SOIL ACIDITY AND LIMING

- "Soil acidity" is the term used to express the quantity of hydrogen (H+) and aluminum (Al^{3+}) cations (positively charged ions) in soils.

- pH is a measure of soil acidity

- pH stand for the potential **(p)** of the hydrogen ion **(H^{+})** in water.

SOIL ACIDITY AND LIMING

- It is actually a way of reporting the concentration of H^+ in solution using an electrical "potential" to measure H^+

- pH = -log[H+] = log1/ [H+] = log [H+] $^{-1}$
- Agricultural soils = 5 – 8
- "Ideal pH" for mineral soil = 6.5.,

  for peat soil = 5.5

SOIL ACIDITY AND LIMING

pH of solution	Hydrogen ion activity (g/liter)
9.0 (very alkaline)	10^{-9} (0.000000001)
8.0 (alkaline or basic)	10^{-8} (0.00000001)
7.0 (neutral, pure water)	**10^{-7}** (0.0000001)
6.0 (slightly acid)	10^{-6} (0.000001)
5.0 (very acid)	10^{-5} (0.00001)
4.0 (extremely acid)	10^{-4} (0.0001)

SOIL ACIDITY AND LIMING

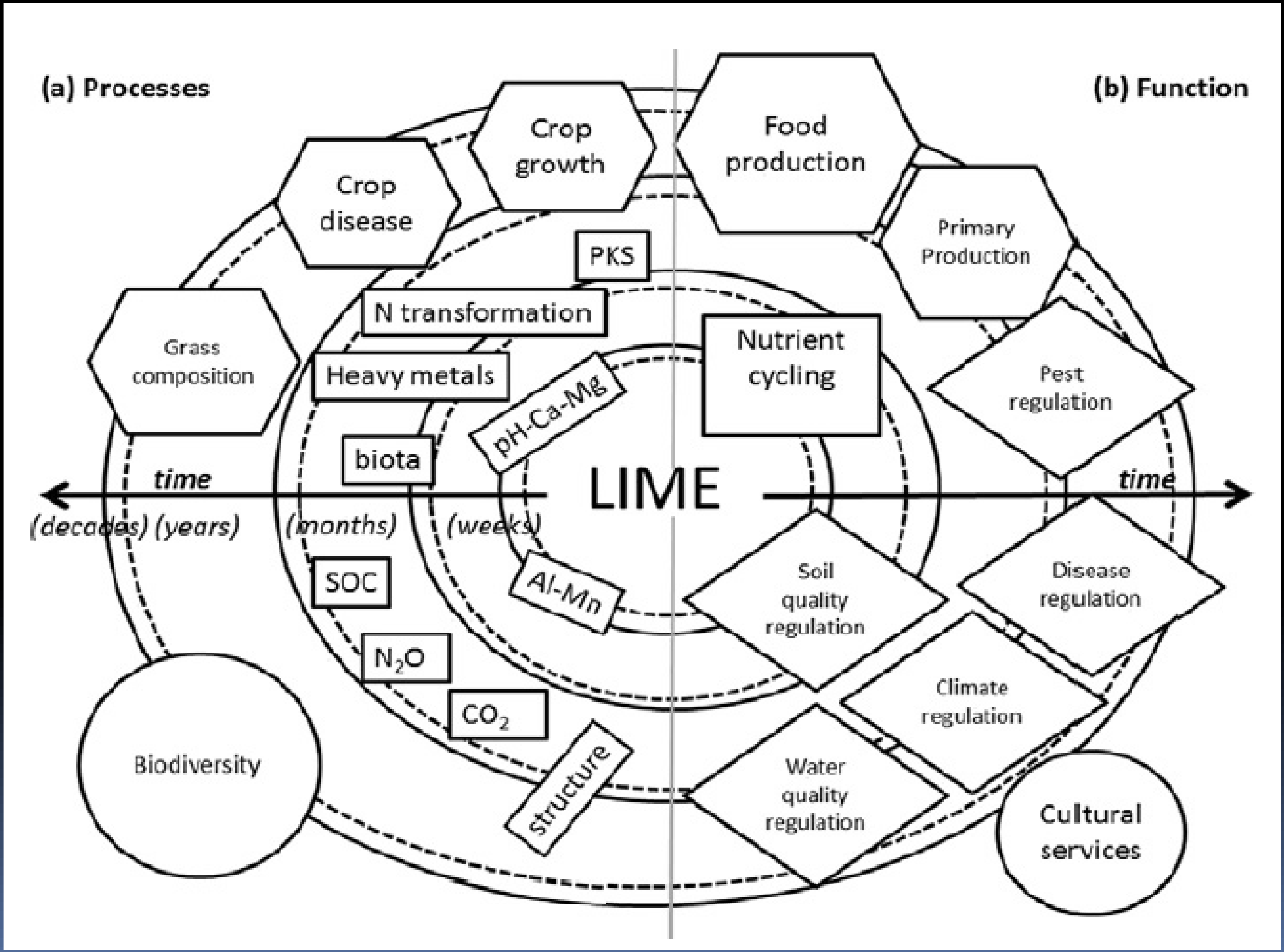


TABLE 1 Areal Extent of Acid Soils in Relation to Total Ice-Free Land Surface and Area Under Cultivation for the Regions of the World

						Asia			America		
Class	World	Africa	Australia/ New Zealand	Europe	Near East	Far East	Southeast and Pacific	North and Central	North	Central	South
Acid land (× 10⁹ ha)	3.950	0.659	0.239	0.391	0.005	0.212	0.314	0.512	0.662	0.036	0.916
Total land (× 10⁹ ha)	13.15	3.01	0.82	0.48	0.50	1.48	0.40	0.85	2.11	0.10	1.75
Acid/total (%)	30	22	30	37	1	12	63	57	30	35	52
Cultivated land (× 10⁹ ha)	1.4	0.158	0.032	0.154			0.519		0.239		0.077
Cultivated/ total (%)	10.6	5.2	3.9	32.1			18.9		11.3		4.4

Source: Data from Ref. 7.

TANAH MASAM YG TERJADI ALAMI

1. Karena Pelapukan Intensif

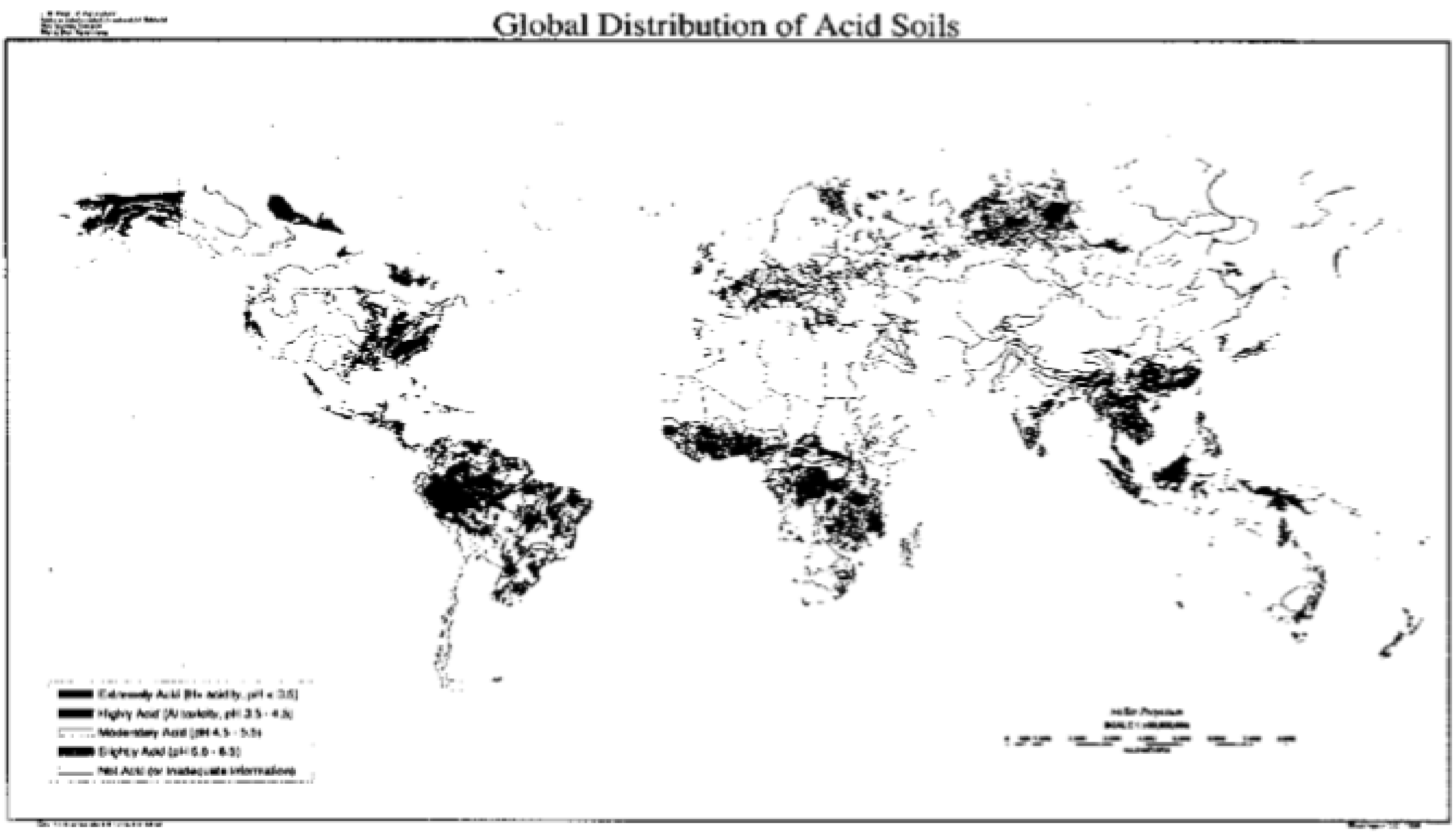


FIGURE 1 Global distribution of soils with acid topsoils. (Reprinted with permission. Copyright Courtesy Natural Resource Conservation Service, USDA, USA.)

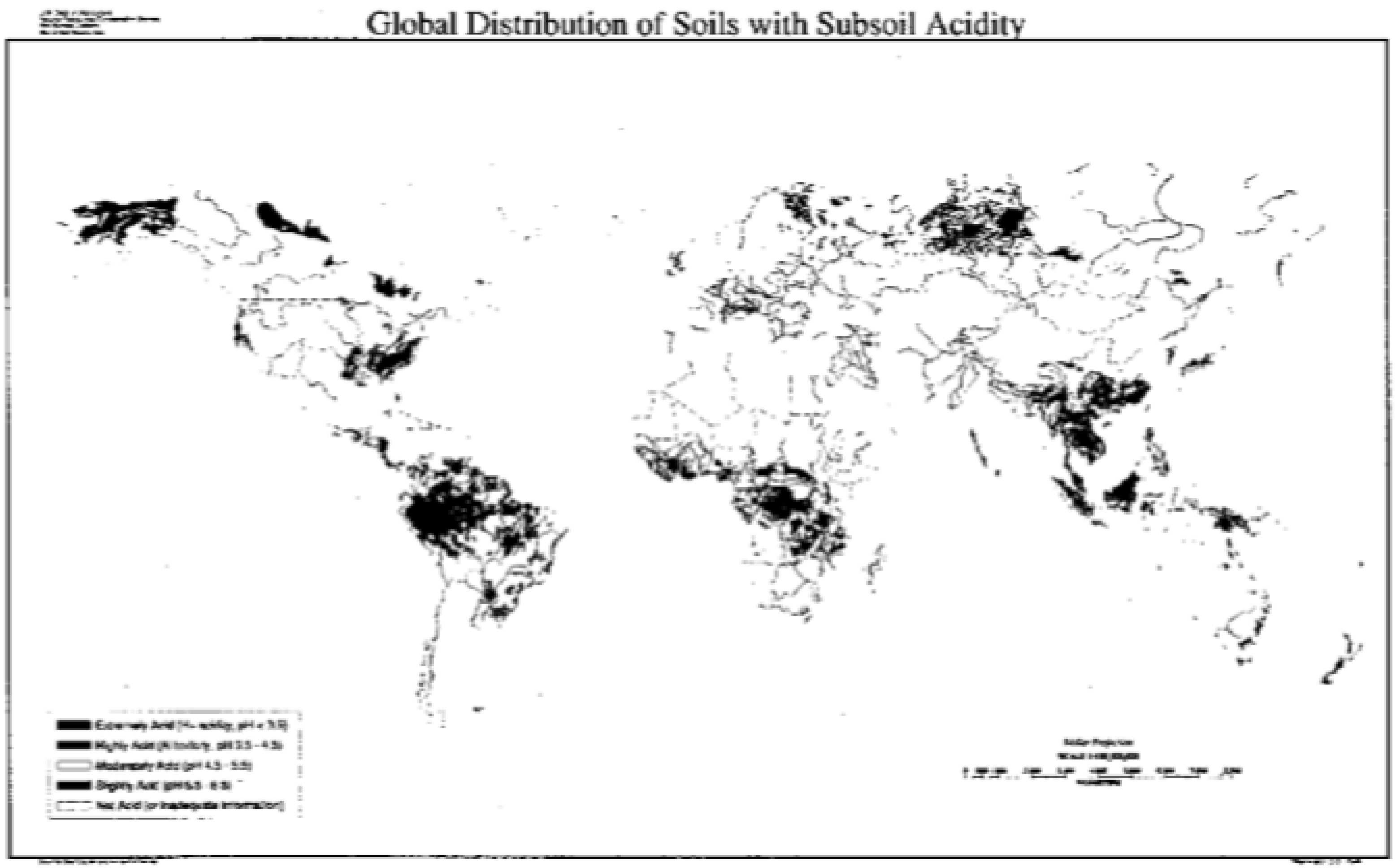


FIGURE 2 Global distribution of soils with acid subsoils. (Reprinted with permission. Courtesy Natural Resource Conservation Service, USDA, USA.)

Table 2 Areal Extent ($\times 10^9$ ha) of Acid Topsoils and Subsoils of Varying Intensity for Various Regions of the World

	World		America North		America South		Africa		South and East Asia		Europe	
Class	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub
Slight (pH_{H_2O} 5.5–6.5)	1.25	0.58	0.21	0.11	0.25	0.12	0.43	0.18	0.17	0.08	0.00	0.00
Moderate (pH_{H_2O} 4.5–5.5)	1.54	1.38	0.30	0.28	0.44	0.42	0.33	0.29	0.19	0.15	0.05	0.11
High (pH_{H_2O} 3.5–4.5)	0.98	0.95	0.09	0.09	0.36	0.36	0.12	0.12	0.32	0.30	0.13	0.01
Extremely acid (pH_{H_2O} < 3.5)	0.15	0.01	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Total	3.78	2.92	0.60	0.49	1.18	0.90	0.88	0.60	0.69	0.54	0.20	0.13

Source: Data from Ref. 6.

TABLE 4 Aerial Extent ($\times 10^9$ ha) of Acid Topsoils for Soil Taxonomy Orders

	Order	
Order	Area	%
Entisols	0.824	20.9
Inceptisols	0.561	14.2
Andisols	0.034	0.9
Spodosols	0.415	10.5
Alfisols	0.255	6.5
Ultisols	0.864	21.8
Oxisols	0.727	18.4
Histosols	0.270	6.8

Source: Adapted from Ref. 7.

