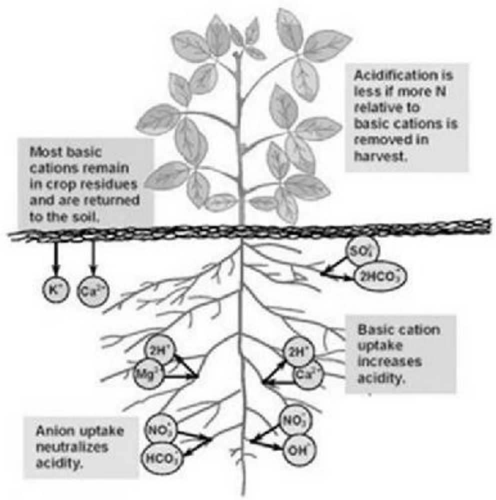
LECTURE 3: NUTRIENT UPTAKE



LECTURE OUTCOMES

After completing the lecture and mastering the lecture materials, students are expected to be able

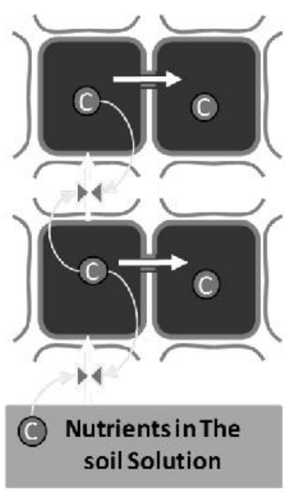
- to explain the selectivity of nutrient uptake
- to explain routes of nutrient transport in plants
- to calculate the amount of nutrient uptake by mass flow
- to calculate the amount of nutrient uptake by diffusion

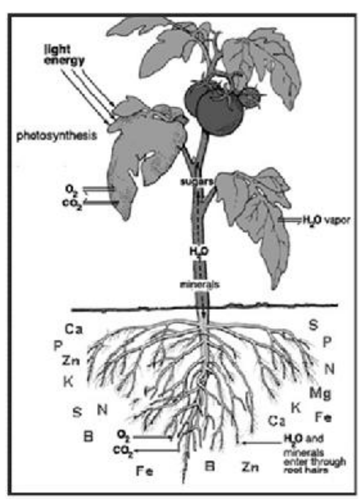
LECTURE FLOW

1. INTRODUCTION
2. SELECTIVITY OF NUTRIENT UPTAKE
3. NUTRIENT UPTAKE
   - ➢Root Interception
   - ➢Mass Flow
   - ➢Diffusion

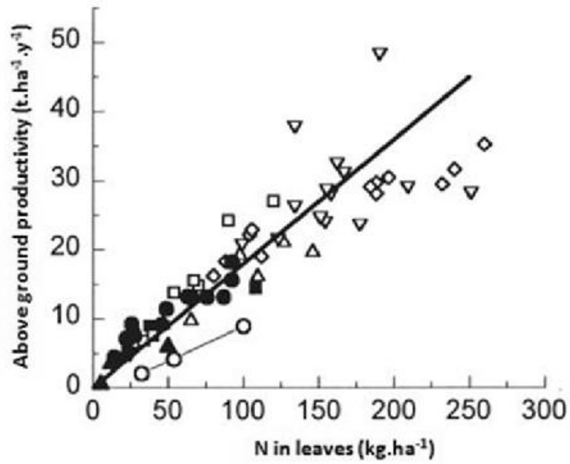
1. INTRODUTION

Why are nutrients taken by plants from the soil?



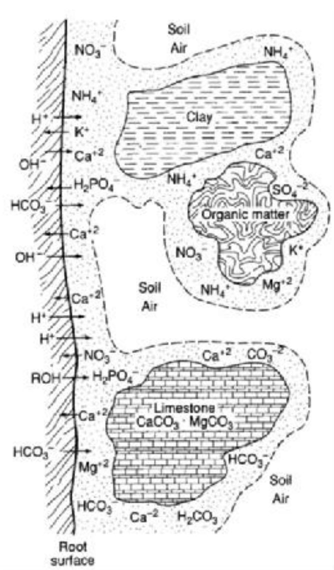


1. You may say that nutrients are taken up by plants because they need them
   - This means the plants control the uptake of nutrients



