10 April 2015

Advanced Global Agricultural Sciences I
IPADS Development Studies

Terrestrial Environment (1)

Global climate, Light, Atmosphere, Geology, and Chemical environment

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Trans-disciplinary approach

Wide knowledge is required in the domestic and global fields

- Example (real case)
- In the Eastern Savanna of Colombia (Llanos Orientales), large-scale rice-pasture system was introduced and the productivity has been raised impressively. But in 1995, an uncommon symptom of the disease of rice plant was discovered. It looked like a virus disease. What action should Rice Program at CIAT take, as the International Institute responsible for rice researches of whole Latin America? What is the role each scientist should take if the program had following scientists of different experts.

Trans-disciplinary approach

Wide knowledge is required in the domestic and global fields

1. Plant pathologist
2. Rice breeder
3. Agricultural economist, Household economics specialist
4. Agronomist (specialist for production technologies)
5. National extension services

One cannot cover all the disciplines, but should have basic knowledge to understand and appreciate other specialists' opinions to be able to actively participate in the discussion.

Elements of terrestrial environment surrounding biological creatures

- Light
- Water
- Gas
- Soil
- Ion, elements
- Organic matter

Light environment : Cyclic period of solar activity and average temperature in the northern hemisphere

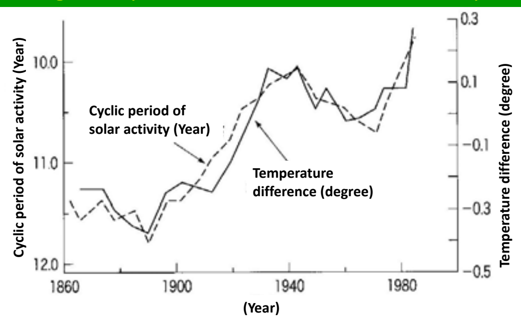


図2-6 太陽活動周期の長さと北半球における気温変動との関係
(Burroughs, W. J. : Weather Cycles, Cambridge, 1992)
Urano et al 2009「Biological and Environmental Climatology」

Radiation energy

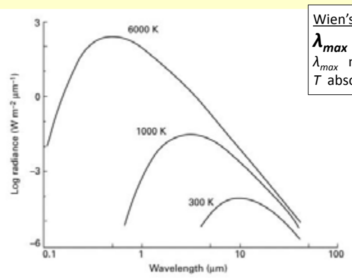


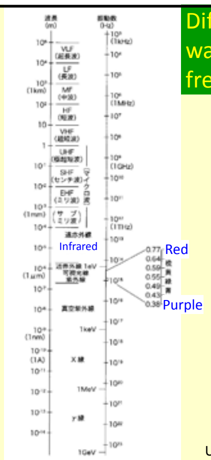
Fig. 6.1 Spectral distribution of black body radiation as calculated with Planck's distribution for bodies at 300, 1000, and 6000 degrees Kelvin (K).

Wien's displacement law (ヴィーンの変位則)
λ_{max} = 2897 / T (μm)
λ_{max} maximum wavelengths of the curves
T absolute temperature (K)

Stefan-Boltzmann law
(シュテファン＝ボルツマンの法則)
$E = \varepsilon \sigma T^4$ (W m^{-2})
E total energy emitted over the entire spectrum
ε emissivity (放射率、射出率)
σ Stefan-Boltzmann constant
T absolute temperature

(Connor et al 2012 "Crop Ecology")

Different kinds of electromagnetic waves, and their wave length and frequency



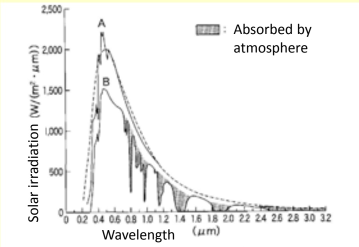


図2-1 波長ごとに見た太陽放射強度
大気圏上面への入射量(A)、地表面への入射量と大気による吸収帯(B)。(Arya, S. P.: Introduction to Micrometeorology, Academic Press, 1988)

Urano et al 2009「Biological and Environmental Climatology」

Light absorption by atmosphere and various gasses

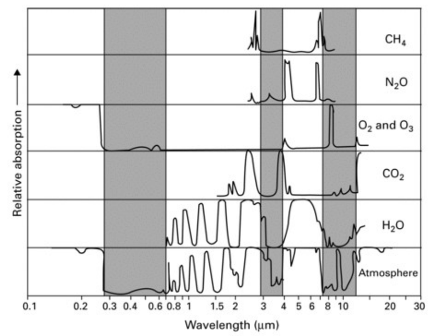


Fig. 6.5 Absorption spectra of normal air and various component gases. (After Fleagle & Businger 1980.) Note the PAR band in the atmospheric spectrum at 0.3 to 0.7 μm and how the width of the atmospheric "windows" to infrared at 3 to 4 and 8 to 12 μm are limited by the absorption bands for CO_2.

Connor et al. 2011 "Crop Ecology"

Daily and seasonal fluctuation of irradiance

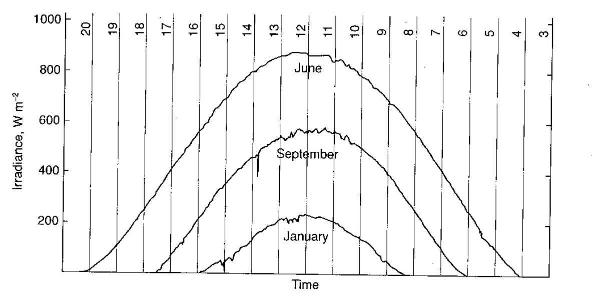
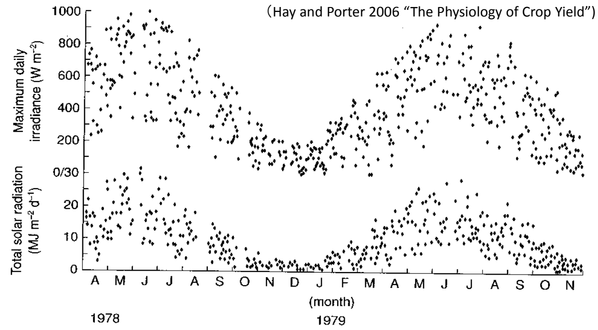


Figure 1.1 Receipts of total solar radiation on three cloudless days at Rothamsted in Central England. The numbers indicate the progression of each day in hours from right to left (from Monteith and Unsworth 1990).

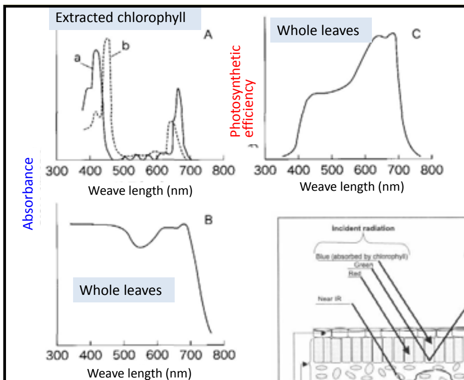
(Hay and Porter 2006 "The Physiology of Crop Yield")

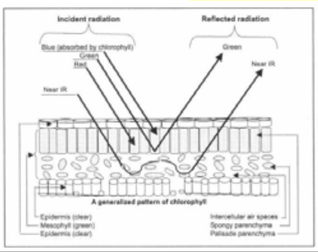
Fluctuation of solar radiation

(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).





