

熱帯農業生態学特論

Tropical Agricultural Ecology



熱帯農業生態学分野
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Tropical agricultural ecology (熱帯農業生態学特論)

- 1 . Climates in the tropics (熱帯の気候)
- 2 . Land use and farming systems
(土地利用と営農動態)
- 3 . Agricultural resources and their changes in
recent years (農業資源とその変化)
- 4 . Present and future sustainable agricultural
production in the tropics
(熱帯地域における持続的農業生産の今
後)

* Significance of studying tropical agriculture

熱帯農業生態学を学ぶ意義

Understanding natural environment in the tropics

Understanding agricultural diversity

Understanding diversity of bio-resources

Understanding agro-environmental problems

Understanding of local societies

Understanding background of international
cooperation

Understanding internationalization of agriculture

Tropical agricultural ecology (熱帯農業生態学特論)

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production in the tropics
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Tropical climates (熱帯の気候)

1. Characteristics of tropical climates

(熱帯気候の特徴)

2. Classification of tropical climates

(熱帯の気候区分)

3. Climates of Mainland Southeast Asia

(東南アジア大陸部の気候)

4. Mechanism of desertification

(砂漠化のメカニズム)

Definition of the tropics by climates

1. 数理気候*による定義

(Definition by mathematical climates*)

北回帰線と南回帰線の間 (Between the tropic of Cancer and Capricorn)

* 太陽の天文学的位置及び緯度によって決定する
仮想気候 (Virtual climates)

2. ケッペンの定義 (Definition by Köppen)

Coldest month: higher than 18°C with tree veg.

3. 吉良の定義 (Definition by Kira)

測量指数 (月平均気温 5°C以上の積算値)

240°C、亜熱帯は180°C

積算気温 (Accumulated temperature)

生物の生長の指標 (Index of growth)

Traits of tropical climates

気候要素 (Element)

気温 (Temperature)

日射 (Solar radiation)

降水量 (Precipitation)

風速 (Wind speed)

蒸発 (Evaporation)

気候因子 (Factor)

緯度 (Latitude)

経度 (Longitude)

地理的条件

(Geographical
conditions)

地形 (Topography)

地表面の状態

Tropics : 暑い ! (Hot !) (Soil surface status)

← high temperature, Intense solar radiation

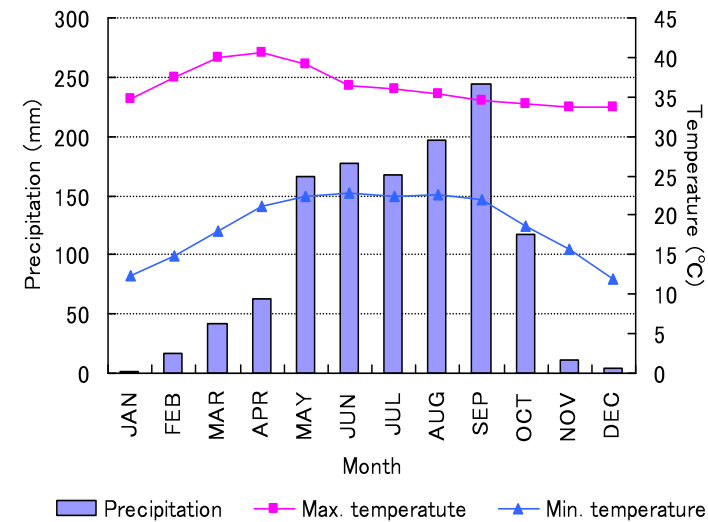
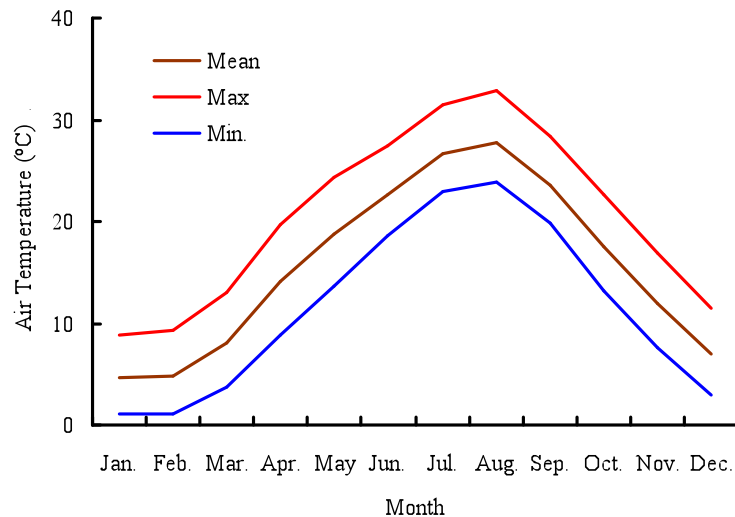
Air temperature traits (熱帯地域の気温特性)

Generally high except area with high altitudes

Small annual difference

Areas with clear dry and rainy season → large

Large diurnal difference (日較差)



熱帯地域の光環境特性 (Light environment)

Solar radiation → Energy source of matter production

Mean daily radiation

6 ~ 8 GJ/m² (Temperate : 4 ~ 5 GJ/m²)

Value at moment : W/m²

Arid area : high、 Equatorial area : Low

→ Cloud effect、 Low in tropical rainforests

R_n , Net radiation $R_n = (1-a) R_s - (F\downarrow - F\uparrow)$

a : albedo

F↑: Long wave radiation from soil surface
(proportionate to 4 power of soil surface temperature)

F↓: Long wave radiation from atmosphere

Humid and semi-humid tropics → high

Desert → Relatively low

熱帯地域の光環境特性 (Light environment)

Photosynthetic active radiation, **PAR**

(光合成有効放射)

Wave length range 400~700 nm

Ration of PAR to solar radiation (R_s) : ca. 0.5

→ Increase by 20~30

Photoperiod, daylength (日長)

→ Large influences on growth and development

Flowering (開花) ・ Bulb

Formation (球形成) ・ Dormancy (休眠)

Day length = 可照時間 + 常用薄明

(Possible sunshine duration)

1. 市民薄明（常用薄明、第三薄明） Civil twilight

Height of sun $-50' \sim -6^\circ$

2. 航海薄明（第二薄明）

Naval twilight

Nautical twilight

Height of sun $-6^\circ \sim -12^\circ$

3. 天文薄明（第一薄明）

Astronomical twilight

Height of sun $-12^\circ \sim -18^\circ$



Calculation of possible sunshine duration (PSD)

$$N_0 \text{ (h)} = 2H / 0.2618$$

$$\sin (H/2) = [A / (\cos\varphi \cos\delta)]^{1/2}$$

$$A = \sin (\pi/4 + (\varphi - \delta + r) / 2) \sin (\pi/4 - (\varphi - \delta - r) / 2).$$

$$\delta = \sin (0.398 \times \sin a_2)$$

$$a_2 = 4.871 + \eta + 0.033 \sin \eta$$

$$\eta = (2\pi / 365) \times DOY$$

N_0 : PSD、 H : Time angle after sunrise to culmination (南中)

φ : Latitude、 δ : declination、 r : anaclastic degree

(=0.01rad、水平屈折度) (赤緯)

DOY : Number of days after January 1

熱帯地域の光環境特性 (Light environment)

