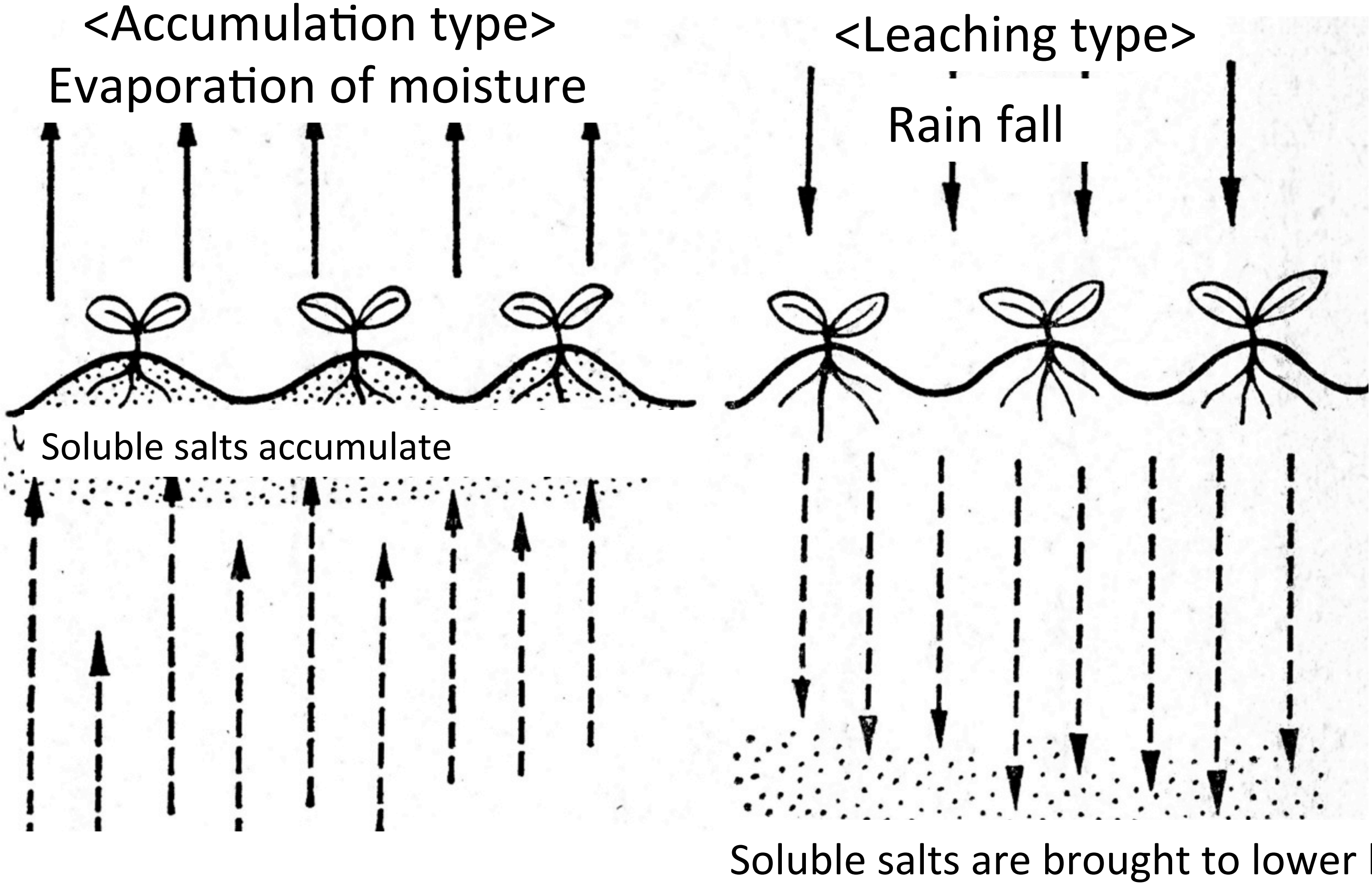
Characteristics and improvement of greenhouse soils

Kiyoshi Tsutsuki

Obihiro University of Agriculture and Veterinary Medicine

My homepage: http://kt-woodpecker.digi2.jp

Difference in open air field soil and greenhouse soil



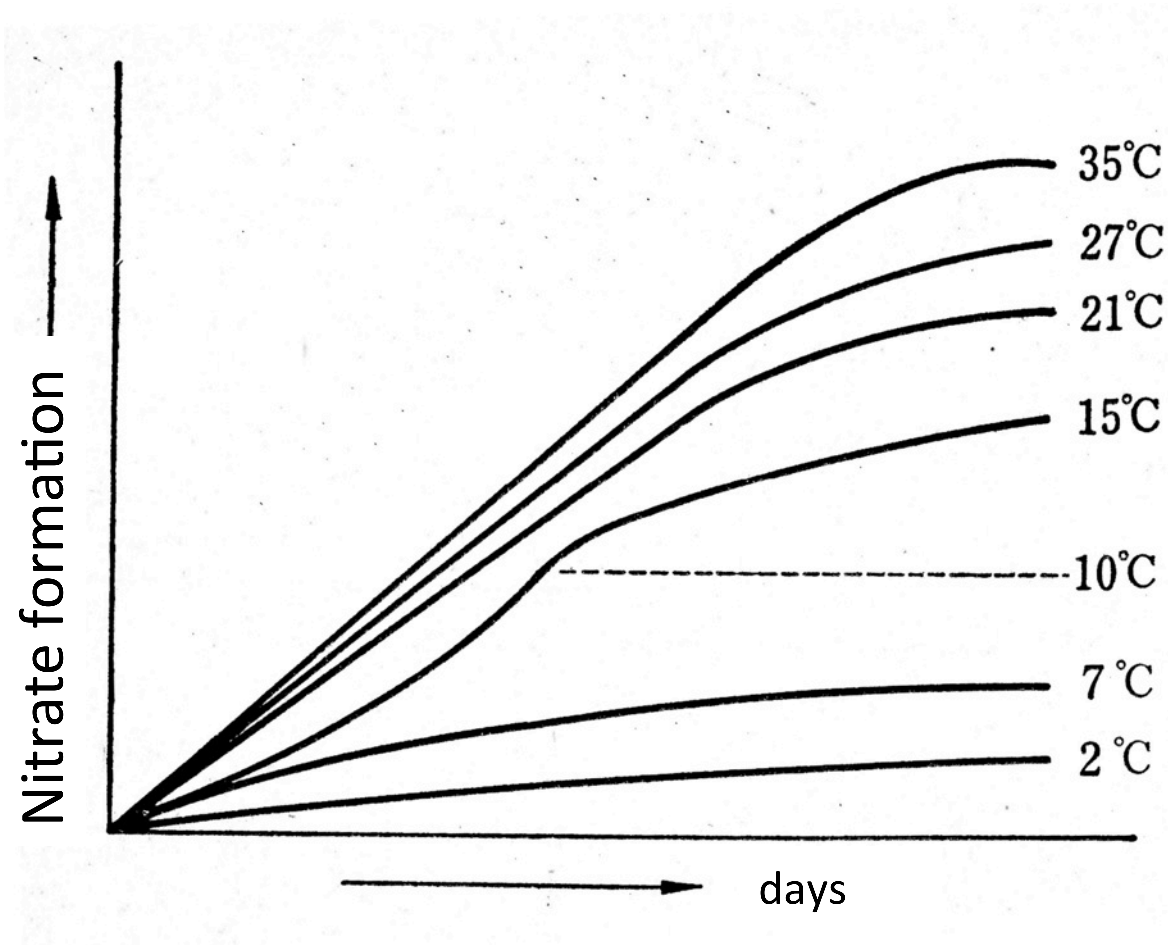
Soil in open field:

- Leaching with rain water
- Leaching of Ca and Mg
- Application of fertilizer
- Residue of acidic anions
- Nitrification ($NH_4^+ \rightarrow NO_3^-$)
- Soil acidification

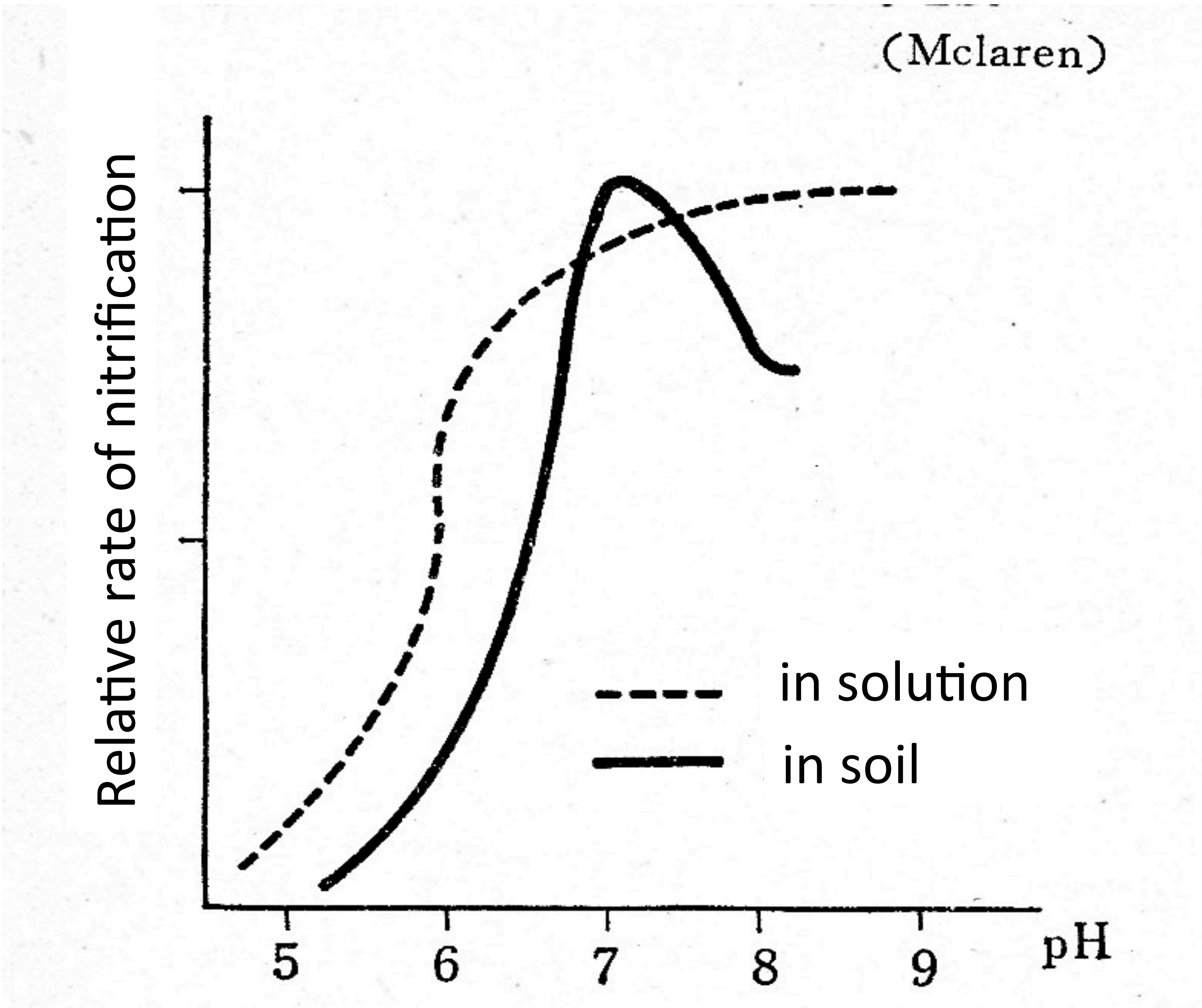
Soil in greenhouse:

- Irrigation water
- Uplifting of water from deep soil layers
- Application of fertilizer
- Accumulation of fertilizer components
- Retardation of Nitrification ($NH_4^+ \rightarrow\times NO_3^-$)
- Increase in salt concentration in surface soil
- Soil pH shows an increasing tendency.

