VIII. KALSIUM

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Outline

- 6.1 Introduction
- 6.2 Functions & Forms of Ca in Plants
- 6.3 Ca Cycles
- 6.4 Soil Ca resources
- 6.5 Soil Ca availability
- 6.6 Agronomic role of Ca
- 6.7 Ca Management

6.1 INTRODUCTION

- Calsium is macro nutrient (essential and required in high amount)
- Calsium in acid mineral soil is limiting factor for high crop productivity.
- Ca deficiency : in Inceptisol, Ultisol, soil developed from quart, acid mineral soil. Why …?
- Ca excess in soil developed from limestone.
- How to manage Ca?

6.1 INTRODUCTION

- Scr umum, Ca dalam tanah sering ketersediaannya rendah dan tidak mencukupi kebutuhan Ca untuk produksi tanaman yang tinggi.
- Akibatnya tanaman sering menunjukkan gejala defisiensi Ca
- Oki, utk produksi yang tinggi perlu penambahan Ca
- Ca sering ditambahkan dalam kegiatan ameliorasi
- Bgm pengelolaan Ca yang efektif dan efisien, faktor-faktor apa saja yang mempengaruhi efektivitas dan efisiensi tersebut?.

6.2. FUNCTIONS & FORMS OF Ca IN PLANTS

Secondary nutrients

Calcium (Ca^{2+})	Component of cell walls; cell growth and cell division; cofactor for some enzymes	Failure in the development of terminal bud, dead spots in the mid rib of some plants. In corn, tip of the new leaves may be covered with a sticky, gelantinous material that causes them to adhere to one another

6.2. FUNCTIONS & FORMS OF Ca IN PLANTS

- **Role of nutrient in plant growth:**

  Required for cell wall rigidity, cell division of meristems and root tips, normal mitosis, membrane function, acts as a secondary messenger, aids in storage of phosphates in vacuoles, actively involved in photosynthesis and found in the endoplasmic reticulum