Estimation of Solar radiation

1. Horizontal radiation at upper end of atmosphere (daily mean)

$$S_{d0} = \frac{I_{00}}{\pi} \left(\frac{d_0}{d} \right)^2 (h \sin\varphi \sin\delta + \sin h \cos\varphi \cos\delta)$$

$$h = \cos^{-1} (-\tan\varphi \tan\delta)$$

$$\left(\frac{d_0}{d} \right)^2 = 1.00011 + 0.034221 \cos\eta + 0.00128 \sin\eta \\ + 0.000719 \cos 2\eta + 0.000077 \sin 2\eta$$

$$\delta = \sin (0.398 \sin a_2)$$

h : Time angle from sunrise to culmination、

φ : latitude、 δ : declination、 DOY : No. of days

d, d_0 : Distance between sun and earth, average、

I_{00} : Solar constant (=1367 Wm⁻² = 118.1 MJ m⁻² d⁻¹)

熱帯地域の光環境特性 (Light environment)

Estimation of **Solar radiation**

2. Possible sunshine duration (Previously shown)

$$N_0 \text{ (h)} = 2H / 0.2618$$

$$\sin (H/2) = [A / (\cos\varphi \cos\delta)]^{1/2}$$

$$A = \sin (\pi/4 + (\varphi - \delta + r) / 2) \\ \times \sin (\pi/4 - (\varphi - \delta - r) / 2).$$

Difference in h and H : H includes horizontal anaclastic degree

3. Solar radiation at outer space (daily mean)

$$S_d/S_{d0} = 0.244 + 0.511 (N/N_0) \quad 0 < N/N_0 \leq 1, \\ = 0.118 \quad N/N_0 = 0$$

S_d : Solar radiation at outer space (daily mean)

N : Sunshine duration、 N_0 : See above

熱帯地域の水環境 (Water environment)

Water environment

← Precipitation (降水)、 Topography (地形)
Soil property (土壌特性)

Precipitation large influence on Vegetation

Farming system, productivity >500mm

総降水量 (Total precipitation)

Pluvial area (Wet area, 多雨地帯)

Near equator, windward mountainous area
(downwind area → Rain shadow)

Rainy and dry seasons → Savanna, Monsoon

Dry and sub-dry areas (Arid and semiarid areas)

季節変化 (Seasonal changes)
or 降水分布 (Distribution of rain)

Onset of the rainy season, duration of the rainy season,
Dry spell

Four patterns of seasonal changes in rainfall

- a) Pluvial all the year round
(1年を通じて多雨)
- b) Rainy and dry seasons (雨季と乾季)
- c) Two rainy seasons (2度の雨季)
- d) Few rains throughout a year
(1年を通じて寡雨)

Characteristics of precipitation in the tropics (熱帯の降水の特徴)

Mechanism of rainfall (降雨のメカニズム)

- a) ITCZ (Inter tropical convergence zone)
and its movement
- b) Monsoon: Seasonality, large area, inversion
- c) Topography
- d) Tropical depression

Intense rainfall for a short time in the afternoon

Large regional differences

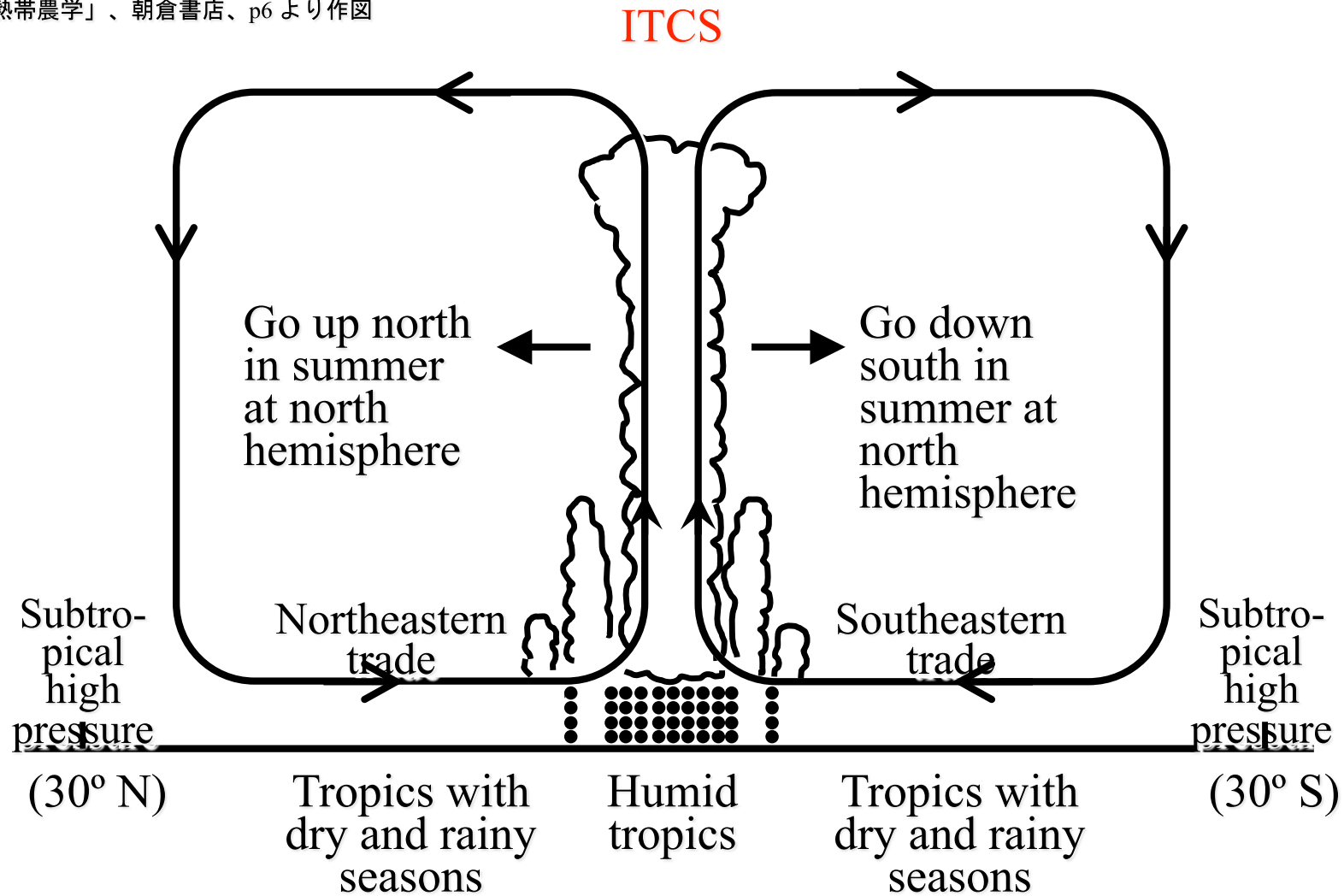
Influence of subtle topographic differences