Soil temperature and nitrate formation



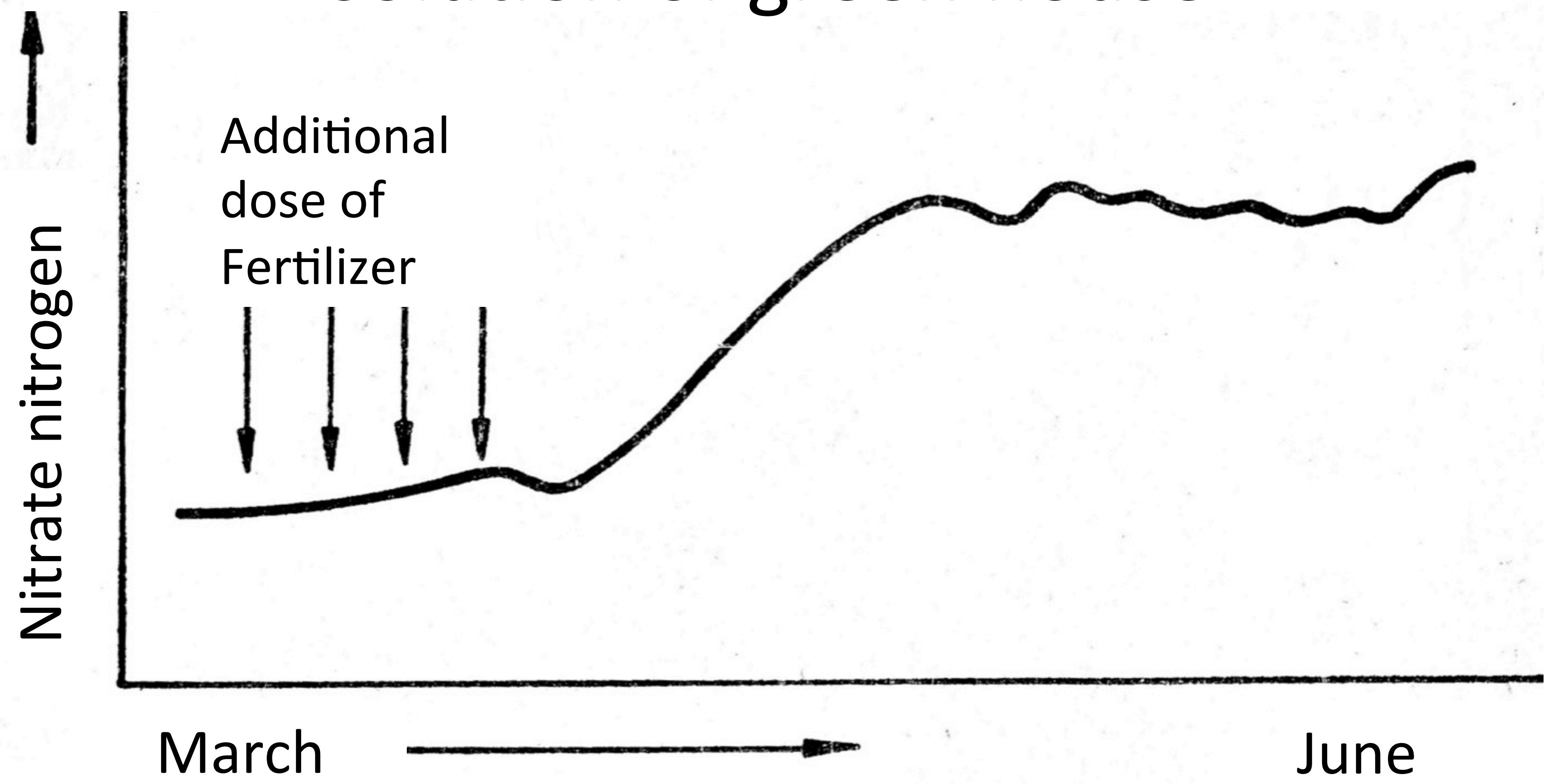
Relative rate of nitrification as related to pH



Greenhouse soil provides bad environment for soil microbes

- Greenhouse is used in cold season.
- Activity of soil microbe is low in cold season.
- Conversion of ammonium to nitrate is retarded in the greenhouse soil condition.
- Upland crops prefer nitrate to ammonium.
- Repeated cultivation of the same crop also causes the deterioration of soil microbial phase (numbers and balance).

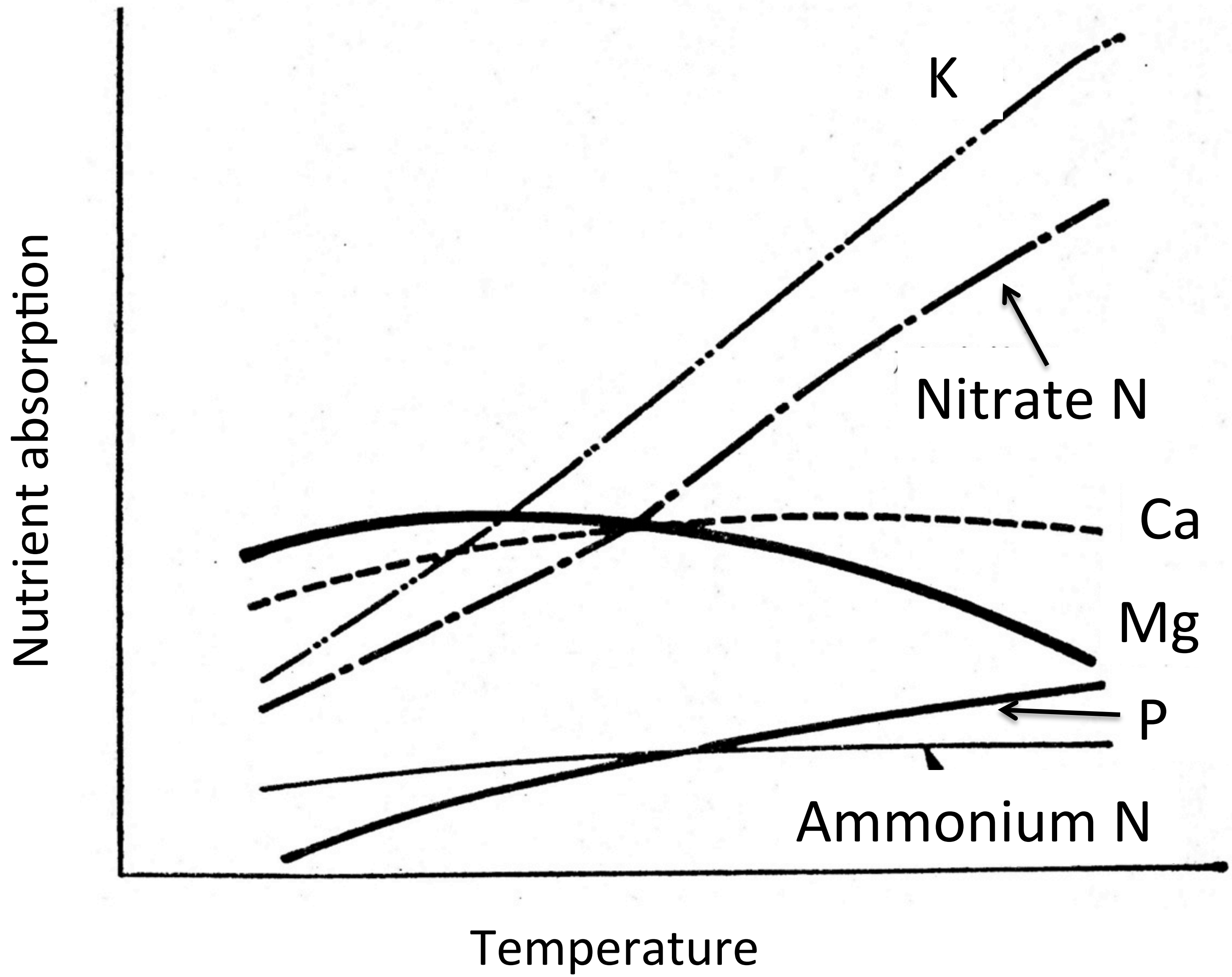
Change in nitrate nitrogen in the soil solution of green house



Low nitrate in cold season

- During a cold season, concentration of nitrate nitrogen does not increase even if farmer applies fertilizers repeatedly, which cause even worse effects to crops.
- It is advisable to increase soil temperature rather than to increase the dose of fertilizer.

