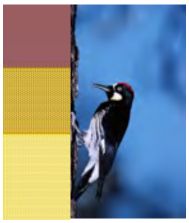
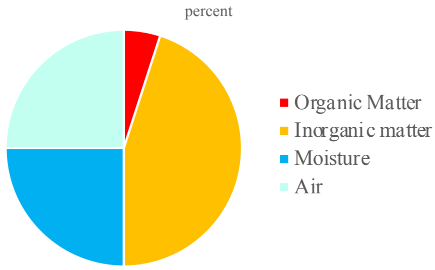
Physical properties of Soil



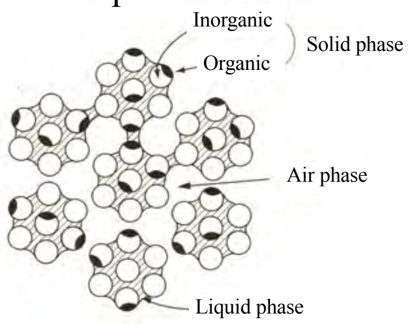
Kiyoshi Tsutsuki

http://timetraveler.html.xdomain.jp

Composition of Soil



Three phases of soil



Specific gravity and Porosity

True specific gravity

Inorganic soil 2.6～2.8 g cm^{-3}

(Quartz: 2.6 g cm^{-3})

Lower in organic soil.

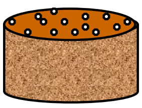
Higher in soils with colored minerals.

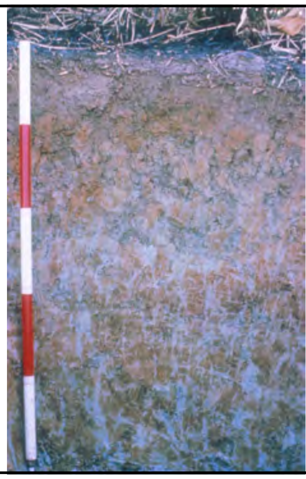
(>3.0 cm^{-3})

Bulk density

Density of undisturbed soil including the pore space.

Sandy soil	1.1～1.8
Volcanic ash soil	0.5～0.8
Peat soil	0.2～0.6





Hard soil

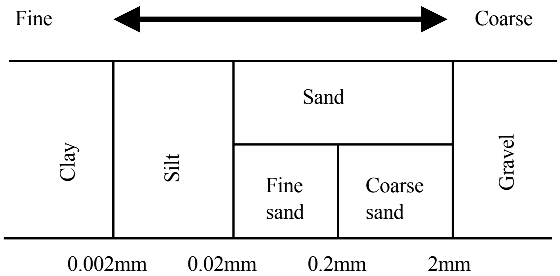
Bulk density: 1.1

Gray terrace soil in Takikawa, Hokkaido

Soft soil

Bulk density: 0.6

Volcanic ash soil in Obihiro University of Agriculture and Veterinary Medicine



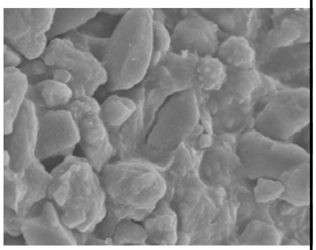
Division of soil particles by the International Method.

Soil particles are formed by the weathering of rocks.

- By observing sand particles, original rock of the soil can be recognized.

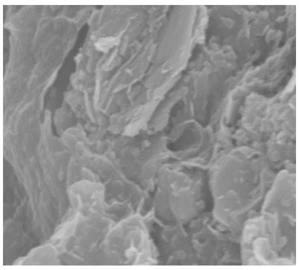
Particles of silt

- Size of silt is 0.002mm-0.020mm
- Most of silt particles are quartz. Other minerals have been lost by weathering.
- Silt has smooth feeling.



Clay: Finest soil particle

- Shaped like flake
- Clay is formed by the recombination of silicates and aluminum hydroxides. It is not the finely ground silt.
- Diameter of clay is less than 0.002mm.



Clay

- Wet clay has high stickiness and plasticity. Its form can be made freely.
- Fine and long strings can be formed.
- Expand and Shrink depending on the types of clay.