(Urano et al 2009「Biological and Environmental Climatology」p.99)

1. Irradiance (*Q*) cont.

$$I = I_0 e^{-kL}$$

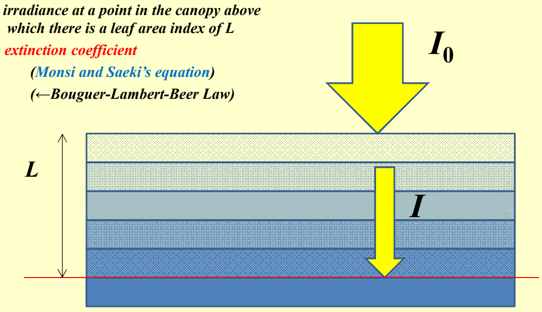
***I_0* : irradiance above the canopy**

I* : irradiance at a point in the canopy above which there is a leaf area index of *L

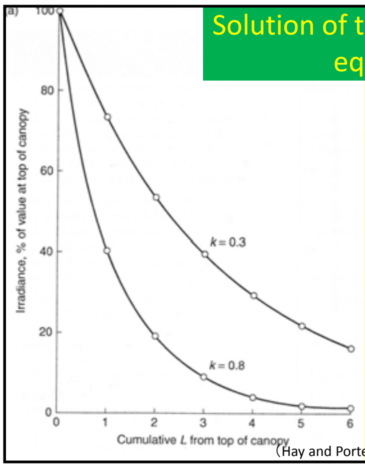
***k* : extinction coefficient**

(Monsi and Saeki's equation)

(←Bouguer-Lambert-Beer Law)



Solution of the Monsi and Saeki equation (a)



(Hay and Porter 2006 "The Physiology of Crop Yield")

Micro-climate in plant canopy

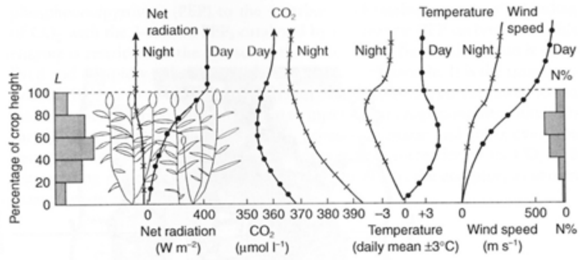


Figure 4.13 Generalised profiles of leaf area index (L) and % of above-ground nitrogen (%N) in different leaf strata of a wheat crop at maximum L. Interception of incident radiation during the day in relation to L is indicated. The profiles of CO_2, temperature and wind speed are shown for day and night situations and the direction of the CO_2 and radiation fluxes are indicated (after Lawlor 2001).

(Hay and Porter 2006 "The Physiology of Crop Yield")

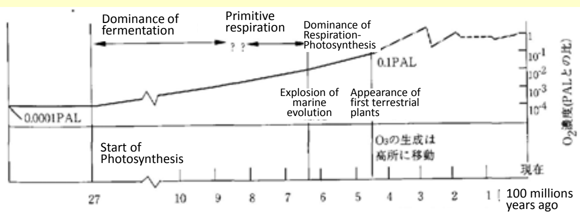
(Photo by K. Okada)

(Photo by K. Okada)

Roles of atmospheric gasses

- CO_2 : Photosynthesis
- O_2 : Respiration
- N_2 : Nitrogen fixation
- CH_4, NOx : Greenhouse effect gas
- Ozone (O_3)

Gas environment：
Historical changes of atmospheric oxygen concentration affected by biological activiei



PAL : Present atmospheric level

表 2-4　地球の標準大気組成

成　分	窒素 N_2	酸素 O_2	アルゴン ^{40}Ar	二酸化炭素 CO_2	水蒸気 H_2O
モル百分率（%）	78.084	20.946	0.934	3.5×10^{-2}	0.1 ～ 2.8
分子量	28.01	32	40	44.01	18.02

（日本気象学会：新教養の気象学，1998 を基に作成）

Urano et al 2009「Biological and Environmental Climatology」

Increase of atmospheric CO_2 concentration

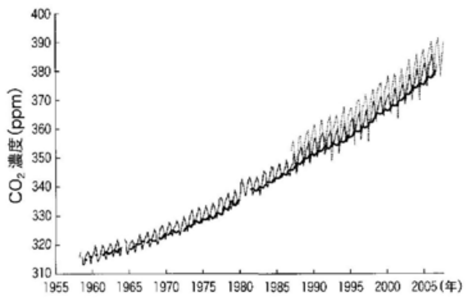


図6-6　大気中の CO_2 濃度の経年変化
Mauna Loa (Hawaii)　Ayari (Iwate)　South pole　気象庁：気候変動監視レポート 2007, 2008)

(Urano et al 2009「Biological and Environmental Climatology」)

Global warming

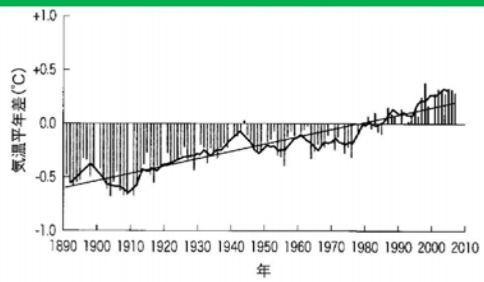


図6-7　世界の年平均気温の経年変化(1891～2007 年)
棒グラフは各年の平均気温の平年差(平年値との差)を示している．太線は平年差の5年移動平均を示し，直線は平年差の長期的傾向を直線として表示したものである．平年値は 1971～2000 年の 30 年平均値．(気象庁：気候変動監視レポート 2007, 2008)

(Urano et al 2009「Biological and Environmental Climatology」)

Changes of temperature, concentrations of CO_2 and methane since 160,00 years ago estimated from ice samples from south pole

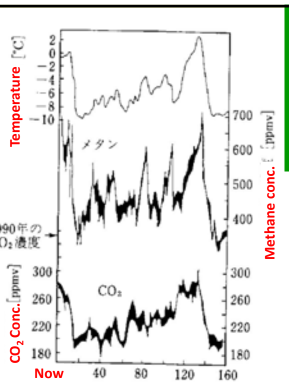
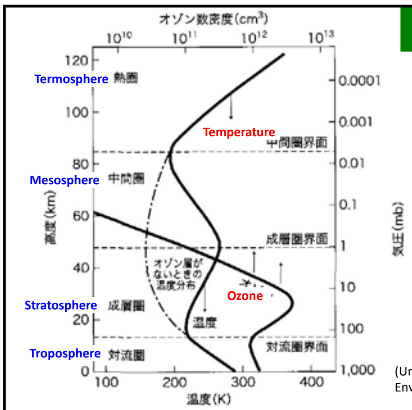


図2.44　南極の氷から推定された16万年前からの気温，CO_2 の濃度，メタン濃度の変化（IPCC レポートより）

Monji et al 1997 "Climatic Environmental Science"