Temperature and nutrient absorption



Effect of low soil temperature on the nutrient absorption

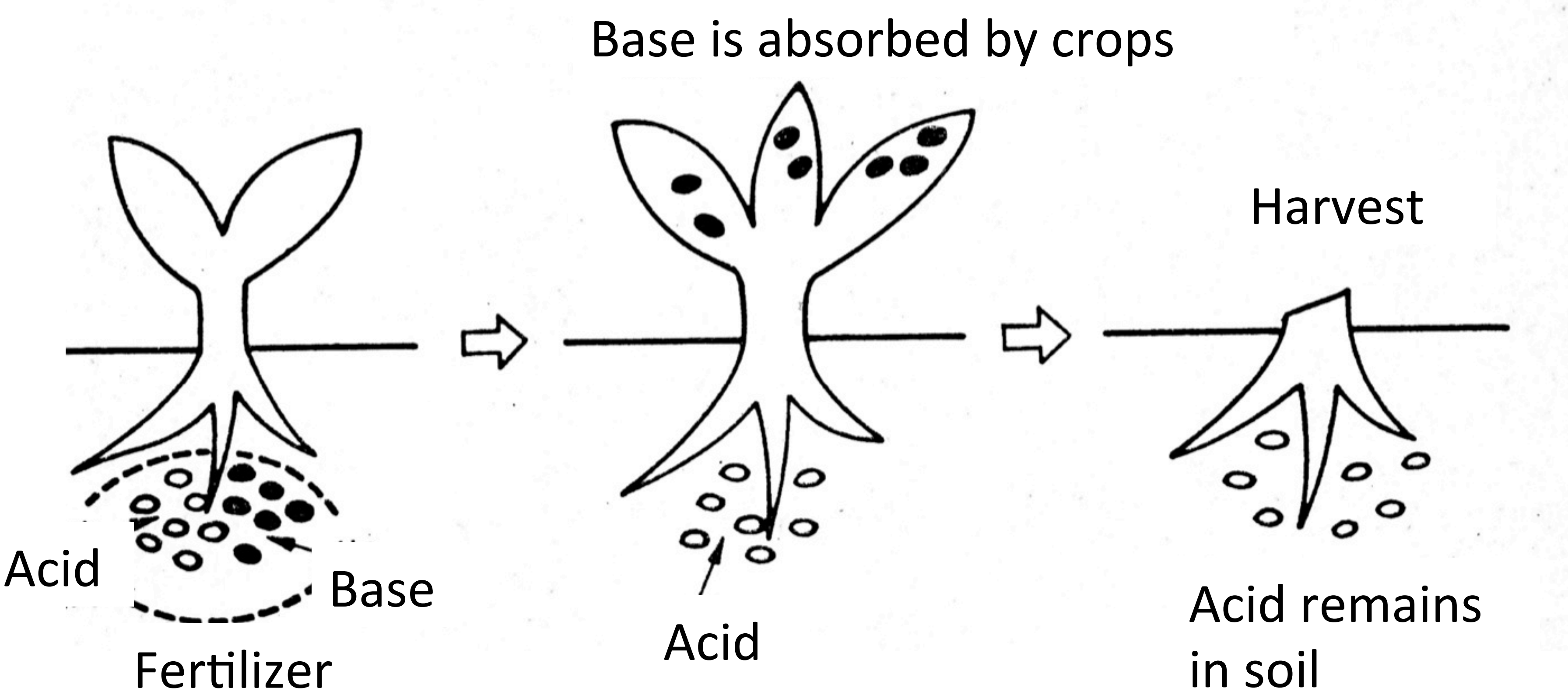
- Absorption of phosphate, nitrate and potassium is suppressed remarkably at low soil temperature
- Absorption of Ca, Mg, and ammonium nitrogen is not affected significantly at low temperature

Effect of soil temperature on the nutrient absorption by tomato

Soil temp.	Nitrate –N	P_2O_5	K_2O	Water
10 ℃	26.3 mg	2.7 mg	42.9 mg	211 L
15	62.0	9.9	79.2	364
20	86.9	22.1	112.6	512

By increasing soil temperature, absorption of above nutrients and water increased remarkably.

Translocation of fertilizer constituents after applied to soil



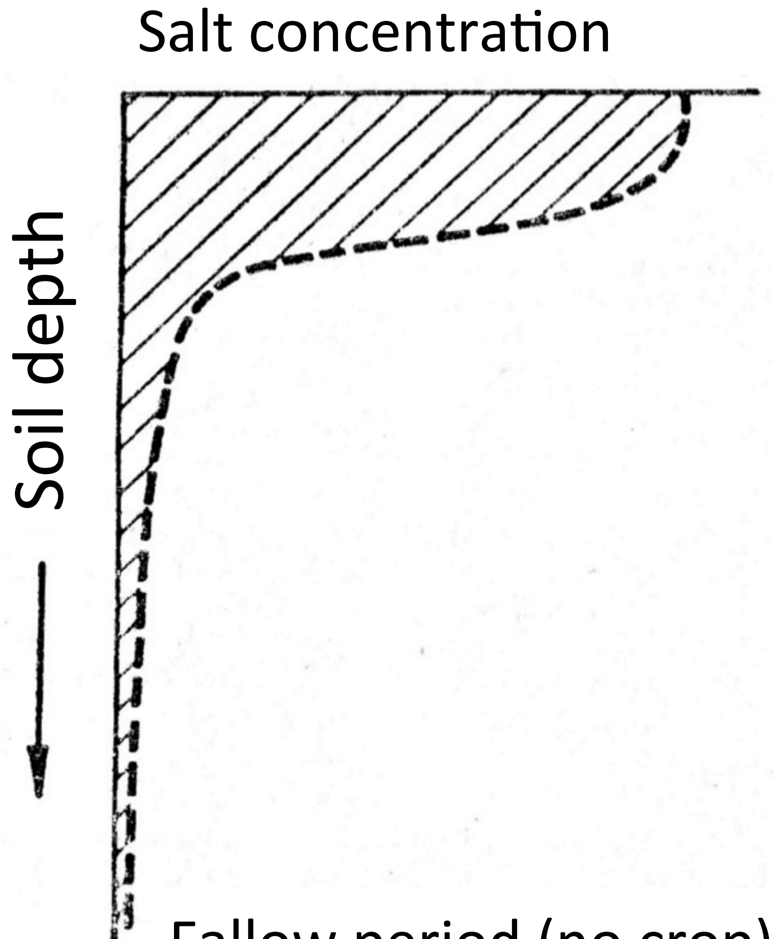
Translocation of fertilizer constituents after applied to soil

- Basic components in fertilizers (NH_4^+, K^+, Ca^{2+}) are absorbed by crops.
- Acidic components (SO_4^{2-} and Cl^-) remain in soil, which causes soil acidification.

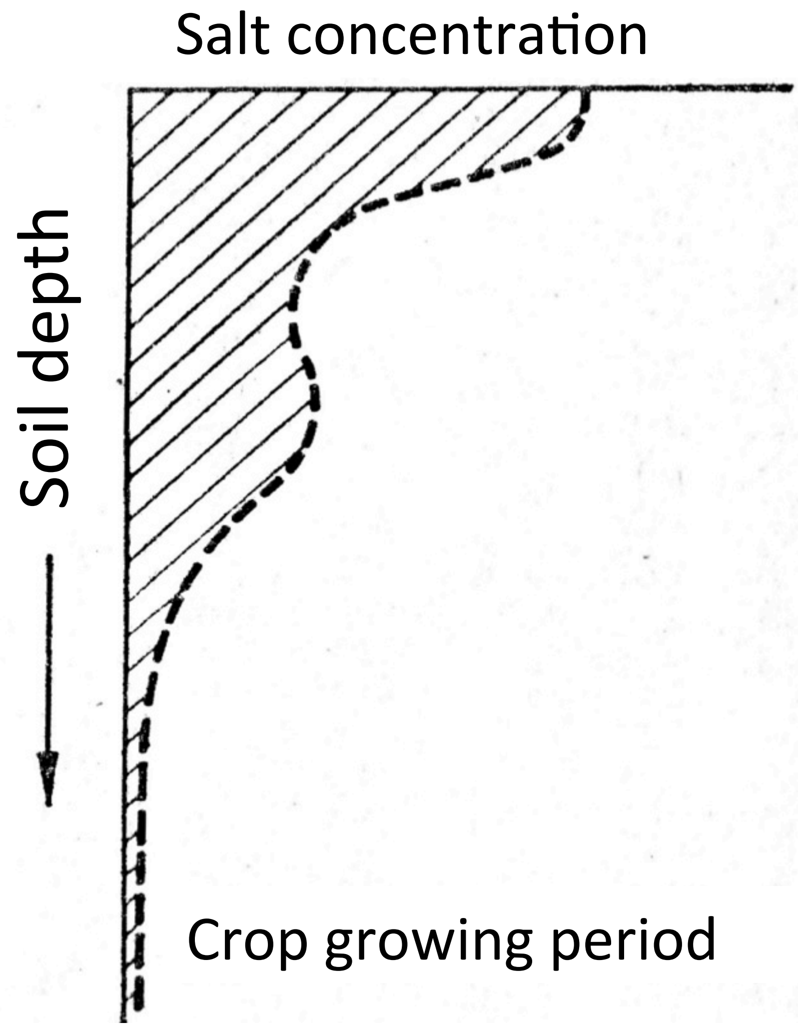
Form of salts accumulating in soils

- Soluble salts are easily accumulated.
- $CaNO_3$, $CaCl_2$, $CaSO_4$, KCl, $MgSO_4$, $(NH_4)_2SO_4$
- Phosphate salts are hardly soluble and do not accumulate in the form of soluble salts.

Mode of salt accumulation



Fallow period (no crop)



Crop growing period

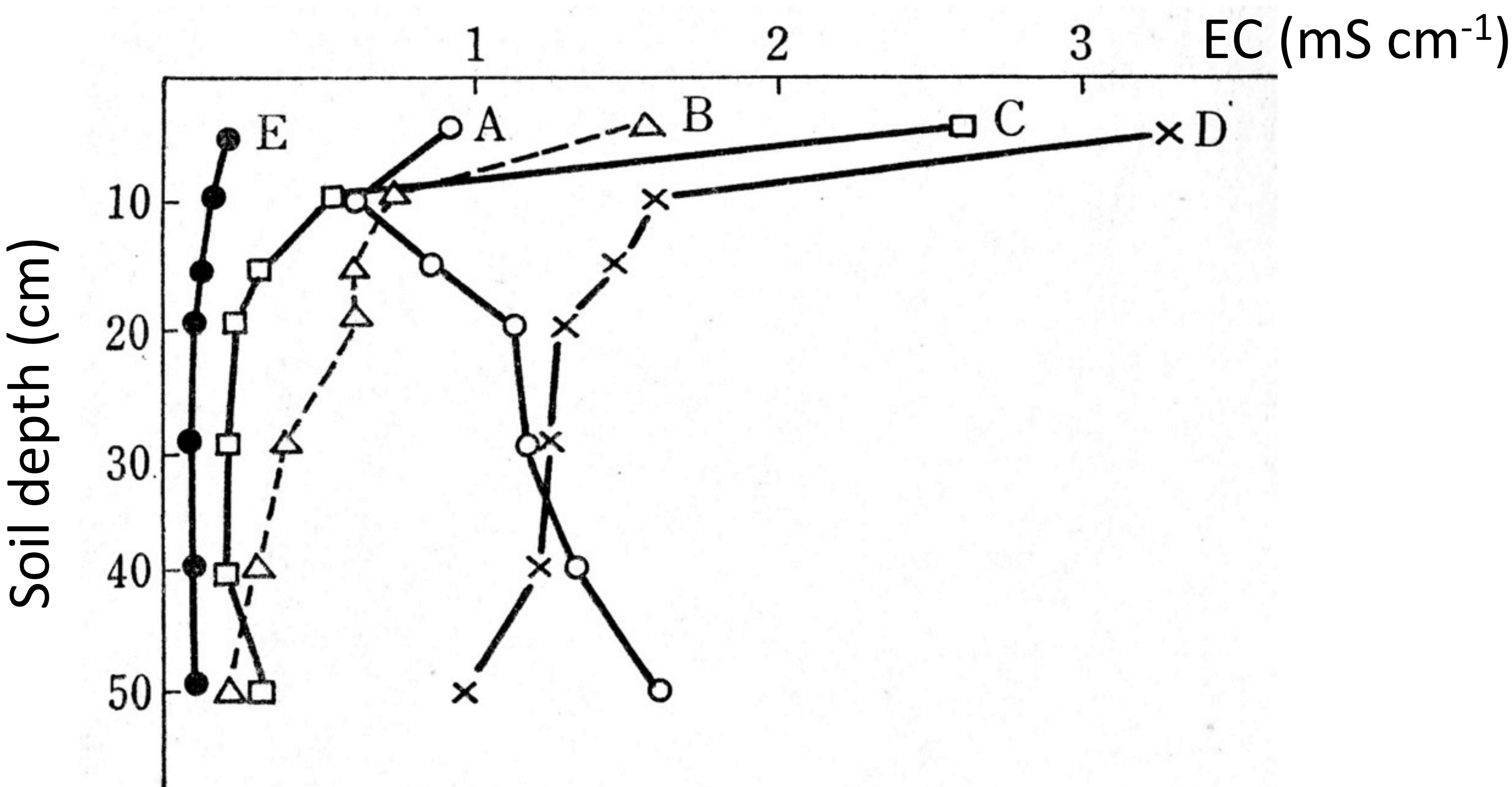
Where salts are accumulated?