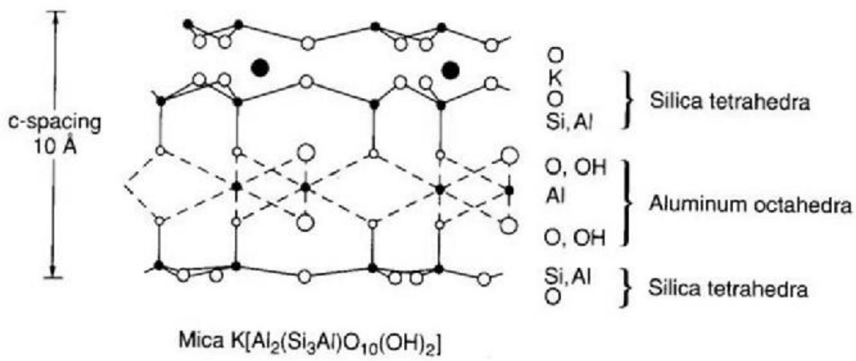
Nutrient elements are in the soil

2. How do the plants know that they need particular chemical elements (nutrients)
3. What is the mechanism applied by plants to tell the roots that required nutrients are needed now
4. What is the mechanism used by the roots to take nutrients from the soil



Root exchange & adsorption sites in soils: The mineral and organic exchange surfaces in soils

2:1 clay: Mica



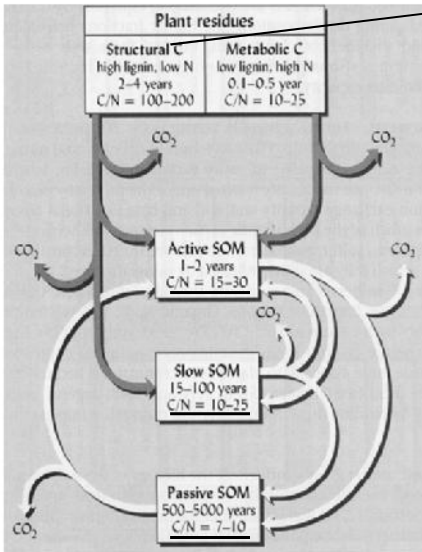
Contribution of specific clays and soil O.M. on CEC of soils

Table 2-1 Common Aluminosilicate Minerals in Soils

Clay Mineral	*Layer Type*	*Layer Charge*	*c-Spacing (A)*	*CEC (meq/100 g)*	*pH-Dependent Charge*
Kaolinite	1:1	0	7.2	1–10	High
Mica (Illite)	2:1	1.0	10	20–40	Low
Vermiculite	2:1	0.8	10–15	120–150	Low
Montmorillonite	2:1	0.4	Variable	80–120	Low
Intergrade*	2:1:1	1.0	14	20–40	High
Organic matter				100–300	High

*Intergrade is a 2:1:1 mineral with a Mg or Al hydroxide interlayer.

Humus



<u>Humic Substances</u>
(polyaromatic)

- **Humins: complex with clays, v. passive**
- **Humic Acids: intermediate half -life**
- **Fulvic Acids: more active SOM, lowest MW**

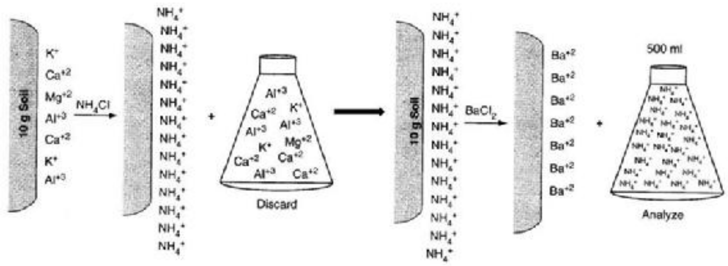
Paustial et al., 1992

Cation Exchange capacity (CEC)

- **CEC** = quantity of negative charges available to attract cations in solution.
  - CEC expressed as *milliequivalents negative charge per 100 g. O.D. soil. (= meq./ 100 g.*)*
  - meq. unit rather than mass because CEC represents the total # of charges associated with the solid phase.
  - *eq.*(equivalent) = moles of *charges*, not atoms. meq. = 1,000 eq.