TABLE 5 Chemical Properties of Representative Oxisols, Ultisols, Andisols, and Alfisols

Depth (m) (horizon)	pH H_2O	pH KCl	OC ($g\ kg^{-1}$)	Clay (%)	Exchangeable cations ($cmol_c\ kg^{-1}$) Ca	Mg	K	Al	CEC pH 7	ECEC
Oxisol (Aquic Hapludox) [10]										
0–02		4.5	14	39.9	3.7	1.6	0.32	0.3		5.92
0.3–0.5		4.0	9	42.1	0.8	0.4	0.13	2.1		3.43
0.6–0.8		4.1	3	45.3	0.3	0.4	0.10	2.9		3.70
Oxisol [11]										
0–0.2	5.0		7	59.0	2.8	1.4	0.25	0.6	6.7[a]	5.05
0.3–0.6	4.8		4	55.0	0.4	0.3	0.08	1.0	3.2	1.78
0.6–0.9	4.7		2	53.0	0.1	0.2	0.05	1.2	2.7	1.55
Ultisol (clayey, kaolinitic, isothermic Humic Hapludult) [12]										
0–0.3 (Ap)	4.4	4.0	20	23.0	0.50	0.03	0.31	2.7	11.9	3.54
0.3–0.6 (Bt1)	4.3	3.7	8	40.2	0.50	0.05	0.15	3.9	13.1	4.60
0.6–1.1 (Bt2)	4.4	3.5	3	40.7	0.63	0.08	0.03	2.6	9.2	3.34
Ultisol (fine, parasesquic, mesix Xeric Haplohumult) [13]										
0–0.1 (A1)	5.1		52	54.2	12.1	3.8	1.1		27.5	
0.2–0.4 (B1)	4.7		11	65.0	4.6	2.4	0.2		17.1	
0.8–1.2 (B31)	4.4		5	79.0	1.7	1.5	0.1		13.6	
Andisol (medial, isothermic Acrudoxic Hapludand) [12]										
0–0.3 (A1)	4.7	4.6	42		0.55	0.09	0.06	1.20	26.8	1.90
0.3–0.6 (Bw1)	4.6	4.8	15		0.50	0.08	0.07	0.30	29.5	0.95
0.9–1.9 (Bw3)	4.3	5.0	5		0.50	0.03	0.03	0.50	26.9	1.06
Andisol (Histic Duraquand) [13]										
0–0.2 (A1)	4.7		106	5.8	5.7	0.6	0.6		48.6	
0.2–0.4 (A2)	5.0		68	1.3	0.8	0.2	0.2		42.7	
0.4–0.6 (Bw)	5.7		39	3.3	0.2	0.1	0.1		28.2	
Alfisol (fine-silty, mixed, mesic Typic Endoaqualf) [13]										
0–0.1 (A1)	5.3		18	16.9	6.2	1.8	0.8		12.1	
0.3–0.4 (B1t)	5.1		3	26.9	9.4	3.6	0.7		16.4	
0.6–0.8 (B21t)	5.5		3	34.1	16.0	8.6	0.9		26.4	
Alfisol (fine-loamy, siliceous, semiactive, thermic Typic Paleudalf) [13]										
0–01 (Ap)	5.2			21.7	1.6	1.3	0.3		6.0	
0.1–0.8 (B21t)	5.2									
0.8–1.1 (B22t)	5.2			23.2	1.1	1.4	0.3		5.4	

[a] At pH 6.0.

2. Tanah Sulfat Masam

3. Tanah dari bahan induk miskin kation basa

Table 6 Chemical Properties of Representative Inceptisols

Depth (m) (Horizon)	pH H_2O	pH KCl	OC ($g\ kg^{-1}$)	Clay (%)	Exchangeable cations ($cmol_c\ kg^{-1}$) Ca	Mg	K	Na	Al	CEC pH 7	ECEC
Inceptisol (sandy-skeletal, mixed, mesic Typic Dystrochrept) [13]											
0–01 (A1)	4.1		55	3.0	1.1	0.6	0.2				2.0
0.2–0.5 (B22)	5.1		7	2.3	0.1	0.2	0.0				0.3
0.5–0.7 (B23)	5.2		2	1.8	0.2	0.1	0.0				0.3
Inceptisol (Typic Sulfaquept) [14]											
0–0.05	2.9	2.8	78		0.7	4.4	0.2	3.7	18.3		27.3
0.15–0.25	3.5	3.2	73		0.1	2.6	0.2	2.6	15.3		20.8
0.35–0.45	3.2	2.8	13		0.2	3.0	0.2	1.8	13.1		18.3

TABLE 7 Chemical Properties of Representative Spodosols, Histosols, and Entisols

Depth (m) (Horizon)	pH H_2O	PH KCl	OC (g kg^{-1})	Clay (%)	Exchangeable cations (cmol$_c$ kg^{-1})					
					Ca	Mg	K	Na	CEC pH 7	ECEC
Spodosol (sandy, siliceous, isohyperthermic Grossarenic Entic Haplohumod) [13]										
0–0.2 (A11)	4.0	3.5		28.8	0.1	0.3	0.1	0.0	0.4	
1.0–1.5 (A24)	4.3	3.8	0	29.2	0.1	0.0	0.0	0.0	0.1	
1.7–1.9 (B12h)	4.5	3.7	5	38.3	0.4	0.2	0.1	0.0	3.3	
Spodosol (sandy, siliceous, thermic Aeric Alaquod) [13]										
0–0.2 (A)	3.4		58	0.4	0.4	1.0	0.2	0.0	16.6	
0.2–0.2 (E)	3.9		3	0.4	0.0	0.0	0.0	0.1	1.1	
0.3–0.4 (Bh)	4.0		26	3.4	0.1	0.0	0.0	0.1	12.4	
Histosol (Dysic Typic Cryohemist) [13]										
0–0/2 (OiL31)	3.9		475		19.1	6.4	3.0	1.0	95.5	29.5
0.2–0.5 (OAL32)	4.6		476		53.1	12.5	0.7	0.9	149.9	67.2
0.5–1.3 (OA233)	4.2		449		29.4	9.3	0.4	0.8	160.5	39.9
Histosol (very-fine, mixed, evic, isohyperthermic Terric Troposaprist) [13]										
0–0.1 (OA1)	5.5	4.7		39.8	20.9	7.2	1.2	2.2	69.8	31.5
0.1–0.4 (OA2)	5.0	4.4		14.9	4.1	2.5	0.0	0.5	36.6	22.0
0.4–0.8 (OA3)	5.1	4.7		15.8	3.8	2.5	0.0	0.5	31.9	22.6
Entisol (mesic, uncoated Typic Quartzipsamment) [13]										
0.01 (A1/B1)	3.4		17	2.0	0.2	0.2	0.2			
0.2–0.5 (B23)	4.3	4.4	2	6.3	0.0	0.0	0.1			
0.5–0.7 (B24v)	4.4	4.3	1	3.9	0.0	0.1	0.1			
Entisol (sandy-skeletal, mixed, mesic, Typic Udorthent) [13]										
0–0.2 (Ap)	5.0	4.3	28	5.1	1.6	0.1	0.2			
0.3–0.4 (B22)	5.3	4.6	6	2.6	0.0	0.0	0.0			
0.6–0.9 (2C2)	5.7	4.8	1	1.2	0.2	0.0	0.2			

TANAH MASAM KRN MANUSIA

1. Dari Deposisi masam

TABLE 8 Change in pH_{H2O} Value with Depth on an Unlimed and Unfertilized Soil Under Woodland (Mainly Regenerated Deciduous Species) at Rothamsted over the Period 1883–1983

	Sampling date			
Depth (m)	1883	1904	1965	1983
0–0.23	7.1	6.1	4.5	4.2
0.23–0.46	7.1	6.9	5.5	4.6
0.46–0.69	7.1	7.1	6.2	5.7

Source: Adapted from Ref. 19.

2. Dari pertanian tanaman baris yang dikelola intensif

TABLE 9 Effect of 18 Years of Continuous Corn Cultivation (Two Crops/Year) on Soil Chemical Properties of a Nigerian Alfisol (Clayey, Kaolinitic, Isohyperthermic Oxic Kandiustalf)

Treatment	Depth (m)	pH H_2O	OC (g kg^{-1})	Exchangeable cations ($cmol_c$ kg^{-1})					
				Ca	Mg	K	Al	H	ECEC
Bush fallow (control)	0–0.1	6.2	19	11.2	1.5	0.7	0.1	0.0	13.5
	0.1–0.2	6.2	6	4.7	1.0	0.4	0.1	0.0	6.2
Corn (residue removed)	0–0.1	4.5	6	1.9	0.4	0.2	0.7	0.3	3.5
	0.1–0.2	4.5	5	2.1	0.5	0.1	0.9	0.3	3.9
Corn (residue retained)	0–0.1	4.8	10	3.6	0.7	0.3	0.4	0.2	5.2
	0.1–0.2	4.7	6	3.0	0.5	0.2	0.5	0.4	4.6

Source: Adapted from Ref. 22.

TABLE 10 Change in Soil pH with Time Due to Varying Annual Rates of Ammonium Sulfate Application on the Park Grass Experiment That Started at Rothamsted in 1856 at an Estimated pH_{H2O} of 5.6 to 5.8.

Nitrogen rate (kg N ha^{-1} $year^{-1}$)	Depth (m)	Sampling date				
		1876	1923	1959	1976	1984
0	0–0.23	5.3	5.7	5.2	5.3	5.0
	0.23–0.46	6.1	6.2	5.3		5.7
48	0–0.23	5.3	4.8	4.0	4.1	3.7
	0.23–0.46	6.2	6.2	5.2		5.1
96	0–0.23	4.8	4.0	3.8	3.9	3.6
	0.23–0.46	6.4	4.8	4.3		4.1
145	0–0.23	4.3	3.8	3.7	3.7	3.4
	0.23–0.46	6.5	4.4	4.1		4.0

Source: Data from Ref. 19.

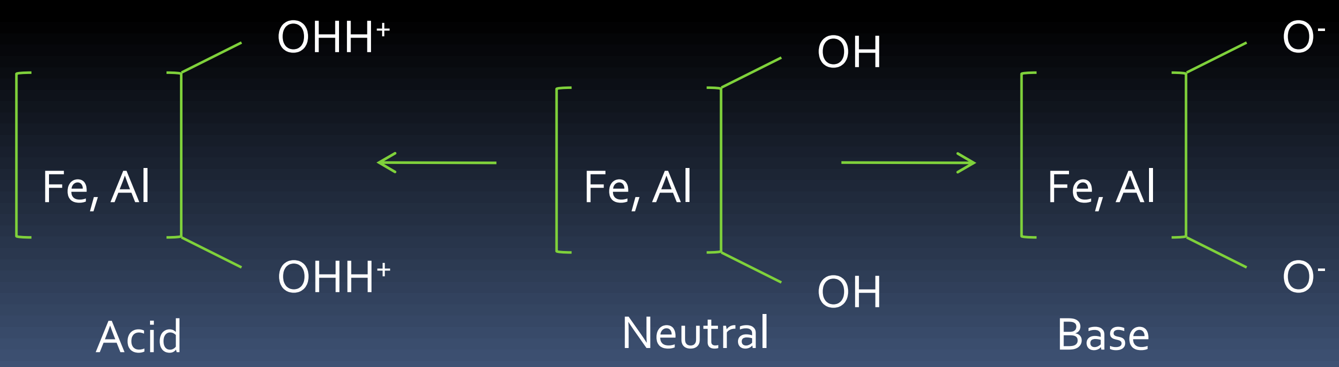
Sources of Soil Acidity

1. **Soil Organic Matter (SOM)** contain reactive carboxylic and phenolic group that behave as weak acids releasing H^+

$$R\text{-}COOH \longrightarrow R\text{-}COO^- + H^+$$

$$R\text{-}OH \longrightarrow R\text{-}O^- + H^+$$

2. **Clay and Oxide minerals.**



Sources of Soil Acidity

3. Al and Fe

$$Al^{3+} + H_2O \longrightarrow Al(OH)^{2+} + H^+$$

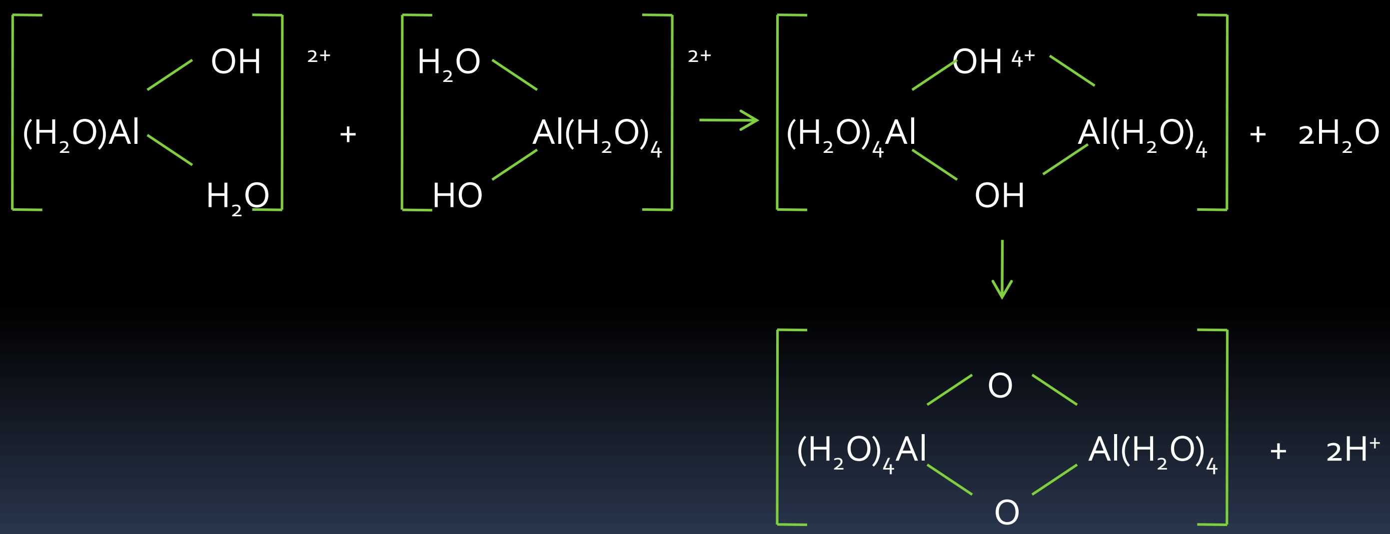
$$Al(OH)^{2+} + H_2O \longrightarrow Al(OH)_2^{+} + H^+$$

$$Al(OH)_2^{+} + H_2O \longrightarrow Al(OH)_3^{o} + H^+$$

$$Al(OH)_3^{o} + H_2O \longrightarrow Al(OH)_4^{-} + H^+$$

Sources of Soil Acidity

4. Al and Fe Polymers



Sources of Soil Acidity

4. Soluble salts

Cation from the salts will displace adsorbed Al^{3+} and thus decrease soil solution pH.

$$\text{Clay}\left]\begin{matrix}\text{Al}\\ \text{Al}\\ \end{matrix}\right. + \text{Ca} \longrightarrow \text{Clay}\left]\begin{matrix}\text{Al}\\ \text{Ca}\\ \end{matrix}\right. + Al^{3+}$$

5. Carbon dioxide

$$H_2O + CO_2 \leftrightarrow H_2CO_3$$

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

Factors affecting Soil pH

- (1) parent material,
- (2) rainfal/leaching,
- (3) fertilizers , and
- (4) plant uptake,

Factors affecting Soil pH

- Acidic parent material
- Use of acid-forming fertilizers
- Bases removed by leaching
- Bases removed by crops
- Carbonic acid from microbial and plant respiration
- Organic acids secreted by plant roots
- Precipitation
- Oxidation of sulfide

1. Parent material

- Soils developed from acid nature of the rocks (granites and sandstones, respectively) have low pH (very acid)
- Soils developed from basic rocks (limestones) have high pH (Alkline)

2. Rainfall/leaching

- Water passing through the soil leaches basic cations such as Ca^{2+}, Mg^{2+}, and K^{+} into drainage water.

- These basic cations are replaced by acidic cations such as Al^{3+} and H^+.
- For this reason, soils formed under high rainfall conditions are more acid than those formed under arid conditions.

Fertilizers

- Both chemical and organic fertilizers may eventually make the soil more acid
- Transformations of these sources of N into nitrate (NO_3^-) releases H^+ to create soil acidity.
- Fertilization with fertilizers containing ammonium or even adding large quantities of organic matter to a soil will ultimately increase the soil acidity and lower the pH.

$NH_4^+ + 2O_2 \rightarrow$ bacteria $\rightarrow NO_3^- + \mathbf{2H^+} + H_2O$

Plant Uptake

- Plants take up basic cations such as K^+, Ca^{++}, and Mg^{++}.
- When these are removed from the soil, they are replaced with H^+ in order to maintain electrical neutrality.

The soil as a buffer

$$\text{Clay}\left]\begin{matrix}H\\H\\H\\H\\H\end{matrix}\right. \rightleftharpoons H^+ + OH^- \rightleftharpoons H_2O$$

Active and Potensial Acidity in Soils

1. Active/Actual acidity

2. Potential acidity

	H	**H**	**H**
	Ca	H	Ca
	H	Ca	H
Clay	K	H	K
	H	H	H
	Mg	Mg	H

Pot. AC. Actual Ac.

