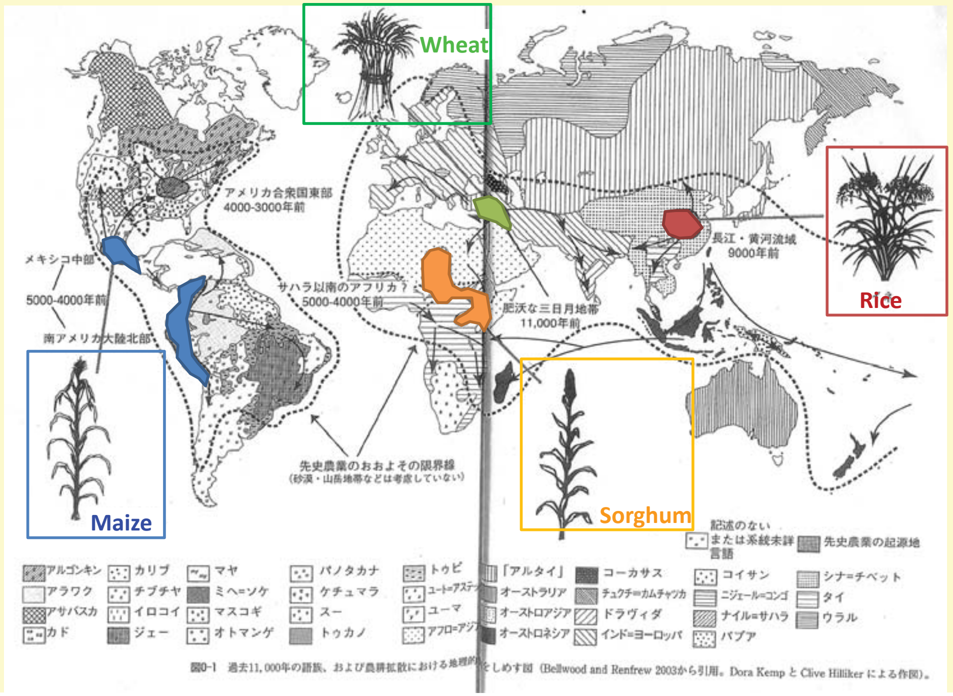
1. Hunters and gathers for tree fruits and wild animals.

2A. Cultivation : start of agriculture.

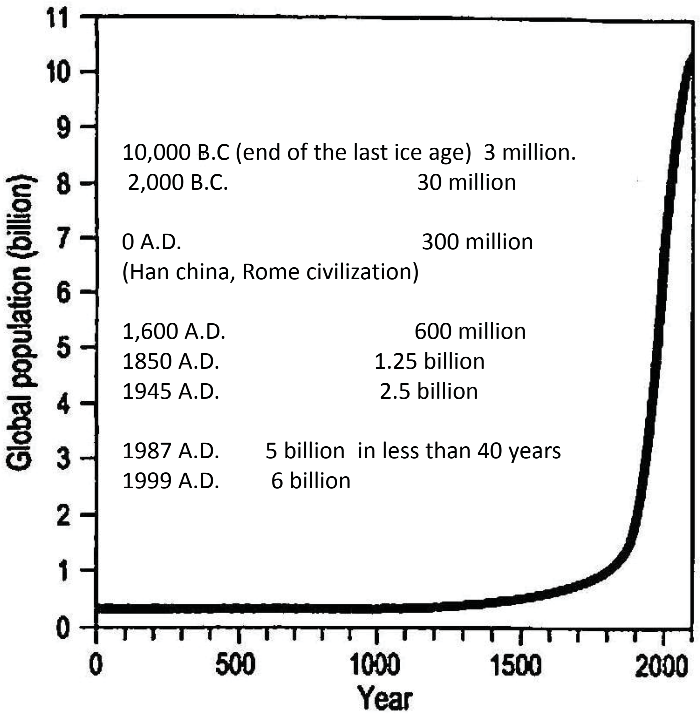
Start of cultivation took places at various places (domestication center) in the world at different ages, not happened at one place on earth.

2B. Domestication of crops and animals were also accompanied.

Domestication of major cereals



Global population (billion)



10,000 B.C (end of the last ice age) 3 million.
2,000 B.C. 30 million

0 A.D. 300 million
(Han china, Rome civilization)

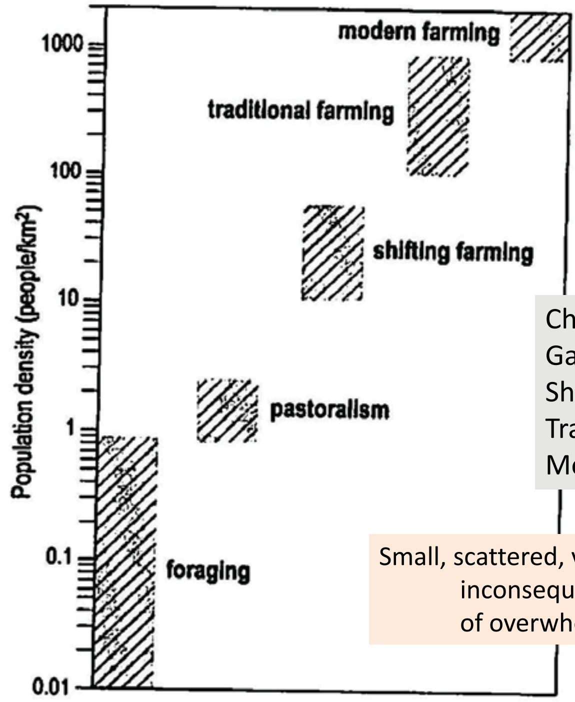
1,600 A.D. 600 million
1850 A.D. 1.25 billion
1945 A.D. 2.5 billion

1987 A.D. 5 billion in less than 40 years
1999 A.D. 6 billion

(Figure 1.1, Smil 2000, After McEvedy and Jones (1979) and UN (1998)

World's **Population Density**

Most numerous population of large, substantially carnivorous mammals on the Earth



Chimpanzees	2 /km2
Gatherers and hunters	1 /km2
Shifting cultivation	10 /km2
Traditional farming	200-300 /km2
Modern agriculture	1000 /km2