**$cmol_c$ / kg soil = SI unit*

Determining the CEC of a soil



Base Saturation Percentage (BSP)

- *BSP = % total CEC occupied by basic cations (Ca, Mg, K, Na)*
- Generally, higher in arid (e.g. 70-90%) than humid region soils (30-50%) *mostly due to high Ca & Mg saturation*
- As BS ↑'s, soil pH generally ↑'s.

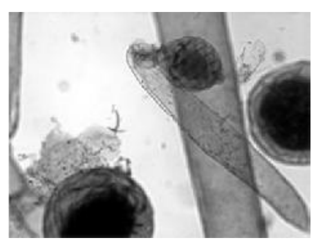
- BS Importance
  - BS indicates *ability of the soil to supply basic cations*
    - *Soil with BS of 80% supplies Ca, Mg, K & Na more readily than does soil w/ BS 40%, b*ut…. clay type and O.M.% also influence
  - BS (& CEC) are used in calculation of lime requirement and CEC is used for calc. of gypsum requirement (GR)

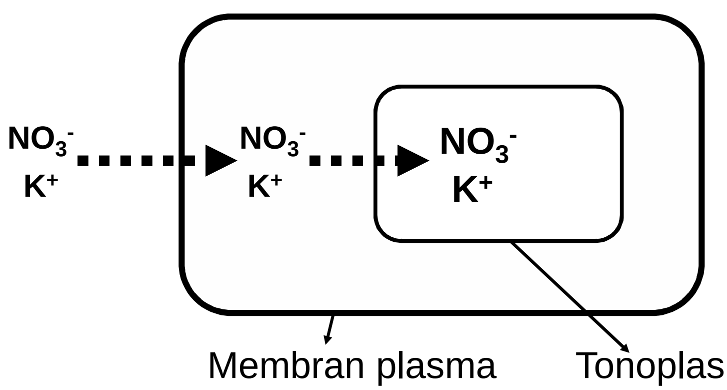
2. SELECTIVITY

1. Is nutrient uptake selective (controlled by plants) ?
   Experiment : *Compare uptake of*
   1. Nutrient and Non-nutrient elements
   2. Macro & Micro Nutrient elements

2. What is the principle ?
   If nutrient uptake is not selective, the process of nutrient uptake will be controlled by factors other than plants such as nutrient concentration in the rooting medium

Valonia & Nitella algae





Is the uptake of nutrients selective or not selective?

Tabel . Relationship between ion concentration in the substrate and in the cell sap of Nitella and Valonia

Ion	Nitella			Valonia		
	Pond water (A1)	Cell (B1)	B1/A1	Seawater (A2)	Cell (B2)	B2/A2
Potassium (K)	0.05	54	1080	12	500	42
Sodium (Na)	0.22	10	45	498	90	0.18
Calcium (Ca)	0.78	10	13	12	2	0.17
Chloride (Cl)	0.93	91	98	580	597	1

Tabel. Changes in the ion concentration of the external (nutrient) solution and in the root press sap of maize (M) and Bean (B)

Jenis Ion	Rooting Medium			Root	
	Initial	M (4 dap)	B (4 dap)	M	B
Potassium (K)	2,00	0,14	0,67	160	84
Calcium (Ca)	1,00	0,94	0,59	3	10
Sodium (Na)	0,32	0,51	0,58	0,6	6
Phosphate (P)	0,25	0,06	0,09	6	12
Nitrate (N)	2,00	0,13	0,07	38	35
Sulfate	0,67	0,61	0,81	14	6