Active and Potensial Acidity in Soils

1. Active/Actual acidity

- **Active acidity**
  – Free hydrogen ions in soil solution
- Measured by soil water pH
- Very small part of total acidity in soil
- Would take less than 1/3 lb/acre limestone to neutralize

Active and Potensial Acidity in Soils

2. **Reserve acidity**

- Neutralizable H ions and aluminum chemically bound to organic matter and clay
- Accounts for virtually all of the total acidity in soil
- Active acidity is in equilibrium with reserve acidity
- This is what limestone must neutralize when acid soils are limed in order to increase pH

Active and Potensial Acidity in Soils

- **Reserve acidity**
  - Soils with large CEC can hold large amount of acidity
- These soils are highly buffered
- Require large amounts of lime to increase soil pH
  - Soils with small CEC (low organic matter, sandy) can hold smaller amount of acidity
- Usually are low in buffering capacity
- Require less lime to increase soil pH

Soil pH for Crop Production

- **Lime Corrects Problems from Excessive Acidity**
  - Reduces Al and other metal toxicities
  - Improves soil physical condition
  - Stimulates microbial activity
    - Including symbiotic bacteria that fix N
  - Increases CEC in variable charge soils
  - Improves availability of essential elements
  - Supplies Ca and Mg for plants

How Lime Reduces Soil Acidity

- Ca^{++} from lime replaces two H^{+} ions on the cation exchange complex
- The H^{+} ions combine with OH^{-} (hydroxyl) ions to form water
- pH increases because the acidity source (H^{+}) has been reduced

$$CaCO3 + 2H^{+} \longrightarrow Ca^{+2} + CO_2^{2-} + H2O$$

- **Liming Soils**

  Lime required depends on soil pH and CEC.

  The more clay and organic matter, the higher the buffering capacity

- **Limestone Quality**
  - Particle Size
  - Effective Calcium Carbonate Equivalent
  - Both combined determine limestone quality

- **Particle size**

Particle size determines limes reactivity

Finer the particle size, more lime reactivity

Use of Lime in Agriculture

1. Direct Benefits
2. Indirect Benefits

a. Effect on P Avaliability

b. Micronutrient Avaliability

c. Nitrification

d. N Fixation

e. Soil Physical Condition

Factors Determining the Selection of a Liming Program

1. Intended Crop
2. Soil Texture and OM Content
3. Time and Frequency of Liming Applications
4. Depth of Tillage

Acidulating the Soil

1. Elemental So
2. Sulfuric Acid
3. Alumunium Sulfate
4. Ammonium Polysulfide
5. Acidification in Fertilizer Bands

Soil Problems regarding soil acidity

Problems in very acid soils	Problems in alkaline soils
*Aluminum toxicity to plant roots	*Iron deficiency
*Manganese toxicity to plants	*Manganese deficiency
*Calcium & magnesium deficiency	*Zinc deficiencies
*Molybdenum deficiency in legumes	*excess salts (in some soils)
*P tied up by Fe and Al	*P tied up by Ca and Mg
*poor bacterial growth	*bacterial diseases in potatoes
*reduced nitrogen transformations	

HOW TO MANAGE ACID SOIL

Characteristic of Acid Soil:

a. Chemical characteristic

- Low pH, organic matter, nutrient
- Low CEC, bases, base saturation

b. Physical characteristic:

- Low WHC
- Suscept to erosion

c. Biological characteristic:

- Low amount and activity of soil organism

HOW TO MANAGE ACID SOIL

2. The Management of Acid soil

   a. The addition of organic matter

   b. Liming

   c. Using tolerance varietas

The addition of organic matter

- The Addition of Organic matter will improve soil physical, chemical, and biological properties

- Physical properties:

- Chemical properties:

- Biological properties:

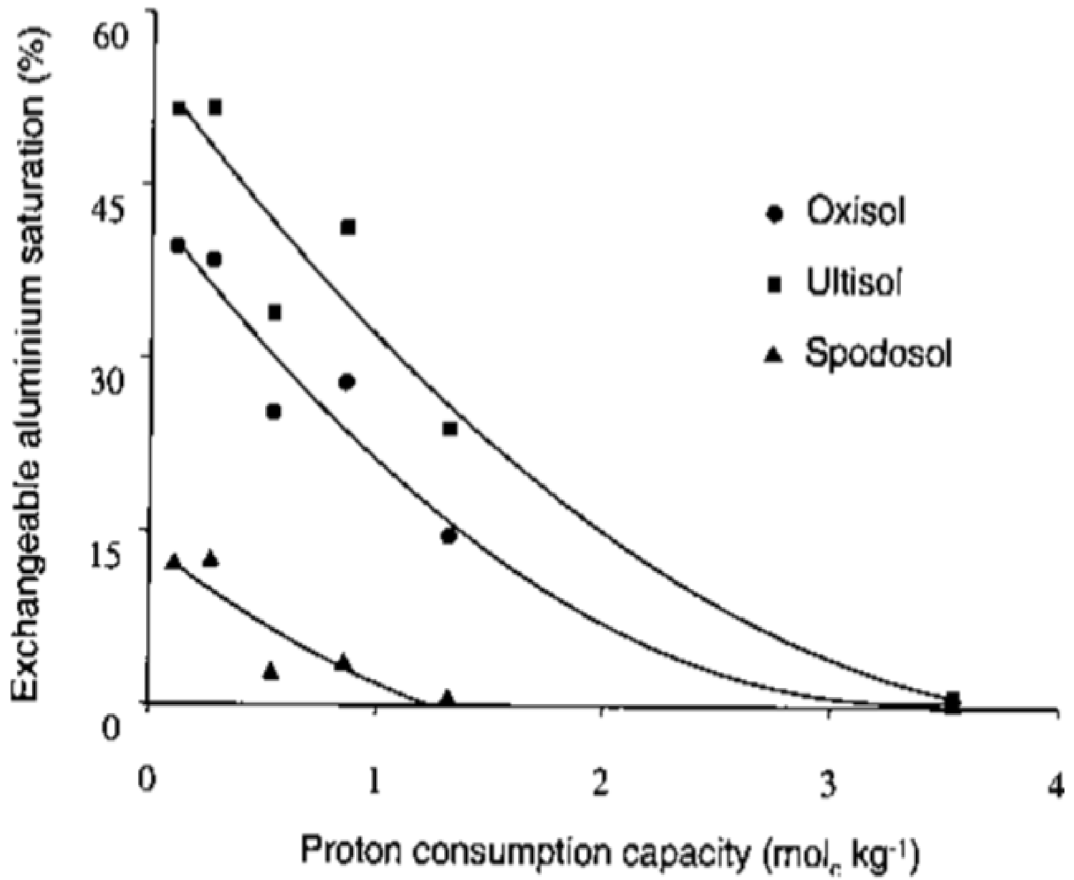


FIGURE 1 Soil exchangeable aluminium following 2 weeks of incubation with 1.5% by weight of organic matter having different proton consumption capacities. (Redrawn from Ref. 22.)

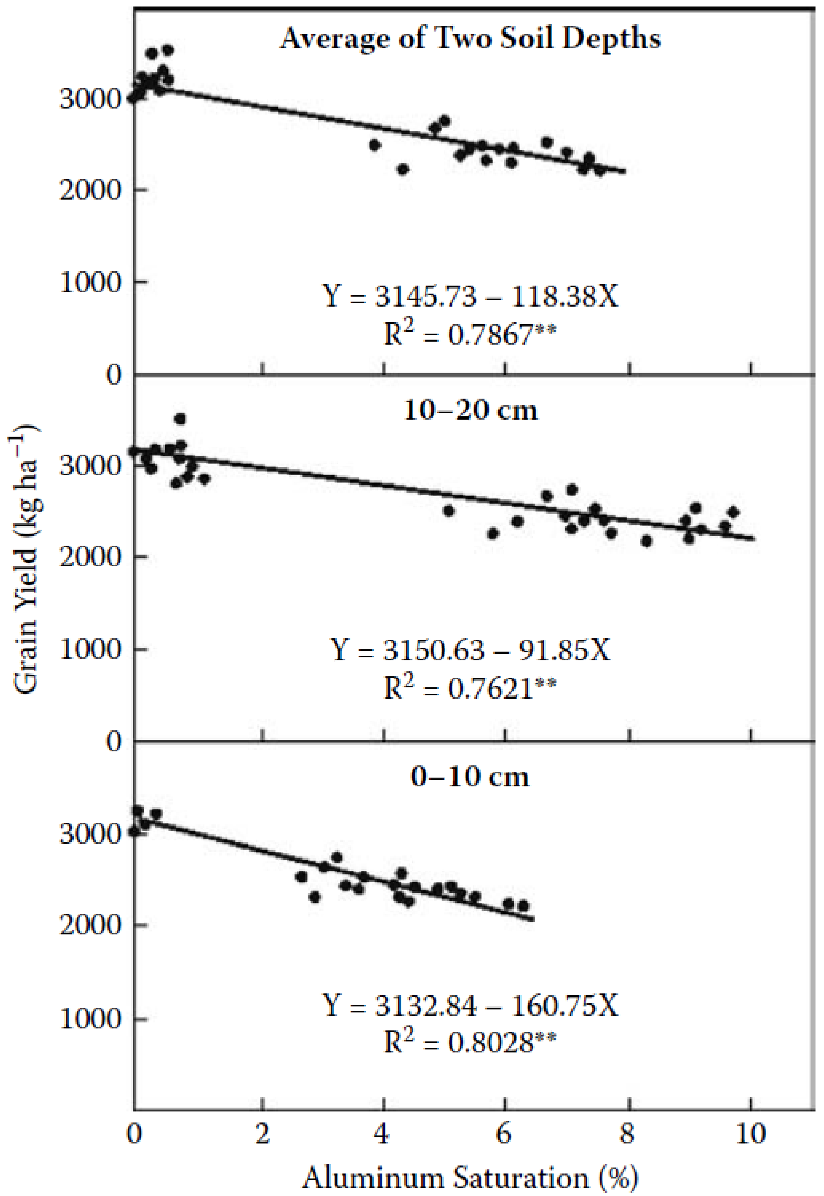


FIGURE 5.12 Relationship between aluminum saturation and grain yield of dry bean. Values are averages of five field trails conducted for 3 years (Fageria, 2008).

TABLE 5.10
Critical Al Saturation for Important Field Crops at 90–95% of Maximum Yield

Crop	Type of Soil	Critical Al Saturation (%)
Cassava	Oxisol/Ultisol	80
Upland rice	Oxisol/Ultisol	70
Cowpea	Oxisol/Ultisol	55
Cowpea	Oxisol	42
Peanut	Oxisol/Ultisol	65
Peanut	Xanthic Halpludox	54
Soybean	Oxisol	19
Soybean	Xanthic Halpludox	27
Soybean	Oxisol/Ultisol	15
Soybean	Not given	<20
Soybean	Ultisol	20–25
Soybean	Histosol	10
Soybean	Ultisol	20
Corn	Oxisol	19
Corn	Xanthic	27
Corn	Oxisol/Ultisol	29
Corn	Oxisol/Ultisol	25
Corn	Oxisol	28
Mungbean	Oxisol/Ultisol	15
Mungbean	Oxisol/Ultisol	5
Coffee	Oxisol/Ultisol	60
Sorghum	Oxisol/Ultisol	20
Common bean	Oxisol/Ultisol	10
Common bean	Oxisol/Ultisol	8–10
Common bean	Oxisol/Ultisol	23
Cotton	Not given	<10

Source: Fageria et al. (1997), Fageria and Baligar (2001), Fageria and Baligar (2003).

LIMING

1. Effect of Liming on Soil properties

   a. The improvement of soil physical properties

   b. The improvement of chemical properties

   c. The improvement of biological properties.

The improvement of soil physical properties

1. **Enhance agregate formation**

- Liming increase electrolite concentration, and the amount of Ca and/or Mg. Both of them cause the EDL of the coloid is thin, so the coloid flocculated.
- The flocculated clay coloid to become cementing agent in agregate formation.

The improvement of soil physical properties

2. Increase total and distribution of pores
3. Increase soil aeration
4. Increase soil infiltration
5. Decrease soil Bulk density

The improvement of soil chemical properties

1. Increase soil pH
2. Increase the amount of Ca, or Ca and Mg
3. Increase P availability
4. Increase CEC for pH dependent charge coloid
5. Increase bases cation
6. Increase base saturation
7. Decrease Al, Fe, Mn toxicity

The improvement of soil chemical properties

Table 3
The impact of liming on soil chemical processes of selected macronutrients, trace elements and heavy metals

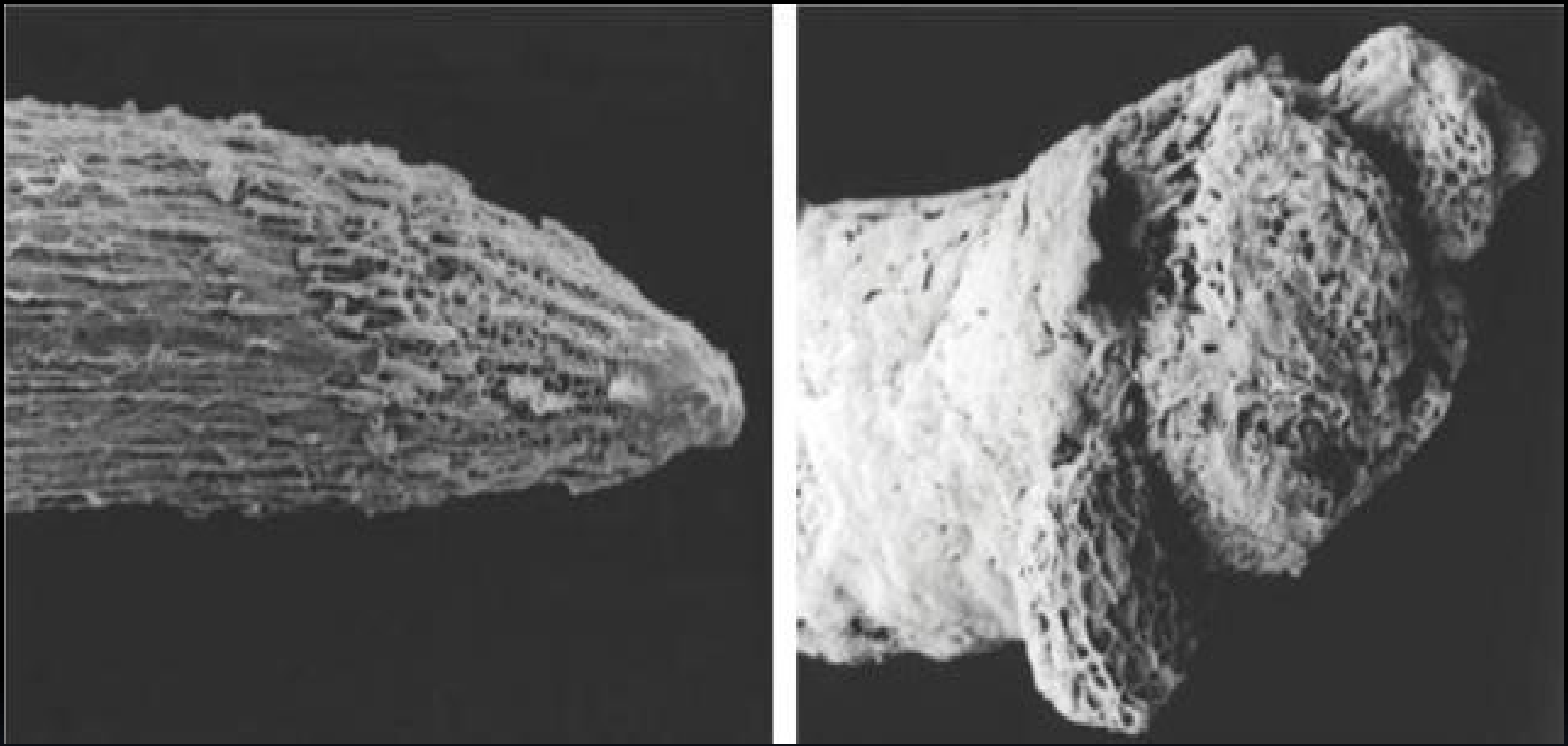
Nutrient/element	Process effect	Reference
Phosphorus	Increased organic P mineralization	(Haynes, 1982)
	Increased risk of P loss	(Murphy, 2007)
	Changes to plant available P	(Condron et al., 1993; McDowell et al., 2002)
Potassium	Increased K adsorption	(Bolan et al., 2003)
	Increased risk of K deficiency	(Bailey and Laidlaw, 1999)
Sulfur	Increased SO_4^{2-} mineralization	(Bolan et al., 2003)
	Increased SO_4^{2-} immobilization	(Valeur et al., 2002)
	Greater release of SO_4^{2-} and more risk of S loss	
Calcium	Increased Ca in the soil solution	(Bailey, 1995)
Trace elements	Increased adsorption of B, Cu, Co and Zn	(Bolan et al., 2003)
	Increased Se availability	(Öborn et al., 1995)
Heavy metals	Increased Cd immobilization	(Hong et al., 2014)
	Increased plant uptake of Mn, Cd, Pb, Ni	(Blake and Goulding, 2002)
	Increased risk of heavy metal leaching	(Fageria and Baligar, 2008)