- **Role in microbial growth:**

  Needed for Rhizobium and Azotobacter

Ca in Plant

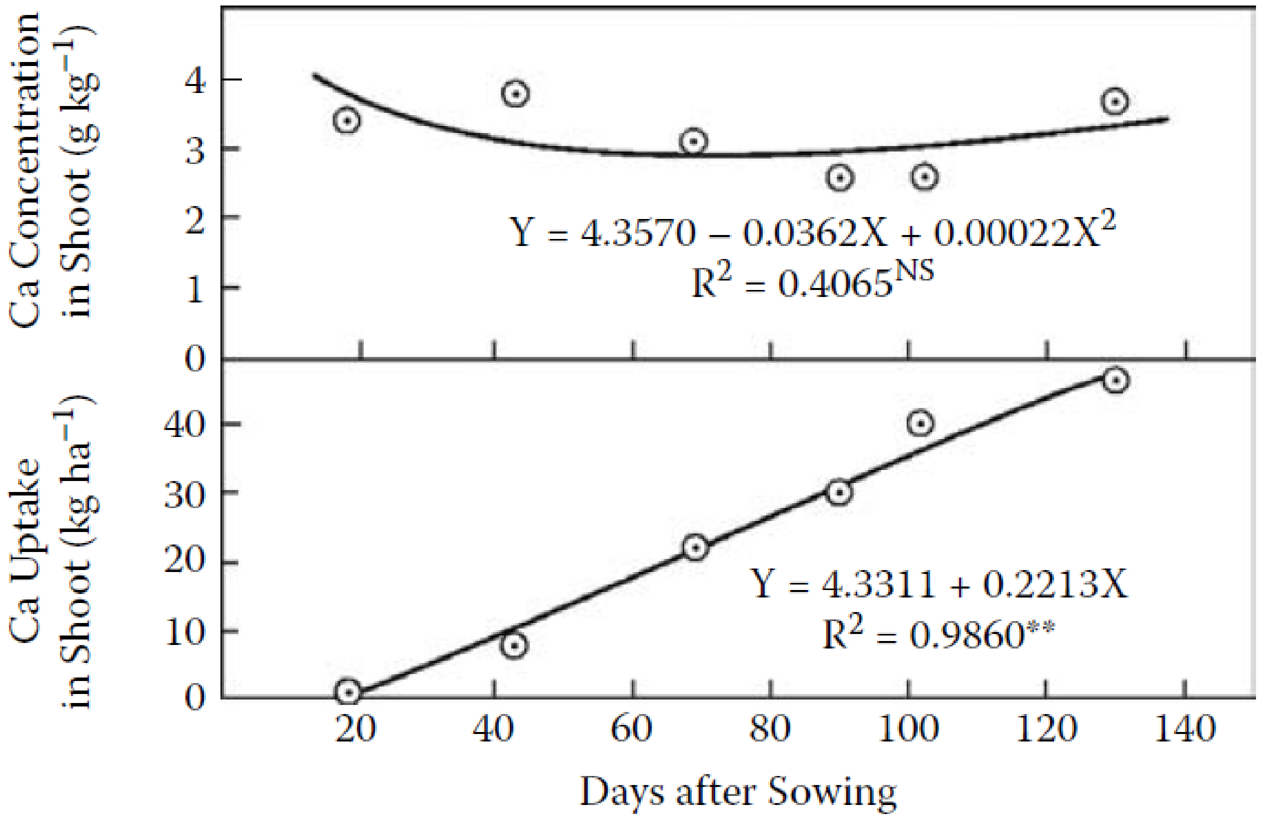


FIGURE 5.1 Relationship between plant age and calcium concentration and uptake in upland rice shoot.