- In the fallow period, there is no crop in greenhouse, and no irrigation water is given.

  Then, salts are readily accumulate in the surface soil.

- When crops are grown, water evaporation is suppressed, and irrigation water is given. Then, salts are moved to deeper layers.
- Crop roots absorb water, and salts also accumulate around the roots.

Distribution of salts (EC) in the soil profiles of greenhouse soils cultivated for different years

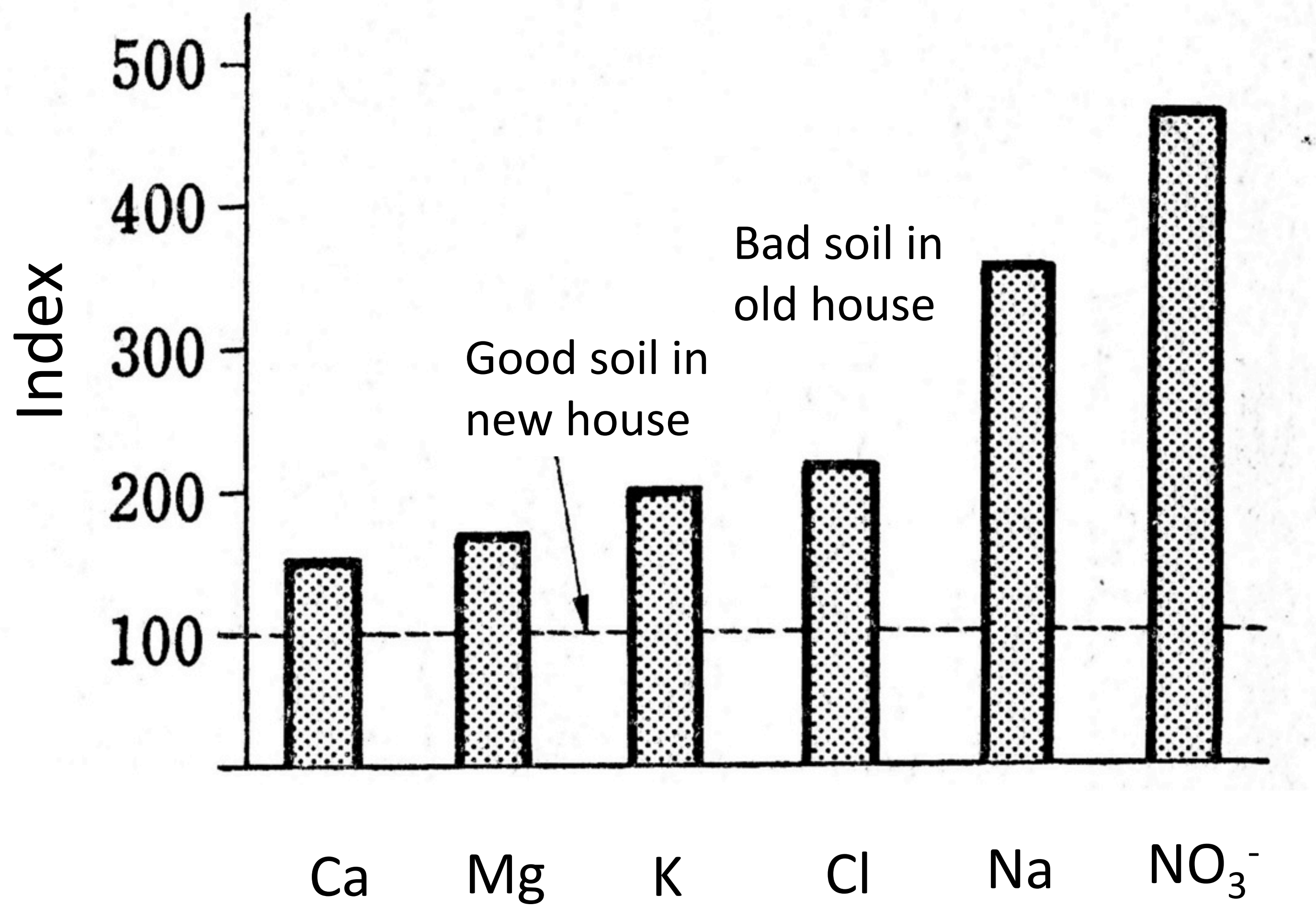


A: 4 years after construction, 8 times cultivation, deep plowed 2 years ago.
B: 3 years after construction, 5 times cultivation.
C: 3 years after construction, 6 times cultivation.
D: 4 years after construction, 8 times cultivation, deep plowed 3 years ago.
E: Newly constructed greenhouse soil

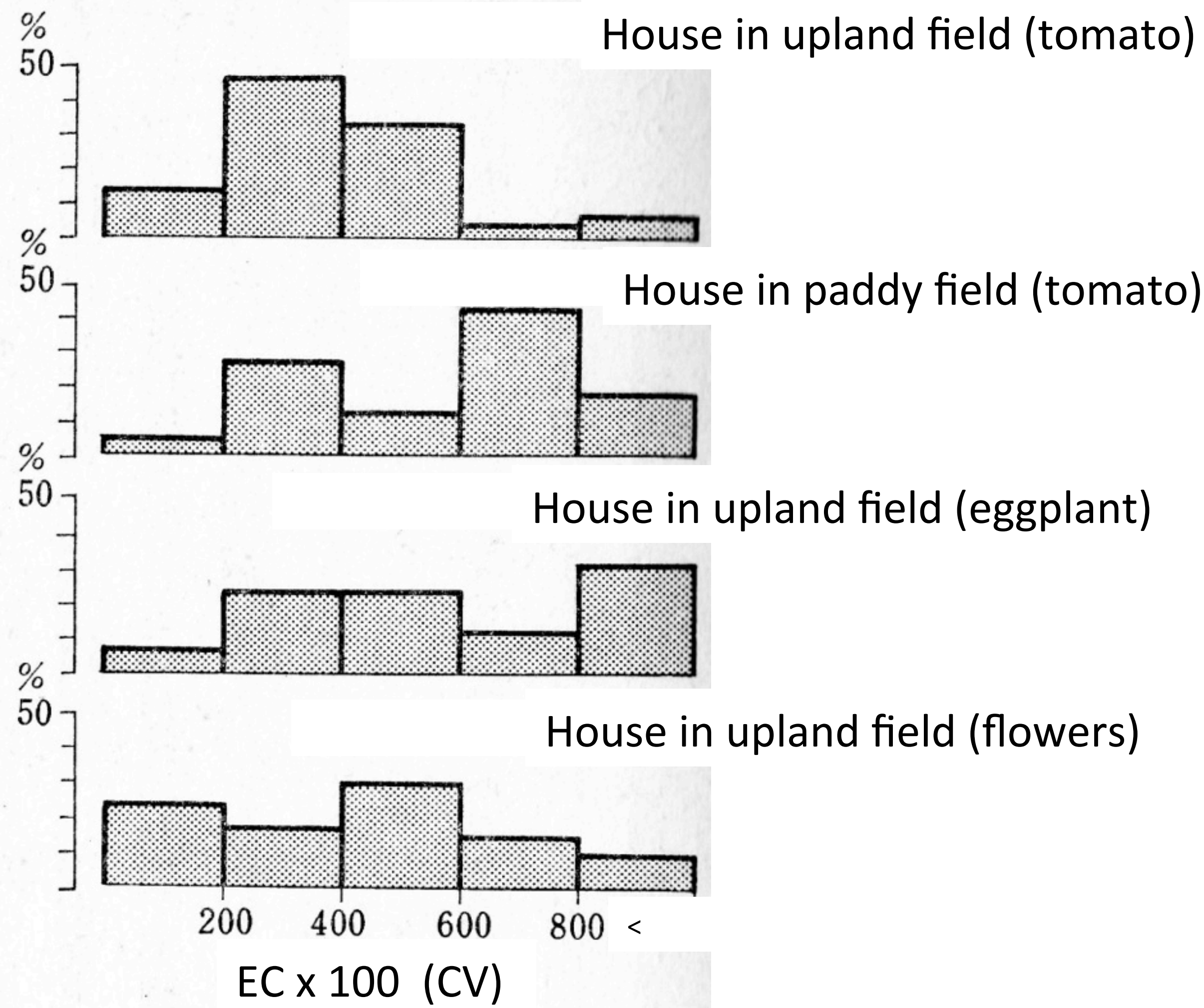
Distribution of salts (EC) in the soil profiles of greenhouse soils cultivated for different years

- In the old greenhouses, salt concentration (EC) increased with the years after construction.
- Increase in EC was especially remarkable in the surface soil.
- By plowing the soil deeply (to 40 cm), EC of surface soil could be decreased.

Difference in the concentrations of soil constituents in good soil and bad soil for green house



Salt concentration in the vinyl house



CV 200……約 2,100 ppm
CV 400……約 5,500 ppm
CV 600……約10,000 ppm
CV 800……約16,000 ppm
注. CV＝EC×100

Ammonia emission in greenhouse soil.

- Large application of nitrogenous fertilizers (urea, ammonium sulfate, rape seed, chicken manure, etc.)
- Formation of NH_4^+ from the fertilizer.
- Inhibition of nitrification due to high salt concentration of salts in soil.
- Increase in soil pH.
- Emission of ammonia (NH_3) gas.

NO_2 gas emission from greenhouse soil.

- Large N fertilizer application.
- Rapid initiation of nitrification with increase in temperature in late spring or early summer.
- Decrease in soil pH.
- Inhibition of further nitrification.
- Soil sterilization also inhibit nitrification.
- Accumulation of NO_2^- ion.
- Formation of NO_2 gas from NO_2^- ion.