The improvement of soil biological properties

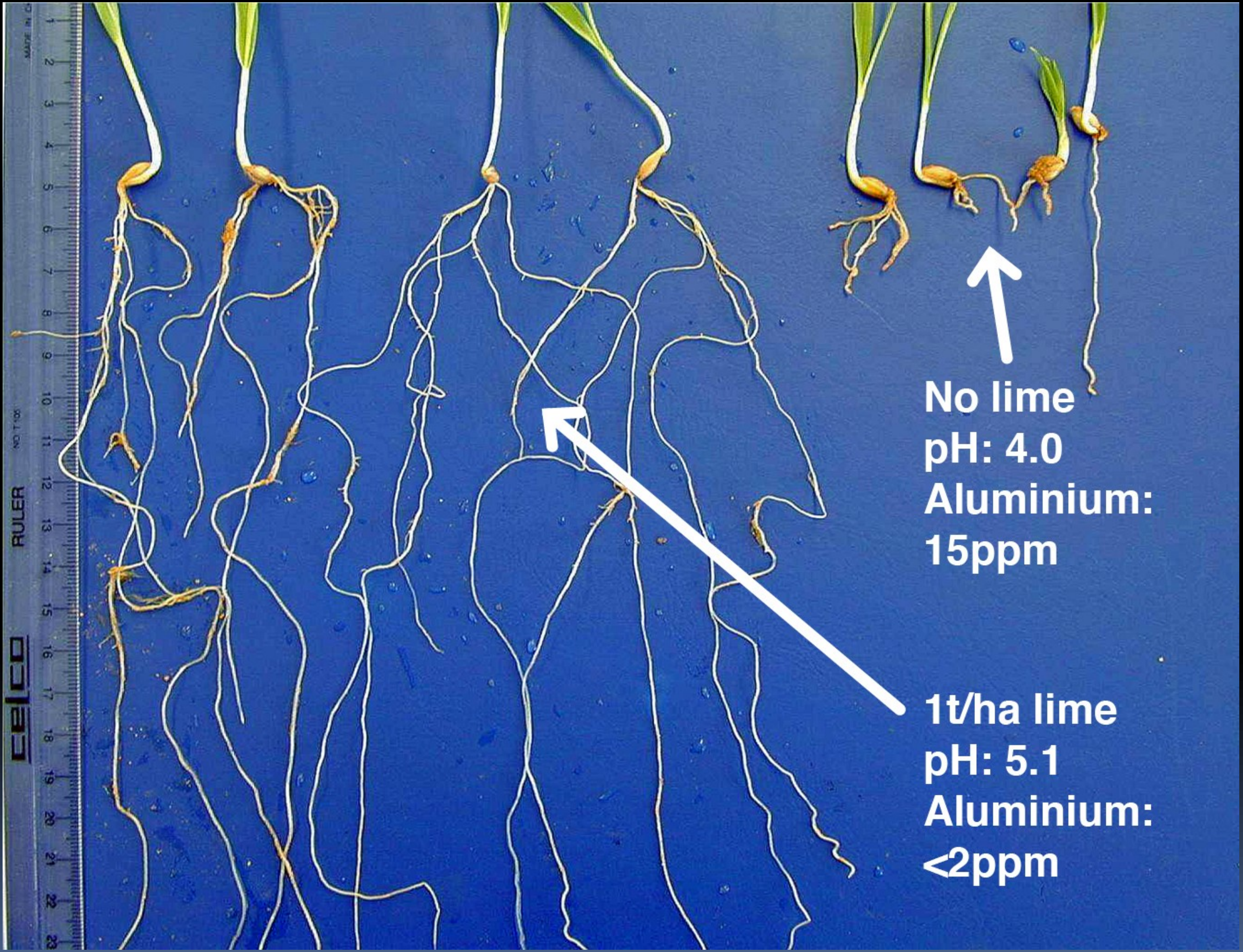
1. Increase amount and activity of soil biota
2. Increase soil biodiversity

Effect of liming on plant growth

- Crop yield improvement
- Nutrient availability effects
- Improved microbial activity
- Improved legume fixation
- Calcium & magnesium addition



Gbr. Kiri ujung akar (root tip) sehat
Gbr. Kanan root tip yang terganggu Al


No lime
pH: 4.0
Aluminium:
15ppm
1t/ha lime
pH: 5.1
Aluminium:
<2ppm

Pertumbuhan akar wheat akibat konsentrasi Al

TABLE 5.12

Grain Yield and Panicle Number of 5 Upland Rice Genotypes at Two Soil Acidity Levels in Brazilian Oxisol

	Grain Yield (g pot^{-1})		Panicle Number (pot^{-1})	
Genotype	High Acidity (pH 4.5)	Low Acidity (pH 6.4)	High Acidity (pH 4.5)	Low Acidity (pH 6.4)
CRO97505	74.3	52.0	38.0	28.3
CNAs8983	55.2	42.9	29.0	25.7
Primavera	53.0	47.2	25.0	21.7
Canastra	51.6	38.9	32.0	26.3
Bonança	48.8	36.5	26.3	20.7
Carisma	50.8	17.5	43.3	17.7
Average	66.7	47.0	38.7	28.1

Source: Adapted from Fageria et al. (2004).

TABLE 5.13
Shoot Dry Weight (g plant^{-1}) of 14 Tropical Legume Cover Crops at Three Acidity Levels

Legume Species	High Acidity	Medium Acidity	Low Acidity	Average
Crotalaria	4.04d	1.97fg	0.91	2.31gh
Sunn hemp	12.32bc	7.76cde	4.23bc	8.10cdef
Crotalaria	4.24d	2.87efg	1.41cd	2.84gh
Crotolaria	5.80d	4.35defg	3.74bcd	4.63fgh
Crotalaria	13.05bc	6.12cdef	3.44bcd	7.53def
Calapogonio	4.88d	3.11defg	1.82cd	3.27gh
Pigeon pea	7.80cd	5.45cdefg	4.09bc	5.78efg
Lablab	14.31b	10.39bc	5.80b	10.17bcd
Mucuna bean ana	12.99bc	8.39bcd	4.32bc	8.57cde
Black mucuna bean	16.39ab	13.46b	6.48b	12.11b
Gray mucuna bean	15.13b	13.79b	4.47bc	11.13bc
White jack bean	21.43a	19.78a	13.52a	18.24[a]
Pueraria	3.76d	1.61fg	0.92cd	2.09h
Brazilian stylo	3.95d	0.32g	0.18d	1.48h
Average	10.00	7.09	3.95	6.69
F-test				
Soil acidity (S)		**		
Legume species (L)		**		
S X L		**		

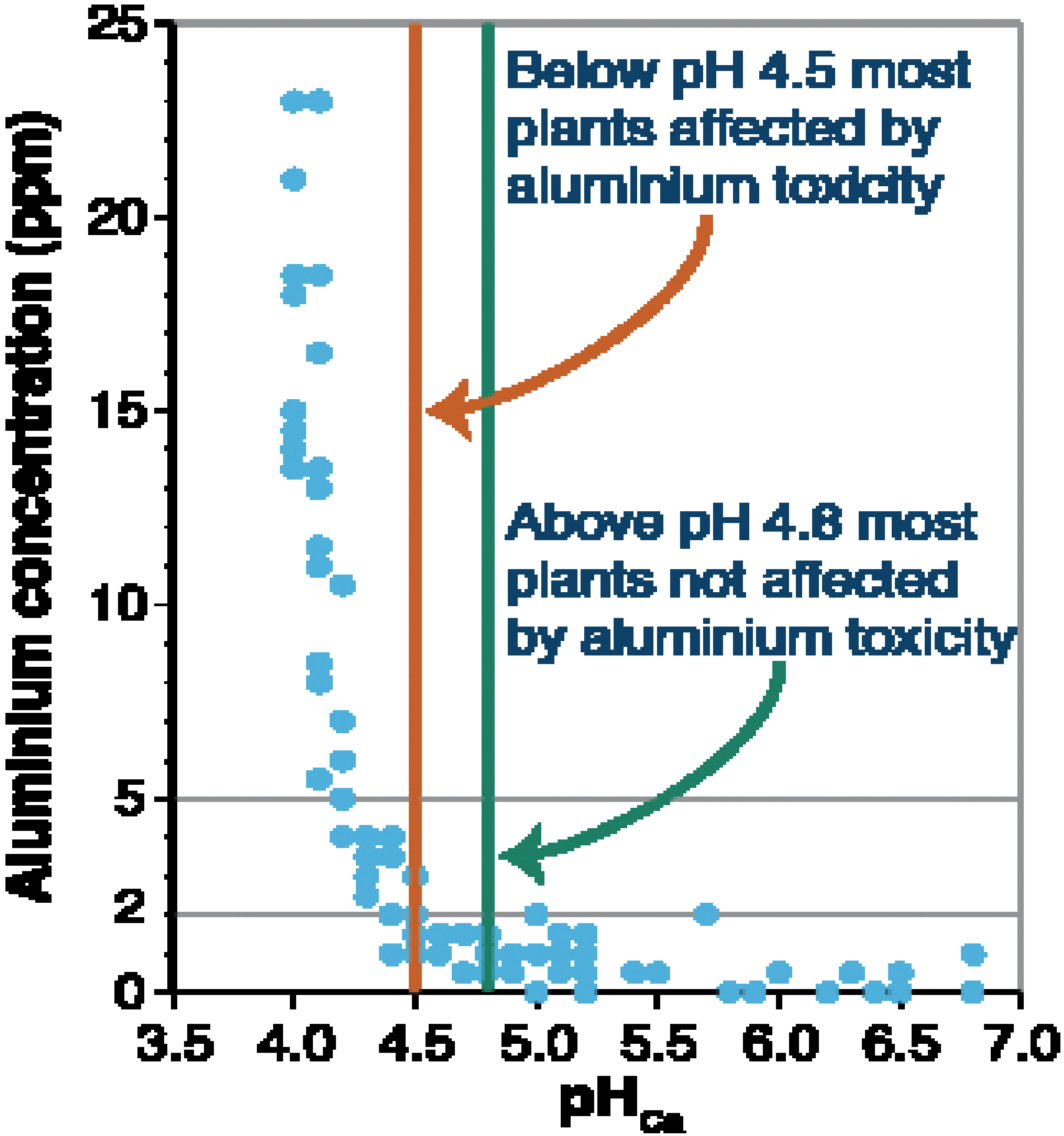
Note: Means followed by the same letter in the same column are significantly not different by Tukey's test at the 5% probability level.

** Significant at the 1% probability level.

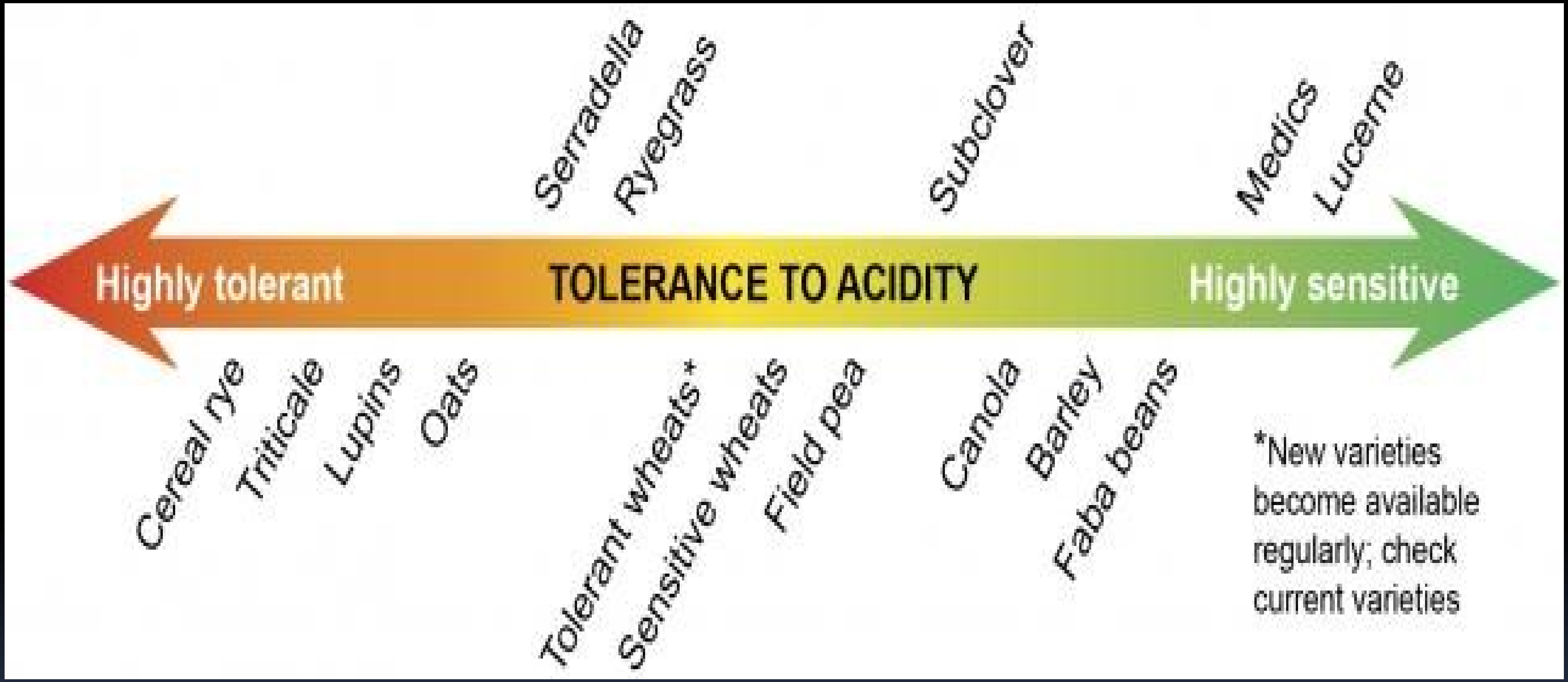
TABLE 5.14
Shoot Dry Weight Efficiency Index (SDWEI) of Legume Species at Medium and Low Soil Acidity Level and Their Classification to Soil Acidity Tolerance

Legume Species	SDWEI at Medium Acidity[a]	SDWEI at Low Acidity
Crotalaria breviflora	0.14S	0.11S
Crotalaria juncea L.	1.62T	1.50T
Crotalaria munocrata	0.21S	0.22S
Crotalaria spectabilis	0.43MT	0.66MT
Crotalaria ochroleuca	1.35T	1.36T
Calapogonium mucunoides	0.56MT	0.27S
Cajanus cajan L. Millspaugh	0.73MT	0.98MT
Dolichos lablab L.	2.49T	2.47T
Mucuna deeringiana L.	1.94T	1.66T
Mucuna aterrima L.	3.76T	3.22T
Mucuna cinereum L.	3.60T	2.04T
Canavalia ensiformis L. DC.	7.15T	8.80T
Pueraria phaseoloides Roxb.	0.09S	0.11S
Stylosanthes guianiensis	0.03S	0.02S

[a] T = tolerant, MT = moderately tolerant, and S = susceptible.
Source: Fageria et al. (2008).