Movement of rain area

Large difference in a short distance

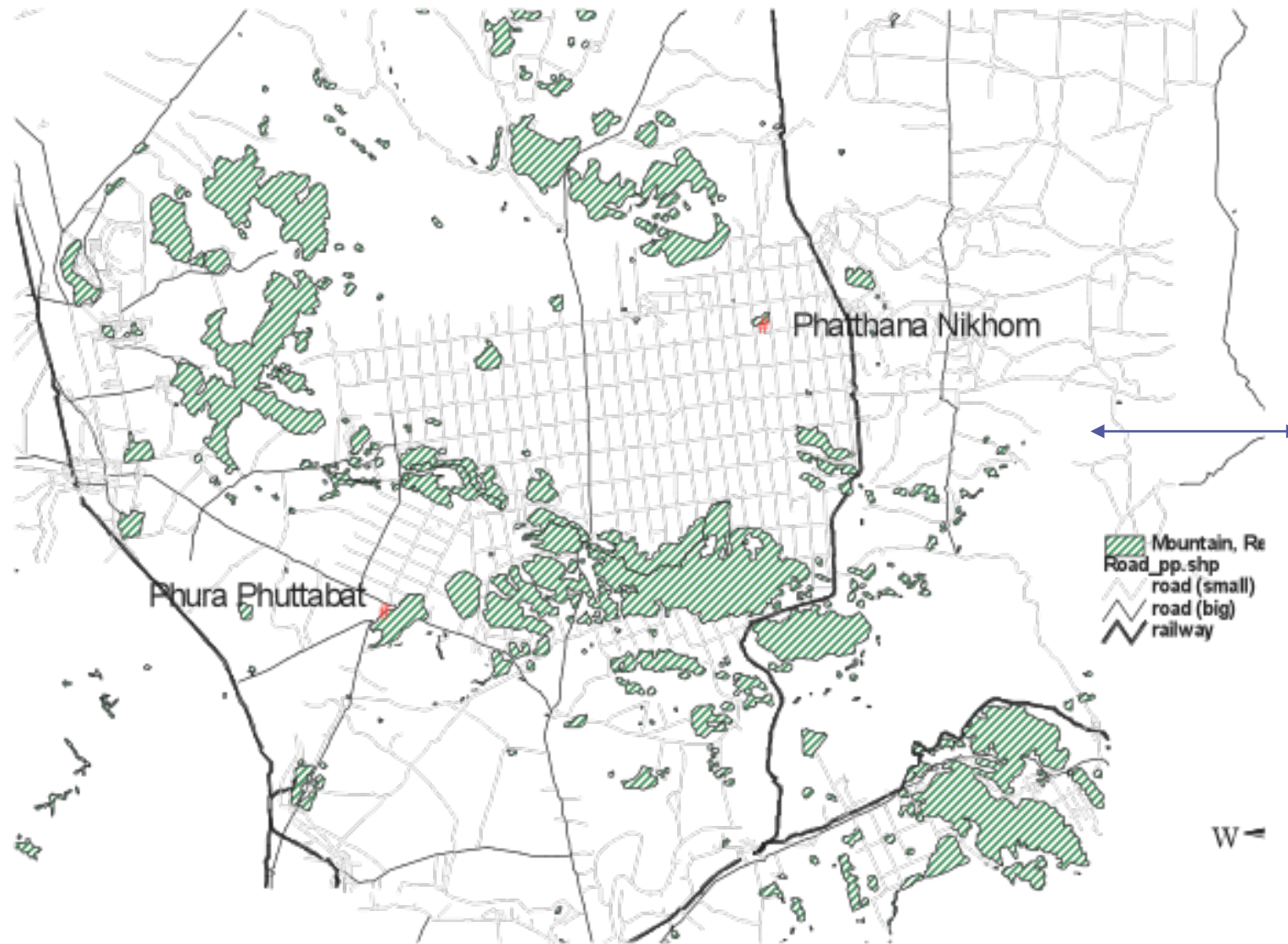
1. Tropical climates

「熱帯農学」、朝倉書店、p6 より作図



Rainfall model in the tropics by ITCS

1. Tropical climates



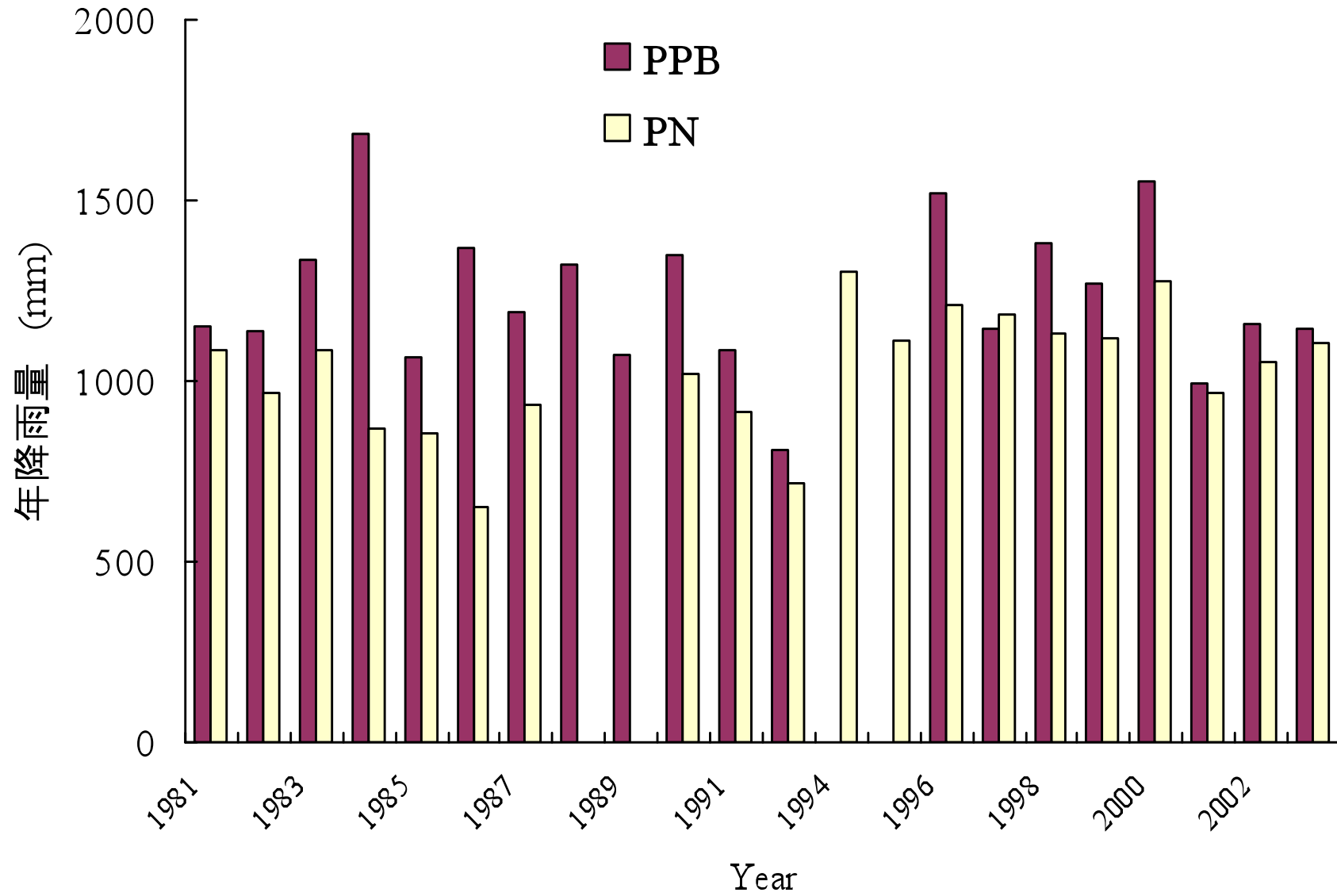


Fig. Comparison of annual rainfall between Phraphutabata and Phatana Nikom in Central Thailand

Characteristics of precipitation in the tropics (熱帯の降水の特徴)

No rain period in the rainy season (Dry spell)

Big impact on agriculture (農業的影響大)

Influence on Cropping systems (作付体系)

- Planted crops (作付作物)

Distribution patterns of Rainy pentad (雨半旬)

Rainy pentad (雨半旬) :

Central pentad of continuous 3 pentads, which satisfy the following 2 conditions

- 1) Total rainfall of 3 pentads $> 76\text{mm}$
- 2) Among 3 pentads, rainfall of at least 2 pentads $> 7.6\text{mm}$

Air humidity and Saturation deficit (飽差)

Saturation deficit (飽差)

Difference between Saturated VP and actual VP

Increase with air temperature increase (Actual VP)