Susceptibility of crops to gas injury (damaged %)

Crops	NO_2 gas		Ammonia gas	
	5 – 10 ppm	12 – 19 ppm	10 – 17 ppm	20 ppm
Tomato	7.8 %	31.2 %	25.9 %	34.0 %
Egg plant	18.3 %	65.0 %	0.8 %	17.3 %
Green pepper	4.0 %	30.0 %	2.5 %	23.9%
Strawberry	2.8 %	18.7 %	14.0 %	27.0 %
Mask melon	5.6 %	9.2 %	-	3.3 %
Cucumber	15.4 %	19.2 %	1.8 %	-

Susceptibility of crops to gas injury (summary)

Kind of gas	Strong	Moderate	Weak
Ammonia	Melon, Cucumber		Tomato, Green pepper, Eggplant, Strawberry
Nitric oxide		Strawberry	Tomato, Green pepper, Eggplant, Cucumber, Melon

Symptoms of ammonia gas injury

- Leaf color becomes dark. Leaves wither suddenly in the daytime.
- Soil pH is higher than 7.
- The pH of the water dew on the glass or vinyl sheet of the house is higher than 7.

Symptoms of NO_2 injury

- Edges and veins of leaves in the middle position become yellow white.
- Soil pH is lower than 5 (strongly acidic).
- The pH of water dew on the glass or vinyl sheet of the house is lower than 6.

Disorder of crop growth due to accumulation of salts in soil

(1) Inhibition due to high salt concentration

Increase in osmotic pressure of the soil solution around the root zone.

High osmotic pressure will inhibit water absorption by crops.

Leaf color becomes dark.

Growth rate will be slowed.

Fruit size will not increase.

Disorder of crop growth due to accumulation of salts in soil

(2) Inhibition due to ammonia

Leaf color becomes dark.

Leaf shrinks, roles, and growth is retarded.

Absorption of Ca is inhibited, causing Ca deficiency symptoms.

Increase in ammonia gas in the air of greenhouse, causing crop growth inhibition.

Disorder of crop growth due to accumulation of salts in soil

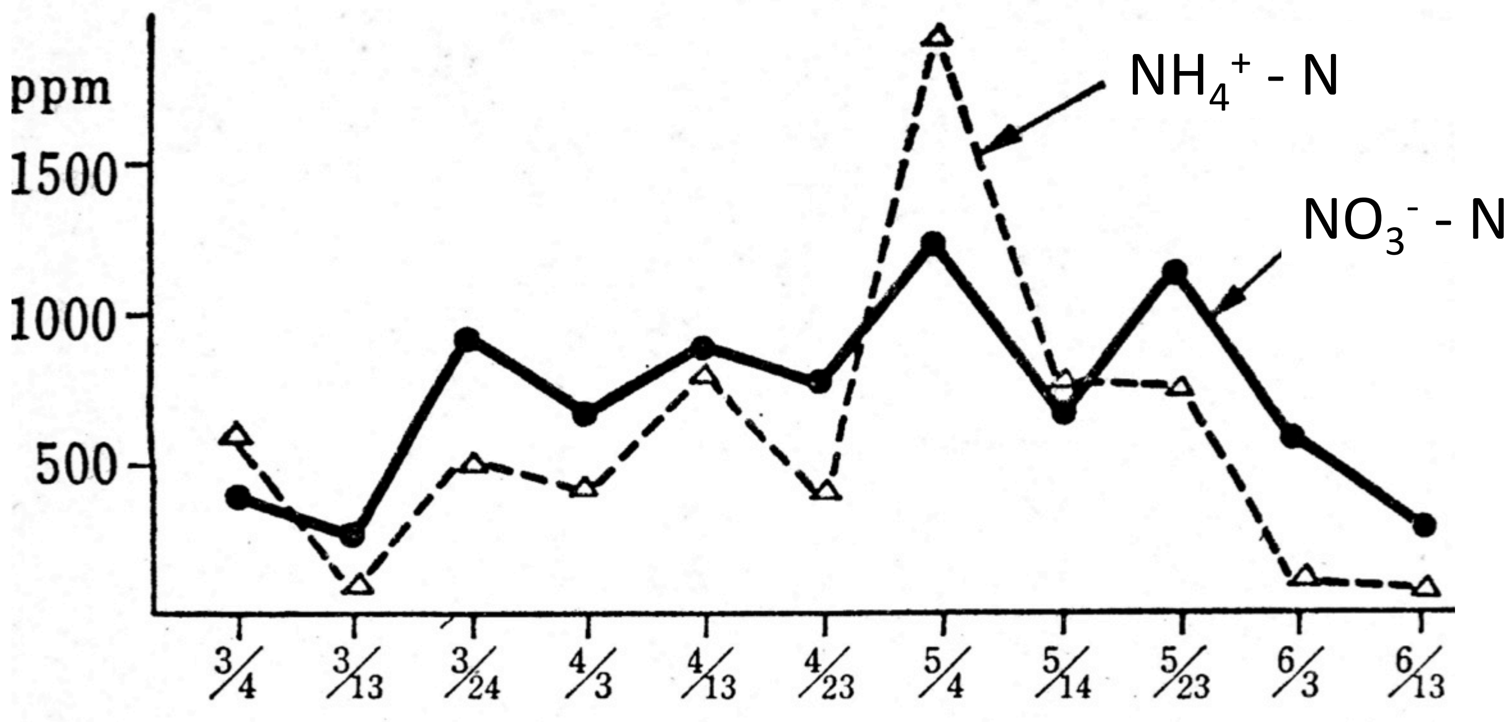
(3) Inhibition due to nutrient deficiency

Calcium becomes deficient often due to competition with ammonium or potassium.

Potassium becomes easily deficient, because the required amount is very large, and often surpasses the applied amount.

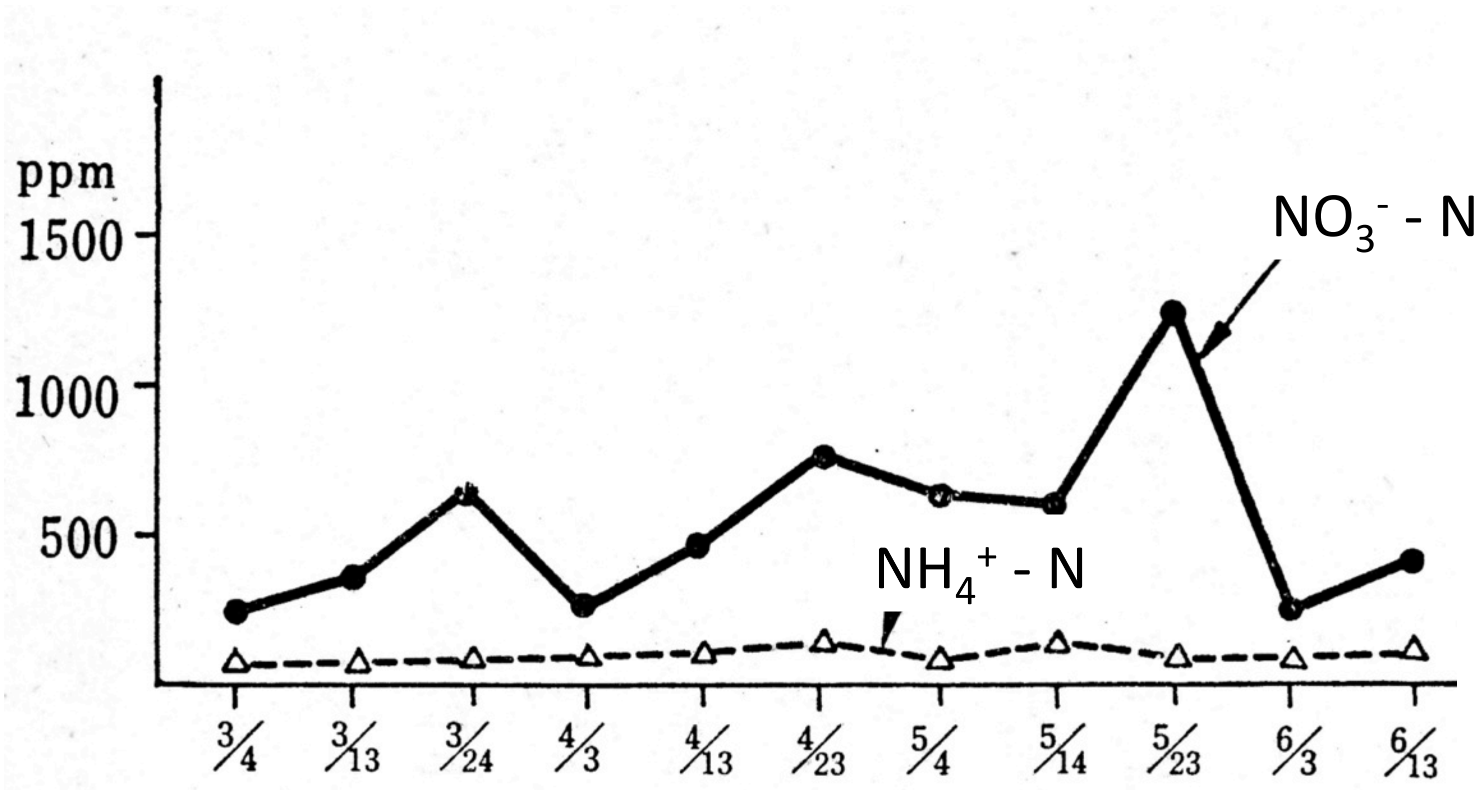
Phosphate deficiency is relatively rare in greenhouse soils, but under cold temperature, it becomes deficient. Phosphate absorption is affected by the physiological condition of crops.

Change in inorganic N concentrations in a greenhouse with large fertilizer application



Tomato: yield 7,060 kg/10 a
Fertilizer: N 67.8 kg, P_2O_5 73.4 kg, K_2O 65.8 kg/10 a

Change in inorganic N concentrations in a greenhouse with small fertilizer application