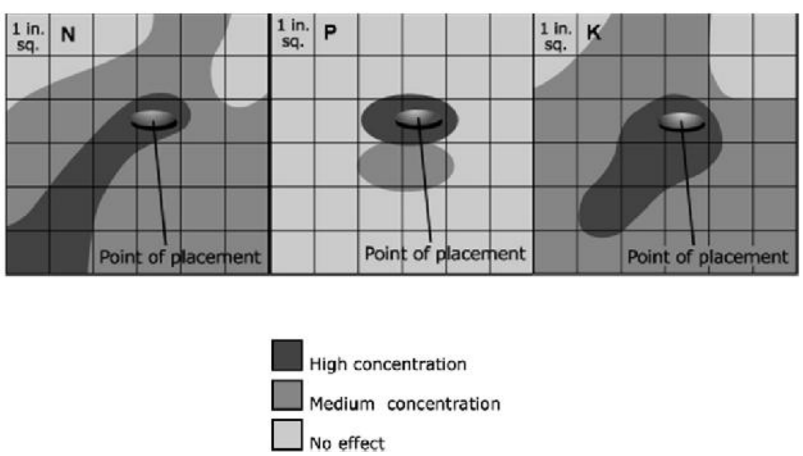
Is the uptake of nutrients selective or not selective?

Conclusion

The results obtained from both lower and higher plants demonstrate that ion uptake is characterized by

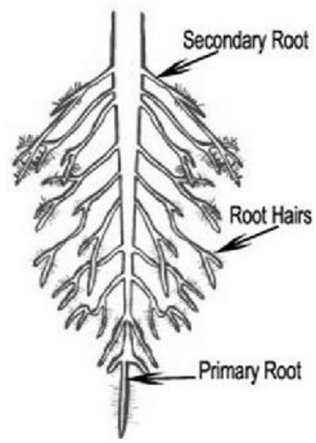
1. Selectivity. *Certain mineral elements are taken up preferentiall, while others are discriminated against or nearly excluded*
2. Accumulation. *The concentration of mineral elements can be much higher in plant cell sap than in external solution*
3. Genotype. *There are distinct differences among plant species in ion uptake characteristics*

Nutrient distribution 17 days after application



3. NUTRIENT UPTAKE

1. Root extension and Interception
   - esp. micronutrients
2. Mass Flow
   - NO_3^-, K^+
3. Diffusion
   - K^+, PO_4-P



Significance of mass flow, diffusion and root interception in nutrient uptake

Table 2-4 Significance of Root Interception, Mass Flow, and Diffusion in Ion Transport to Corn Roots

Nutrient	Nutrient Required for 200 bu/a of Corn	Percentage Supplied by: Root Interception	Mass Flow	Diffusion
N	225	1	99	0
P	45	2	4	94
K	200	2	20	78
Ca	50	120	440	0
Mg	55	27	280	0
S	25	4	94	2
Cu	0.12	8	400	0
Zn	0.40	25	30	45
B	0.25	8	350	0
Fe	2.5	8	40	52
Mn	10.40	25	130	0
Mo	0.012	8	200	0

Note: The contribution of diffusion was estimated by the difference between total nutrient needs and the amounts supplied by interception and mass flow.

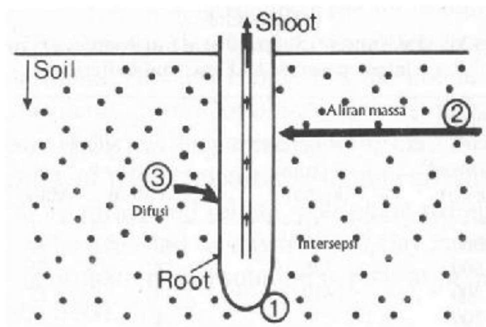
Estimated amounts of mineral nutrients supplied to maize roots in fertile Silt Loam Soil

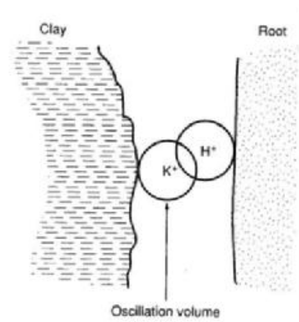
Nutrient	Avail able (kg/ha)	Uptake (kg/ha) by			
		Inter-ception	Mass flow	Diffu-sion	Total
Calcium	4000	40	90	-	45
Magnesium	800	8	75	-	35
Potassium	300	3	12	95	110
Phosphorus	100	1	0.12	28.9	30

1. Root Interception
   - Root interception is the uptake of nutrients by plant roots as roots grow through the soil and incidentally come into contact with nutrients.
   - Nutrient uptake by root interception is directly related to the volume of the root system, which in most cases is less than 1% of the total soil volume.
   - Consequently, root interception makes a small contribution to total nutrient uptake
   - Plant-mycorrhizal associations increase functional root volume
   - Mycorrhizal fungi infect plant roots and produce their own root-like structures called hyphae, which act as extensions of the plant's root system.