Below pH 4.5 most plants affected by aluminium toxicity
Above pH 4.8 most plants not affected by aluminium toxicity
Aluminium concentration (ppm)
25
20
15
10
5
2
0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
pHCa

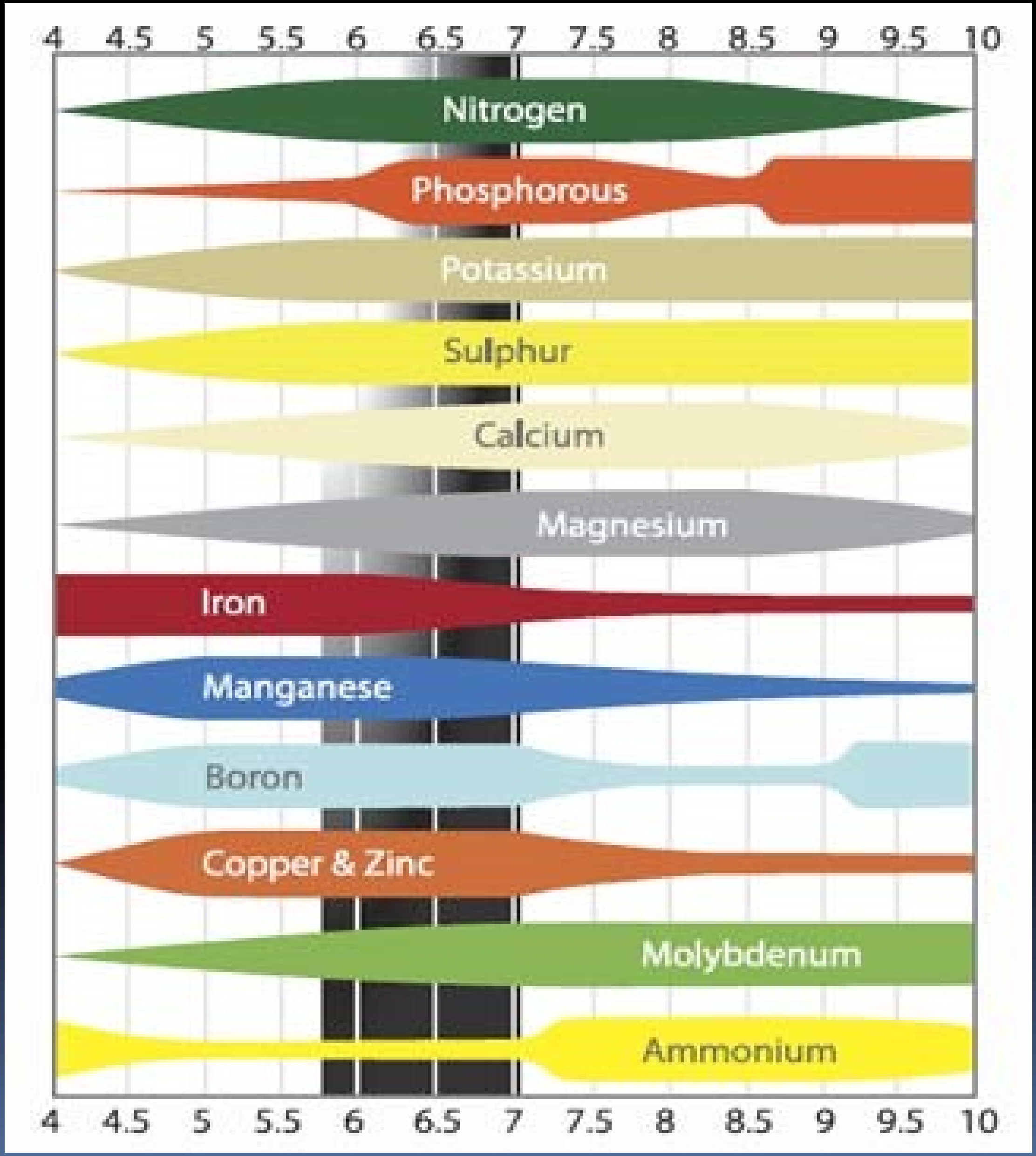
Crop growth/yield improvement



Serradella
Ryegrass
Subclover
Medics
Lucerne
Highly tolerant
TOLERANCE TO ACIDITY
Highly sensitive
Cereal rye
Triticale
Lupins
Oats
Tolerant wheats*
Sensitive wheats
Field pea
Canola
Barley
Faba beans
*New varieties become available regularly; check current varieties

Crop	Lime rate (t/ha)	Grain yield response (% yield change) 0 years after liming	Grain yield response (% yield change) 1-4 years after liming	Grain yield response (% yield change) 5+ years after liming
Wheat	1-1.5	1 (16 trials)	8 (34 trials)	6 (11 trials)
Wheat	2-2.5	2 (19 trials)	13 (35 trials)	12 (18 trials)
Canola	1-3	21 (3 trials)	15 (18 trials)	12 (7 trials)
Barley	1-3.2	-4 (1 trial)	7 (18 trials)	47 (5 trials)

pH and nutrients availability



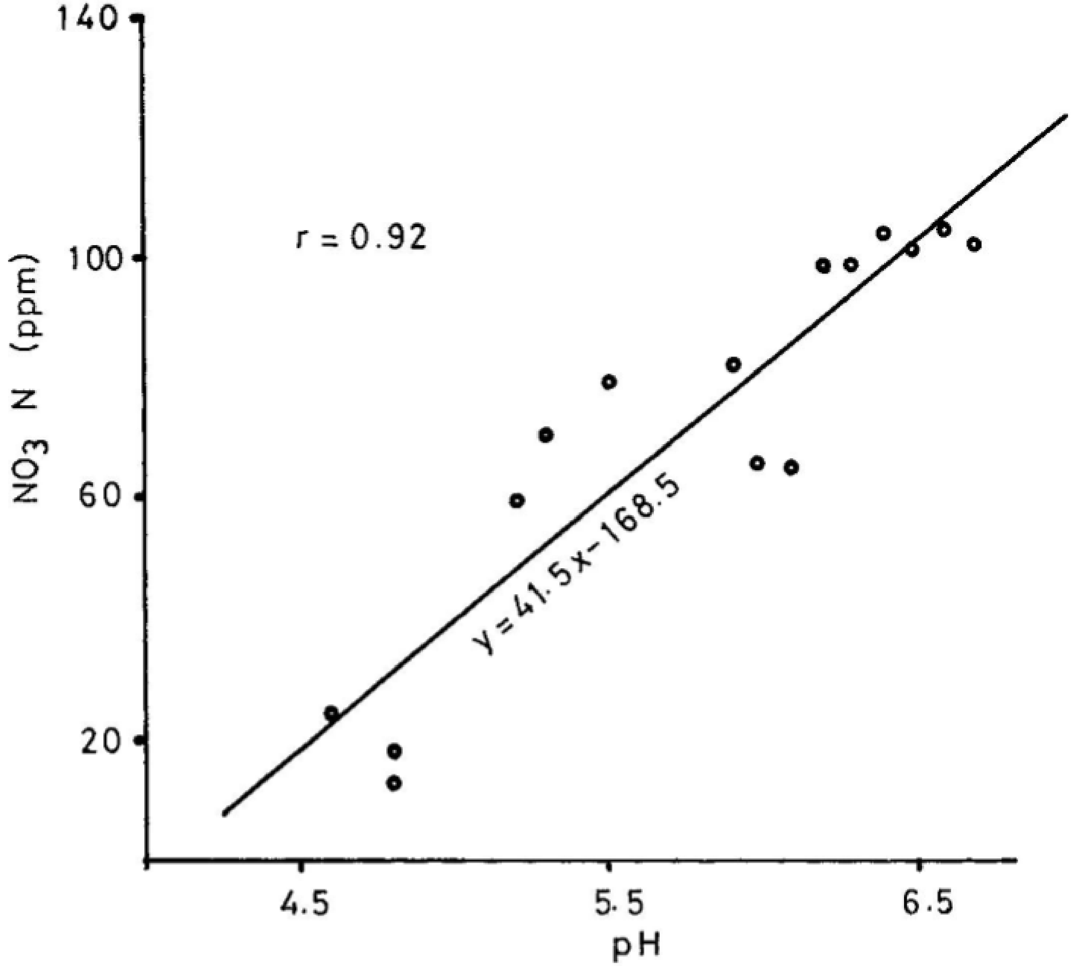


Figure 8.3. Relation between soil pH and NO_3^--N accumulation in soils treated with 100 ppm of NH_4^+-N as $(NH_4)_2SO_4$ and incubated for 15 days at 23°C. (From Dancer et al., 1973. Soil Sci. Am. Proc. 31:67–69. With permission of SSSA.)

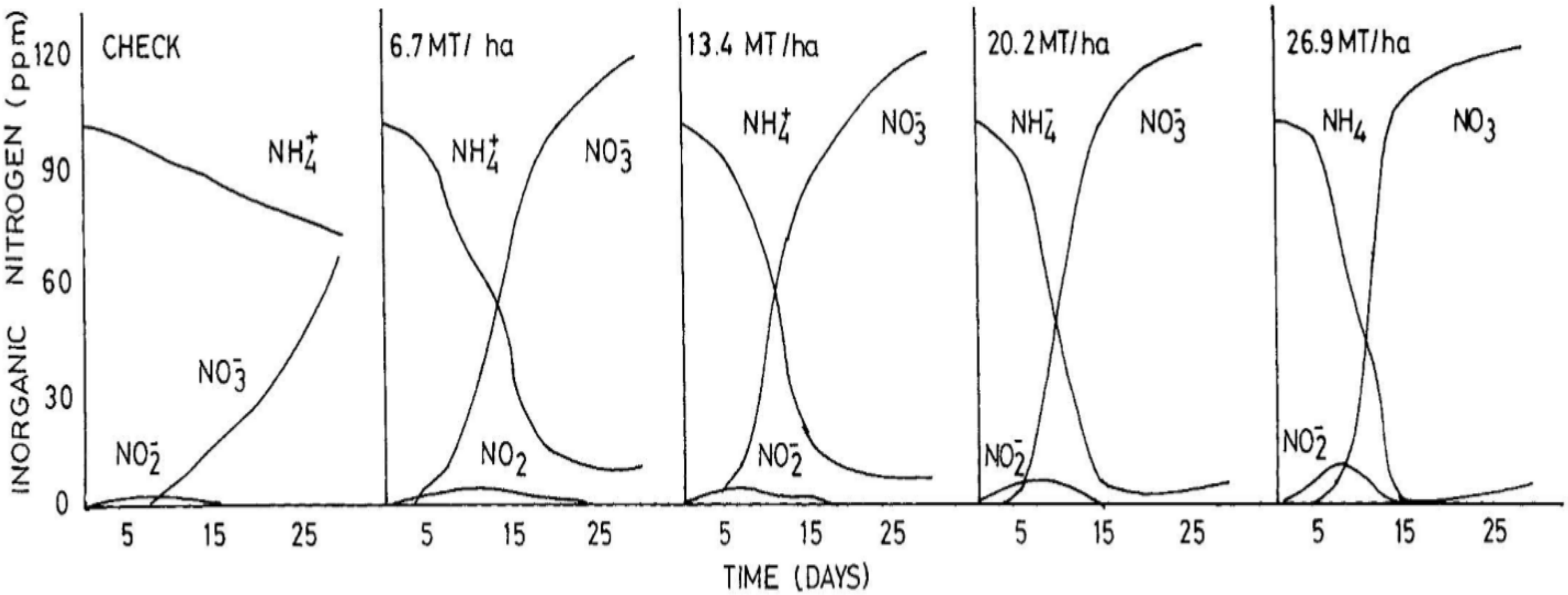


Figure 8.4. Effect of liming and soil pH on the concentration of NH_4^+, NO_2^- and NO_3^--N in soil treated with 100 ppm of NH_4^+-N as $(NH_4)_2SO_4$ and incubated for 30 days at 23°C. Treatments 0, 6.7, 13.4, 20.2, and 26.9 metric tons ha^{-1} of lime correspond to pH values of 4.7, 5.3, 6.0, 6.3, and 6.6, respectively. (From Dancer et al., 1973. Soil Sci. Soc. Am. Proc. 31:67–69. With permission of SSSA.)

Improved microbial activity

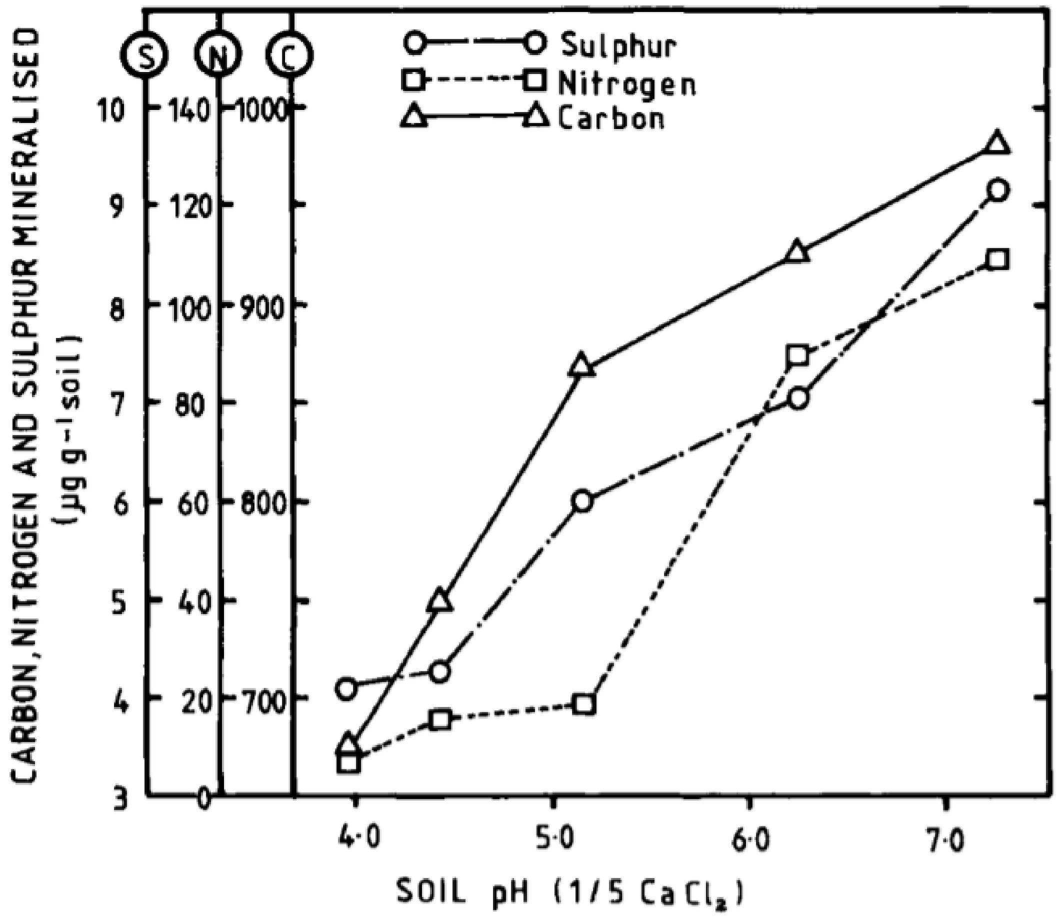


Fig. 1. Effects of soil pH on the mineralisation of carbon, nitrogen and sulphur after incubation of Coolup sand for 32 days at 27°C (after Barrow, 1965).

Improved microbial activity

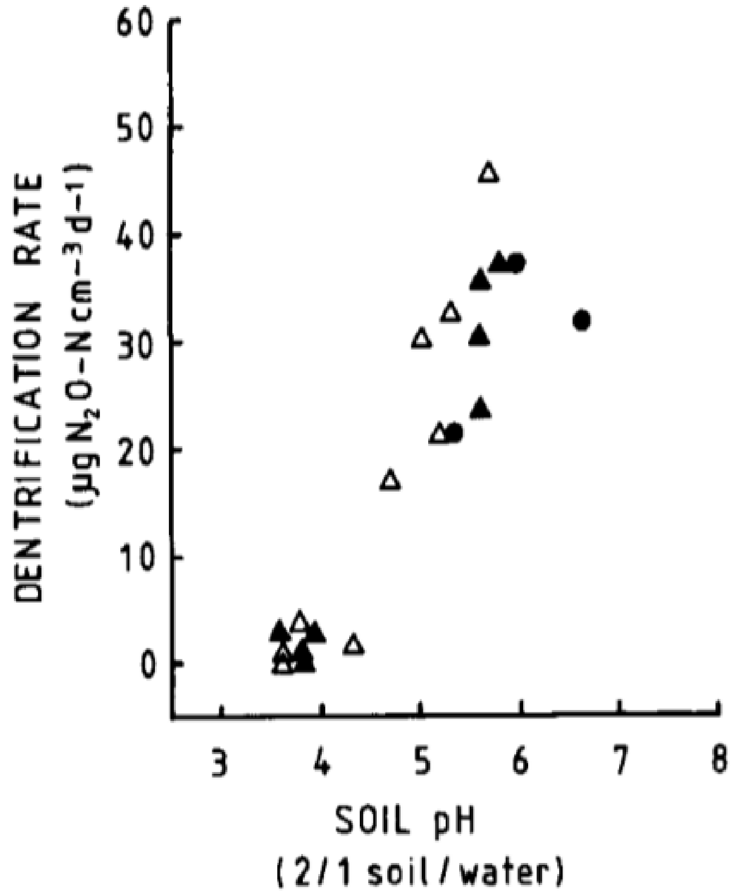


Fig. 3. The relationship between rate of denitrification and soil pH for surface horizons of mire (▲), forest ((△) and agricultural (●) soils (data from Müller *et al.*, 1980).