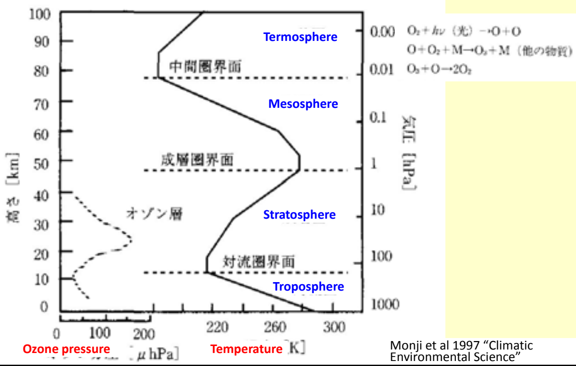
Ozone layer



(Urano et al 2009「Biological and Environmental Climatology」)

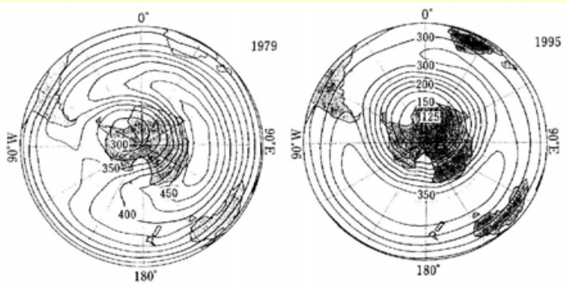
図2-14　大気の圧力，温度，オゾン濃度の高度分布概略（富永　健・巻出義紘，1990）

Vertical distribution of temperature and ozone



Monji et al 1997 "Climatic Environmental Science"

Ozone hole in south pole



南極上空からみたオゾンホール．1979年（左）にはほとんど認められないが，1995年（右）には著しく拡大している（気象庁，1997）．

Monji et al 1997 "Climatic Environmental Science"

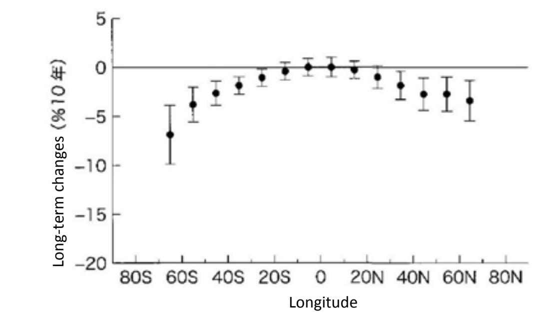


図6-8 衛生観測による緯度帯別のオゾン全量の長期変化傾向
緯度10度ごとの平均オゾン全量(1979〜2000年)から，季節変動，太陽活動などの影響を除去して評価した変化率(% 10年)を示す．縦線は95%信頼限界である．(気象庁：異常気象レポート2005，2005)

(Urano et al 2009「Biological and Environmental Climatology」)

Increased ozone holes

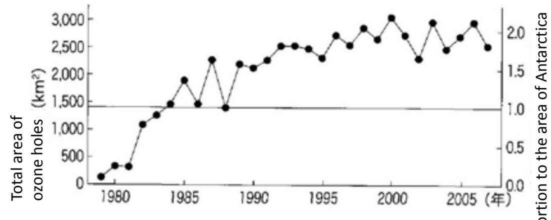


図6-9 Changes of the area of ozone holes
オゾンホールの目安であるオゾン全量が220m atm-cm以下の面積の年最大値を示す．(気象庁：気候変動監視レポート2007，2008)

Urano et al 2009 "Biological and Environmental Climatology"

Effect of ozone on plants

Visible symptoms of ozone damage for Taro

Ozone effect on Chinese spinach

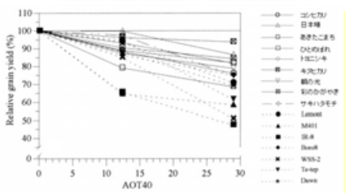


図4. Effect of ozone on yield of rice varieties

写真4. オゾン濃度の制御可能な温室(埼玉県環境科学国際センター)

T. Yonekura

Carbon isotopes

	Half life	Natural abundance
11C	20.3 min	
12C	Stable	98.9 %
13C	Stable	1.1 %
14C	5704 yr	10^{-10} %

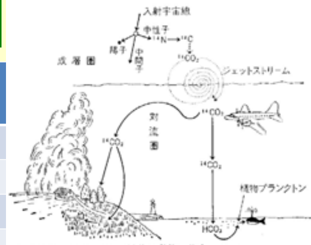


図8 宇宙線でできた14Cは植物や動物の体内にはいる
(Kigoshi 1978「Measuring Ages」)

Primary cosmic ray produces secondary cosmic ray at the stratosphere. 14C is produced by the interaction between neutron in the secondary ray and nitrogen, and immediately bound with oxygen to produce $^{14}CO_2$ and diffuse into the atmosphere. Natural decay of ^{14}C is approximately balanced with the supply from stratosphere. →**^{14}C Dating**

The plants fix lighter carbon more rapidly, and the plants contain less ^{13}C. $\Delta^{13}C$ is -27‰ for C_3 plants and -12‰ for C_4 plants. **(carbon discrimination)**

Nitrogen isotope

	Half life	Natural abundance
13N	9.965 min	
14N	Stable	99.64 %
15N	Stable	0.36 %

$\delta^{15}N$ is used to estimate atmospheric nitrogen fixation

Thermal environment

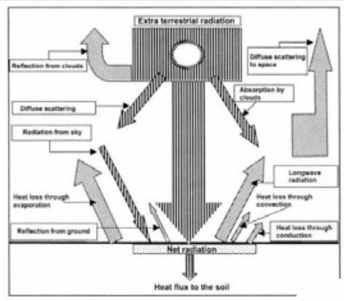


FIGURE 2.1. Daytime radiation balance over the earth's surface

TABLE 2.4. Disposal of solar radiation

Solar energy	$W\ m^{-2}$
Incident on the top of the atmosphere	342
Reflected by clouds, aerosols, and atmosphere	77
Reflected from the earth	30
Total reflected	107
Absorbed by the atmosphere	67
Absorbed by the earth	168
Total absorbed by earth-atmosphere system	235

Source: Adapted from Kiehl and Trenberth, 1997.

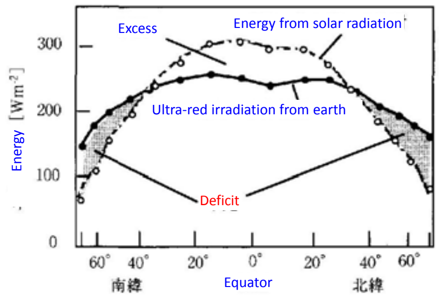
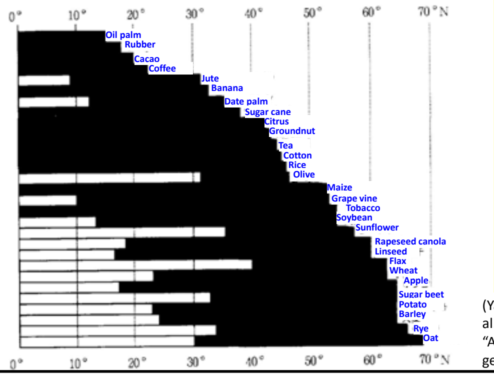


図2.10 Energy balance at different latitude (Vonder Haar, Suomi, 1969)

Monji et al 1997 "Climatic Environmental Science"

Range of longitude for major crops in northern hemisphere



(Yamamoto et al. 1998 "Agricultural geography")