Root Interception

- Root extension and Interception
  - Nutrient absorption is enhanced since the hyphae can increase the absorptive surface area of root systems by up to ten times compared to noninfected root systems.





Conceptual model for root interception (contact exchange) of nutrients between ions on soil and root exchange sites

- Bulu akar

  Peranan dari bulu akar ditinjau terutama dari perpanjangannya sangat besar dalam penyerapan unsur hara. Suatu hasil penelitian menunjukkan bahwa luas permukaan bulu akar berkisar diantara 88 - 94% dari total luas permukaan akar, sedang panjang bulu akar lebih dari 99% dari total panjang akar (Tabel 2.1)
- Pori tanah

  Jumlah unsur hara yang diserap tanaman dapat ditaksir dari proporsi pori tanah yang ditempati akar dan konsentrasi unsur hara dalam larutan tanah (Tabel 2.2)

Tabel 2.1 Luas (A) dan panjang (P) akar dan bulu akar serta volume (V) tanah yang ditempati total akar dari tiga spesies tanaman

Spesies tanaman	Akar		Bulu akar		Vol. (%)
	A (cm^2)	P (m)	A (cm^2)	P (km)	
Oat	22	45,7	162	8,06	0,55
Rye	502	64,0	7677	16,80	0,85
Poa pratensis	2141	181,0	15783	51,5	2,80

Tabel 2.2 Taksiran serapan unsur hara dengan intersepsi pada tanaman jagung

Parameter	Jenis unsur hara				
	N	P	K	Ca	Mg
Jlh dalam tanah (kg/ha)[1]	300	100	300	4000	750
Jumlah intersepsi (kg/ha)[2]	6	2	6	80	15
Kebutuhan jagung (kg/ha)[3]	225	45	180	90	60
Tingkat intersepsi %)[4]	2,6	4,4	3,3	88,9	25,0

Catatan: 1 = taksiran tersedia, 2 = taksiran dengan asumsi 2% ruang pori tanah ditempati akar, 3 = untuk jagung dengan hasil 2500 kg/ha & 4 = persentase intersepsi dari kebutuhan

2. Mass Flow

- Mass Flow is the transport of nutrients with water due to water absorption by the root that creates water deficit near the root
- Mass flow is a significant mechanism for the uptake of some nutrients, such as nitrogen.
- Nutrient uptake by mass flow is reduced in dry conditions and at lower temperatures because the rate of transpirational water uptake is reduced
- The quantity of nutrients transported by mass flow is

$$J = VC$$

J = the quantity of nutrients flowing across a unit of surface per unit time
V = rate of water flow ($g.cm^{-2}.s^{-1}$)
C = nutrient concentration ($mol.cm^{-3}$)

Tabel 2.4. Taksiran serapan unsur hara dengan aliran massa (**AM**) pada tanaman jagung

Parameter	Jenis unsur hara				
	N	P	K	Ca	Mg
Kons. Dlm larutan tanah (ppm)	10	0,05	4	30	25
Serapan dg AM (kg/ha)*	45	0,23	18	135	113
Kebutuhan (kg/ha)	225	45	180	90	60
Kapasitas AM (%)	20	5	10	150	188

Contribution of mass flow to nutrient uptake

Species (soil)	Contribution of mass flow (% of uptake)				
	N	K	Mg	Ca	Na
Sugar beet (L)	100	7	60	640	Nd
Spring wheat (L)	40	4	150	1700	2500
Spring barley (P)	110	130	180	700	610