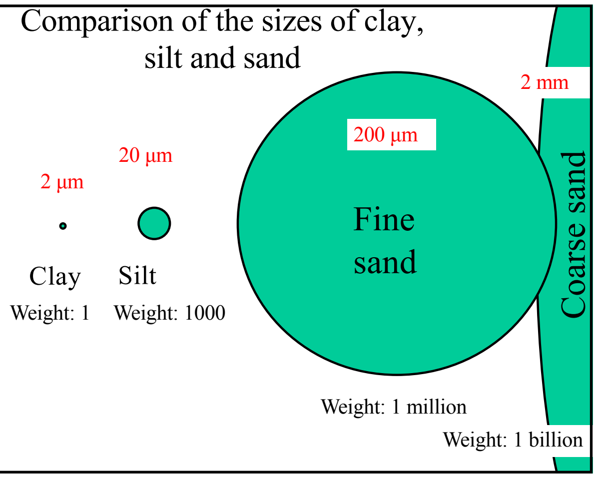
Problem of clayey soil

- Sticky when wet.
- Very hard when dry.





Comparison of the sizes of clay, silt and sand



Relationships between the composition of soil constituents and the surface area (example)

	Diameter	Weight %	Surface area %
Sand	100 µm	33%	0.1%
Silt	20 µm	33%	1%
Crystalline clay	1 µm	32%	14%
Allophane	0.005 µm	1%	85%

Soil texture

Soil texture is defined by the relative percentages of sand, silt and clay in the soil.

From the soil textue,

1) Permeability of water

2) Water holding capacity

3) Soil fertility

4) Ability of the land to support buildings

can be judged.

Terms showing soil textures

- **Clay: Soil rich in clay**
- **Loam: Soil with proper compositions of clay, silt and sand. Such soil is fertile.**
- **Sand: Soil rich in sand**

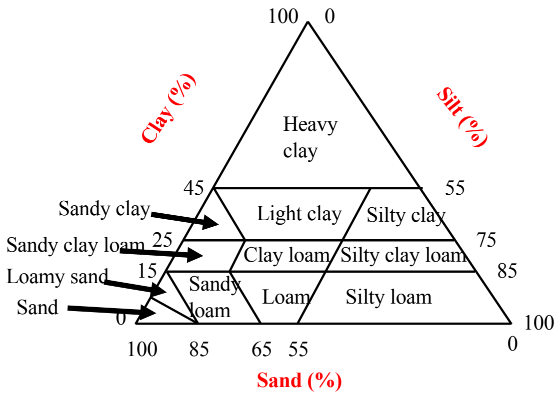
How to judge soil texture in the field?

Soil texture	Feeling
Sandy soil	Feel only sand. Not sticky.
Sandy loam	Feel sand strongly. Stickiness is slightly recognized.
Loam	Feel sand moderately. Feel also stickiness. Feel sand and clay to the same extent.
Silt loam	Feel like wheat powder. Do not feel sand so much.
Clay loam	Slightly feel sand, but considerably sticky.
Light clay	Feel almost no sand. Very sticky.
Heavy clay	No sand. Very sticky.

Soil texture in the field: Difference between sandy loam and loamy sand

Sandy loam:
With plasticity

Loamy sand:
Easily collapsed

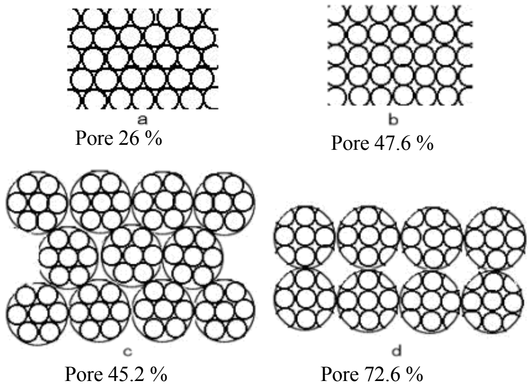


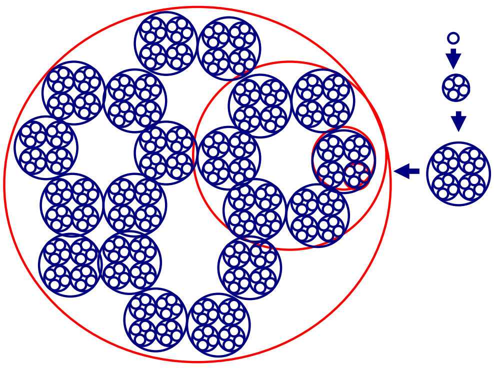
Expression of soil texture by triangle diagram