Net phosynthesis

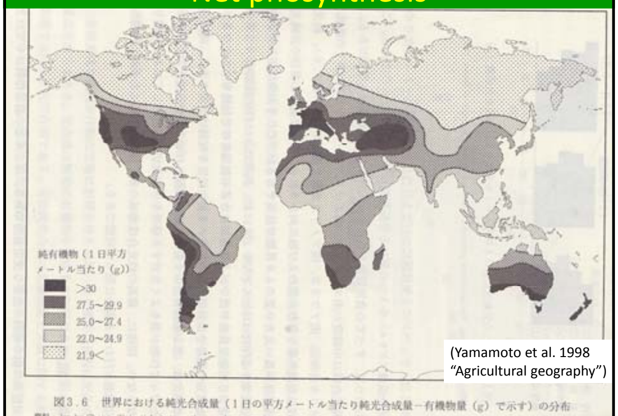


図3.6 世界における純光合成量（1日の平方メートル当たり純光合成量ー有機物量（g）で示す）の分布

(Yamamoto et al. 1998 "Agricultural geography")

High photosynthesis at cooler climate

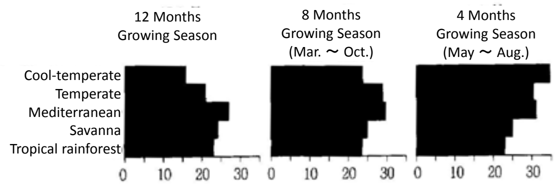


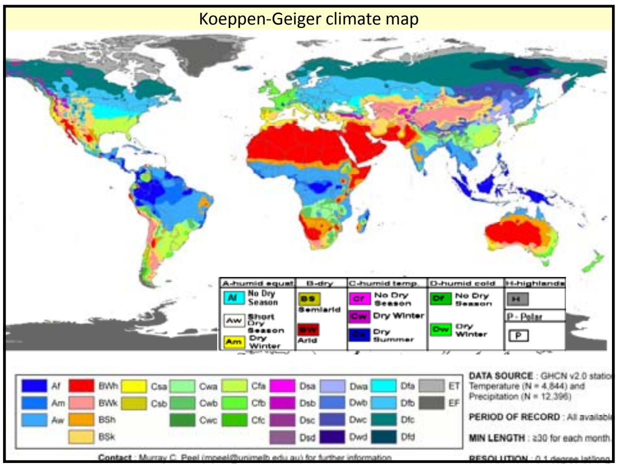
図3．5 Daily photosynthesis (g/m2/day) at 5 climatic zone

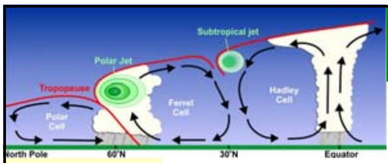
資料：Jen-hu Chang, 'The agricultural potential of the humid tropics', *Geographical Review*, 1986, vol.58, pp.333－336.

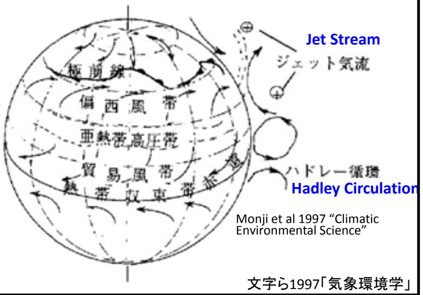
(Yamamoto et al. 1998 "Agricultural geography")

ATMOSPHERIC CIRCULATION : CLIMATE AND WEATHER

Koeppen-Geiger climate map



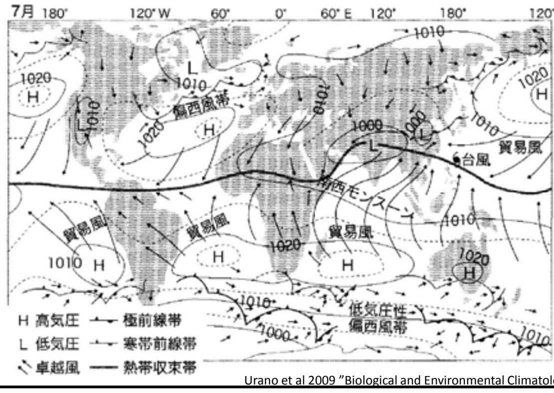




Monji et al 1997 “Climatic Environmental Science”

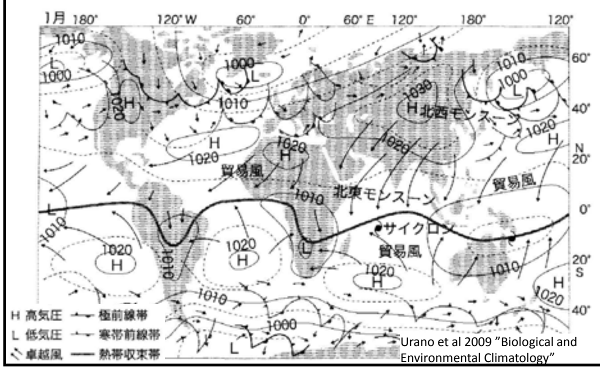
文字ら1997「気象環境学」

High and low pressure area (July)



Urano et al 2009 "Biological and Environmental Climatology"

High and low pressure area (January)



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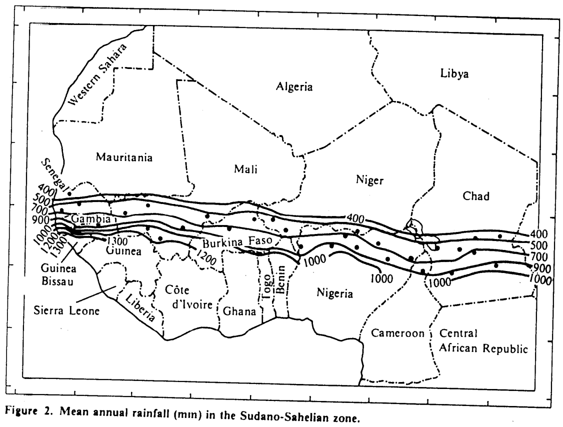


Figure 2. Mean annual rainfall (mm) in the Sudano-Sahelian zone.

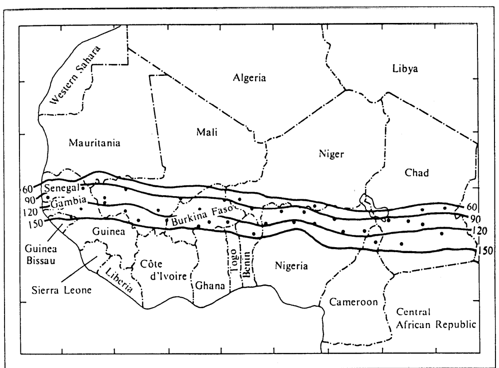
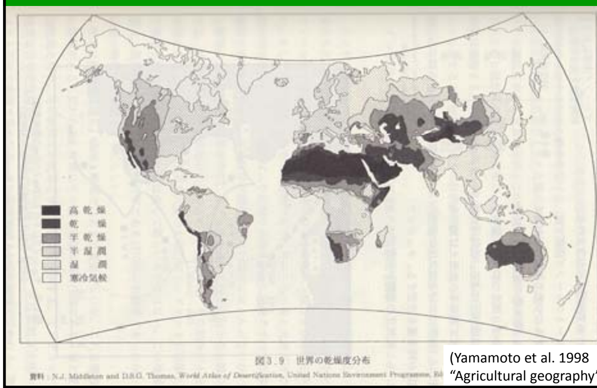


Figure 13. Mean length of the growing season (days) in the Sudano-Sahelian zone.