Improved microbial activity

Table IV. The effect of soil pH on the germination of spores and hyphal growth of *Acaulospora laevis* and *Glomus* sp. WUM 3 (after Porter *et al.*, 1987b).

Species	Soil[a]	Treatment	pH[b]	Spore germination (%)	Hyphal growth (mm hyphae per germinated spore)
A. laevis	Ulva sandy loam	Nil	4.6	30	28
		$CaCO_3$	7.4	1	1
		$CaSO_4$	4.6	15	6
		Nil	7.6	4	2
		H_2SO_4	4.9	23	8
		$CaSO_4$	7.5	2	1
Glomus sp. WUM 3	Merredin sandy clay loam	Nil	4.6	4	2
		$CaCO_3$	7.4	67	75
		$CaSO_4$	4.6	5	6
		Nil	7.6	64	111
		H_2SO_4	4.9	1	8
		$CaSO_4$	7.5	55	64

[a] Soil descriptions from Bettenay and Hingston (1961)

[b] (1/5, 0.01 M $CaCl_2$)

Improved microbial activity

Table V. The effects of soil pH and nitrate concentration on the colonisation of roots of seedlings of *Pinus radiata* and of glass fibres by *Rhizopogon luteolus* (after Theodorou and Bowen, 1969).

pH	Nitrate conc. ($\mu g.g^{-1}$ soil)	Percentage colonised		Length colonised (mm)	
		Fibres	Seedlings	Fibres	Seedlings
5.0	12	55	95	4.8	26.5
5.0	115	70	88	8.5	16.0
8.0	12	15	0	0.8	0.0
8.0	115	25	0	1.4	0.0

Table VI. Effect of soil acidity on disease.

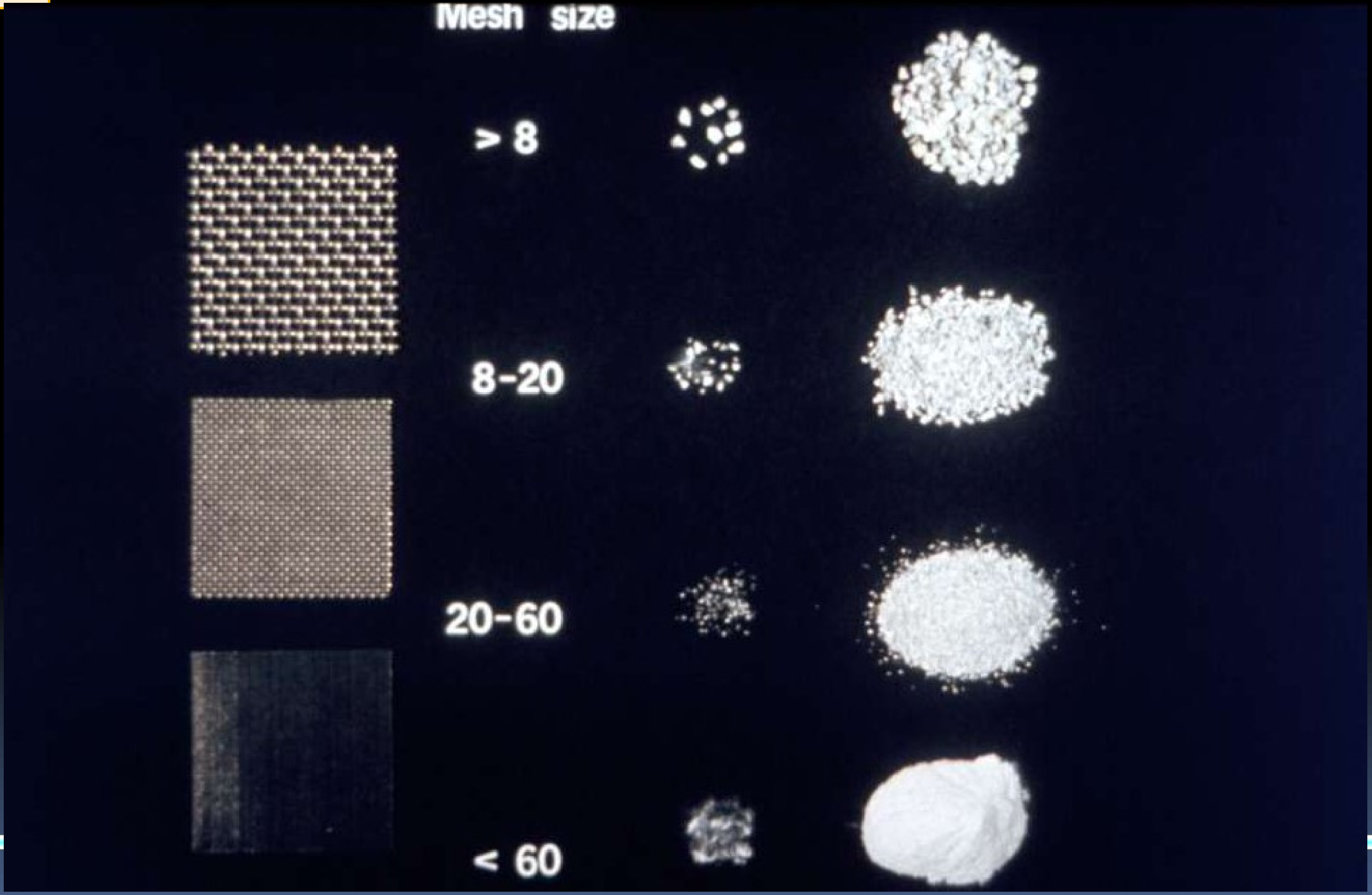
Disease	Pathogen	Reference
Diseases decreased by acidification of alkaline soil or increased by liming acid soils.		
Scab of potato	*Streptomyces scabies*	Martin (1920)
Take-all in wheat	*Gaeumannomyces graminis* var. *tritici*	Trolldeiner (1981)
Phytophthora root rots	Various species	Schmitthener and Canaday (1983)
Pythium root rots of pines	*Pythium irregulare*	Roth and Riker (1943)
Verticillium wilt of sunflowers	*Verticillium albo-atrum*	Orellana *et al.* (1975)
Diseases increased by acidification of alkaline soils or decreased by liming acid soils.		
Fusarium wilt of tomato	*Fusarium oxysporum* f.sp *lycopersici*	Jones and Overman (1971)
Club root of brassicas	*Plasmodiophora brassicae*	Garrett (1970)
Damping off in medics	*Pythium ultimum* *Pythium irregulare*	Kleinig (1965); MacKenzie *et al.* (1972)
Bacterial canker of peach	*Pseudomonas syringae*	Weaver and Wehunt (1975)

The purity factor (CaCO3) Equivalent

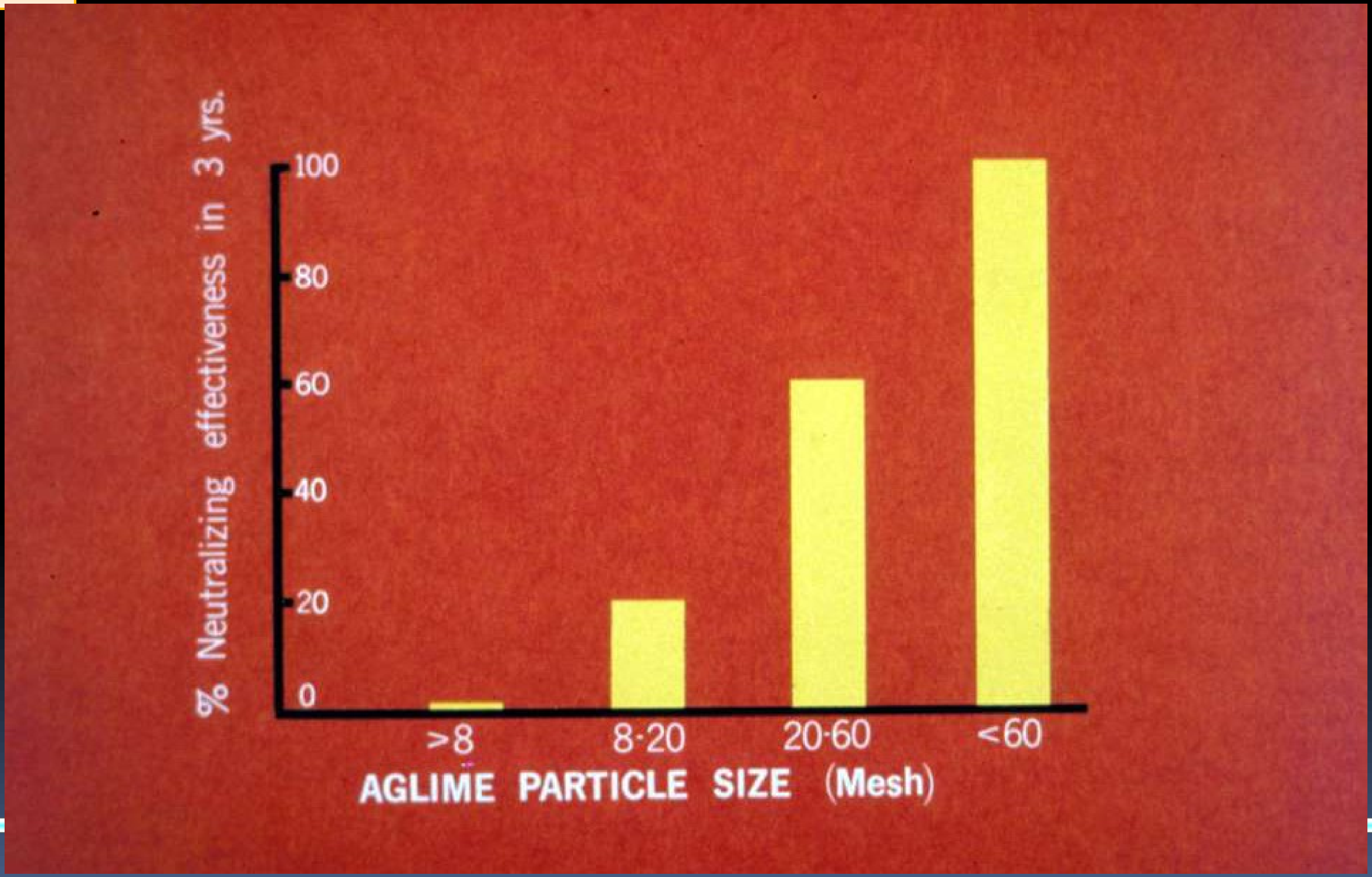
Table 6-5. Liming materials and their calcium carbonate ($CaCO_3$) equivalent

Liming material	Neutralizing agent	$CaCO_3$ equivalent of pure material (%)
Dolomitic limestone	$CaCO_3 \cdot MgCO_3$	110–118
Papermill lime sludge	Mainly $CaCO_3$	*
Marl	Mainly $CaCO_3$	variable
Calcitic limestone	$CaCO_3$	100
Water treatment lime waste	$CaCO_3$	variable
Wood ash	K_2CO_3, $CaCO_3$, $MgCO_3$	20–90
Fly ash	CaO, $Ca(OH)_2$, $CaCO_3$	variable
Hydrated lime	$Ca(OH)_2$	135
Air-slaked lime	$Ca(OH)_2 + CaCO_3$	100–135

* *According to the Wisconsin Lime Law, one cubic yard of papermill lime sludge is equivalent to one ton of aglime having a neutralizing index of 60–69.*


Mesh size
> 8
8-20
20-60
< 60

Lime Effectiveness over a three-year period



Calculating the Neutralizing Index of a liming material

Example 2: Lime B (90% calcium carbonate equivalent)

Screen size	Screen analysis		Effectiveness factor		
	%				
greater than 8 mesh	5.0	x	0.0	=	0.0
8 to 20 mesh	25.0	x	0.2	=	5.0
20 to 60 mesh	20.0	x	0.6	=	12.0
less than 60 mesh	50.0	x	1.0	=	50.0
			Total	=	67.0

NI = 67.0 x 90% = 60.3

Lime Requirement Conversions

- Recom. = 4 tons/acre, 60-69 lime
- Convert to requirement as 70-79 lime

- LR (70-79) = 4 x 65/75 = 3.47 tons/acre

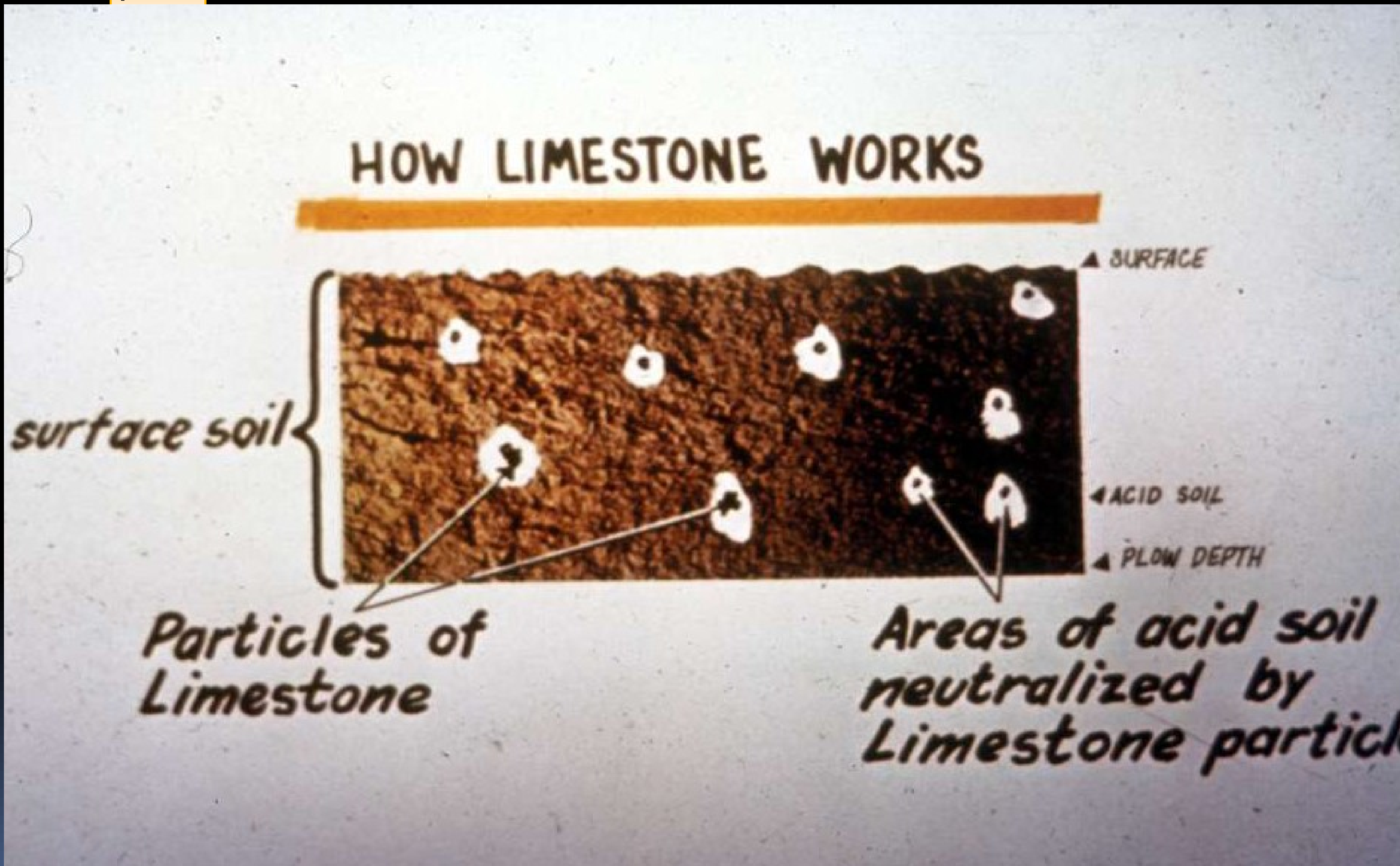
Table 6-7. Aglime conversion table for different neutralizing index zones