Tomato: yield 8,000 kg/10 a

Fertilizer: N 27.7 kg, P_2O_5 34.5 kg, K_2O 25.5 kg/10 a

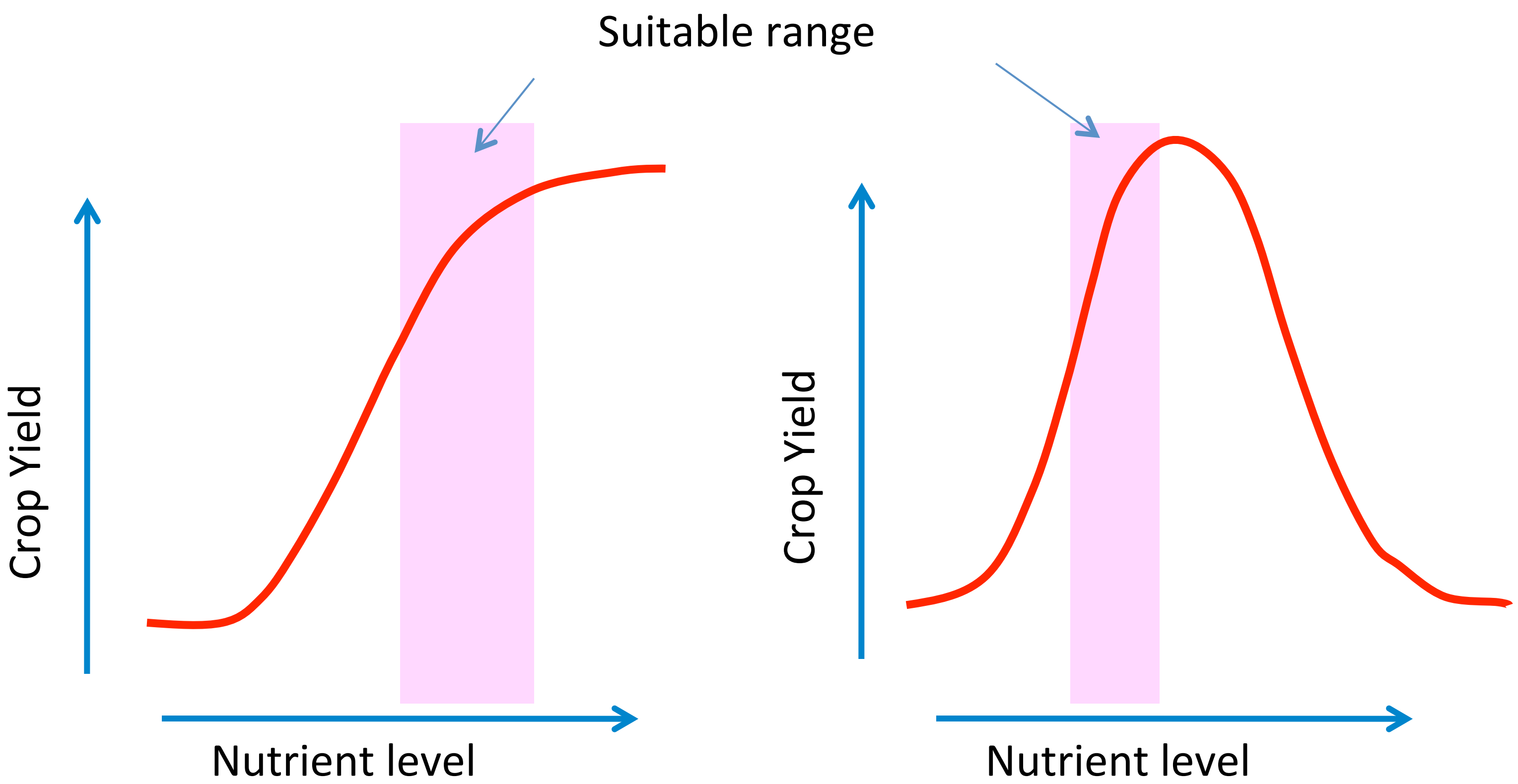
Balance in requirement and applied amount of fertilizer

- Usually, tomato requires 20 kg N, 3-5 kg P_2O_5, and 40 kg K_2O / 10 a.
- In the upland field culture, loss of nutrient due to leaching by rain water is expected. Then, farmer applies more fertilizers than the required amounts by the crop.

Result of high fertilizer application rate in greenhouse

- In the greenhouse culture, no loss of fertilizer due to leaching occurs, therefore, excess application of fertilizer is not necessary.
- Due to too high application of fertilizer, salt accumulation in surface soil, retardation of nitrification, and the accumulation of ammonium are resulted.
- Accordingly, crop yield will decrease in spite of large fertilizer application rate.