Distribution of dry zone in the world



(Yamamoto et al. 1998 “Agricultural geography”)

Examples of extreme weather in the world（1）

Semi-Arid Tropics

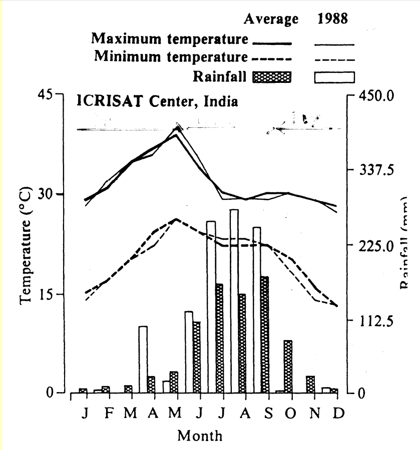
(1) Tropics

(2) Rainy season ------ 2 to 7 months
(mean monthly rainfall > mean potential evapotranspiration)

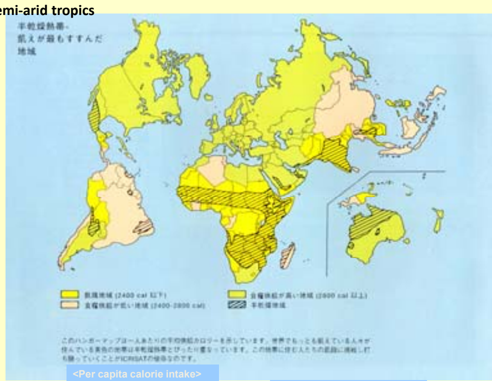
2 to 4.5 months : dry SAT
(thorn Savannah vegetation)

4.5 to 7 months : wet-dry SAT
(dry Savanna vegetation)

[after Troll (1965)]



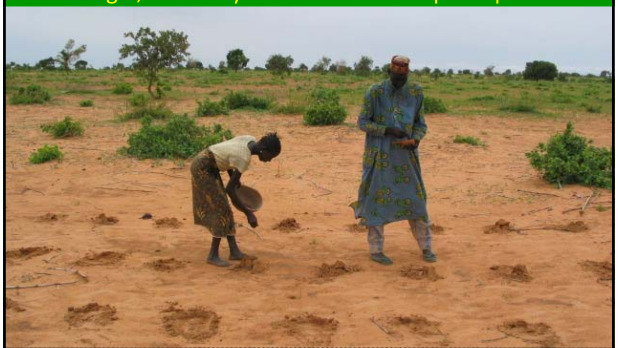
Semi-arid tropics



<Per capita calorie intake>
←less than 2400 cal
←2400 to 2800 cal

←higher than 2800 cal
←*Semi-arid Tropics*

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



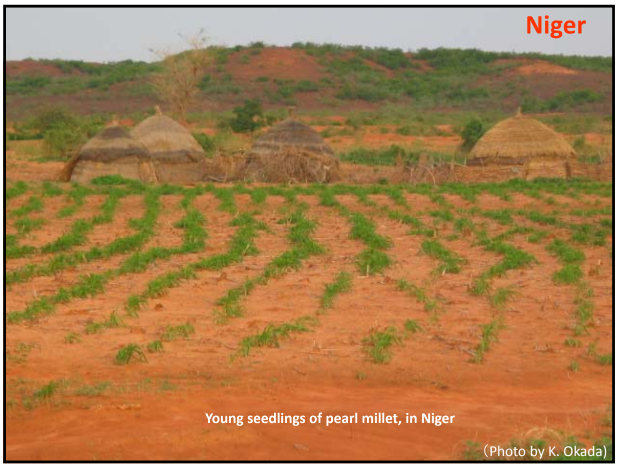
Sowing of pearl millet in a sandy soil of Niger at the beginning of rainy season

Seasonal changes of vegetation in the Sahel

(Niger)

Sowing of pearl millet
(in June, Niger)

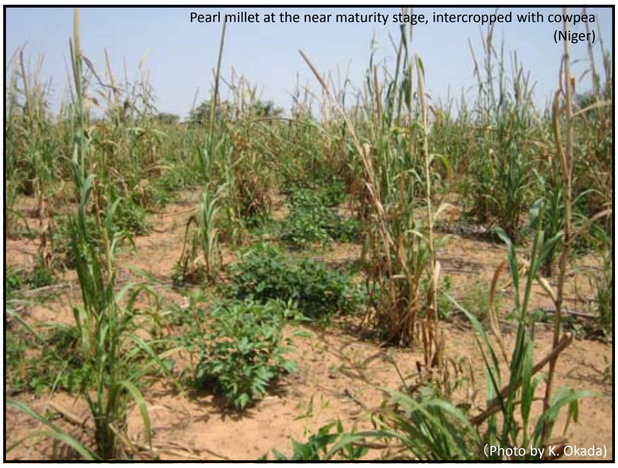
(Photo by K. Hayashi, JIRCAS)

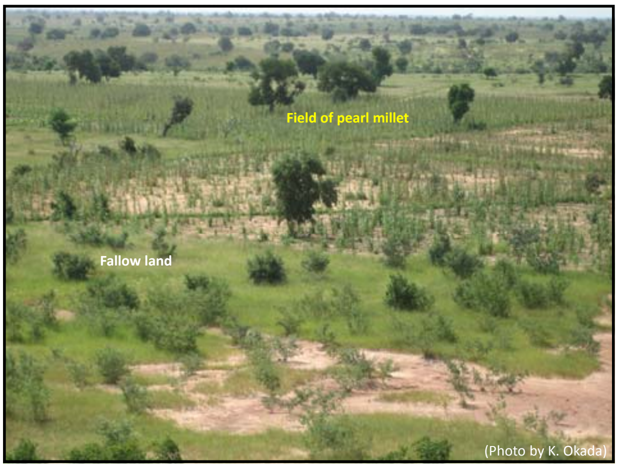

Niger
Young seedlings of pearl millet, in Niger
(Photo by K. Okada)


Pearl millet at vegetative stage, Niger
(Photo by K. Okada)


Conventional weeding with special hoe, in the experimental field at ICRISAT Sahelian Center, Niger
(Photo by K. Hayashi, JIRCAS)

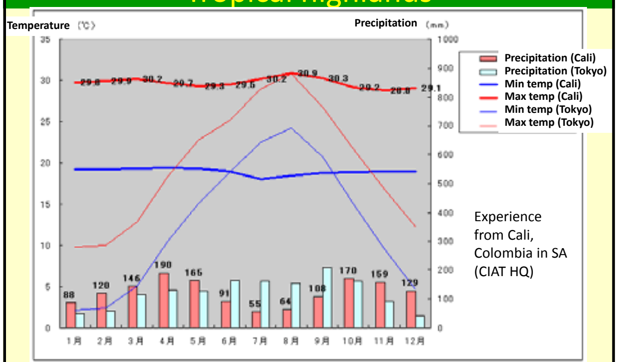

Mother and children near the village in Fakara region, Niger
(Photo by K. Hayashi, JIRCAS)


Pearl millet at the near maturity stage, intercropped with cowpea (Niger)
(Photo by K. Okada)


Field of pearl millet
Fallow land
(Photo by K. Okada)

igure 5. Millet growth around this village near Niamey reflects the underlying soil ertility gradient, which is highest close to human habitation.