Ca in Plant

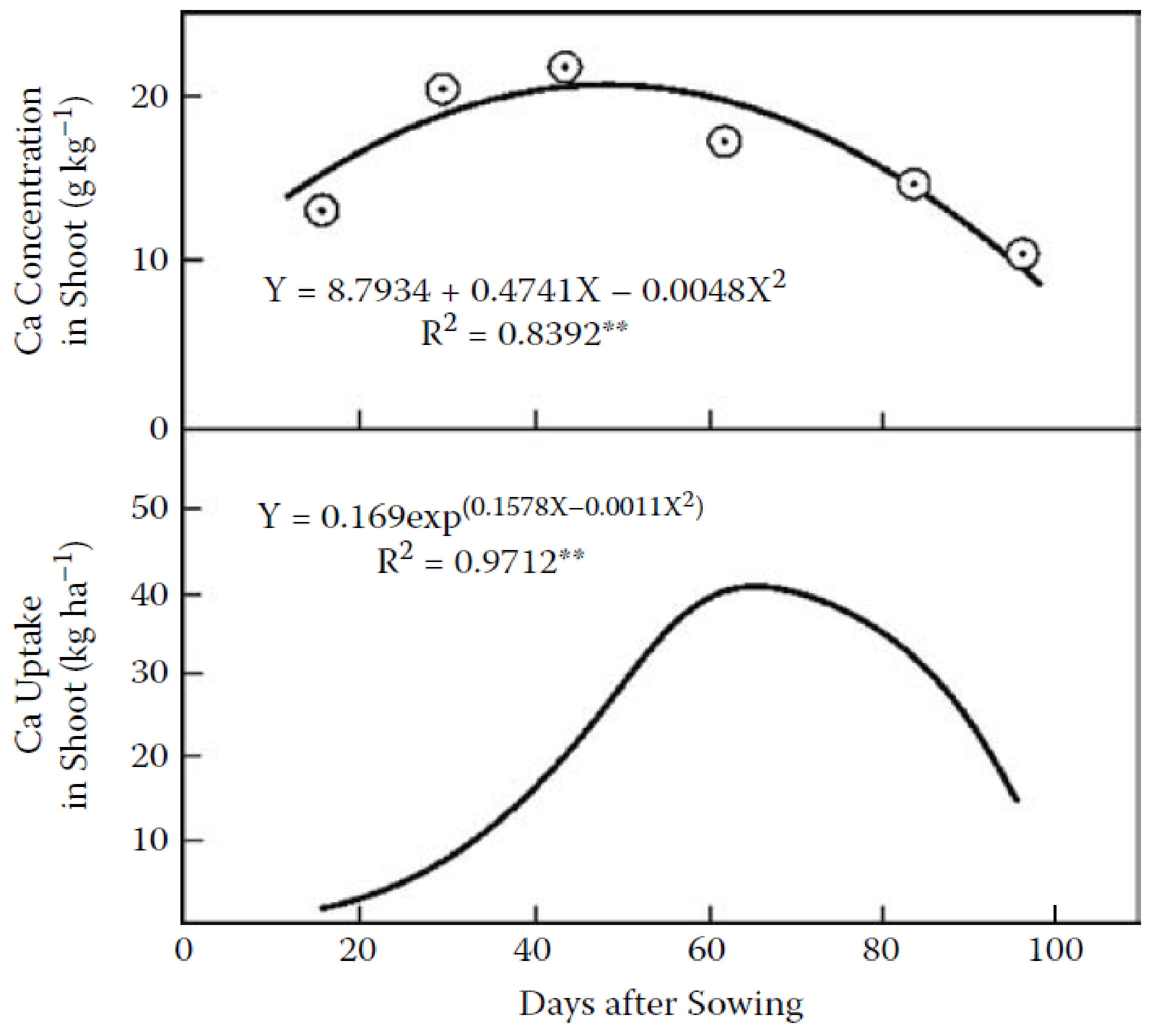


FIGURE 5.2 Relationship between plant age and calcium concentration and uptake in dry bean shoot.

TABLE 5.1
Deficient and Adequate Concentrations of Calcium in Leaves and Shoots of Various Plant Species

Plant Species	Plant Part	Type of Culture	Concentration in Dry Matter (mg kg^{-1}) Deficient	Adequate	Reference	Comments
Avena sativa L. (oat)	Tops	Pot culture, soil	1100–1400	2600	88	Plants at flowering
	Straw	Sand culture	1000–1400	3600–6400	88	At harvest
Bromus rigidus Roth	Shoot	Flowing nutrient solution	900	1010	81	Plants grown in 0.3 and 1000 mmol m^{-3} Ca^{2+}, respectively
Capsicum annuum L. (pepper)	Leaves	Nutrient solution		Up to 30000 5000	89	Mature leaves Juvenile leaves
Citrus aurantium L. (orange)	Leaves Shoots	Sand culture	1400–2000 2300–2800	14800 11700	88	Measurements taken in September
Ficus carica L. (fig)	Leaves	Orchard		30000 30000 29000 35000	90	Values for May, July, September and October. 10 trees surveyed in 9 areas of 2 orchards, for 3 years
Fragaria x ananassa Duchesne (strawberry)	Leaves	Sand culture	2300/9000	15000	91	'Adequate' plants had 1% of leaves with tipburn. 'Deficient' plants had 33.2% of leaves with tipburn (plants supplied 1/40th control Ca and 3x K) or 9% of leaves with tipburn (plants supplied control Ca and 3x K)
Hordeum vulgare L. (barley)	Shoots	Flowing nutrient solution	1100	7300	81	Plants grown in 0.3 and 1000 mmol m^{-3} Ca^{2+}, respectively
Linum usitatissimum L. (flax)	Tops	Field	2000–4500	3700–5200	88	
Lolium perenne L. (perennial ryegrass)	Shoots	Flowing nutrient solution	600	10800	81	Plants grown in 0.3 and 1000 mmol m^{-3} Ca^{2+}, respectively
Lupinus angustifolius L.	Shoots	Flowing nutrient solution	1400	13900	81	Plants grown in 0.3 and 1000 mmol m^{-3} Ca^{2+}, respectively
Lycopersicon esculentum Mill. (tomato)	Leaf blade	Sand culture	1700	16100	36	Upper leaves (yellow in deficient plants)
	Leaf blade		11000	38400		Lower leaves (still green in deficient plants)
	Petioles		1100	10800		Upper petioles
	Petioles		2600	22300		Lower petioles
	Stem		Trace	6700		Upper stems