Large saturation deficit → dry conditions

→ Stomatal closure (氣孔閉鎖)

→ Reduction in dry matter Production (物質生産低下)

Evapotranspiration (蒸発散)

Sum of Transpiration (蒸散) from vegetation and
Evaporation from soil surface

Evapotranspiration (ET) ← Climates, vegetation, soils

Potential ET Appropriate soil moisture, dense vegetation

熱帯の蒸発散 (Evapotranspiration in the tropics)

Potential evapotranspiration (可能蒸発散量) :

Increase under hot and dry conditions

→ High under tropical dry climates and in the dry season of tropical savanna

Actual evapotranspiration (実蒸発散量)

Decrease as soils dry

Large under rain forest climates

Water balance

Rainfall $>$ Potential evapotranspiration : Humid

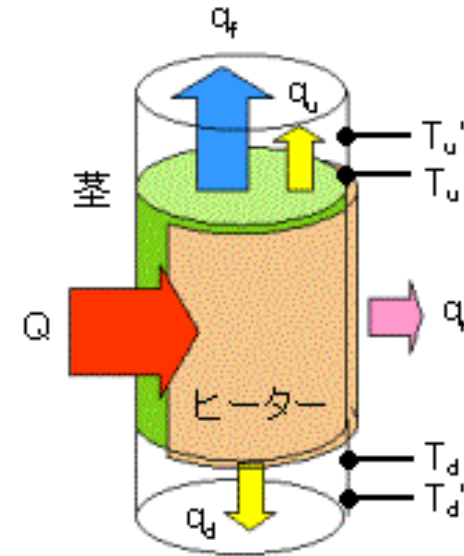
Rainfall $<$ Potential evapotranspiration : dry

Monthly balance : Index of humidity

Methods to measure Evapotranspiration

1. Potometer (ポトメータ法, for individual)
Direct measurement of water loss from soil
2. Lysimeter (ライシメータ法, for population)
Direct measurement of water loss from soil, large facility
3. Chamber method (チャンバー法, individual & organs)
Humidity differences between inlet and outlet
4. Stem flow method
(蒸散流測定法, for individual and organs)
Measure stem sap flow by thermodynamic method
5. Bowen ratio method (ボーエン比法, population)
6. Eddy correlation method (渦相関法, population)

Methods to measure Evapotranspiration



4. Stem flow method

(蒸散流測定法, for individual and organs)

Measure stem sap flow by thermodynamic method

Methods to measure Evapotranspiration



5. Bowen ratio method (ボーエン比法, population)

Bowen ratio (ボウエン比, β)

$$\beta = H / lE$$

(H: sensible heat flux、 lE : latent heat flux)

$$\beta = \frac{C_p (\bar{T}_1 - \bar{T}_2)}{l (\bar{q}_1 - \bar{q}_2)}$$

(C_p : specific heat of air、 T_1, T_2 : air temp. at different height、 q_1, q_2 : specific humidity at different height)

$$lE = (R_n - G) / (1 + \beta)$$

Tropical climates (熱帯の気候)

1. Characteristics of tropical climates (熱帯気候の特徴)

2. Classification of tropical climates (熱帯の気候区分)

3. Climates of Mainland Southeast Asia (東南アジア大陸部の気候)

4. Mechanism of desertification (砂漠化のメカニズム)

Classification of climatic zones by Köppen

Af : Tropical Rain Forest (熱帯雨林気候)

Rainfall amount of the minimum month $> 60\text{mm}$

Aw : Tropical Monsoon (熱帯気候モンスーン)

Rainfall amount of the minimum month $(y) < 60\text{mm}$

$y > 100 - x/25$ (x: annual rainfall)

Am : Tropical Savanna (熱帯サバンナ気候)

Rainfall amount of the minimum month $(y) < 60\text{mm}$

$y \leq 100 - x/25$ (x: annual rainfall)

Subtropical Climates (亜熱帯気候)

Month with mean air temperature higher than 20°C
exceeds 4 months

Classification of climatic zones by Thornthwait

Moisture index, based on water balance

PE : Potential evapotranspiration (可能蒸発散量)

Full crops of PE more than 400mm

Water balance : Average monthly rainfall - PE

+ : Surplus、 - : Deficit

s : Annual moisture surplus

d : Annual moisture surplus

Humidity index (湿潤指数) : $I_h = 100s/PE$

Aridity index (乾燥指数) : $I_d = 100d/PE$

Moisture index (水分指数) : $I_m = I_h - 0.6 I_d$
 $= (100s - 60d)/PE$

Classification of climatic zones by Thornthwait

Estimation of PE by Thornwaite

$$PE = 0.533 D_o (10t_j/J)^a$$

$$a = 0.000000675J^3 - 0.0000771J^2 \\ + 0.01792J + 0.49293$$

$$J = \Sigma(t_j/5)^{1.514} \quad (J=1 \sim 12)$$

D_o : Possible sunshine duration
(12h/day=1)

t_j : Monthly average air
temperature at jth month ($^{\circ}\text{C}$)

Classification of climatic zones by Thornthwait

Classification by air temperature (PE)

A' (Megathermal) : PE \geq 1140 mm

B' (Mesothermal) : PE = 1140 ~ 570 mm

C' (Microthermal) : PE = 570 ~ 285 mm

Tropics : PE more than 1140mm

Classification by humidity (water index, Im)

A (Perhumid) : Im \geq 100

B (Humid) : Im = 100 ~ 20

C (Subhumid) : Im = 20 ~ -20

D (Semi-arid) : Im = -20 ~ -40

E (Arid) : Im = -40 ~ -60

Detailed classification : w (summer rain), s (winter rain),
r (humid throughout a year), d (dry throughout a year)

Comparison of Köppen's method with Thornthwaite's one

Köppen

Af (tropical rain forest)

Am (tropical monsoon)

Aw (tropical savanna)

BShw (semiarid)

BWh (tropical and subtropical arid)

Thonrthwaite

AA'r

AA'r or BA'r

BA' or CA'w

DA'w or DA'd

EA'd

☆ Classification by Köppen

A : Precipitation > Evaporation

B : Precipitation < Evaporation

Characteristics of Tropical rain forest climate

- 1 . Distributed near the Equator
ITCZ (Inter tropical convergence zone, 熱帶收束帶)
- 2 . Much rain, humid and hot throughout a year
- 3 . Small annual difference in air temperature

Tropical monsoon and savanna climates

- 1 . Distributed between the Equator and mid-latitude dry zones
Subtropical high pressure zone (亞熱帶高压帶)
- 2 . Existence of clear rainy and dry seasons
- 3 . Large annual difference in air temperature
- 4 . Large area, important agriculturally

Characteristics of desert climate

- 1 . Distributed at mid-latitude area with large acreage
← Stable downward current (沉降气流)
(Subtropical high pressure zone,
backside of mountains)
- 2 . Coastal deserts
← Restriction of convection activity by cold
marine currents like Humboldt Current
distributed at coastal zones in south America
and eastern coasts of Africa (Peru, Atacama,
Patagonia, Namib Deserts)
- 3 . Inland deserts ← Restriction of humid air flow
Sahara, Kalahari, Great Victoria,
Gobi, Takla Makan
- 4 . Large annual and diurnal changes in air temp.