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

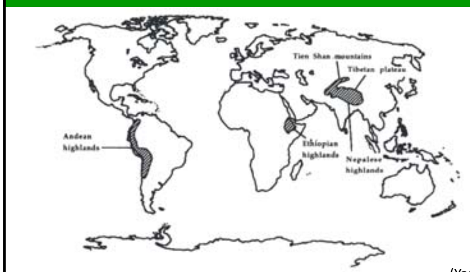


図 8. 世界の3大高地（標高2500以上の高地で、大きな人口を擁している山岳地域）。
[Fig 8. Areas of the world above 2,500m(Pawson & Jest, 1978).]

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

(Yamamoto et al. 1996)

- The temperature is constant through out the year
- The temperature is fixed for different altitude
- Life in the highland (agriculture, pasture), Shifting cultivation using different altitude
- Vegetable and flower production year round using cool but stable climate, tea and coffee (export)
- Issues for sustainable agriculture (soil erosion, drain of young ages)

ex. Land utilization in Equador

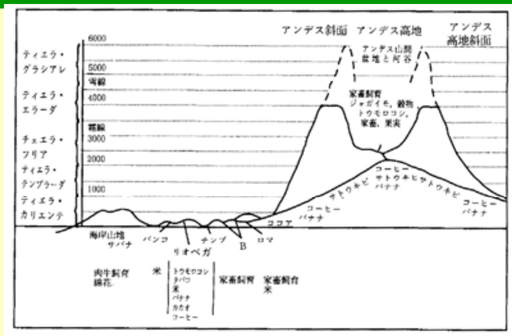


図5.2 エクアドルの土地利用断面（文字ら1997

出典：W. Manshard, Tropical Agriculture : A Geographical Introduction and Appraisal, London, Lon

Monji et al 1997 "Climatic Environmental Science"

ABNORMAL CLIMATE

Interaction between atmosphere and oceans

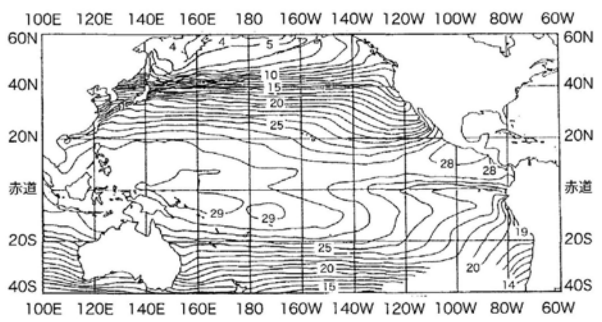
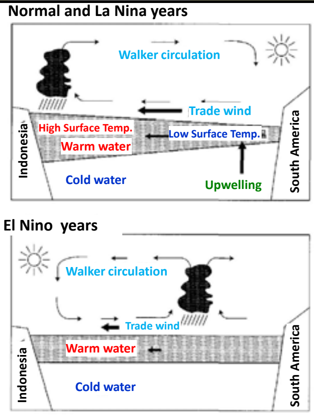


図6-3 太平洋の年平均海面水温分布
(気象庁：異常気象レポート'89, 1989)（浦野）

Urano et al 2009 "Biological and Environmental Climatology"

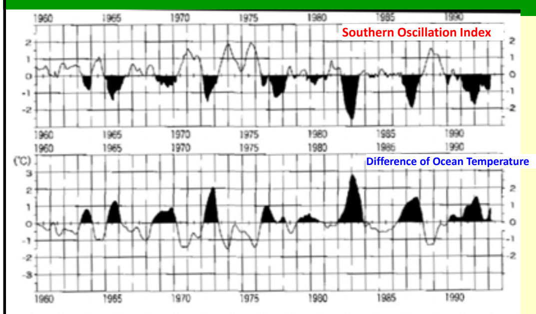
El Nino and La Nina



Distribution of ocean temperature and atmospheric circulation

（Urano et al. 2009）

Southern Oscillation Index



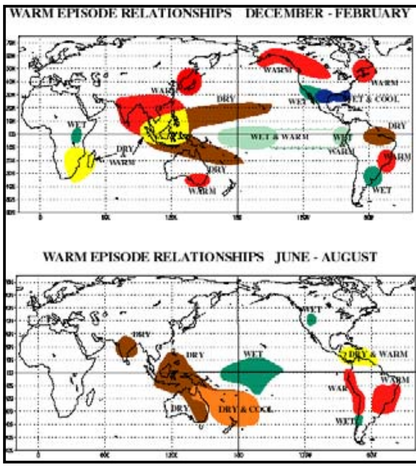
SOI =(BP at Tahichi (East)) - (BP at Darwin, Australia (West))

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



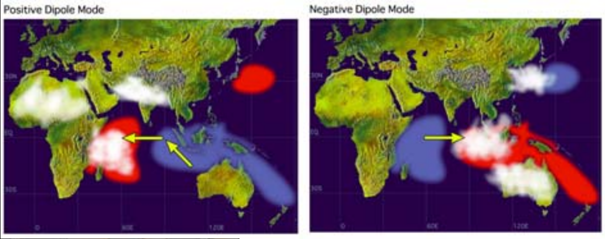
Maximu El Nino (1997-1998)

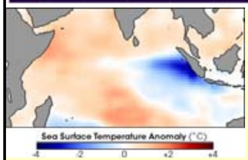
・Drought at Tropical Rain forest in Indonesia and Brasil, large forest fire

・Flood in the dry area in Peru and East Africa.

Extraordinary warm winter in Japan.

Indian Ocean Dipole





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

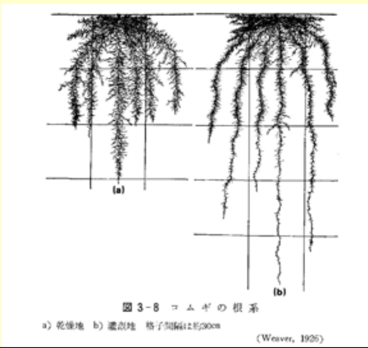
Application of climate predictions to agriculture

Southern Indian Ocean diploe affects the weather pattern for South Africa

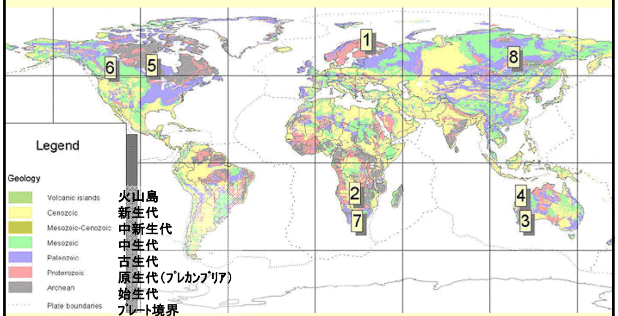
http://www.diginfo.tv/v/12-0010-a-en.php#.U1nuATzAs0M.mailto