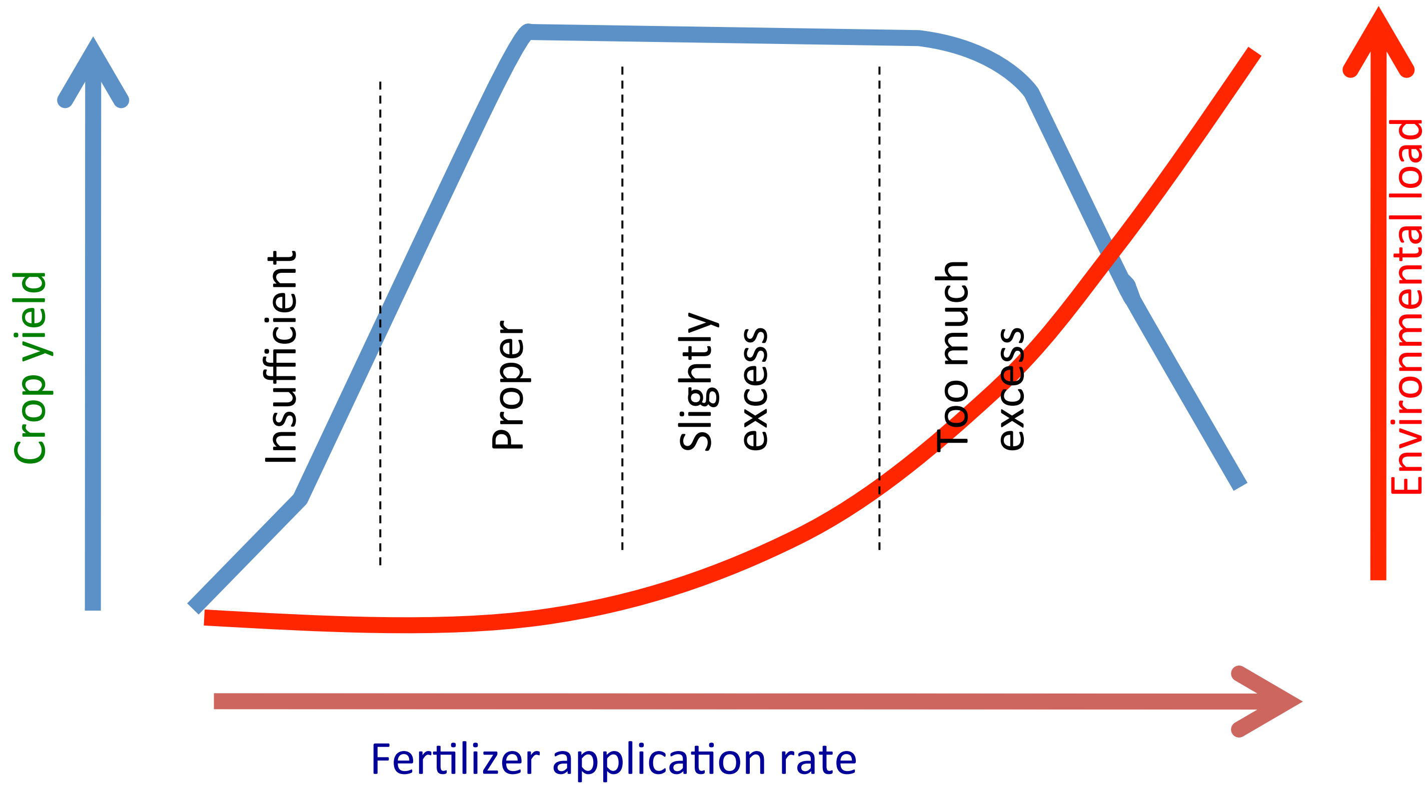
Crop yield and nutrient level



P

N, K, Ca, Mg, trace elements

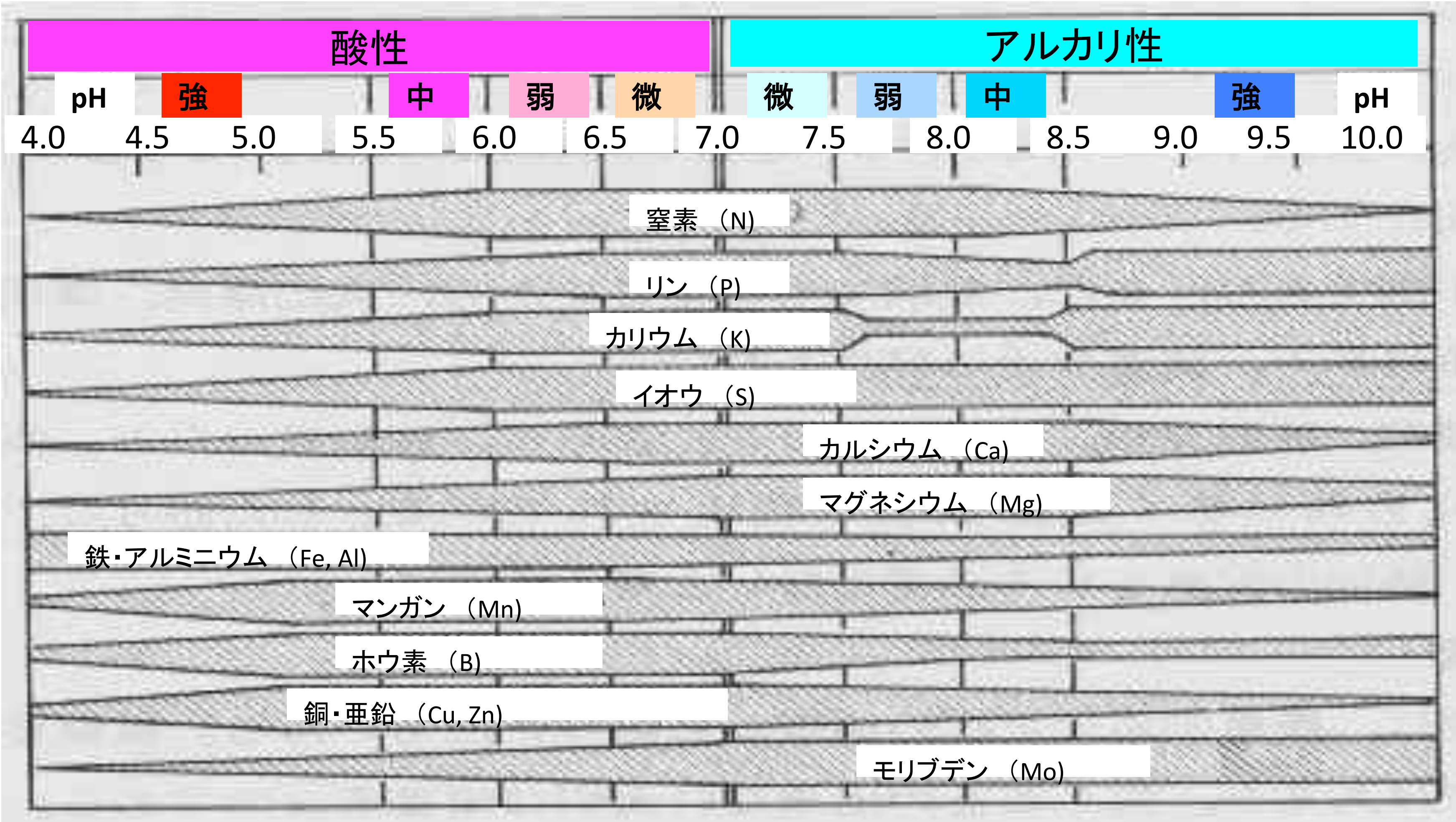
Crop yield and environmental load



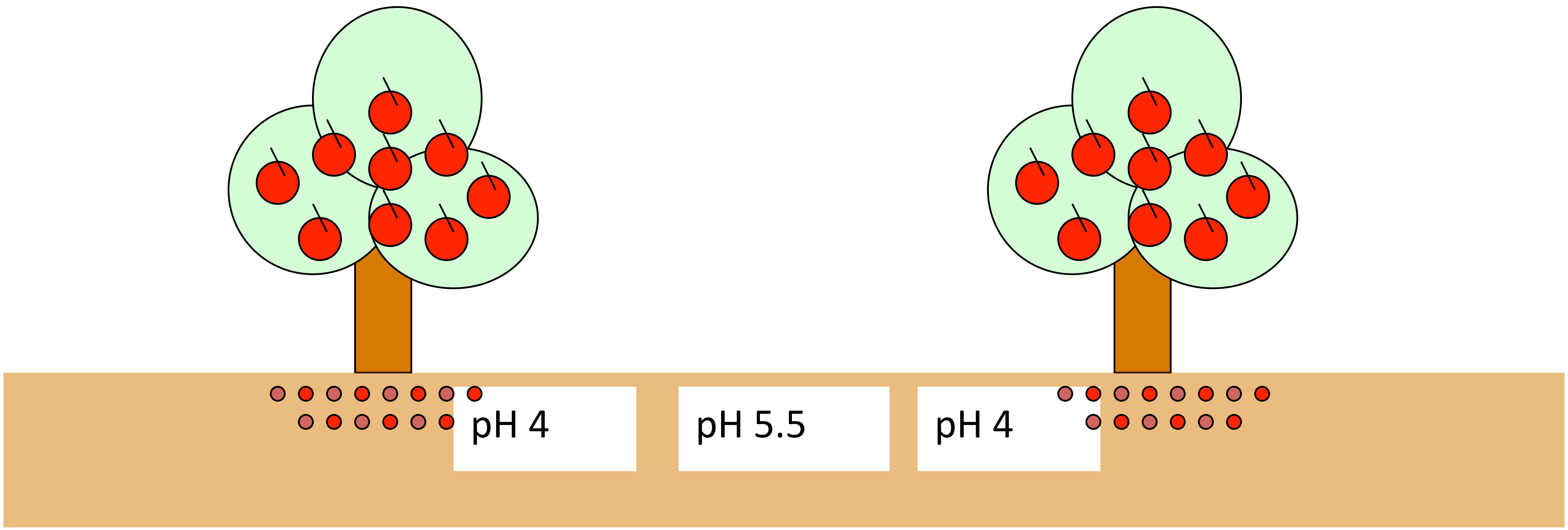
pH and crop growth
(vegetables, root crops)

Low pH tolerance	Kind of crops
strong (4.0~5.0)	potato･taro
Little strong (4.5~6.0)	Sweet potato･radish･turnip･kidney bean･carrot･cucumber･parsley
Little weak (5.5~6.5)	tomato･egg plant･cabbage･broccoli･celery･green pea･melon
Weak (6.0~7.0)	spinach･onion･leek･burdock･asparagus･red pepper･lettus

Soil pH and availability of nutrients



Soil acidification by fertilizer



$(NH_4)_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$ fertilizer

NH_4^+ is absorbed by plants,、

H^+ is supplied from soil colloids, root exudates, and H_2CO_3

Physiologically acidic fertilizers

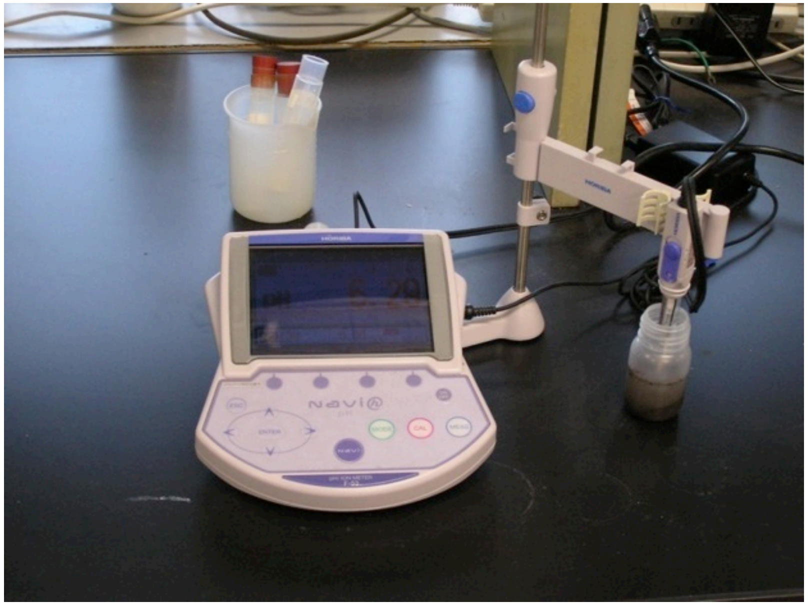
- Ammonium sulfate $(NH_4)_2SO_4$
- Ammonium chloride NH_4Cl
- Potassium sulfate K_2SO_4
- Potassium chloride KCl

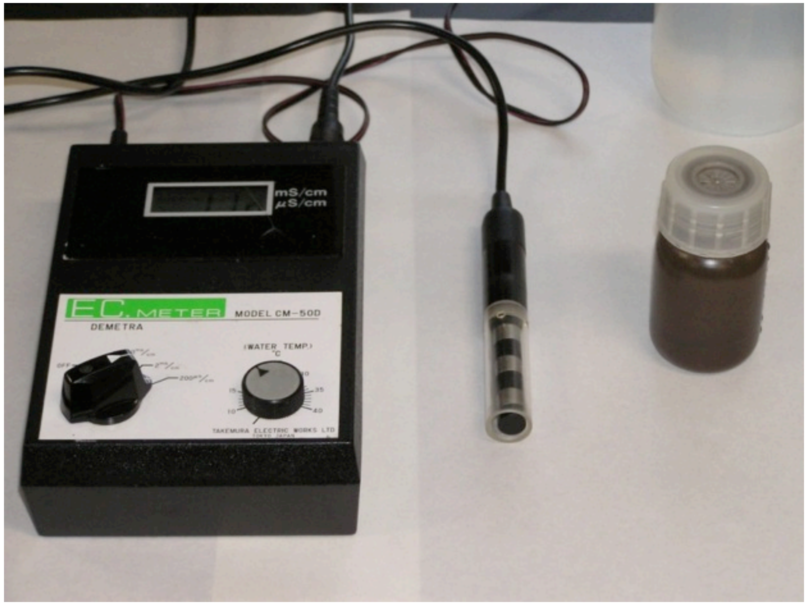
NH_4^+ and K^+ are absorbed, but SO_4^{2-} and Cl^- are not absorbed and remain in soil.

$pH(H_2O)$

- Concentration of free form H^+ in soil solution
- $pH = - \log (H^+)$
- Add 25 ml of water to 10g of soil.
- Shake 30 minutes.
- Measure the pH of turbid suspension using pH meter.

pH meter & EC meter





Meaning of soil pH

< 5.0	Very acidic
5.0 – 5.5	Acidic
5.5 – 6.0	Weakly acidic
6.0 – 6.5	Slightly acidic
6.5 – 7.0	Neutral
7.0 – 7.5	Slightly alkaline
7.5 – 8.0	Weakly alkaline
8.0 – 8.5	Alkaline
8.5 <	Very alkaline

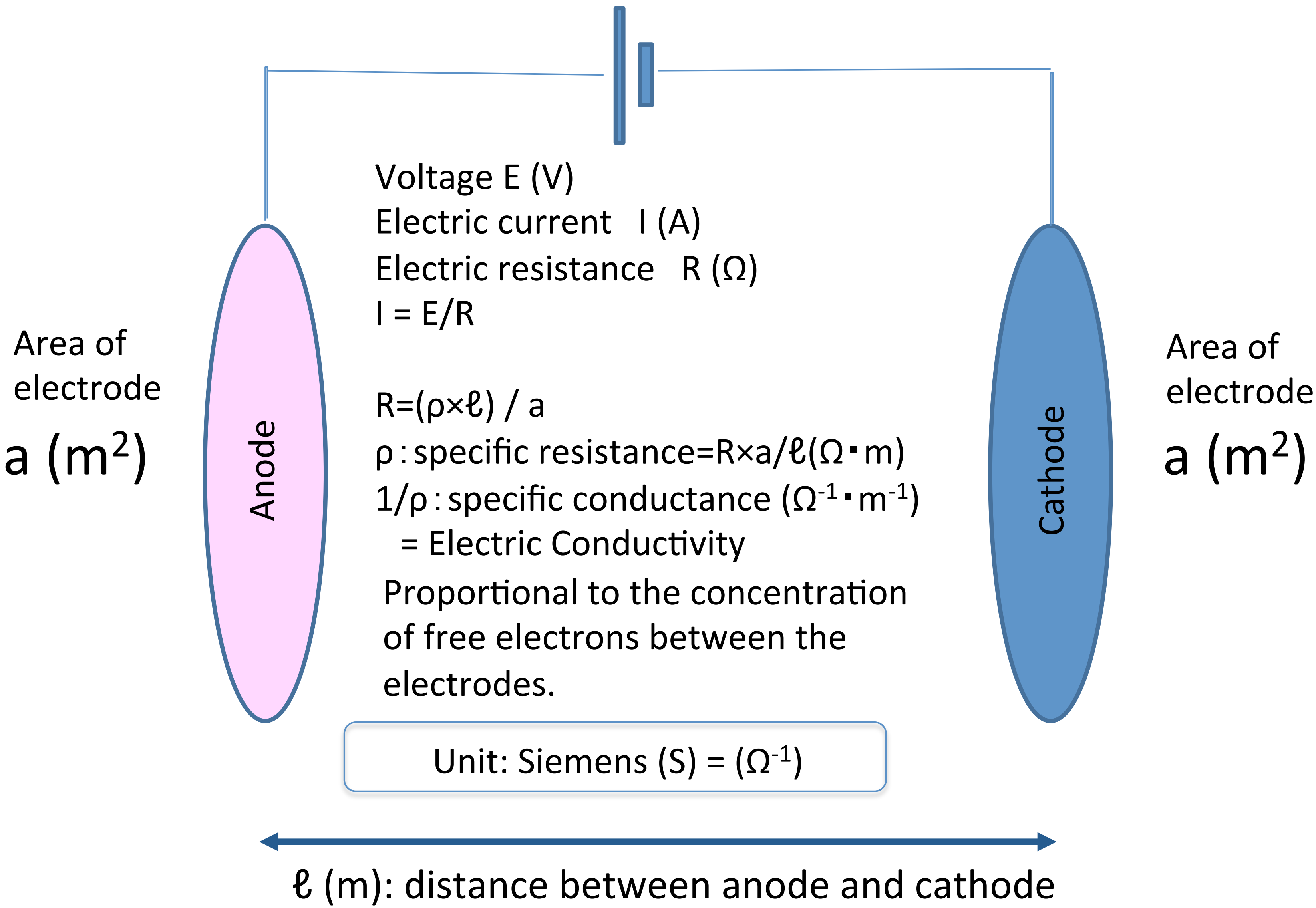
Effect of pH on plant growth

- H^+ ion inhibits the function of root (pH < 4)
- Increase in Al^{3+} ion (Inhibit growth at >1 ppm level)
- Inhibit absorption of N, P, K, Ca, Mg, B, Mo and symptom of deficiency（in acidic range）
- Excess in Cu, Zn, Mn, Fe（in acidic range）
- Deficiency in Cu, Zn, Mn, Fe（in alkaline range）