Tropical climates (熱帯の気候)

1. Characteristics of tropical climates (熱帯気候の特徴)
2. Classification of tropical climates (熱帯の気候区分)
- 3. Climates of Mainland Southeast Asia (東南アジア大陸部の気候)**
4. Mechanism of desertification (砂漠化のメカニズム)

1. Tropical climates

(Nawata et al., 2005より)

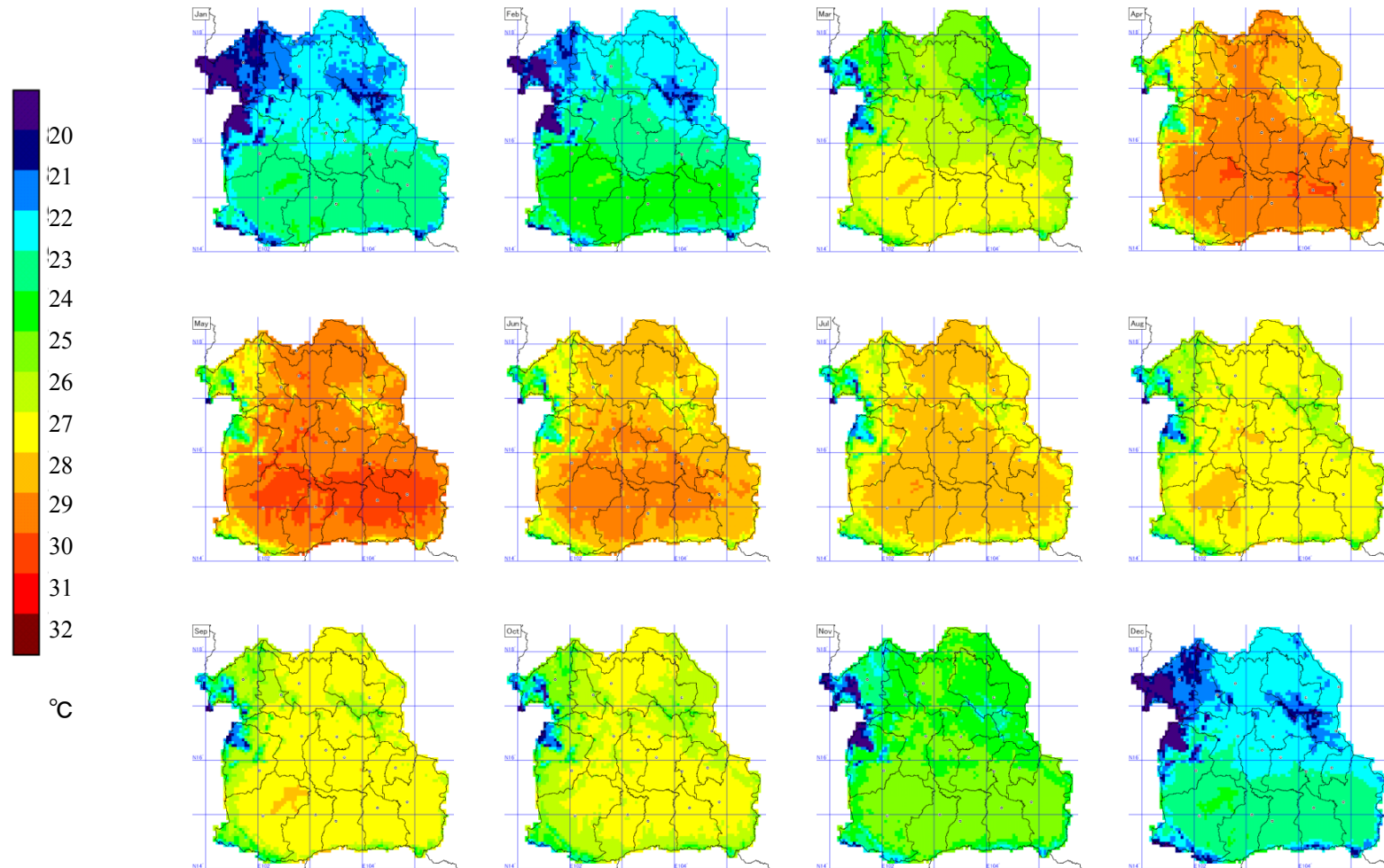


Fig. Monthly average of daily mean air temperature over 20 years in Northeast Thailand

◎ : Provincial capital, lines in the map: provincial boundaries

1. Tropical climates

(Nawata et al., 2005より)

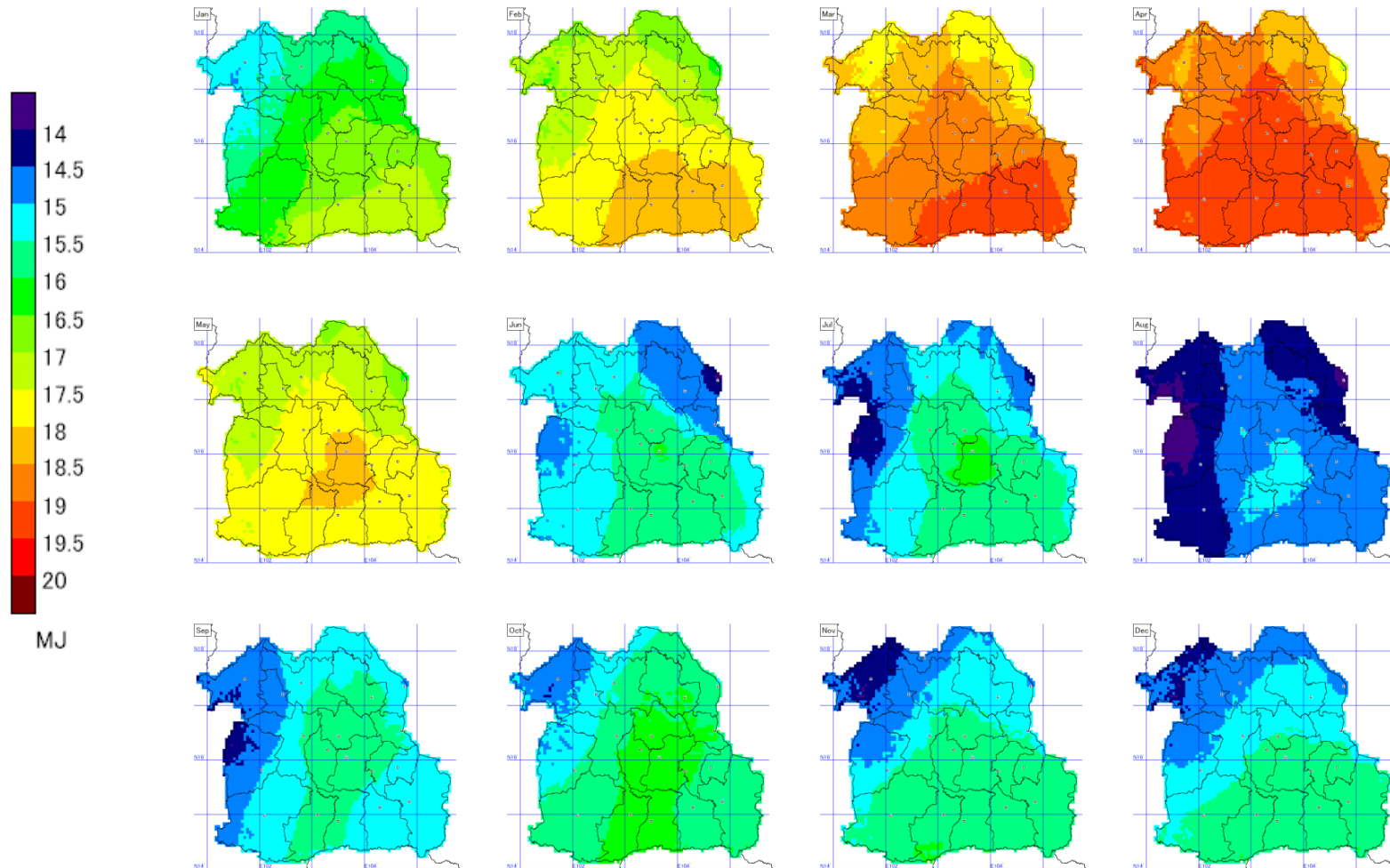


Fig. Monthly average of daily mean solar radiation over 20 years in Northeast Thailand