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

Below-ground environment

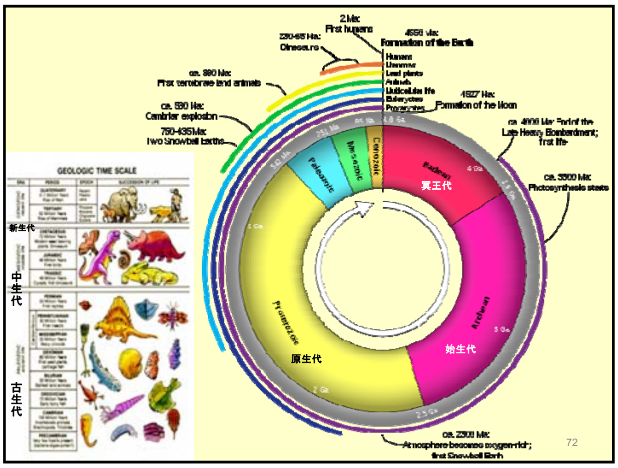


Factors which decide the character of the soil
①Mother rock



Pangaea

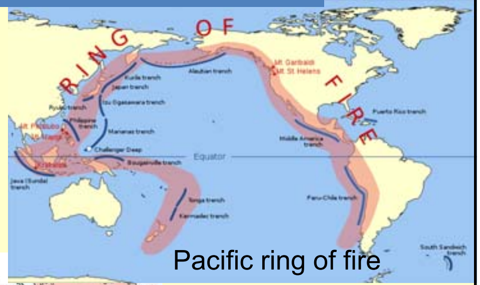
Permian period 290-251 million ago (ペルム紀)
Triassic period 250-200 million ago (三畳紀)

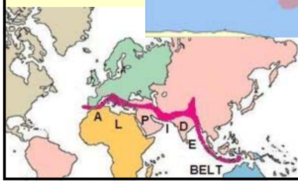


Igneous rocks（火成岩）

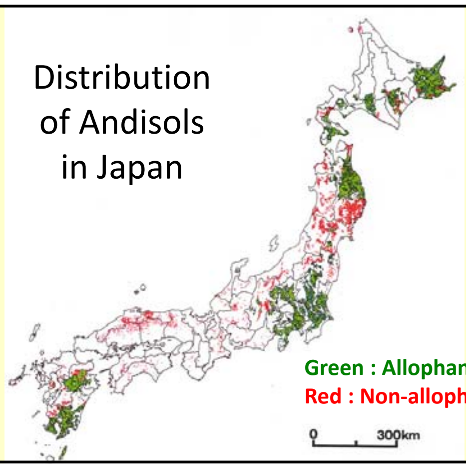
	Felsic Acid rock 酸性岩	Intermeadite 中性岩	Mafic Basic rock 塩基性岩	Ultra mafic 超塩基性岩
volcanic rock 火山岩	rhyolite 流紋岩	andesite 安山岩	basalt 玄武岩	kimberlite ｷﾝﾊﾞｰﾗｲﾄ
plutonic rock 深成岩	granite 花崗岩	diorite 閃緑岩	gabbro 斑糲岩	peridotite 橄欖岩

Two major volcanic belts in the world

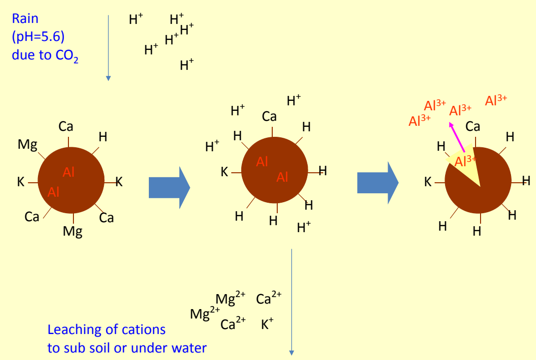




Alpide belt



Cause of natural soil acidification in humid climate

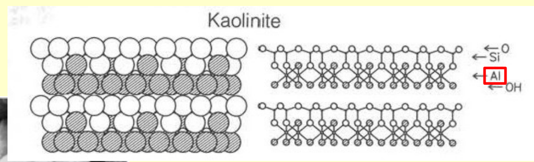


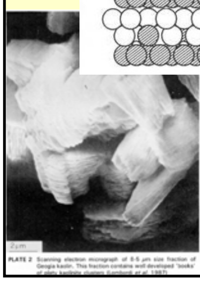
Soil acidity problem

(1) Cause of natural soil acidification in humid climate

1. Theoretically rain water is acid (pH=5.6) because it is saturated with CO_2 in the atmosphere.
2. In the region where the rainfall exceeds evaporation, the proton (H^+) in the water displaces the cations on the surface of the soil colloids.
3. Then the cations are leached.
4. The remaining H^+ destroyed part of the clay mineral which consists of Al-Si-Fe and liberate them.
5. **Al^{3+}**, due to its selective adsorption, displaces H^+ and become the major exchangeable cation in the acid soils.
6. If the acidification proceeds, the clay minerals are further destroyed and more Al^{3+} will exists in the soil solution.

Structure of clay minerals (eg. kaolinite)





Al and Si are in the core of the clay minerals

Additional soil acidification mechanisms

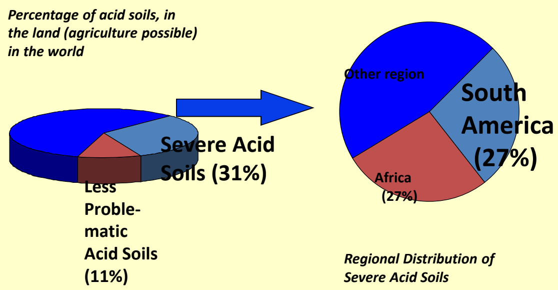
- Ammonium fertilizer application and organic matter decomposition acidify the soils through **nitrification**

  $NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$
- **Acid rain** caused by petroleum combustion

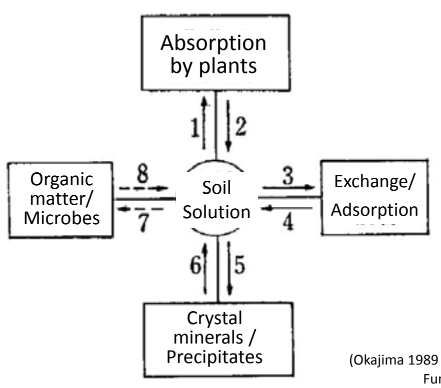
  $NO_2 + H_2O \rightarrow HNO_3$ (nitric acid)

  $SO_2 + H_2O \rightarrow H_2SO_4$ (sulfuric acid)
- Uptake of cations (Ca^{2+}, Mg^{2+}, K) by plants and N_2-fixation produces H^+

Acid Soils in the World



Dynamic equilibrium of soil solution



(Okajima 1989 "Structure and Function of Soil")

Concentration of ions in soil solution (soil from the field in Hokkaido University)

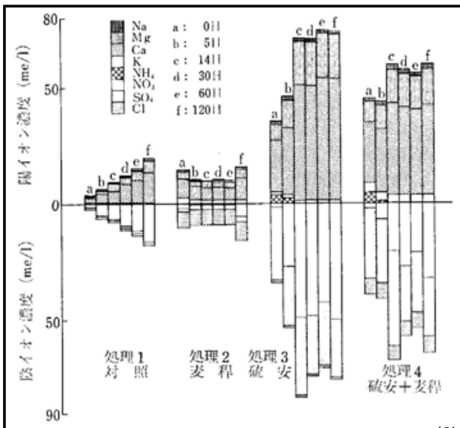


図 3-3 土壌溶液のイオン組成（北大十）

(Okajima 1989 "Structure and Function of Soil")