Lime recommendation[a]	Zones of lime quality according to neutralizing index values						
	40–49	50–59	60–69	70–79	80–89	90–99	100–109+
(ton/a)	ton/a lime to apply						
1	1.4	1.2	1.0	0.9	0.8	0.7	0.6
2	2.9	2.4	2.0	1.7	1.5	1.4	1.2
3	4.3	3.5	3.0	2.6	2.3	2.1	1.9
4	5.8	4.7	4.0	3.5	3.1	2.7	2.5
5	7.2	5.9	5.0	4.3	3.8	3.4	3.1
6	8.7	7.1	6.0	5.2	4.6	4.1	3.7
7	10.1	8.3	7.0	6.1	5.4	4.8	4.3
8	11.6	9.5	8.0	6.9	6.1	5.5	5.0
9	13.0	10.6	9.0	7.8	6.9	6.2	5.6
10	14.4	11.8	10.0	8.7	7.6	6.8	6.2

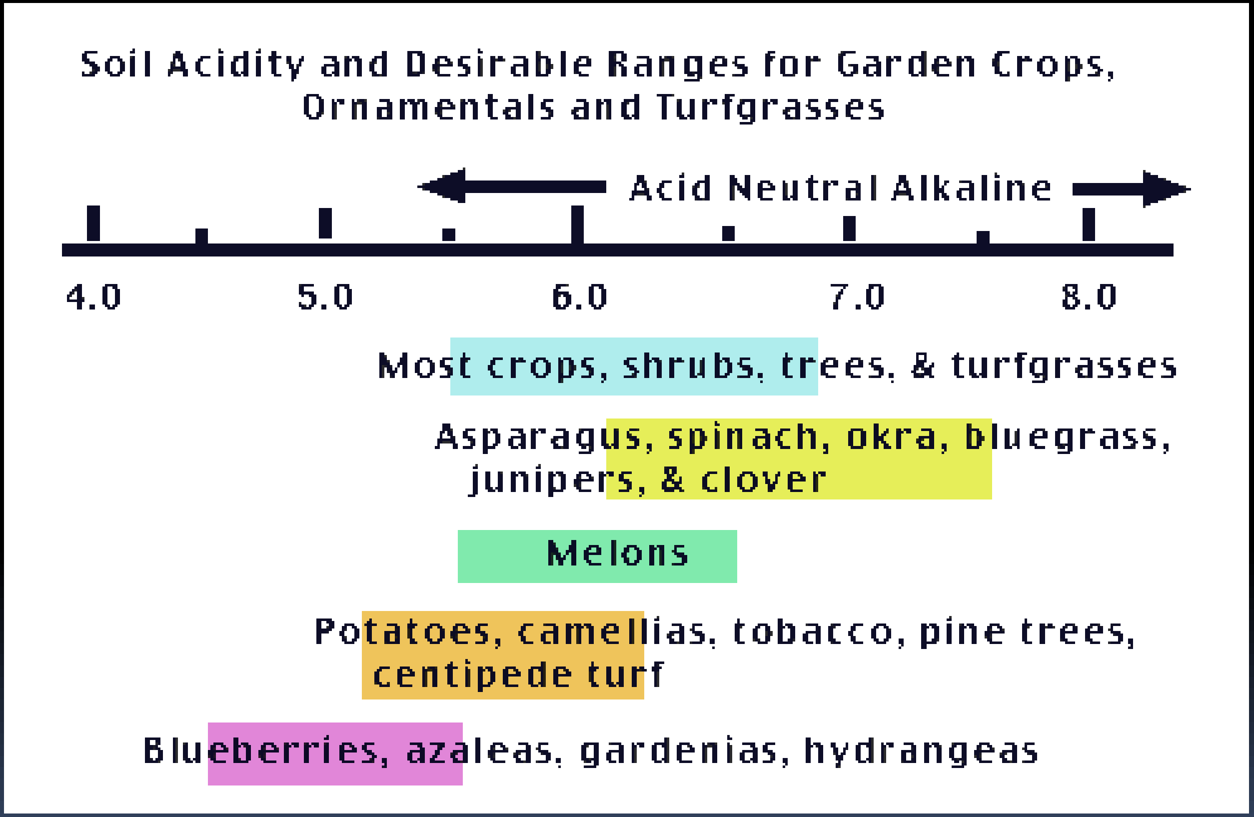
[a] *Soil test recommendations are made for lime having a neutralizing index zone of 60–69. To convert a recommendation to a liming material with a different grade, read across the table to the appropriate column.*

Depth of tillage affects the lime requirement of soils

Tillage depth (inches)	Factor used to adjust lime recommendations for depth of tillage
<7.1	1.00
7.1–8.0	1.15
8.1–9.0	1.31
>9.0	1.46


HOW LIMESTONE WORKS
SURFACE
surface soil
ACID SOIL
PLOW DEPTH
Particles of Limestone
Areas of acid soil neutralized by Limestone particl

SOIL ACIDITY AND LIMING



- Kebutuhan kapur (KK) meningkat bila pH target meningkat. Pada pH di atas 5,5, KTK permanen dr koloid tnh mineral dijenuhi dg basa2 dan tdk ada lagi sumbangan thd KK.
- Tdp disparitas nilai KK antara bbg prosedur pH buffer. Hal itu disebabkan oleh 2 penyebab utama: 1). akurasi kalibarasi mempengaruhi rekomnedasi. Kalibrasi hrs mengatur pengukuran kemasaman oleh buffer tak sempurna. 2). ketidakcocokan antara tnh-buffer dg pH target mempengaruhi jumlah dan proporsi kemasaman yg terukur.

- Akurasi Rekomendasi KK bgtg pd 3 postulat yg saling terkait. 1). prosedur pH-buffer hrs scr akurat dikalibrasi. Akurasi khususnya penting utk penentuan KK tnh dg kapasitas menyangga rendah, krn bisa overlime. 2). pengapuran akurat memerlukan aplikasi yg merata. Juga memerlukan takaran yg diberikan dlm volume atau berat tnh yg tepat. 3). Penggunaan faktor pengapuran umum mempengaruhi akurasi.

- Hasil tanaman terbaik dalam tnh dg pH antara 6,0 dan 7,0. Kapur ditambahkan utk meningkatkan pH tnh2 masam. dan jumlah kapur yg diperlukan utk meningkatkan pH ke 6,0-6,5 disebut kebutuhan kapur (KK).
- Sejumlah metode tersedia utk menentukan KK tnh2 masam, diantaranya: prosedur SMP (Shoemaker, McLean, and Prat; metode Buffer tunggal Woodruff; Buffer tunggal Mehlich; Buffer tunggal Woodruff baru; Buffer tunggal Adams dan Evans; Buffer tunggal Nommik; Buffer ganda Yuan; Buffer ganda SMP.

- Dr. Slamet Setijono dr UNBRAW mengembangkan metode penentuan KK di dasarkan pd Al-dd.
- Dalam kuliah ini akan dijelaskan metode Buffer tunggal Adams dan Evans (1962) dan Metode Al-dd dr Setijono (1982).

- **Metode Adams dan Evans**

Reagen

Buffer Adams dan Evans dipersiapkan dg melarutkan 15,75 g, 30,0 g p-nitrophenol, dan 22,5 g H_3BO_3. dlm air destilasi 1125 ml (dibawah pengadukan tetap). Jika perlu panaskan sedikit, utk melarutkan kristal. Biarkan larutan dingin, dan tepatkan 1,5 L dg air destilasi. Bila dipersiapkan dg baik, pH nya harus 8,0.

Prosedur

- Timbang 20 g tnh dlm gelas piala. Tambahkan 20 ml air destilasi, aduk , dan biarkan suspensi selama 30 menit. Tntukan pH dg pH meter, dan amankan suspensi tanah. pH yg terukur disebut pH air.
- Analisis dilanjutkan dg menambahkan ke suspensi tnh di atas 20 ml buffer Adams dan Evans, aduk selama 5 mnt.
- Kalibrasi pH meter utk pembacaan pH 8,0 dg buffer Adams dan Evans enceer (20 ml buffeer + 20 ml air). Cuci elektrode, dan ukur pH suspensi tnh yg mengandung buffer. Itu yang disebut pH buffer.
- Tentukan jml KK ($CaCO_3$) utk mencapai pH 6,5 dr Tabel 6.1.

- **Metode penentuan KK bdsk Al-dd**

1. Tentukan brp me/100 g Al-dd tanah. Cara penentuan Al-dd sudah sdr praktekan pada kuliah DDIT atau lainnya.
2. Tentukan tanaman yang akan ditanam pada tnh masam yang akan dikapur. Tanaman di golongkan ke dalam 3 gol utama, yaitu yang peka, sedang, dan kurang peka thd kemasaman tnh. Masing-masing memiliki KK > 2xAl-dd, 1,5x Al-dd, dan <1x Al-dd.

3. KK dihitung dg cara: jika Al-dd = 2 me/100 g, tanaman yang akan ditanam adalah jagung yang butuh 1xAl-dd, maka jumlah kapur yang diperlukan = 1X2 me Al-dd /100g = 2 me $CaCO_3$/100 g = 20 me $CaCO_3$/kg = 2 ton $CaCO_3$/ha. Dg rincian perhitungan sbb:

2 me Ca/100g = 20 me Ca/kg = 20 x 40/2 mg Ca/kg = 20 x 40/2 x 100/40 x 2 x 10^6 mg $CaCO_3$ /Ha.=

2 ton $CaCO_3$ /Ha.

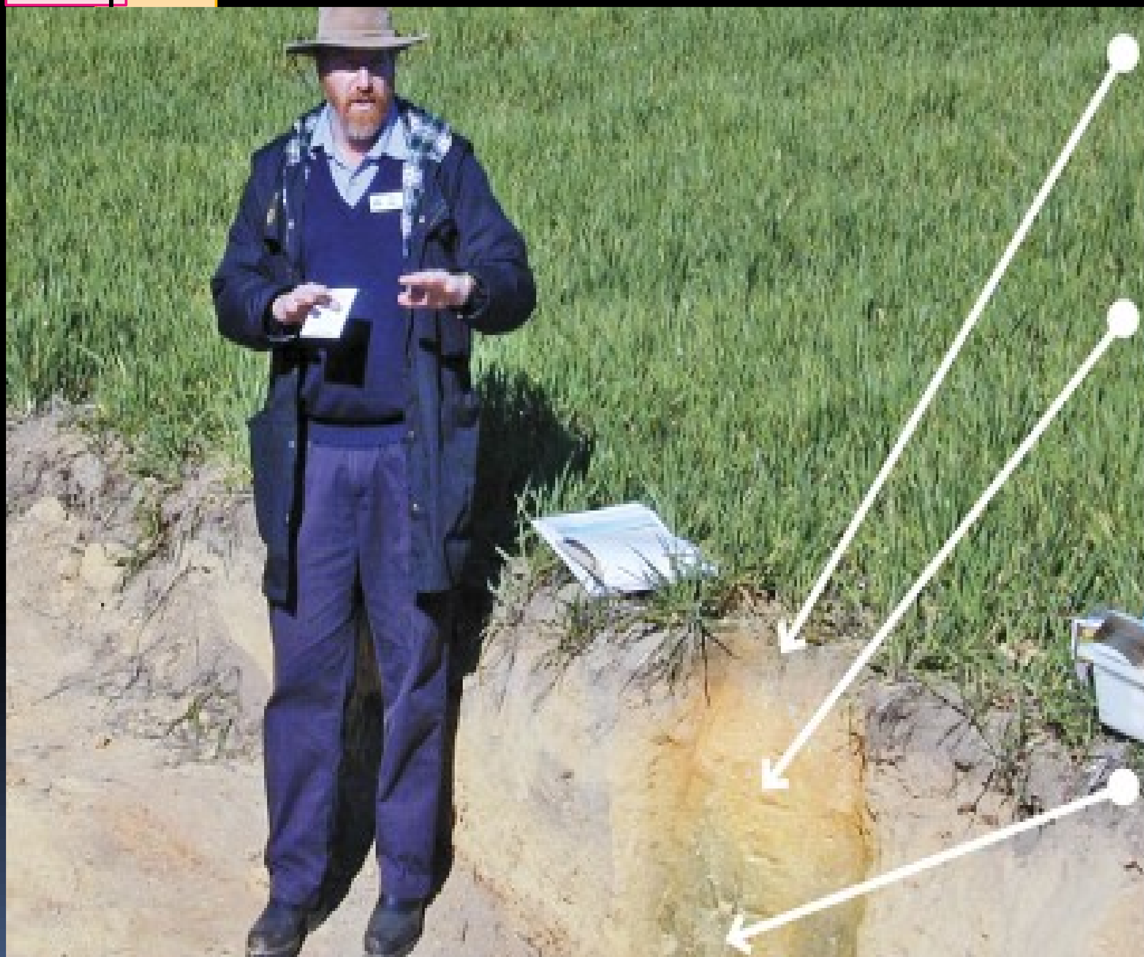
- Metode Penentuan KK Tidak Langsung

1. Joret et al. (1934) mengusulkan persamaan berikut yg menghubungkan kadar BOT dan liat dg KK: 0,11 [%liat + (5 x %BO)].
2. Keeney dan Corey (1963) mengusulkan persamaan : KK = (pH 6,5 – pH tanah) x (%BO).
3. dll.

- **Penentuan KK Histosol Masam**

  Histosol masam biasa dikapur ke pH sekitar 5,2 sampai 5,4 (air), yg scr agronomi sebanding dg 6,5 utk tnh mineral (McLean, 1971, 1973, 1982; van Lierop, 1983).

  Prosedur penentuan KK pH-buffer dpt diterapkan, namun kalibrasi yg berbeda diperlukan utk itu.



Testing topsoil pH only tells you about topsoil pH.

Extra lime is required to treat the acidic subsurface layer from about 10 to 40cm.

If you know your subsurface soil pH, you can apply the right amount of lime to treat it if necessary.

The acidic layer prevents roots from growing into the good soil below 40cm.

TABLE 5.11
Liming Materials, Their Composition, and Their Neutralizing Power

Commercial Name	Chemical Formula	Neutralizing Value (%)	Characteristics
Dolomitic lime	$CaMg(CO_3)_2$	95–109	Contains 78–120 g kg^{-1} Mg and 180–210 g kg^{-1} Ca
Calcitic lime	$CaCO_3$	100	Contains 284–320 g kg^{-1} Ca
Dolomite lime	$MgCO_3$	100–120	Contains 36–72 g kg^{-1} Mg
Burned lime	CaO	179	Fast reacting and difficult to handle
Slaked lime	$Ca(OH)_2$	136	Fast reacting and difficult to handle
Basic slag	$CaSiO_3$	86	By-product of pig-iron industry; also contains 1–7% P
Wood ash	Variable	30–70	Caustic and water soluble

Source: Fageria (1989), Bolan et al., (2003), Brady and Weil (2002), and Caudle (1991).