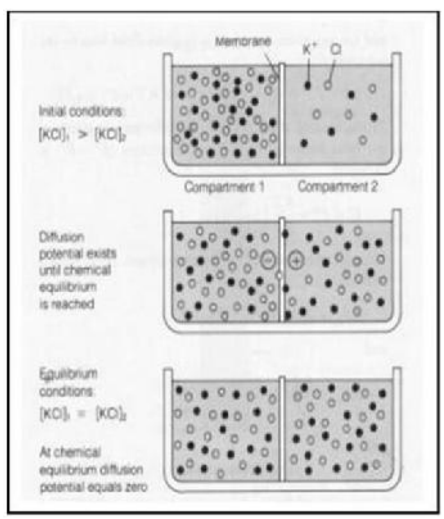
L = luvisol & P = podzol

3. Diffusion
   - Diffusion is the process by which nutrients spread from areas of high concentration to areas of low concentration.
   - When roots absorb nutrients from soil solution, the concentration of nutrients surrounding the root drops.
   - As a result, nutrients in areas of higher concentration in soil solution migrate toward the root. Diffusion is an important process in crop uptake of P and K
   - In contrast to mass flow, diffusion is an important process of ion mobility only in the immediate vicinity of the root surface and thus is closely related not only to soil conditions but also to plant factors such as root growth and root surface area

Percent of nutrients taken up by a corn crop normally supplied by root interception, mass flow and diffusion			
Nutrient	Root interception	Mass flow	Diffusion
	% of uptake possible		
Nitrogen	<1	80	19
Phosphorous	2	5	93
Potassium	2	18	80
Calcium	150	375	0
Magnesium	33	600	0
Sulfur	5	300	0

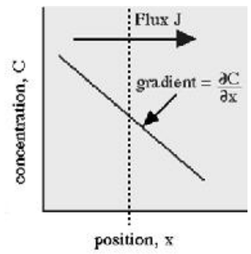
Basic Principle

1. **Pergerakan unsur hara melalui proses difusi terjadi akibat perbedaan konsentrasi yang dipertimbangkan merupakan peristiwa dominan dalam pergerakan ion-ion seperti NO_3^-, K^+ & $H_2PO_4^-$ ke permukaan akar**



2. According to the First Law of Diffusion, the transfer of diffusing materials per unit area in a 1-dimensional flow can be described by the following equation

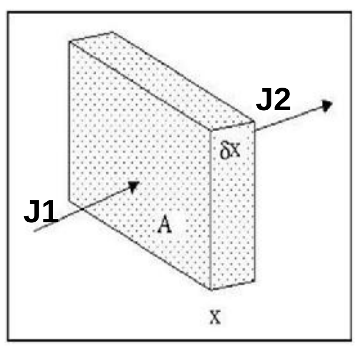
$$J = -D\frac{\delta C(x,t)}{\delta x}$$



where
   J is the particle flux,
   C is the concentration of the solute,
   D is the diffusion coefficient,
   x is the distance into the substrate, and
   t is the diffusion time.

The negative sign indicates that the diffusing mass flows in the direction of decreasing concentration

3. Fick’s First Law does not consider the fact that the gradient and local concentration of the diffusing a material decreases with time, an aspect that’s important to diffusion processes
4. The flux entering a section of a bar (J1) with a concentration gradient is different from the flux leaving the same section (J2).



5. From the law of conservation of matter, the difference between J1 and J2 must result in a change in the concentration of diffusing material within the section (assuming that no impurities are formed or consumed in the section).
6. This leads to the Fick's Second Law, which states that the change in concentration over time is equal to the change in local diffusion flux

$$\frac{\delta c(x,t)}{\delta t} = \frac{-\delta J}{\delta x}$$

- If the diffusion coefficient is independent of position, such as when the impurity concentration is low, then Fick's Second Law may be further simplified into the following equation

$$\frac{\delta C}{\delta t} = D\frac{\delta}{\delta x}\left(\frac{\delta C}{\delta x}\right) = D\frac{\delta^2 C}{\delta x^2}$$

- Persamaan ini hanya berlaku untuk difusi linier, sementara akar tanaman berbentuk silinder dengan jari-jari "r" dan unsur hara bergerak dari semua arah yaitu secara radial ke arah akar, sehingga

4. Diffusion in a sphere and cylinder

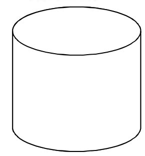
- Simple purely radial diffusion can be described by the following equarions.