Small, scattered, vulnerable, and environmentally inconsequential (=not important) groups of overwhelmingly vegetarian foragers

Smil.2000 "Feeding the World"

1-2. First age agriculture

- Sowing and harvest
- Slash and burn system
- Cultivation
- Irrigation
- Weeding
- Crop Rotation
- Application of organic matter
- Selection of useful plants
- Crop-livestock integration

Cultivation

Wooden Hoe

Iron parts of Hoe

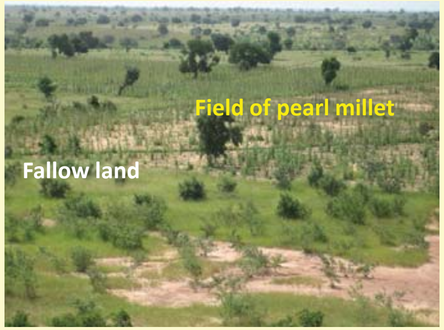
In Japan, agricultural tools of both wooden and iron were used during Yayoi era (BC3 to AD3 centuries). Excavated from Yoshinogari relic site.

Use of animal for cultivation

Manual agricultural technologies from old time

Sowing pearl millet in Sahel

Weeding with hand hoe



Crop-Livestock Integration in West Africa

Corralling by sticks (Kano, Nigeria)

Corralling in a village in Niger (near Niamey)

Millet seedlings under corralled field (Niger)

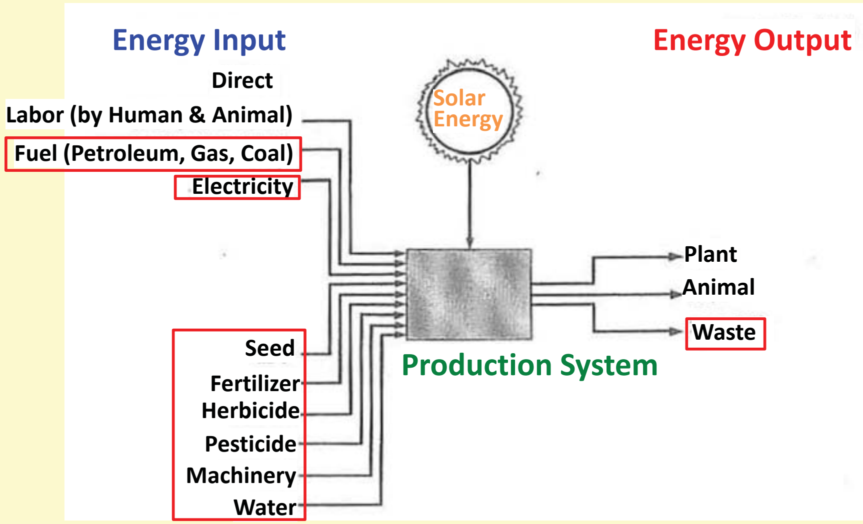
1-3. Second Age (=Industrial) agriculture

- Modern breeding with crossing
- Nitrogen (N) fertilizer
- Phosphorus (P) fertilizer
- Agricultural machinery

Features

- **Increase of input**
- Large-scale, mono-cropping type of agriculture

Input and output of energy in agro-ecosystems

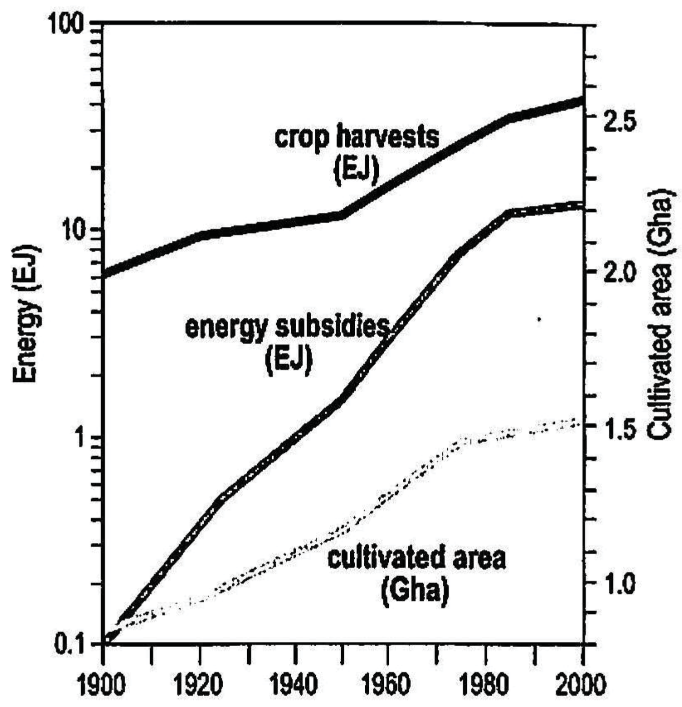


(after Tivy and O'Hare, 1981)

Energy input and output for rice production (1000 kcal/ha)

			Borneo	Japan	California
Input	Direct	Labor	0.63	0.80	0.01
		Hoe and harrow	0.02		
		Machinery		0.19	0.36
		Diesel oil			3.26
		Petroleum		0.91	0.66
		Gas			0.35
	Indirect	Nitrogen fertilizer		2.09	4.12
		Phosphorus fertilizer		0.23	0.20
		Seed	0.39	0.81	1.14
		Irrigation		0.91	1.30
		Pesticides		0.35	0.19
		Herbicides		0.70	1.12
		Drying			1.22
		Electricity		0.01	038
		Transportation		0.05	0.12
Output	Rice yield		7.32	17.60	22.37
Energy efficiency			**7.08**	**2.45**	**1.55**

(after Pimentel, David and Harcia, 1979)



1900-～ Machine (fossil fuels and electricity)

Area increase ×1.3

Yield ×4

Production ×6

External energy input ×80 (fossil fuels)

Human impacts on environment

NATURE|Vol 451|17 January 2008|doi:10.1038/nature06592 YEAR OF PLANET EARTH FEATURE

An Earth-system perspective of the global nitrogen cycle

Nicolas Gruber & James N. Galloway

With humans having an increasing impact on the planet, the interactions between the nitrogen cycle, the carbon cycle and climate are expected to become an increasingly important determinant of the Earth system.