Root system absorption zone vs. Root surface absorption zone

(Okajima 2001 in "Plant Nutrient Acquisition")

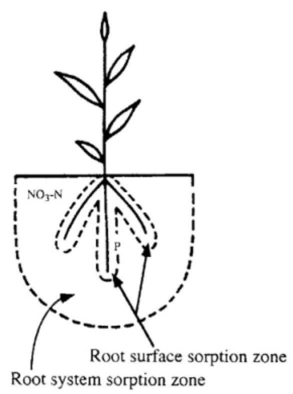


Fig. 4. Root system sorption zone for mobile nutrients and root surface zone for immobile nutrients (modified from Bray 1954)

P is absorbed at the rhizosphere

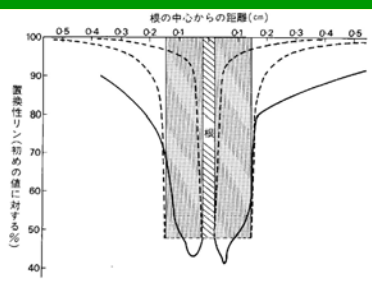


図 10-7 8日齢のナタネ（*Brassica napus*）の根に接する土壌中のリン酸濃度の状況（実線）

(Simulation result)

(Russel 1981 "Crop Root System and Soil")

Rhizosphere, Rrhizoplane

図 3-4　X線殺菌土壌で育ったエンドウ（*Pisum sativum*, 品種：Meteor）根毛の縦断図

Mucigel (m) contains many soil particles (arrow) and it covers the surface of root hair (r)

×11000

(Grieves and Darbyshire 1972)

(Russel 1981 “Crop Root System and Soil”)

Organic environment of rhizosphere

Root exudates

(Russel 1981 “Crop Root System and Soil”)

Composition of root exudates

Carbohydrate	Glucose, Fructose, Sucrose, Xylose, Maltose, Rhamnose, Arabinose, Raffinose, Oligosaccharoides
Amino acids	Leucine/Isoleucine, Valine, γ-amino lactic acid, Glutamine, α-alanine, Asparagine, Serine, Glutamic acid, Aspartic acid, Cystine/Cystein, Glycine, Phenyl alanine, Threonine, Tylocine, Proline, Methyonine, Tryptphane, Homoserine, β-alanine, Arginine
Organic acids	Tartaric acid, Oxalic acid, Citric acid, Malic acid, Acetic acid, Propione acid, Lactic acid, Valeric acid, Succinic acid, Fumalic acid, Glycol acid
Enzymes	Phosphatase, Invertase, Amylase, Protease, Polygalacturonase
Others	Biotine, Thiamine, Pantoteic acid, Niacin, Choline, Inositol, Pyridoxine (Vitamin B6), p-amino salicylic acid, n-methil nicotic acid Many unidentified compounds which inhibit the activities of fungi, bacteria and nematode

Organic matter exudation from plant roots

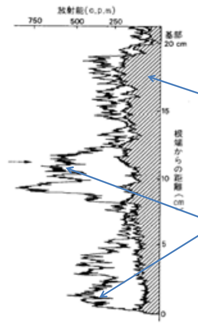


図 6-1　6日齢のコムギ（*Triticum aestivum*）の根の各部からの^{14}C-標識物質の浸出を示すクロマトグラフ

茎葉部を24時間 $^{14}CO_2$ の中においた後色相分析を行なった。斜線部は根がクロマトグラフ紙と接した部位から1 mm以上拡散した浸出物を示す。矢印は若い分枝根の位置

(Rovira and Davey, 1974)

Diffusive organic matter (hatched area) : even at the base of the roots

Non-diffusive organic matter : Mainly from the root tip and the region where branch roots emerge

(Russel 1981 “Crop Root System and Soil”)

Mucigel

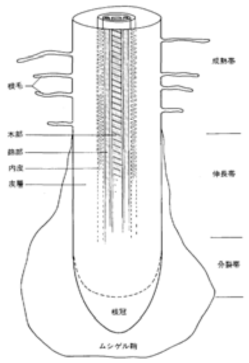


図 3-1　植物根の頂端部縦断面略図

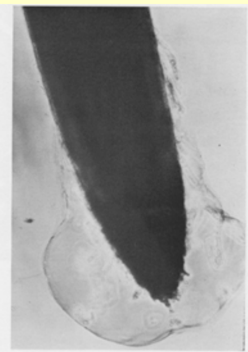
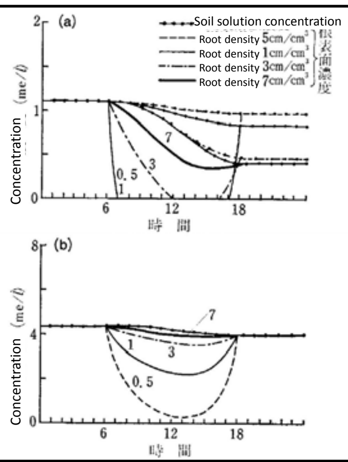


図 3-3　水耕栽培したオオムギの根のムシゲル鞘

鞘の直径は約 0.9mm

Changes of ion environment in rhizosphere



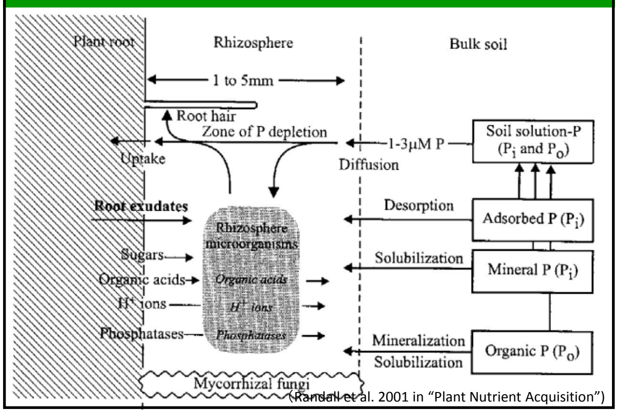
Changes of NO_3-N concentration at the root surface (loamy soil)

(a) NO_3-N 0.05 me/100cm³

(b) NO_3-N 0.2 me/100cm³

(Okajima 1989 “Structure and Function of Soil”)

Factors which influences absorption of phosphorus



(Randall et al. 2001 in “Plant Nutrient Acquisition”)

References

＜Aboveground environment＞

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2. Yamamoto et al. 1998 "Agricultural Geography"　Nourin Toukei Kyokai
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＜Belowground environments＞

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7. Hay R and Porter J 2006 "The Physiology of Crop Yield 2nd edition" Blackwell Publishing
8. Russell、R.S.　1981　"The Root System of Crops and Soil" Noubunkyo
9. Ae N, Arihara J, Okada K and Srinivasan A. 2001 "Plant Nutrient Acquisition –New Perspective" Springer
10. Bridges 1990 "World Soils"　Kokin Shoten

Topics covered in this lecture

1. Multi-dimensional understand of above- and below-ground environments
2. Hints to start thinking about abnormal weather and climate change
3. Understanding of the climate and geography unfamiliar for Japanese
4. The uniqueness of belowground environments for plants

- 「Pick up one environmental factor that you are interested in, and summarize the content of the seminar regarding the factor」（400 letters in Japanese or ca. 200 words in English）
- Deadline : by the midnight of 15 April 2015 (Wed)