Soil aggregate

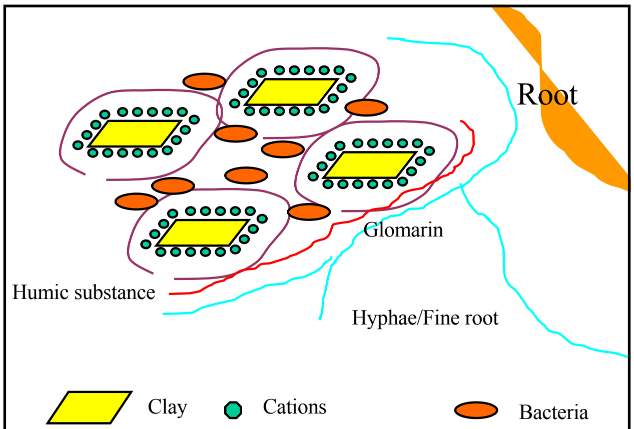
Mechanism of formation and its role

Orientation of particles and the pore percentage.



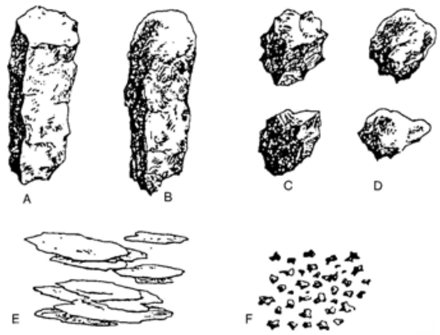


Hierarchical structure of soil aggrigate



Various binders for soil aggregates

Soil structures



A: prismatic, B: columnar, C: angular blocky, D: sub-angular blocky, E: platy, F: granular

Soil structures

Granular

Platy

Sub-angular blocky

Columnar

Soils with good soil structure are healthy soils.

Causes of soil structure formation

- Repetition of drying and wetting
- Freezing
- Plant root activity
- Soil animal activity

Soil water

Expression of water holding potential (matric potential)

Definition of the unit for the pressure: Pa (Pascal)

$1\ Pa = 1\ N/m^2 = 1\ kg\ m/sec^2/m^2$

Conversion with the height of water column:

Pressure of 1 m high water column:

$100\ gw/cm^2 = 10^6\ gw/m^2 = 10^3\ kgw/m^2$

$= 9.8 \times 10^3\ kg\ m/sec^2/m^2$

$= 9.8\ kPa$

Maximum water holding capacity (Saturated water holding capacity)

- Soil water content when all the pore is filled with water.

Gravity water $\varphi = 0$ kPa

It can not be expressed by pF

(because $\log 0 = -\infty$).

Field water holding capacity

- Soil water content 1-2 days after the heavy rain or irrigation, when the descending speed of water becomes very slow.

Readily available water: φ= − 6 kPa

pF = 1.78

(Varies according to the types of soils)

Growth inhibition point

- Moisture in the range of healthy growth of crops.

Readily available water :

φ= -49 ～ -98 kPa, pF = 2.7 ～3.0

Height of water column: 5 ～ 10 m

Initial wilting point

- Moisture content when plants start wilting.

Hardly available water:

φ= − 600 kPa, pF = 3.78

Permanent wilting point

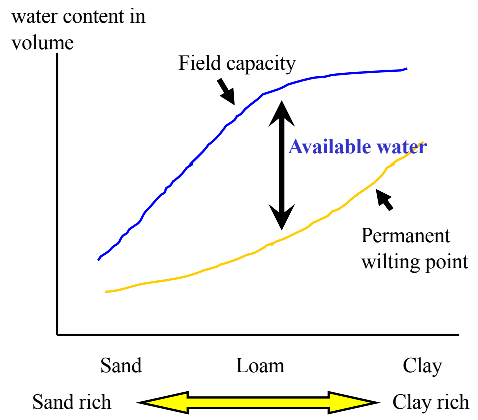
- Water content at the point plants do not recover from wilting even if moisture is supplied at the saturated vapor pressure.