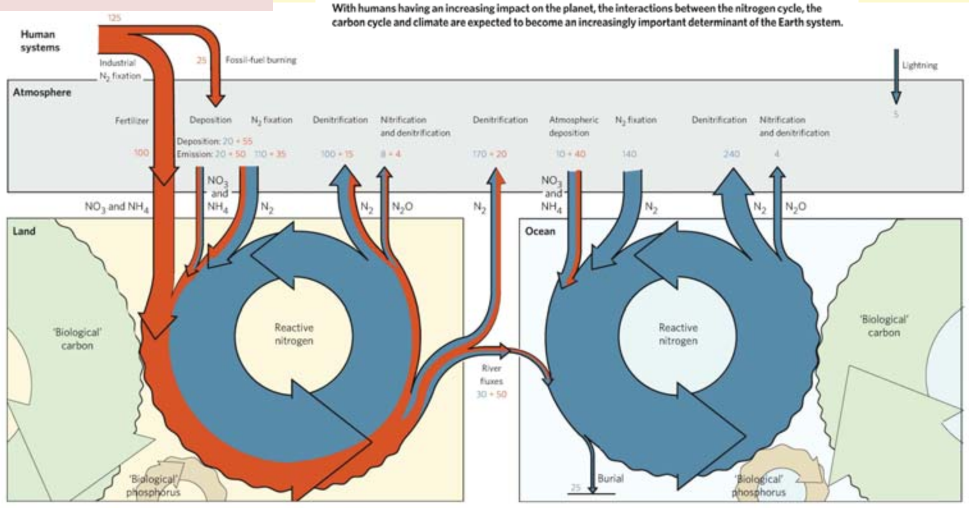
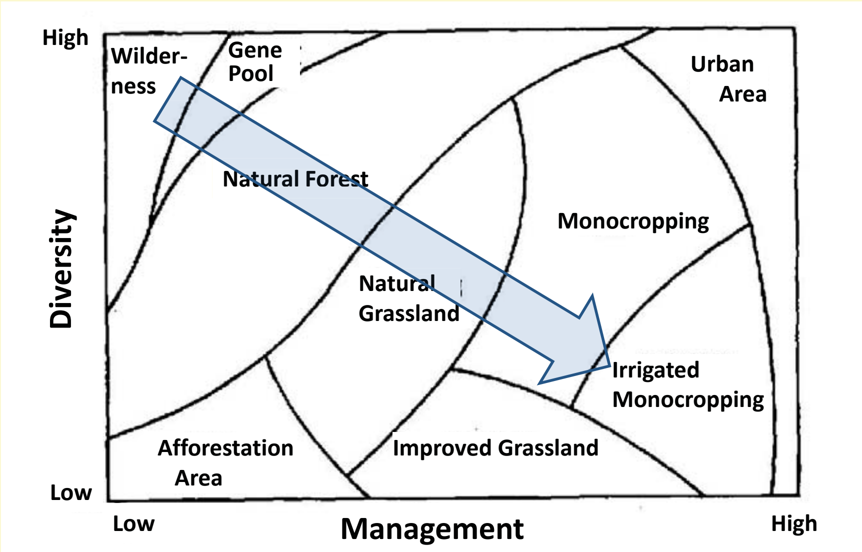


Figure 1 | Depiction of the global nitrogen cycle on land and in the ocean. Major processes that transform molecular nitrogen into reactive nitrogen, and back, are shown. Also shown is the tight coupling between the nitrogen cycles on land and in the ocean with those of carbon and phosphorus. Blue fluxes denote 'natural' (unperturbed) fluxes; orange fluxes denote anthropogenic perturbation. The numbers (in Tg N per year) are values for the 1990s (refs 13, 21). Few of these flux estimates are known to better than ±20%, and many have uncertainties of ±50% and larger[13,21].

Agro-ecosystem vs. Natural Climax ecosystems

- Less species diversity
- Less genetic diversity in each species or genotype
- Simpler spatial structure
- Shorter route of solar energy conversion
- Less complexity (2-3 levels) in food-web
- Larger biomass pool in large herbivore (cow, sheep, goat)
- Smaller energy pool in detritus and soil humus
- Faster nutrient cycle (and loss)
- Lower stability
- Open system

The relative position of agro-ecosystems in term of their intensity of management



(after Smith and Hill, 1975)

1-4. Third Age Agriculture

- IPM
- ISFM
- Conservation agriculture
- Precision agriculture
- Organic farming
- Efficient biological function (plants, microbes)
- In situ plant genetic utilization
- Resource exchange

Features:

- Adjustment, not the increase of scale and input
- Use of ICT technologies
- Use of biological functions
- Human oriented

Question 4

To which generation can the Green Revolution be categorized?

3. SELECTED TOPICS

3-1. CONSERVATION AGRICULTURE (CA)

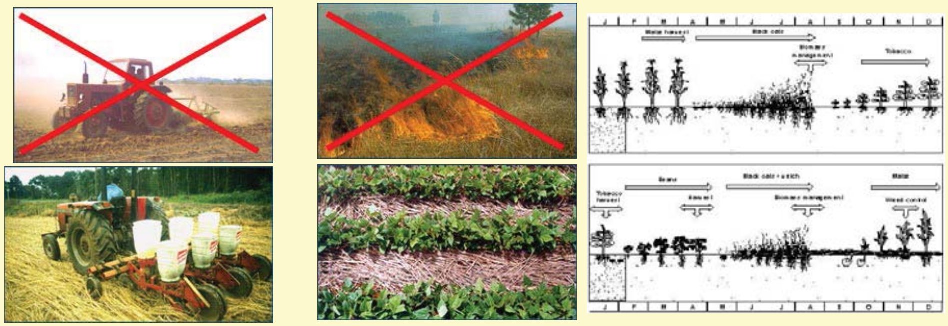
Conservation agriculture (CA)

The three principles of conservation agriculture:

1. Direct planting of crop seeds

2. Permanent soil cover, especially by crop residues and cover crops

3. Crop diversity



FAO site for CA
http://www.fao.org/ag/ca/index.html

No-till (Conservation agr.)