Effect of Al activity on Plant growth

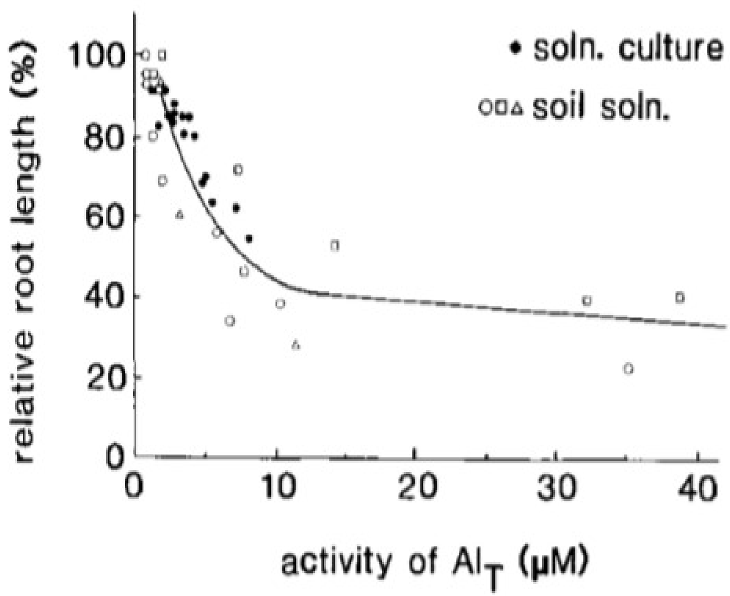


Fig. 5. Effect of molar activity of Al_T in subsoil solutions (○, □, △) and in nutrient solutions (●) on growth of primary roots of cotton (taken from Adams and Lund, 1966).

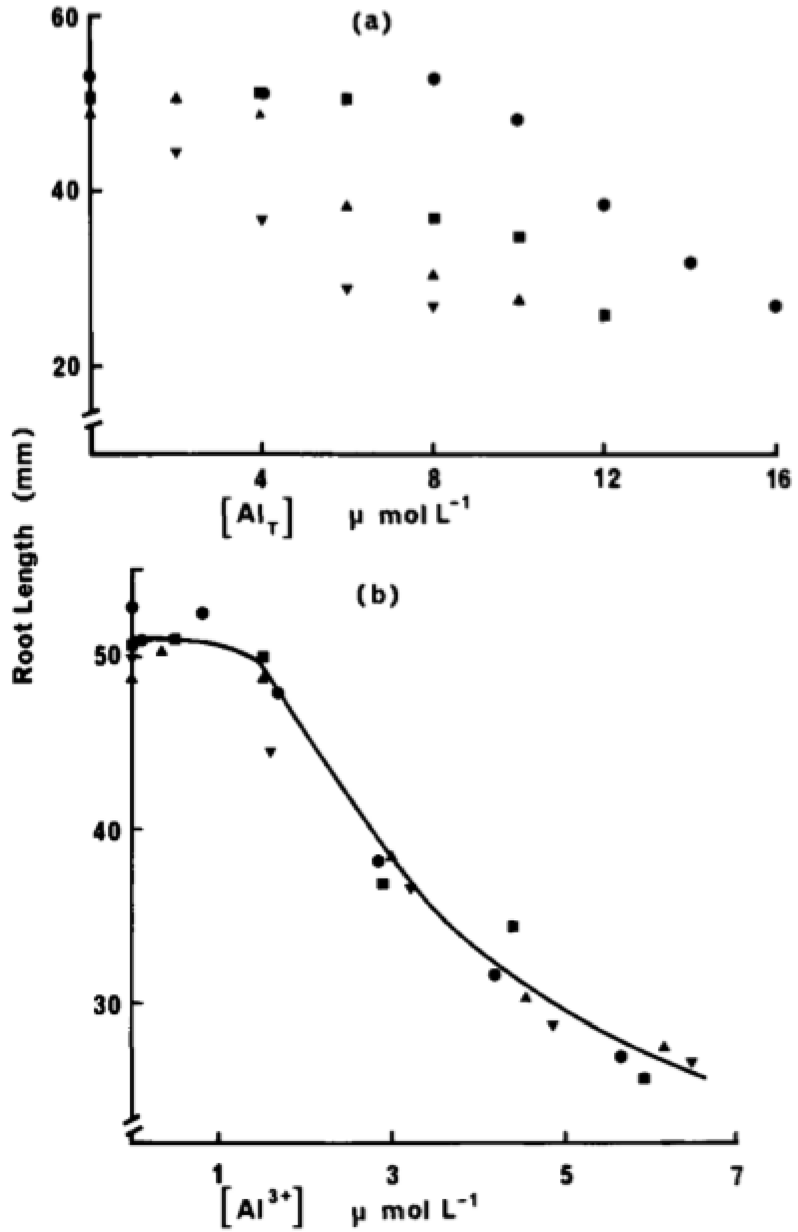


Fig. 6. The variation in root length of barley with (A) $[Al_T]$ and (B) $[Al^{3+}]$ in the presence of 0 (▼), 2.5 (▲), 5 (■) and 10 (●) μM fluoride (taken from Cameron *et al.*, 1986).

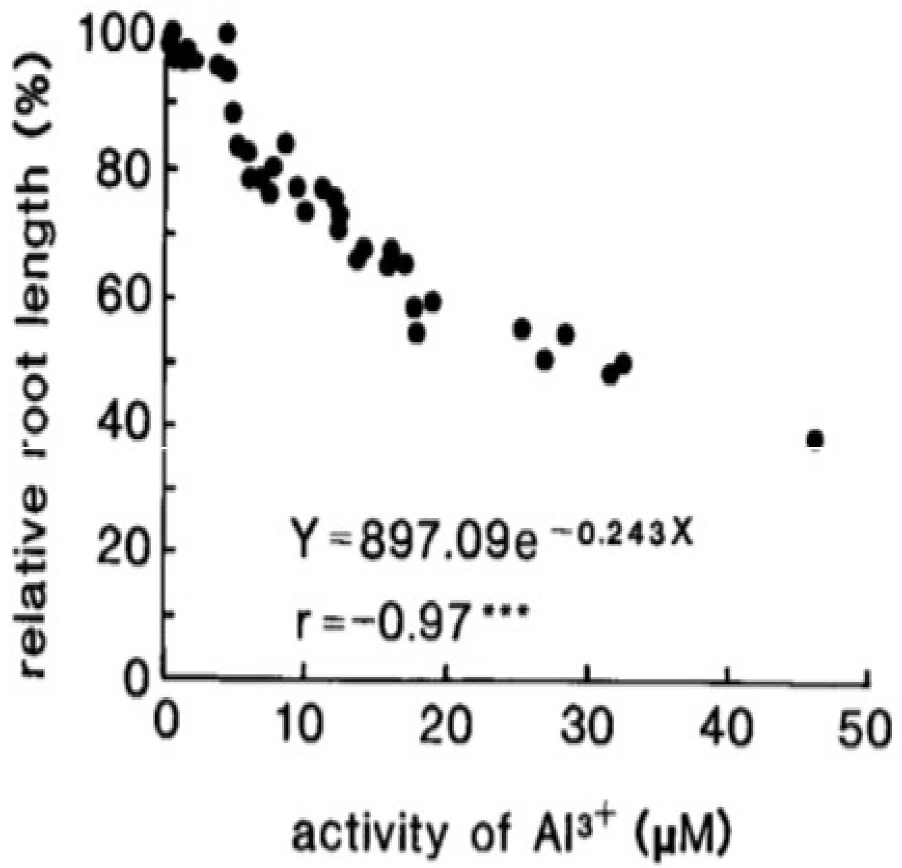


Fig. 7. Relative root growth of coffee in relation to activity of Al^{3+} in soil solution (***: significant at the 0.001 level) (taken from Pavan *et al.*, 1982)

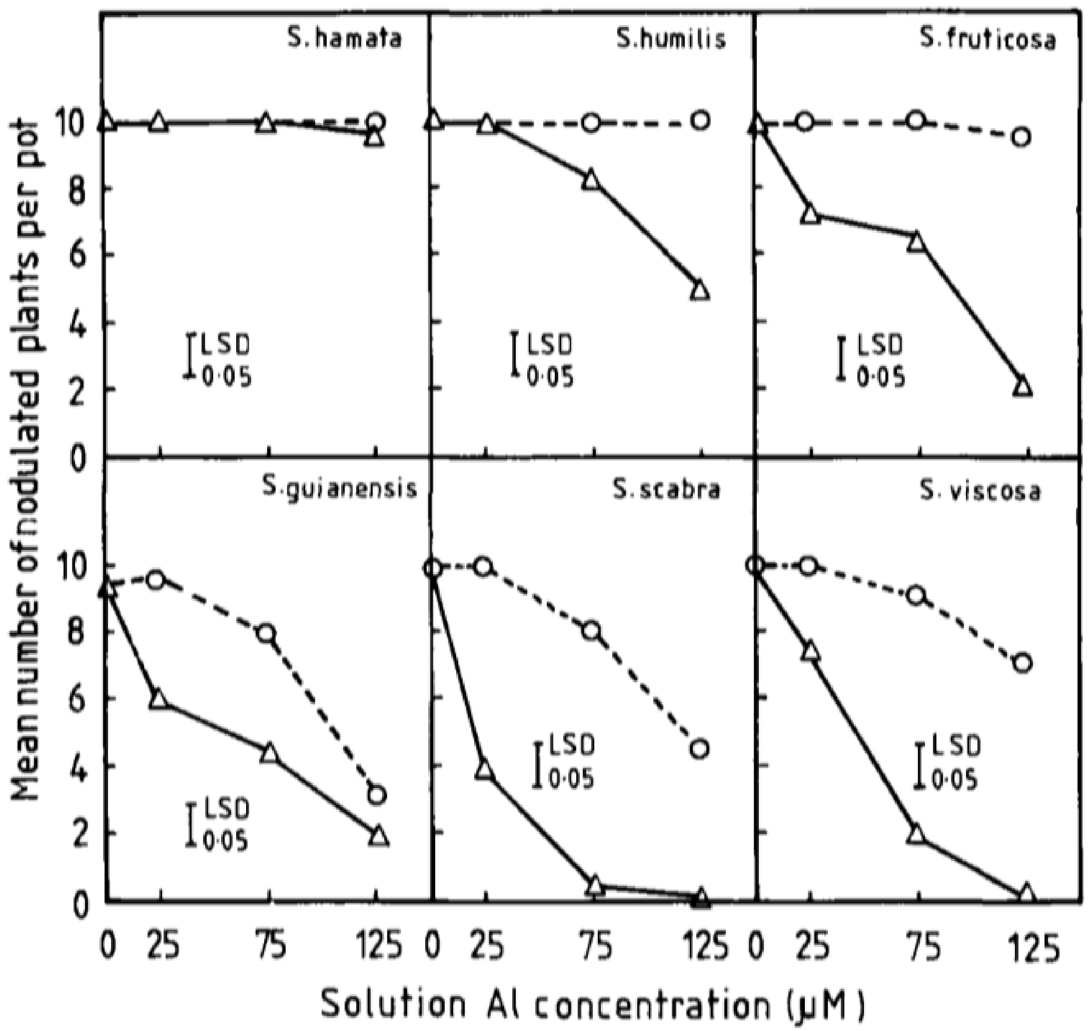


Fig. 2. Effect of solution aluminium concentration on the number of nodulated plants per plot of six *Stylosanthes* species, harvested at 4 and 8 weeks after germination. Bars show LSD at 5% level. △ 4 weeks; ⊙ 8 weeks. After de Carvalho *et al.* (1981).

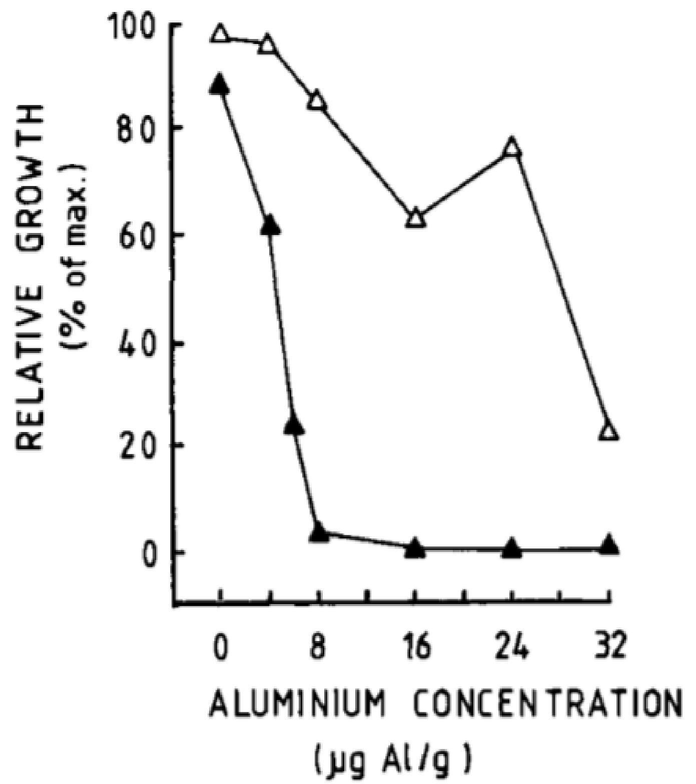


Fig. 7. The effect of soluble aluminium on the relative growth of *Verticillium albo-atrum* (▲) and *Whetzelinia sclerotiorum* (△) in a defined nutrient medium at pH 4.7. Growth is expressed as a percentage of the weight of each fungus in Al-free medium maintained at pH 6.3 (data after Orellana *et al.*, 1975).

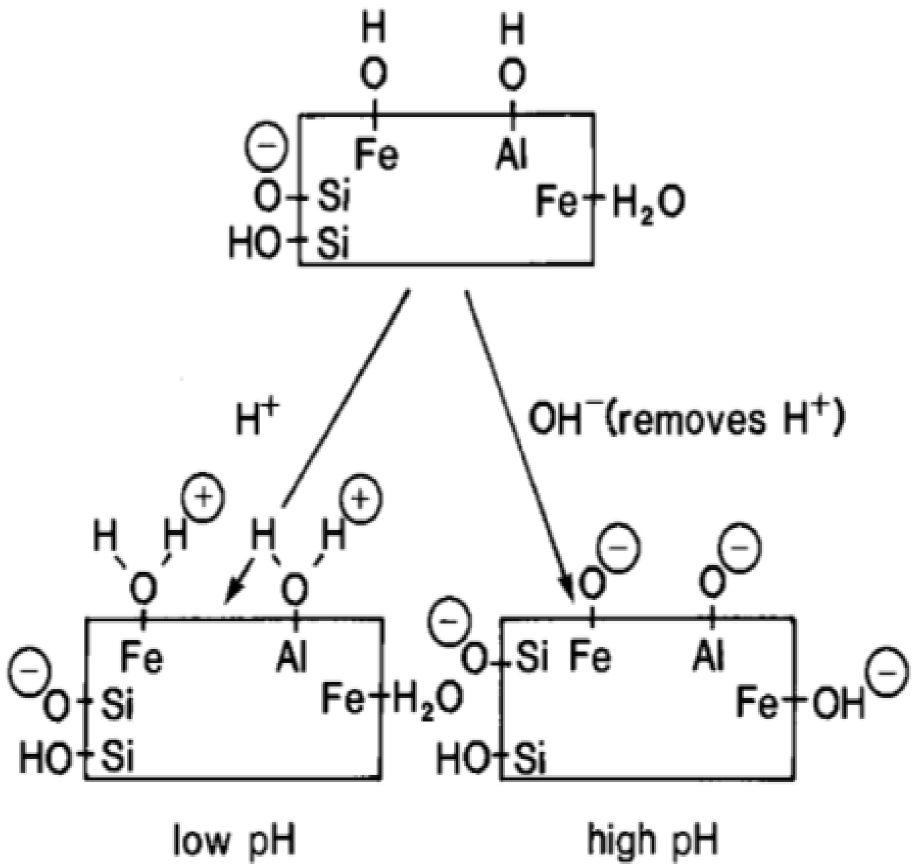


Fig. 8. Schematic representation of the development of positively and negatively charge sites on surfaces of soil constituents, at low and pH (taken from parfitt, 1980)

Table II. The cation exchange capacity of organic matter, and its equivalent in t $CaCO_3$.ha^{-1} over 0–10 cm for different soil organic matter and pH levels (soil bulk density assumed to be 1.37 g cm^{-3}). Values calculated from
$OM - CEC = a(pH - 1.5)$.

Soil OM (%)	OM − CEC (cmol(+).kg soil^{-1})			$CaCO_3$ equivalent (t.ha^{-1} 10 cm)		
	pH 4	pH 6	pH 8	pH 4	pH 6	pH 8
1	0.79	1.36	1.92	0.54	0.93	1.32
2	1.58	2.72	3.84	1.08	1.86	2.63
5	3.95	6.80	9.60	2.71	4.66	6.58
10	7.90	13.60	19.20	5.41	9.32	13.20
20	15.80	27.20	38.40	10.80	18.60	26.30