Unavailable water:
φ= - 1,500 kPa, pF = 4.18

1,500 kPa = 10.2 × 1,500 cm = 15,300 cm = 153 m (Tension equivalent to 153m high water column).

Available water is the moisture between field capacity and permanent wilting point

- Matric potential: -6 ～ -1,500 kPa
- pF : 1.78 ～ 4.18
- Height of water column:
  60.2 cm ～ 15136 cm (= 152 m)
- Radius of capillary tube :
  0.0244 mm (fine sand) ～
  9.67×10^{-5} mm (ca. 0.1 µm: radius of fine clay)



Available water

Larger in loam, and less in sand and clay.

Available water can be increased also by soil organic matter and compost.

Soil air

Features of soil air

Constituents	Volume % in atmosphere		Ratio of soil air to the content in atmosphere
N_2	78.1		0.96 – 1.15
O_2	20.9	>>	0.09 – 1.0
Ar	0.93		1.0 – 1.2
CO_2	0.0345	<<	3 – 30
CH_4	0.00017	<<<	~30000
N_2O	0.00003	<<<	~ 33000
Humidity	30 – 90 %	<	100 %

Required air volume % of various crops

extent	Required air volume	Crops
maximum	> 24 %	Cabbage, Green bean
high	> 20 %	Turnip, Cucumber, Wheat, Barley, Common vetch
medium	> 15 %	Oats, Sorghum
low	10 %	Italian Ryegrass, Rice, Onion (initial growth)

Proper soil air composition

- Air phase %: 10 – 15 %
- Oxygen: higher than 10 %
- CO_2 : lower than 8 %

Oxygen concentration in soil air

Volcanic ash soil in Isehara city (Kanagawa)		Non-volcanic ash soil in Taketoyo, Aichi	
Soil depth	Oxygen %	Soil depth	Oxygen %
20 cm	20.2 – 20.8	0 – 10 cm	19.1 – 20.7
50 cm	20.0 – 20.6	10 – 20 cm	19.4 – 20.8
100 cm	19.5 – 20.0	20 – 30 cm	14.2 – 14.8

Concentration of CO_2 in soil air

Volcanic ash soil in Isehara city (Kanagawa)		Non-volcanic ash soil in Taketoyo town, Aichi	
Soil depth	CO_2 %	Soil depth	CO_2 %
20 cm	0.14 – 0.25	0 – 10 cm	0.43 – 1.51
50 cm	0.30 – 0.54	10 – 20 cm	0.60 – 1.91
100 cm	0.51 – 0.98	20 – 30 cm	5.89 – 6.20

Soil air moves easily in volcanic ash soil.
Suitable for the growth of crops.

Effects of plowing on agricultural soils

Items of soil diagnosis standards related to physical properties

Hardness of subsoil 16 - 20
Solid phase % of plowed soil:
25 – 30 (volcanic ash soil)
< 40 (lowland and terrace soils)
Bulk density: 0.70 – 0.90 (volcanic ash soil)
9.0 – 1.10 (lowland and terrace soils)
Coarse pore %: 15 - 25
Easily available water %: 15 - 20
Harrow rate: > 70

Items of soil diagnosis standards related to physical properties (continued)

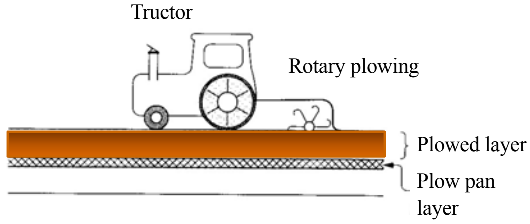
- **Depth of plowed layer: 20 – 30 cm**
- **Effective soil layer: > 50 cm**
- **Saturated hydraulic conductivity: 10^{-3} – 10^{-4} cm/sec**
- **Ground water level: lower than 60 cm**
- **Plow pan layer: >20 by Yamanaka type soil hardness tester, > 1.5MPa by penetration hardness tester.**

Effects of plowing soil

- Make soil soft, and increase the holding capacity of water and air.
- Cut the cycle of weeds and pests.
- Mix the crop residue, compost, and fertilizers.
- Make the uniform distribution of soil nutrients.
- Suitable conditions for germination and initial growth are provided.
- Increase the root area and promote soil microbial activity.