(= **zero tillage**, **direct planting**)

- Definition : Growing crops from year to year without disturbing the soil through tillage.

<u>**Technological components**</u> :

1. Residue management
2. Direct seeding with no-till planter
3. Herbicide use for weed management

No-till planter (1)
http://www.youtube.com/watch?v=pX5tud-2tgc&feature=related
3:00 Row Cleaner, 4:03 Spike wheel, 5:25 Coulter

Direct-drilling wheat at 14 mph
http://www.youtube.com/watch?v=6vspPAtT_og 4:25 Emergence

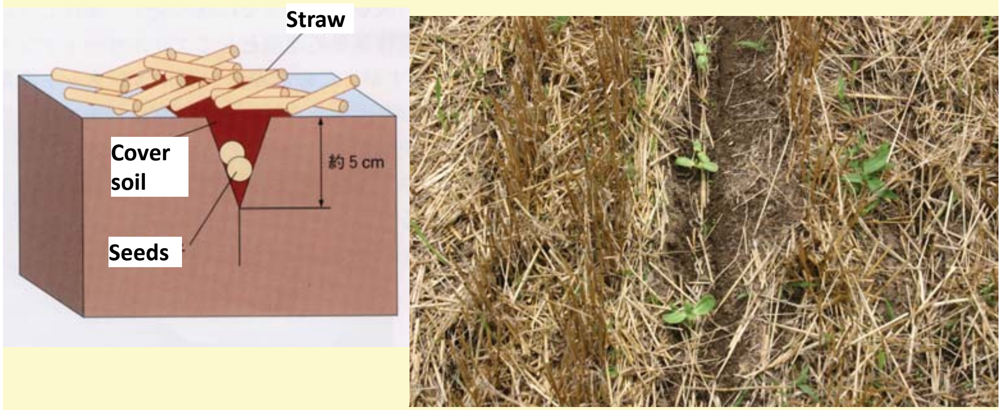
Non-till planter

Mechanical sowing (1)

Non-till planter

May 17, 2005 **Sowing sunflower by non-till planter**

No-till planter with herbicide sprayer



Seed position by no-till planter and germination

Advantages of no-till seeding

- No need for ploughing
- High efficiency（4 to 5 m/second）
- Best-timing operation（shortly after rain）
- One-time operation（sowing, fertilization and herbicide application）

Disadvantages

- Highly risk of **excess moisture**
- Less weed suppression

Strip-till

First, a parial width of the row (20-25cm) is cultivated with special equipment. Fertilizers and chemicals are usually applied at the same time.

In the second run, the seeds were sown on the strip.

Benefit: The higher soil temperature compared with non-till , less erosion, etc.

http://www.youtube.com/watch?v=J1OZWZ2yAaY

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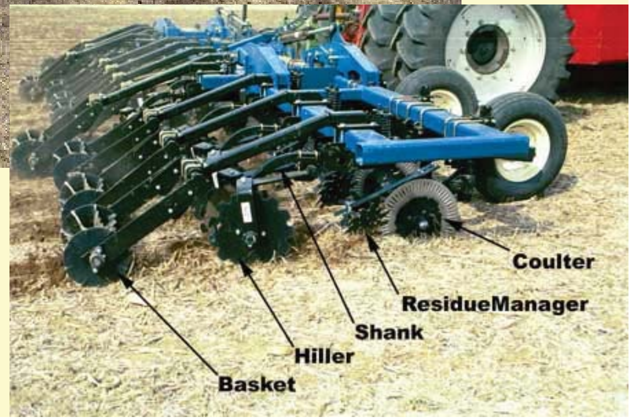
First, a parial width of the row (20-25cm) is cultivated with special equipment. Fertilizers and chemicals are usually applied at the same time.

In the second run, the seeds were sown on the strip.

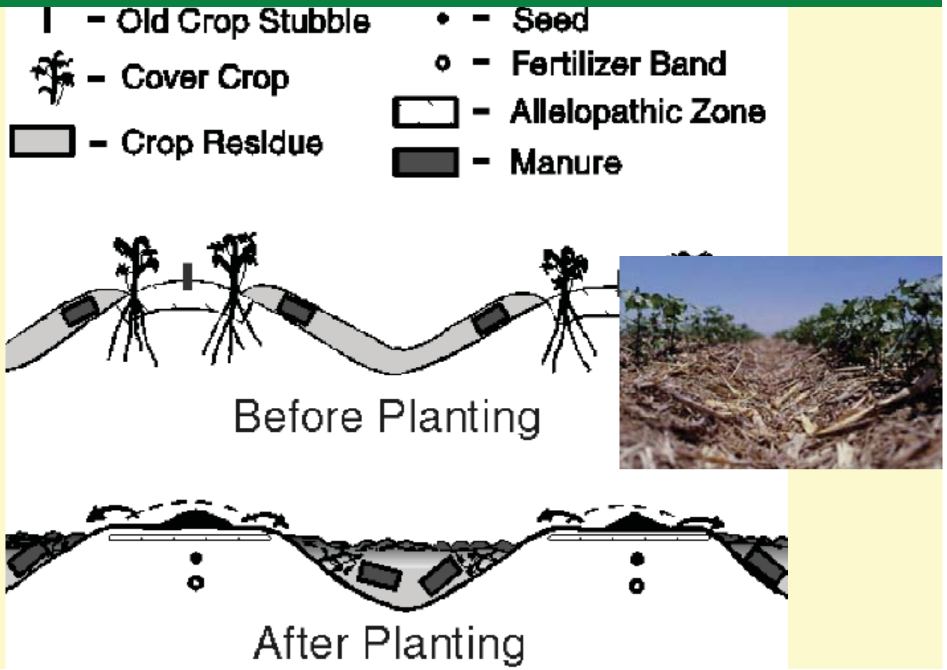
Benefit: The higher soil temperature compared with non-till , less erosion, etc.