(a) for a sphere

$$\frac{\partial C}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(Dr^2\frac{\partial C}{\partial r}\right)$$

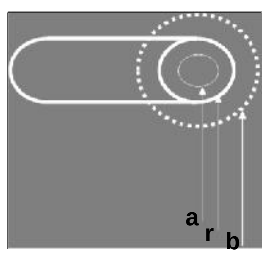
(b) For a long cylinder

$$\frac{\partial C}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(Dr\frac{\partial C}{\partial r}\right)$$



with r is the radius

- Crank (1975) menurunkan persamaan yang menggambarkan difusi zat, pada keadaan tetap (steady state) dengan suatu koefisien difusi yang konstan, ke dalam benda bulat atau silinder yang berlubang ditengahnya.



- Bayangkan suatu benda bulat dengan a≤ r ≤ b dengan konsentrasi yang tetap C_2 pada r = b, dan C_1 pada r = a.
- Konsentrasi pada setiap titik dinyatakan dengan persamaan berikut

$$C = \frac{aC_1(b-r)+bC_2(r-a)}{r(b-a)}$$

- *Kuantitas zat Q yang lolos melewati penampang bulat dengan waktu "t" adalah*

$$\frac{Q_t}{t} = \frac{4\pi Dab}{(b-a)}(C_2 - C_1)$$

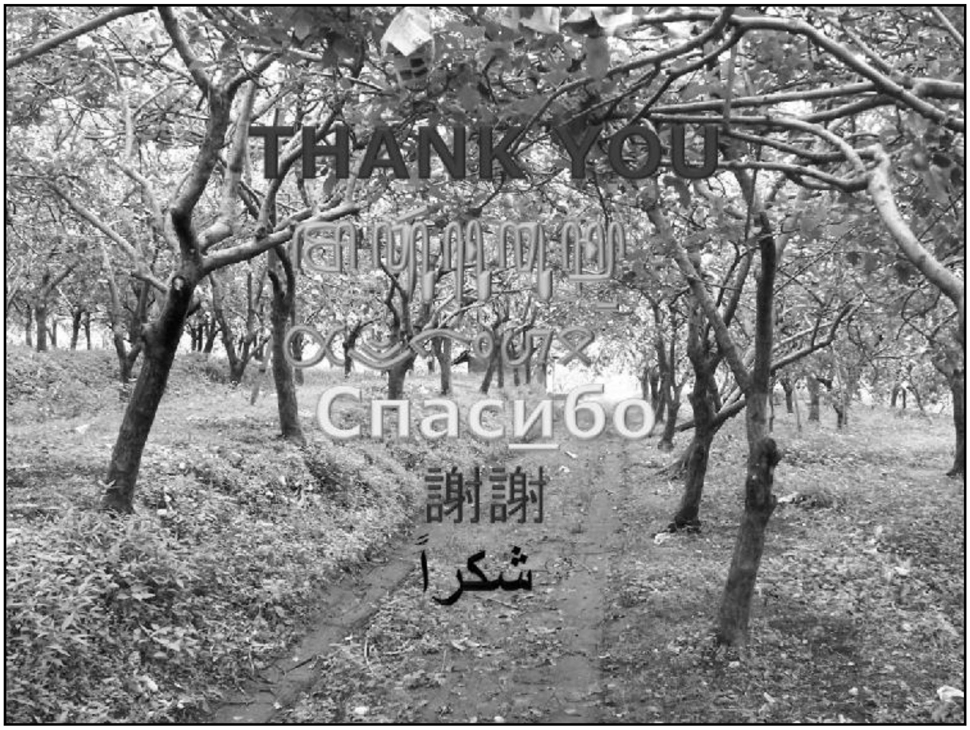
- Untuk silinder berlubang aYrYb dengan konsentrasi yang tetap C_2 pada r = b dan C_1 pada r = a, konsentrasi pada setiap titik diberikan oleh persamaan berikut

$$C = \frac{C_1 \ln(b/r) + C_2 \ln(r/a)}{\ln(b/a)}$$

- Kuantitas zat Q yang berdifusi per satuan panjang silinder dengan waktu "t" adalah

$$\frac{Q_t}{t} = \frac{2\pi D}{\ln(b/a)}(C_2 - C_1)$$

- Untuk suatu silinder dengan panjang L, total fluks diperoleh dengan mengalikan hasil persamaan tersebut dengan L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