◎ : Provincial capital, lines in the map: provincial boundaries

1. Tropical climates

(Nawata et al., 2005より)

a) Annual rainfall (AV)

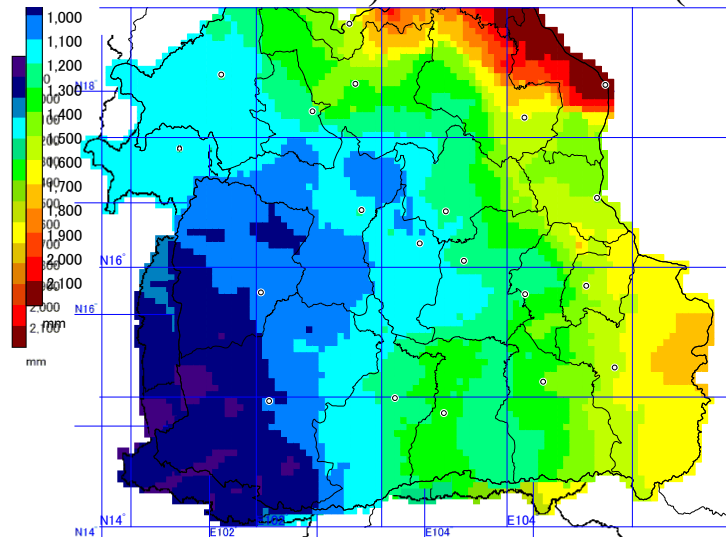


Figure: Annual Rainfall (average)

b) Annual rainfall (CV)

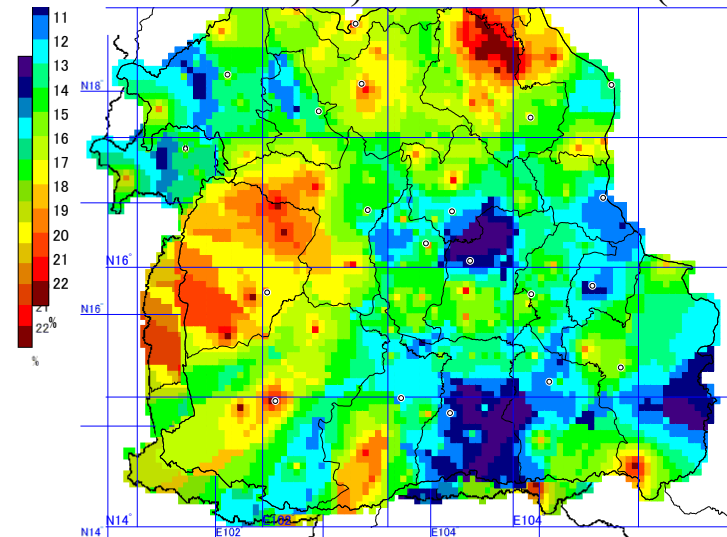


Figure: Annual Rainfall (CV)

c) Rainfall per rain-day

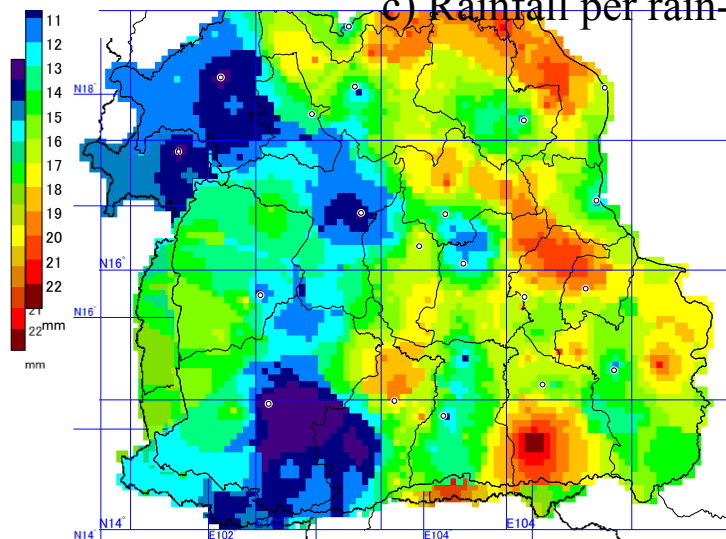


Figure: Mean Rainfall in the Rainy Season (average)

d) No. of rain-day

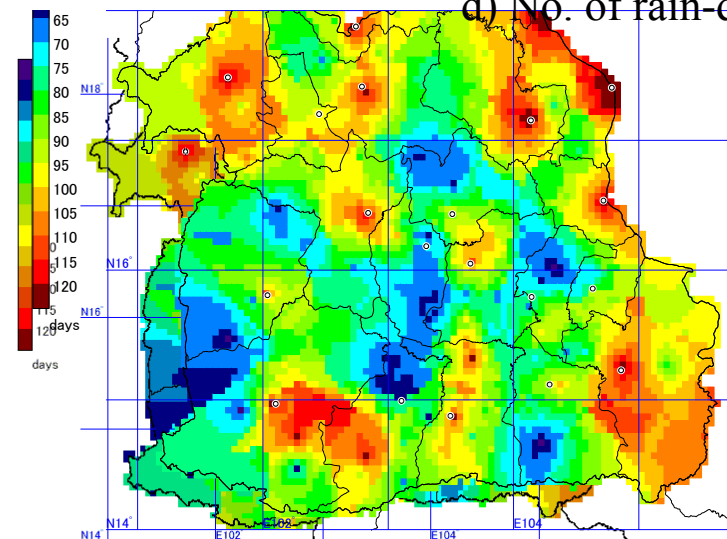


Figure: Rainy Days in the Rainy Season (average)

(Nawata et al., 2005より)