http://www.youtube.com/watch?v=J1OZWZ2yAaY

Strip-till

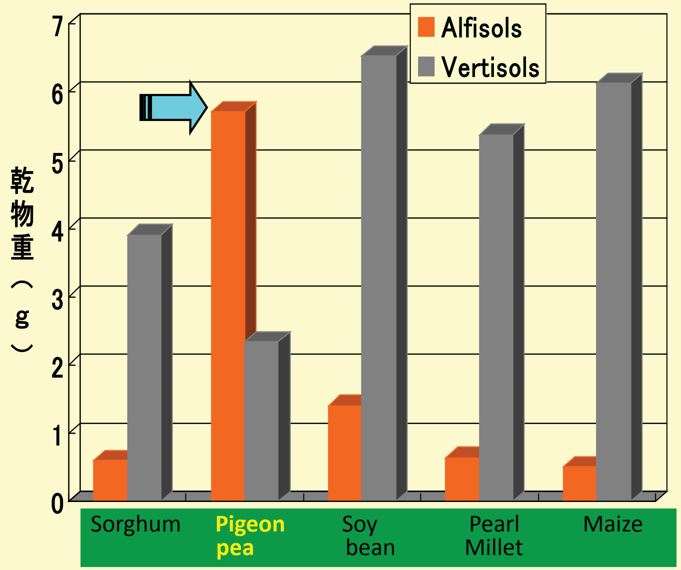


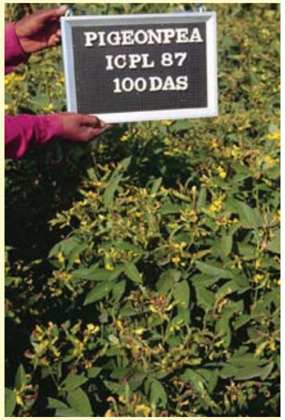
Ridge-till



3-2. UTILIZING PLANT'S ABILITY TO ACQUIRE NUTRIENTS FROM SOILS

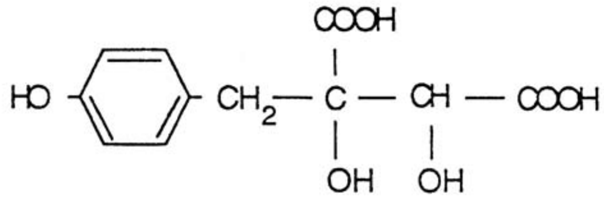
P uptake by plants (shoot) without P application (Grain filling stage, pot exp.)





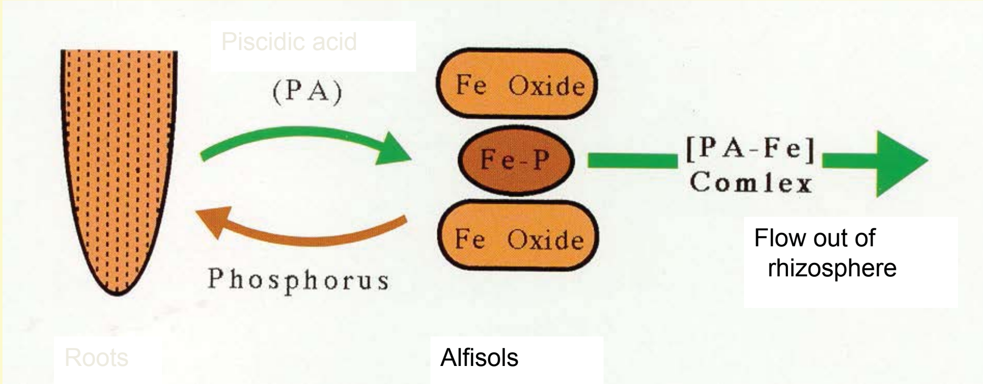
Pigeonpea has a special ability to solubilize Fe-fixed P in Alfisols in the semi-arid tropics

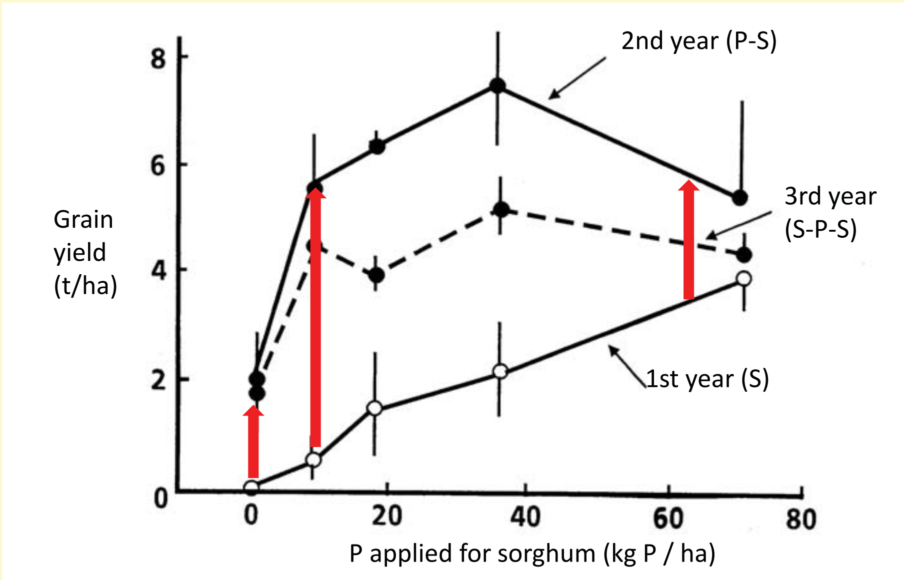
Special mechanisms of pigeonpea to absorb Fe-P