Electric conductivity（EC）

- Reflect total concentration of water soluble ions in soil solution
- Add 50 ml of deionized water to 10g of air dry soil, shake 30 min.
- Measure EC of turbid suspension using EC meter.
- Unit is $S\ m^{-1}$, $dS\ m^{-1}$, $mS\ cm^{-1}$ or $\mu S\ cm^{-1}$
- S: Siemens (1S = 10 dS = 100 cS = 1000 mS)
- $1\ dS\ m^{-1} = 1\ mS\ cm^{-1} = 10^3\ \mu S\ cm^{-1}$ (m^{-1} = /m)

Principle of Electric Conductivity



Meaning of soil EC (1)

- Proportional to total soluble ion concentration

Total cation (anion) concentration : C

$$C\ (\text{mmol}_c\ \text{L}^{-1}) \fallingdotseq 10 \times EC\ (\text{dS m}^{-1})$$

- Proportional to osmotic pressure

$$\text{Osmotic pressure (kPa)} = 28 \times EC\ (\text{dS m}^{-1})$$

Meaning of soil EC (2)

- High correlation with nitrate NO_3^- content
- Malnutrition under low EC(< 0.1 mS cm^{-1})
- Nutrient excess damage

  at high EC (> 1 mS cm^{-1})
- Adjust fertilizer application rate according to EC

Salt concentration (EC) and the disorder in vegetable growth

Type of soils	EC at disorder is recognized		EC at the growth is severely hindered	
	cucumber	tomato	cucumber	tomato
Sandy soil	1.3 – 1.6	1.3 – 1.8	1.6 – 2.2	1.8 – 2.2
Alluvial soil	1.6 – 2.1	1.8 – 2.3	2.3 – 2.7	2.3 – 3.3
Humic volcanic ash soil	2.1 – 3.0	1.8 -	3.5 -	2.8 -

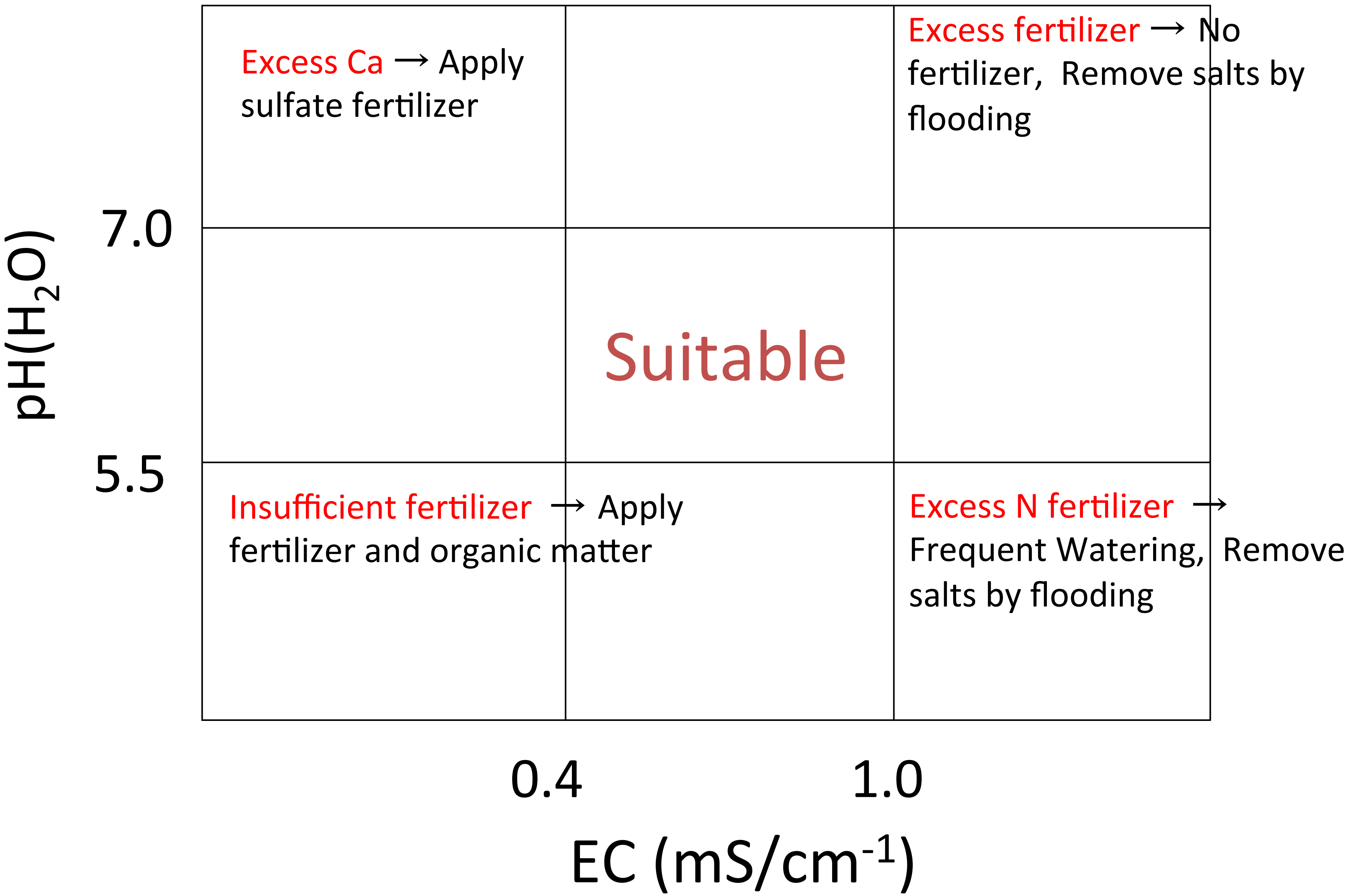
EC was measured in the soil : water (1:5) suspension.
Unit: mS cm^{-1}
Data from Kanagawa prefecture.

Tolerance of crops to high salt concentration

Crops	Concentration at the ½ growth	Crops	Concentration at the ½ growth
Brassica rapa var. chinensis	11,000 ppm	Tomato	3,500 ppm
Spinach	8,000	Cucumber	3,000
Cabbage	6,500	Pepper	3,000
Radish	6,000	Strawberry	1,000
Celery	6,000	Hornwort	1,000
Egg plant	4,000		

Brassica plants are relatively tolerant to high salt concentration. Vegetables common for greenhouse cultivation are relatively weak to high salt concentration.

Greenhouse soil diagnosis according to pH and EC



Application rate of basal fertilizer (N, K) according to soil EC（dS m^{-1}） in upland field

Soil Type	< 0.3	0.4-0.7	0.8-1.2	1.3-1.5	1.6 <
Humic andosoil	Standard rate	2/3	1/2	1/3	No fertilizer
Sandy・Fine textured	Standard rate	2/3	1/3	No fertilizer	No fertilizer
Sand dune/ immature	Standard rate	1/2	1/4	No fertilizer	No fertilizer

How to remedy salt accumulation 1

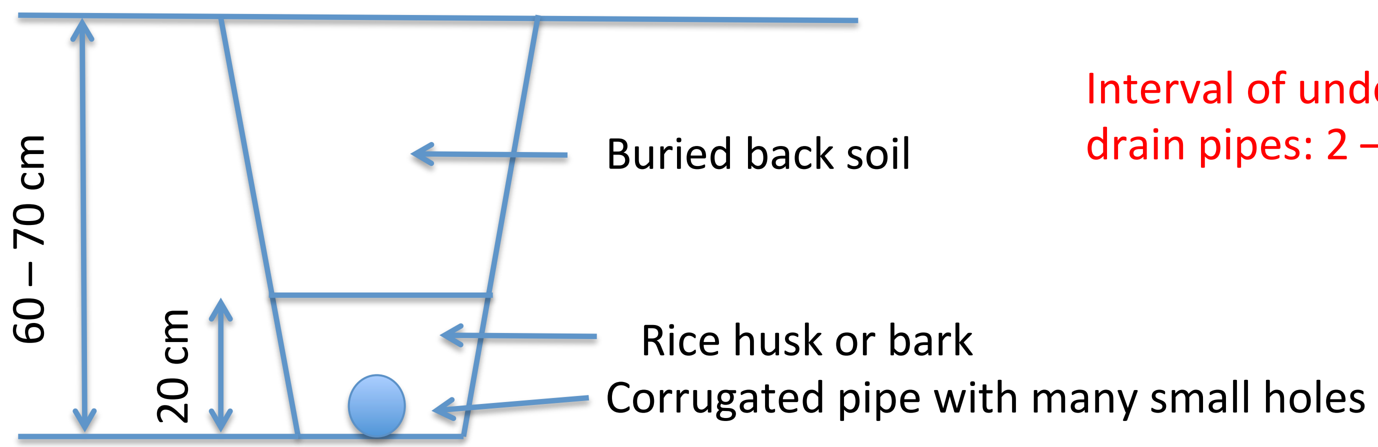
Waterlogging method

- Introduce water into greenhouse, and make it like a submerged paddy field.
- Plow and mix the soil layer.
- Leave the soil for one day.
- Remove the excess water from the greenhouse.
- Introduce the new water and drain the excess water for 3 – 4 days.

How to remedy salt accumulation 2

Under-drain method

- Install under-drain pipes below the plowed soil layer.
- Collect the seepage water and drain.



Interval of under-drain pipes: 2 – 3 m

How to remedy salt accumulation 3

Absorption by gramineous green manure plants, such as corn, rye, and sorghum.

- During the fallow period, such plants are grown, and excess salts are absorbed.
- Harvested green manure is plowed into the soil.
- Nutrients are released slowly from the incorporated green manure.
- It also fixes excess inorganic N due to its high C/N ratio.

Change in soil EC ($mS\ cm^{-1}$) after growing sorghum

Treatment	Before planting	After 38 days	After 65 days	After 96 days
Control	1.18	0.91	0.90	1.03
Sorghum	1.18	0.81	0.51	0.58

Data: Miyagi Prefecture, Horticultural Experiment Station

How to remedy salt accumulation 4

Application of organic matter with high C/N ratio.

- Rice straw (C/N 65), wheat straw (C/N 100 – 150), oat straw (C/N 50 – 100) are good material for this purpose.
- These material fix excess inorganic nitrogen into organic form in soil.
- Too much application may cause nitrogen deficiency to crops.

How to remedy salt accumulation 5

Deep plowing or moving plowed layer soil

- Plow the soil deeply (40 cm).
- Bring the subsurface soil to the surface, and surface soil to deep layer.

参考書:嶋田永生「ハウス土壌の特性と改良」
農山漁村文化協会 (1979)
Reference book: Dr. N. Shimada, "Characteristics and improvement of house soils", 1979, Nosan-Gyoson-Bunka-Kyokai (Tokyo, Japan)