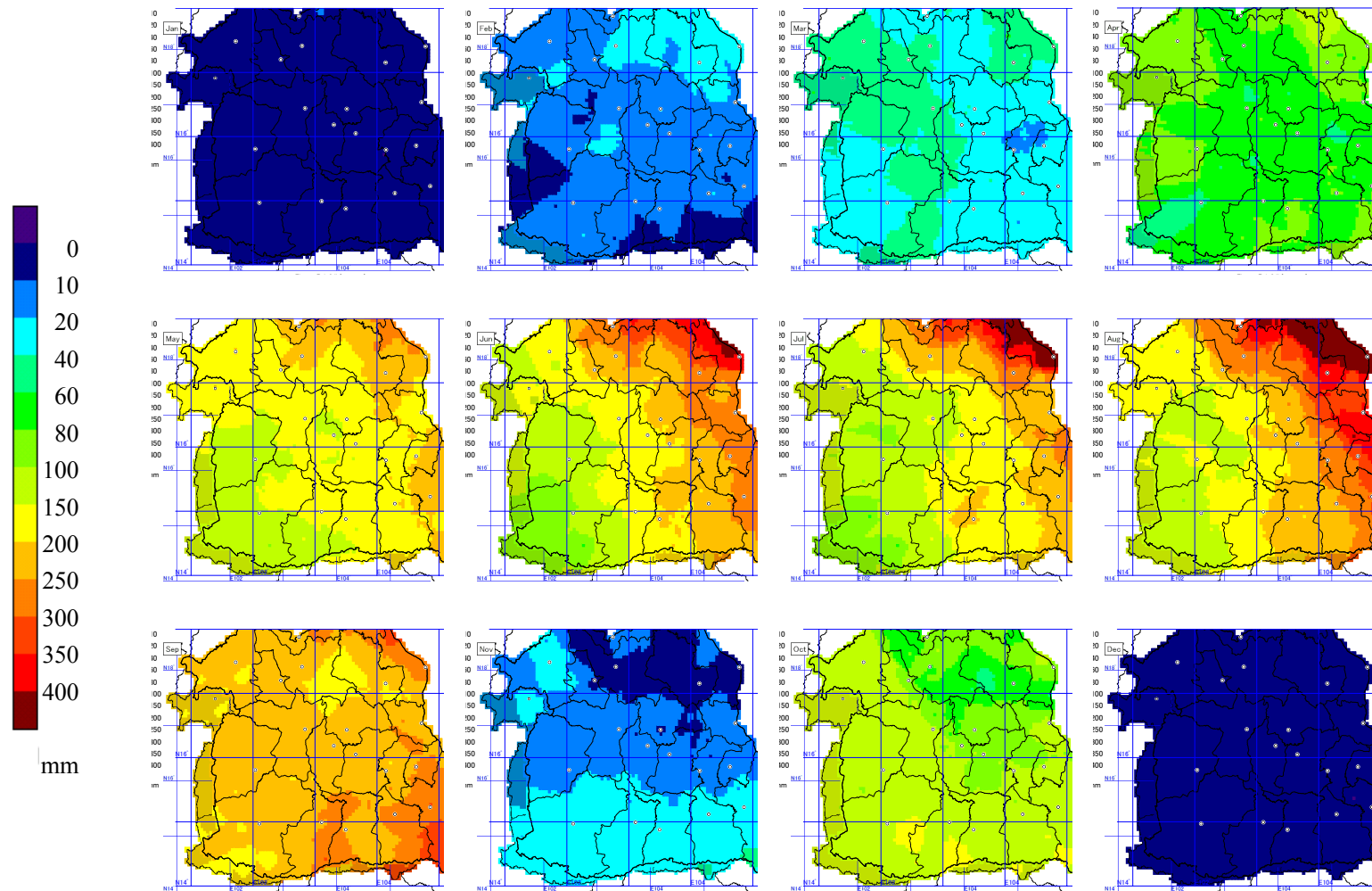


Fig. Average monthly rainfall over 20 years in Northeast Thailand
◎ : Provincial capital, lines in the map: provincial boundaries

Northeast Thailand

Tropical plains

Gentle undulation

Rainy and dry seasons

Tropical savanna

Scarce water resources

Unstable rainfall

Original vegetation :

Sparse forests

Rainfed agriculture

Predominance of poor-nutritious
sandy soils

Large scale agricultural development

1. Tropical climates

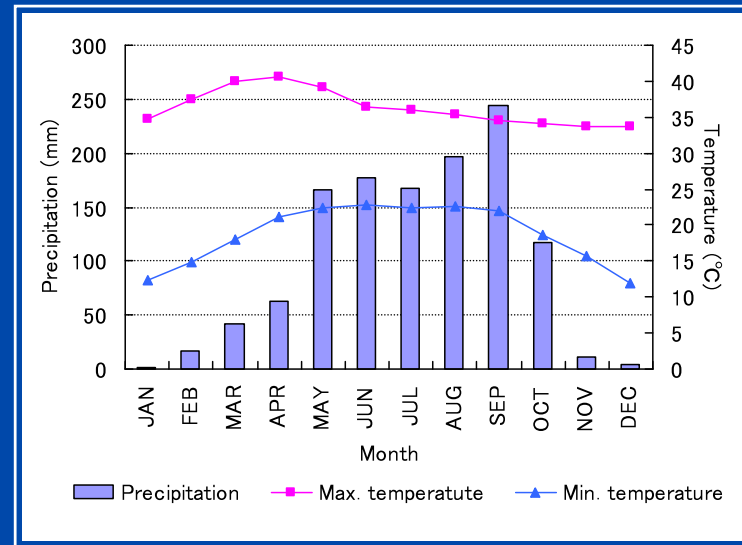
Rainfed Rice Cropping Systems (Northeast Thailand)

Single Cropping (local varieties)

Transplanting time :
depending on rainfall

Irrigated Paddy Fields

Double Cropping



Transplanting

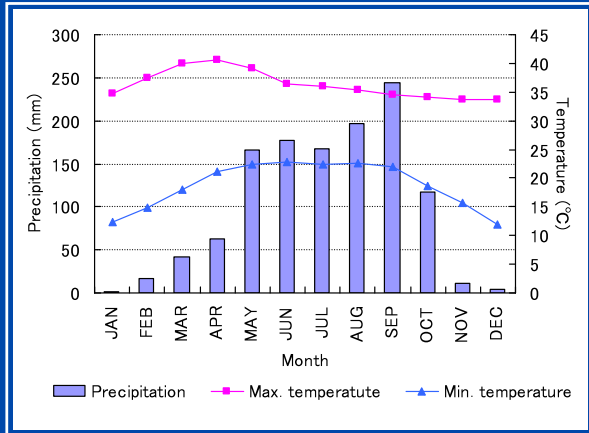
Apr. May June July Aug. Sept. Oct. Nov. Dec.

Rainy S. Rice

Photosensitive

Rainy S. Rice

Permanent Upland Fields (Northeast)



Sugarcane

Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct.

Cassava

Cassava

Monsoon and Topography

1. Mainland Southeast Asia (大陸部)

The rainy season caused by southwest monsoon
(April - October)

The dry season caused by northeastern monsoon
(November – March)

Mountains, plains & deltas: similar trend

Delta: Coastal area

Smaller annual & diurnal differences in air temp.

Influences of tropical low air pressure

→ limited influences in Chao Phraya Delta

Plains : Inland area

Larger annual & diurnal differences in air temp.

Predominance of soils with low water-holding capacity → high frequency of drought occurrence

Monsoon and Topography

1. Mainland Southeast Asia (大陸部)

Montane area

Upward current, frequent rainfall

Increase in rainfall as altitudes increase

Dry season : Occurrence of fog

2. Insular Southeast Asia (島嶼部)

Southwestern and northeastern monsoon

Trade wind from Australia

Rainy and dry season

South Thailand : West coast : similar to
mainland area

East coast : reverse of the mainland area

Java, Indonesia : reverse of the mainland S.E.A.