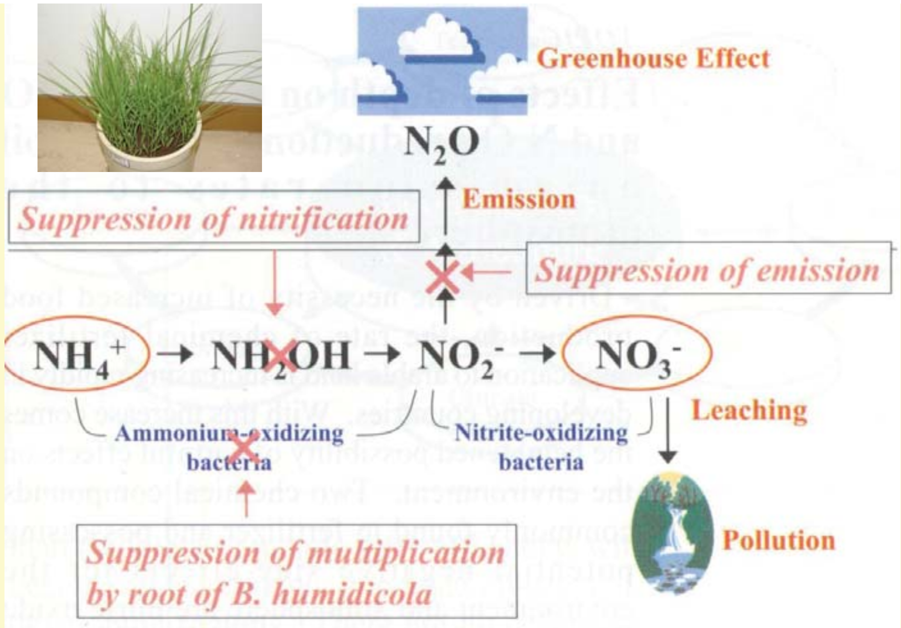
(p-hydroxybenzyl) tartaric acid

[Piscidic acid]





Effect of pigeonpea on the following sorghum in low-P alfisols.



(a). The mechanisms of nitrification suppression and inhibition of nitrous oxide emission by *Brachiaria humidicola*

Uptake and utilization of organic nitrogen (N) by some crop plants

Organic vs. Inorganic Nutrition Theory

- **Thaer**, A. D. (1752-1828)
  "Humus (organic matter) of the soils is the nutrients for plants."

- **von Liebig**, J., (1803-1873)

"CO_2 and ammonia from air, and H_2O, P, S, Si, Ca, Mg, K, Na, Fe, NaCl from soil are the important nutrients for plants."

"Manure are not utilized by plants directly, only after decomposition."

"Plants can grow only with inorganic nutrients"

Proposed new nitrogen pathway

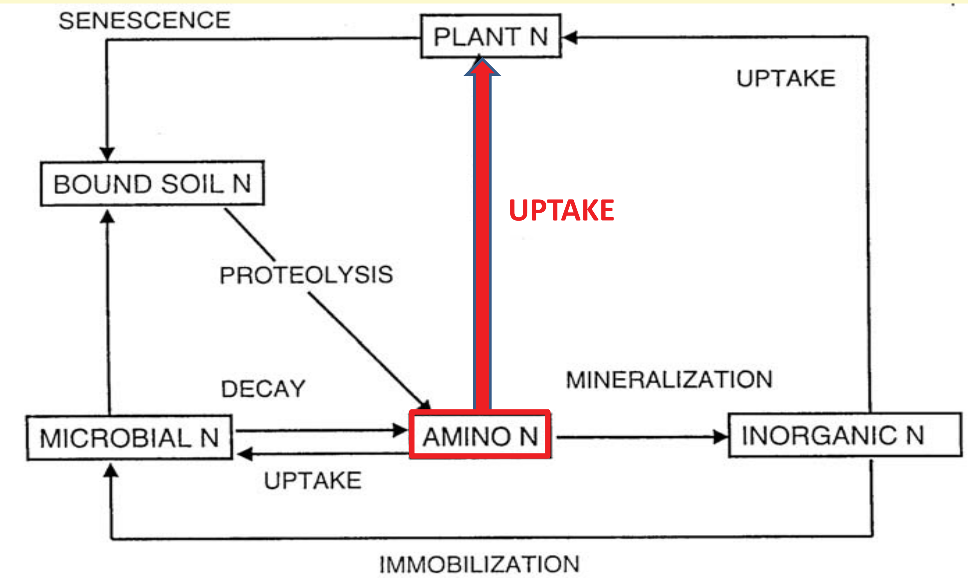
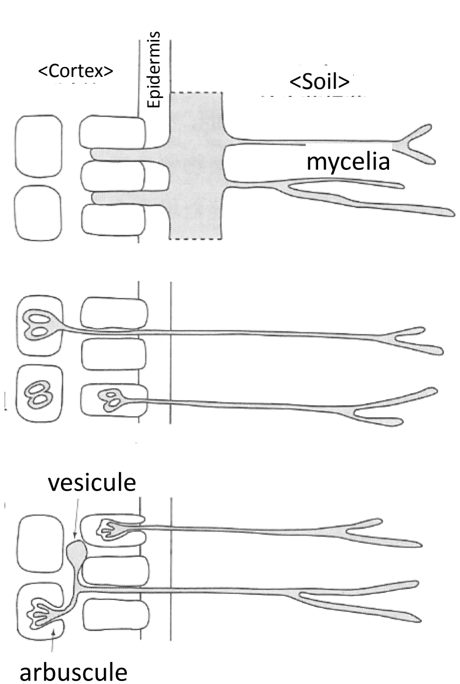


Fig. 9. Schematic diagram of the nitrogen cycle in tundra ecosystems showing the hypothesized role of organic nitrogen. (From Kielland 1994).

3-3. UTILIZING MICROBIAL ABILITY TO ACQUIRE NUTRIENTS FROM SOILS

Three types of mycorrhiza

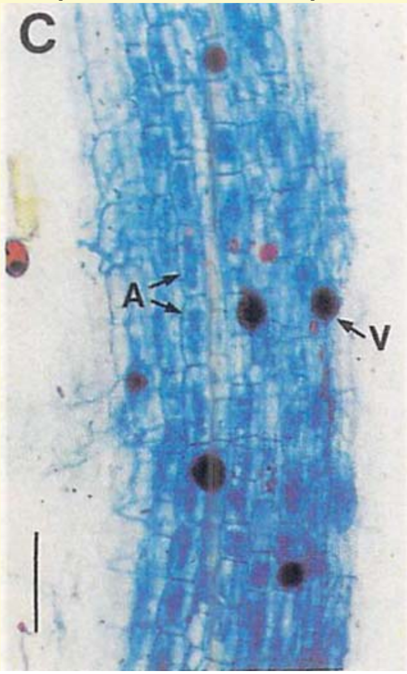


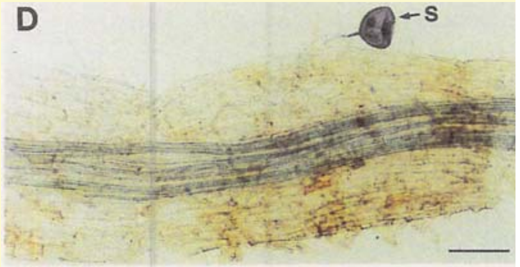
Ectomycorrhizal fungi
for trees, Basidiomycetes