Demerits of plowing soil

- Energy consumption is very large.
- By making the soil bare, soil erosion may be caused.
- Decrease in land supporting capacity. Can not operate agricultural machines after the rain.
- Crust (clay film) is formed after heavy rain.
- Subsoil is mixed with plowed layer soil.
- Plow pan is formed by the operation of heavy machines.
- Decomposition of soil organic matter is enhanced.



Formation of plow pan in the upland field

Subsoil is important for the growth of crops

- Upland crops absorb more than half of nutrients from the subsoil.
- Water absorption from the subsoil is also important.
- Plow pan disturb the penetration of roots to subsoils.
- Ill drainage inhibits the growth of roots in the plowed layer.

No-till Till farming

Comparison of labor time between till and no-till farming.

method	Labor time（min / 10a）			
	Rotary plow	**Seeding**	**Herbicide application**	**Total**
Till	38	26	11	75
No-till	**← 15 →**			**15**

Effect of no-till cultivation

- Decrease the soil loss due to wind and water erosion.
- Repress the soil organic matter decomposition.
- Saving labor and lower the costs.
- Workable under rainy weather.
- Covering the soil surface with crop residues. Decrease the damage by birds.
- Superior water penetration and water holding capacity.
- Enrich crop residues on the soil surface and maintain soil fertility.

Demerit of no-till cultivation

- Increase in soil hardness, retard crop growth, cause moisture damage.
- Lower the efficiency of fertilizers (due to evaporation and denitrification).
- Decrease soil temperature by crop residue. Cause uneven germination and pest damage.
- Increase the use of herbicides.
- Root crops are difficult to grow.

Deterioration of soil physical properties.
Causes and measures.
Natural factors

Land form

Amend the inclination, make the land flat. Improve the drainage by under drain and open drain.

Soil types (heavy clay, sandy soil)

Soil improvements, soil dressing, application of organic matter, growing green manure, conduct rotational cropping

Deterioration of soil physical properties.
Causes and measures.
Human factors

- Agricultural machinery

  Improving the machines, Change the working process

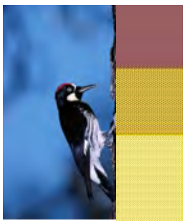
- No-application of organic matter and compost.
- Decomposition of soil organic matter, soil erosion
- Inactivation of soil organisms

  Application of compost, growing green manure, rotational cropping, non-till culture

Deterioration of soil physical properties in Japan

- Plowed layer of paddy field became shallower. → Caused the decrease in yield and quality of rice.
- Plowed soil in upland became hard and the drainage became worse. → Caused the decrease in yield and quality of vegetables (especially cabbage).
- Formation of plow pans in upland field → Yield and quality of root crops (radish and carrot) decreased.

Let's consider toether.



How can we protect our soil and agriculture?

The remains of ancient Roman city Ephesus in Turkey

"The Nation that destroys its soil destroys itself" -- Franklin D. Roosevelt

Volcanic ash soil with thin plowed layer in Memuro, Hokkaido

Thanks to soil

- Life is born from soil

All the life on the land comes are born from the soil. Fertile soils support the agriculture.

- Soil is protecting the environment.

Decompose the biological remains and feces.

Keeps the composition of atmosphere, and moisture.

Buffer the environmental change.

Soil records the history

Fall of volcanic ashes, floods and Tsunami, remains of ancient human lives.

Soil is burying and keeping the past history.

Tradition handed down by the American native people, Hopi.

Though our land is inherited from our ancestors, it is also borrowed from our descendants. Therefore, we have to return it in unchanged state to our descendants.