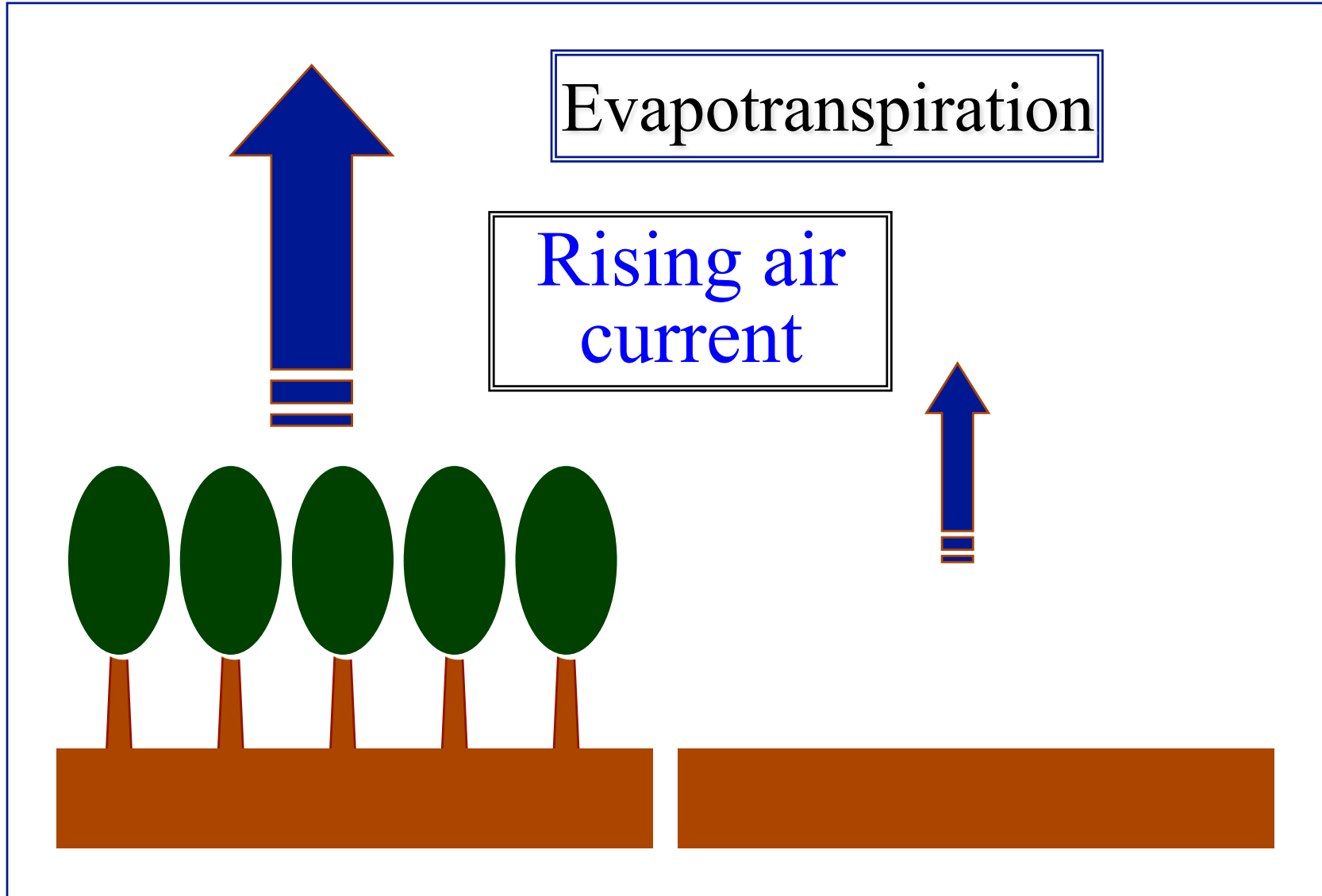
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1. Characteristics of tropical climates (熱帯気候の特徴)
2. Classification of tropical climates (熱帯の気候区分)
3. 東南アジア大陸部の気候
(Climates of Mainland Southeast Asia)
4. Mechanism of desertification
(砂漠化のメカニズム)

Desertification

Definition: Land deterioration in semi-arid and dry, semi-humid area caused by various factors including climatic changes and human activities

Desertification



Desertification

Definition: Land deterioration in semi-arid and dry, semi-humid area caused by various factors including climatic changes and human activities

Causal factors for desertification

1. Wind erosion

2. Erosion

Sheet erosion (面状) → Rill erosion (細流)

→ Gully erosion (ガリー)



Desertification

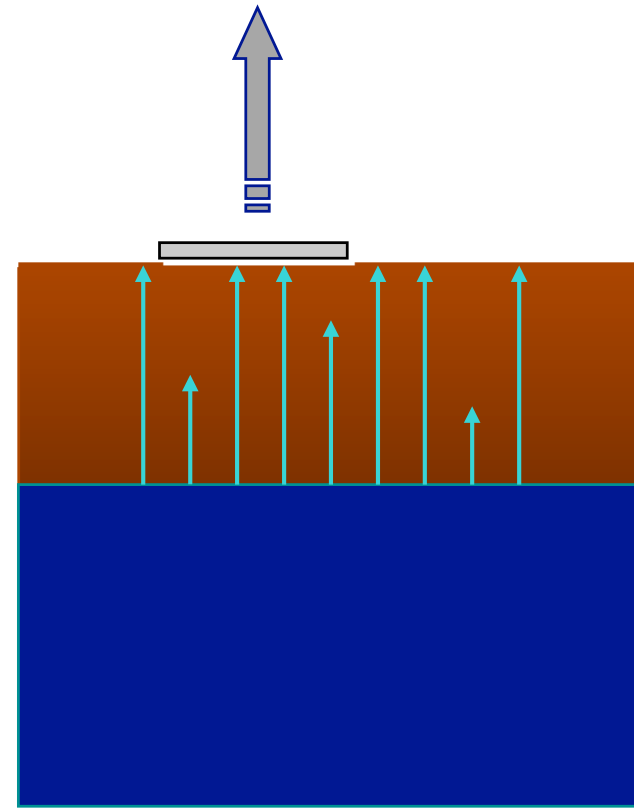
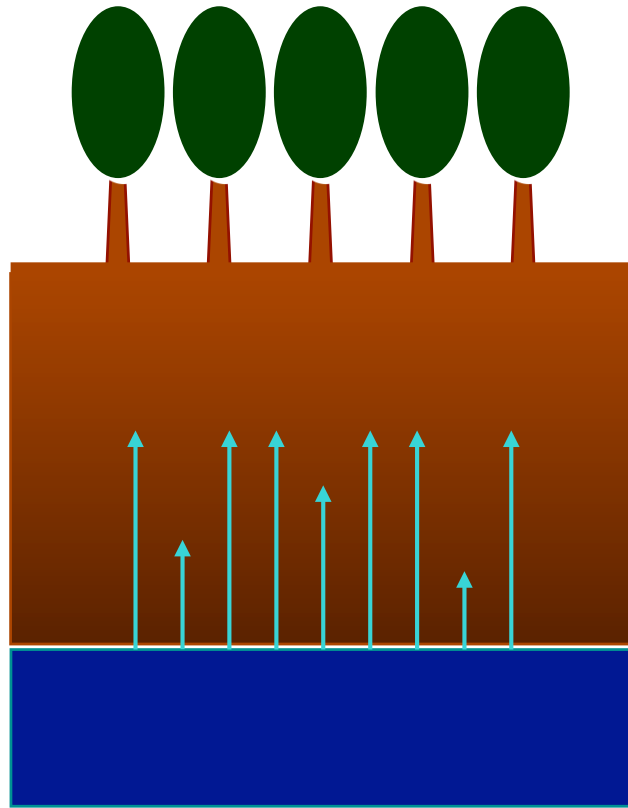
Definition: Land deterioration in semi-arid and dry, semi-humid area caused by various factors including climatic changes and human activities

Causal factors for desertification

1. Wind erosion
2. Erosion
Sheet erosion (面状) → Rill erosion (細流)
→ Gully erosion (ガリー)
3. Chemical deterioration (化学的劣化)
Salinization (塩類化)・ Leaching (養分の溶脱)

Desertification

Capillary movement



Soil salinization

Desertification

Definition: Land deterioration in semi-arid and dry, semi-humid area caused by various factors including climatic changes and human activities

Causal factors for desertification

1. Wind erosion
2. Erosion
Sheet erosion (面状) → Rill erosion (細流)
→ Gully erosion (ガリー)
3. Chemical deterioration (化学的劣化)
Salinization (塩類化) · Leaching (養分の溶脱)
4. Physical deterioration (物理的劣化)
5. Desertification by human activities
Over-cultivation · Over-grazing · Over cutting