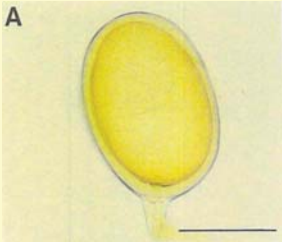
Ericoid mycorrhizal fungi
for orchids, Ericaceae

Arbuscular mycorrhizal fungi (AMF, VAM)
Important for many plant species

(Vesicular-) Arbuscular Mycorrhiza







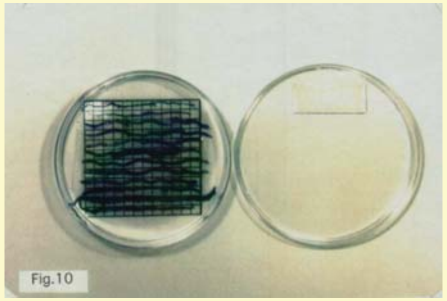
Spore
Bar = 0.1 mm

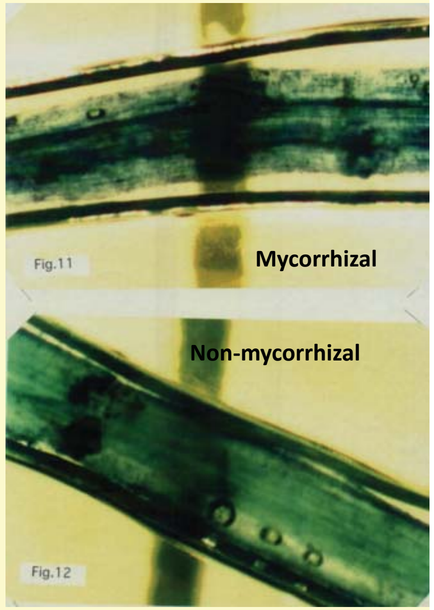
(Ueda et al 1992)

AM measurement (1) % root infection

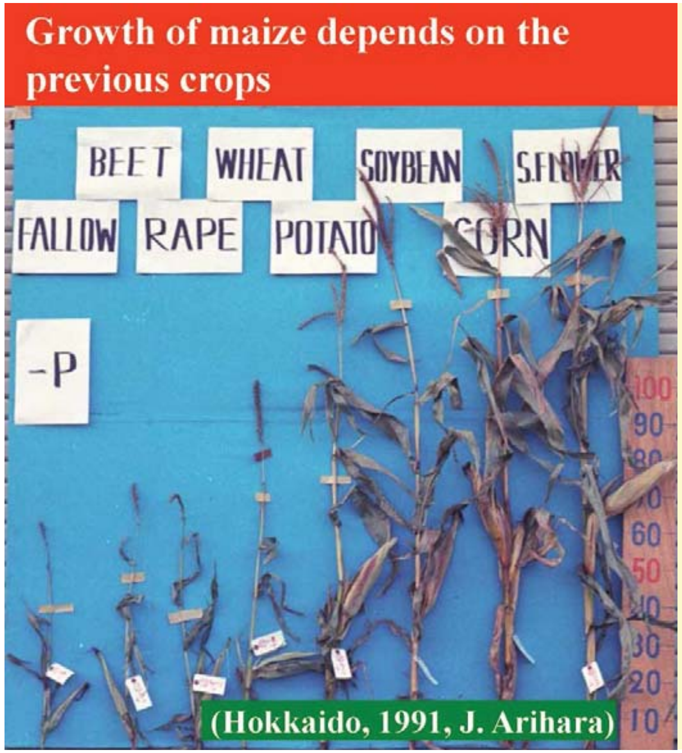
Dying with trypan blue

Fixation





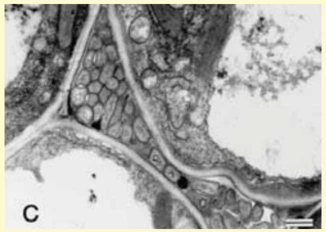
(Usuki, personal communication)



Effect of the previous crops on the growth of maize in Hokkaido, Japan

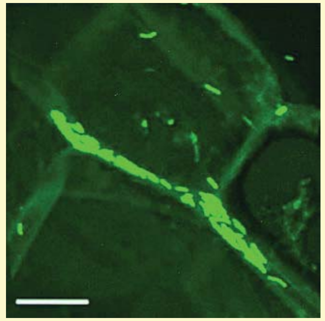
Endophyte

- endo (within)+ phyte (plant)
- Definition : An endophyte is an symbiotic microbes in plant tissue, often a bacterium or fungus, that lives within a plant for at least part of its life without causing apparent disease. Endophytes are ubiquitous and have been found in all the species of plants studied to date.



Bacteria colonized in 3rd leaf of rice

(Elbeltagy et al 2001)



Fluorescence micrographs of GFP-tagges *Herbaspirillum* sp. strain

(*Lolium temulentum*)

Endophyte history

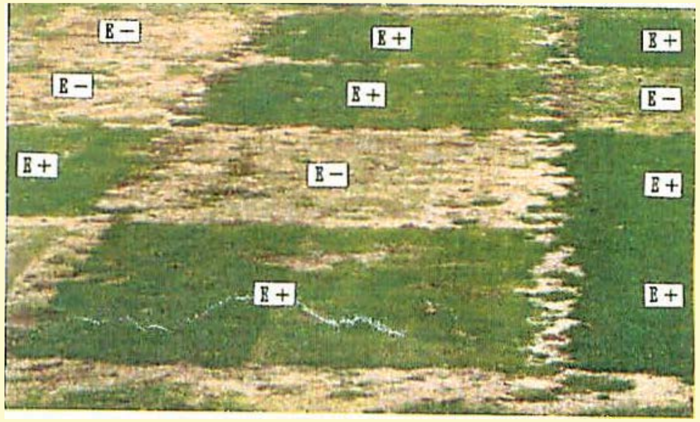
- Darnel (毒麦) (*Lilium temulentum*) was known from old age (mentioned in New Testament), but it was rather recent that the toxins were produced by fungus which colonizes in the plants.
- Since 1970's these were found to be the cause of the animals' intoxication. In 1975 the cause of the fesucue toxicosis was found to be the endophytic fungi in tall fescue (*Festuca arundinacea*) in North America, and in 1979 ryegrass staggard was found to be caused by enophyte in perennial ryegrass (*Lolium perenne*).

(Tall fescue)

-E +E

(rye)

- But Prestidge (1982) reported that endophytic perennial ryegrass is more tolerant to a kind of weevil (Argentine stem weevil).



Perrenial ryegrass affected by *Crambus spp.*)
E+ Variety infected by endophyte : E- Variety not infected by endophyte

Power of endophyte (NHK video)
http://cgi4.nhk.or.jp/gendai/kiroku/detail.cgi?content_id=2958

Endophytic N_2 fixation in Sugarcane

Table 3. Total nitrogen accumulation of sugar cane and *Brachiaria arrecta* and estimates of nitrogen derived from BNF using N balance and ^{15}N isotope dilution techniques ($g\,N\,m^{-1}$). means of 4 replicates. After Urquiaga et al. (1991)

Variety/Species	Final N content of soil	N accum. whole plant 3 years	Estimates of BNF contribution: All three years, N balance[1]	All three years, ^{15}N[2]	Annual mean, N balance	Annual mean, ^{15}N
CB 47-89	835	61.4bc	39.7	34.8c	13.2	11.6
CB 45-3	864	84.3ab	62.6	52.6b	20.9	17.5
NA 56-79	884	57.8c	36.1	32.6c	12.0	10.9
IAC 52-150	924	59.6bc	37.9	33.8c	12.6	11.3
SP 70-1143	852	77.5bc	55.8	51.9b	18.6	17.3
SP 71-799	860	56.9c	35.2	33.3c	11.7	11.1
SP 79-2312	845	63.6c	41.9	35.4c	14.0	11.8
Chunee	826	33.0d	11.3	16.9d	3.8	5.6
Caiana	857	11.6d	−10.1	6.7d	− 3.4	2.2
Krakatau	857	102.8a	81.1	71.8a	27.0	23.9
B. arrecta	830	24.9d	3.2	—	1.1	—
CV (%)	5.1ns	25.0***	—	29.2***	—	29.2

(Boddey et al. 1991)

Plants associated with N_2-fixing endophytes

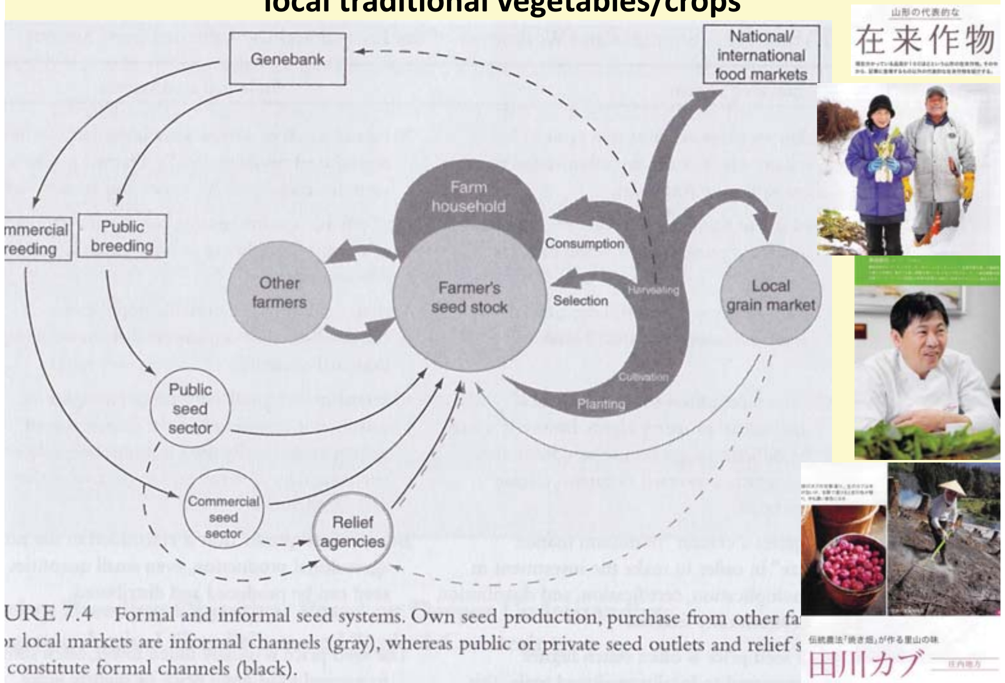
- sugarcane
- rice
- palm (date, oil, etc.)
- sweet potato
- pineapple
- tea
- coffee
- and more?

crisis in the Middle-East

Recent attempts to isolate diazotrophic bacteria from palm trees at various sites, including the Amazon region, showed the abundant occurrence of diazotrophic bacteria. Dendê and Pupunha are colonized by *Azospirillum brasilense*, *A. amazonense*, *Herbaspirillum seropedicae*, and other as-yet-unidentified N_2-fixing bacteria. These bacteria are present in the roots, stems, leaves, and in the endosperm of the fruit. Probably a new *Herbaspirillum* species is present in roots, stems, and leaves of these palm trees (Ferreira et al., 1995 and 1997).

(Reis et al 2000)

Discovery of <u>Informal seed system</u>, *in situ* genetic conservation, local traditional vegetables/crops



Report

- Which innovation(s) at this age will contribute to the third generation agriculture, and how? (1 page) Pick up the innovation(s) not mentioned in today's lecture.

6. Future Direction

Present issues for agriculture and food for consumers

- Safety of the food
  - Additives, Remaining antibiotics, BSE, Virus, Radioactivity
- High price
- Unbalanced nutrients
  - Convenient food

Present issues for agriculture and food for producers

- Low benefit, fluctuation
- Unbalanced labor / price
- Working conditions
- Two extremes
  - Quest of the high value-added products, which will not lead to the benefit of the consumers