TABLE 5.1 *(Continued)*

Plant Species	Plant Part	Type of Culture	Concentration in Dry Matter ($mg\ kg^{-1}$) Deficient	Adequate	Reference	Comments
	Stem		5300	9900		Lower stems
	Shoots	Flowing nutrient solution	2700	24900	81	Plants grown in 0.3 and 1000 mmol m^{-3} Ca^{2+}, respectively
Malus pumila Mill. [*M. domestica* Borkh.] (apple)	Leaves		7200		88	Leaves of terminal shoot, stated value below which deficiency symptoms occur
Medicago sativa L. (alfalfa)	Shoots	Flowing nutrient solution	1100	15000	81	One cultivar, in 0.3 and 1000 mmol m^{-3} Ca^{2+}, respectively
Nicotiana tabacum L. (tobacco)	Leaves	Field trial	9400–13000	13300–24300	88	
Phaseolus lunatus L. (lima bean)	Stem		6000	9000	88	Poor seed set below first value, good seed set above second value
Prunus persica (L.) Batsch (peach)	Leaves	Orchard		14500 17000 18200	92	Soil pH 5.6 Soil pH 5.9 Soil pH 6.2
Prunus insititia L. *Prunus domestica* L. *Prunus salicina* (Lindl.) × *Prunus cerasifera* (Ehrh.) (plum)	Leaves	Nutrient solution		5300/8200 6600/10300 6300/10100	93	Values for days 45 and 96
Secale cereale L. (rye)	Shoots	Flowing nutrient solution	900	8300	81	Plants grown in 0.3 and 1000 mmol m^{-3} Ca^{2+}, respectively
Solanum tuberosum L. (potato)	Young leaves	Nutrient solution	Below 900	Above 4500	18	21-day-old plants
Trifolium subterraneum L. (subterranean clover)	Shoots	Flowing nutrient solution	1400	19100	81	One cultivar, in 0.3 and 1000 mmol m^{-3} Ca^{2+}, respectively
Triticum aestivum L. (wheat)	Shoots	Flowing nutrient solution	800	4700	81	One cultivar, in 0.3 and 1000 mmol m^{-3} Ca^{2+}, respectively
Zea mays L. (corn)	Shoots	Flowing nutrient solution	300	9200	81	Plants grown in 0.3 and 1000 mmol m^{-3} Ca^{2+}, respectively

Note: Values in dry matter.

TABLE 5.2
Deficient and Adequate Concentrations of Calcium in Fruits of Various Plant Species

Plant Species	Plant Part	Type of Culture	Concentration in Fresh Matter (mg kg^{-1}) Deficient	Adequate	Reference	Comments
Capsicum annuum L. (pepper)	Fruits	Nutrient solution		1500–1800 (dry wt)	86	Proximal pericarp tissue
				1000–1200 (dry wt)		Distal pericarp tissue (healthy)
			600 (dry wt)			Distal pericarp tissue (BER-affected)
Cucumis sativus L. (cucumber)	Fruits	Rockwool and nutrient solution		3000–6000 (dry wt)	87	Range of values according to salinity treatment and size of fruit
Fragaria x ananassa Duchesne (strawberry)	Fruits	Sand culture		65/120/201 (559/1192/2060) (dry wt)	91	Values from left to right for plants that had 33.2% of leaves with tipburn (plants supplied 1/40th control Ca and 3x K), 9% of leaves with tipburn (plants supplied control Ca and 3x K) 1% of leaves with tipburn (control)
Lycopersicon esculentum Mill. (tomato)			210/240 (dry wt)	280 (dry wt)	94	For 'deficient' values, first value is for an experiment in which 44.5% of fruit had BER, second value for an experiment in which 18.9% of fruit had BER. For 'adequate' value 0.9% of fruit had BER
Malus pumila Mill. [*M. domestica* Borkh.] (apple) cv Jonagold	Fruitlets in July	34 different orchards	105	190	95	Fruitlets with 'deficient' concentration showed much higher incidence of physiological disorders in storage
cv Cox's Orange Pippin	Fruit at harvest	Orchard grown	33 36 38	64 64 62	45	Range found in fruit harvested in 3 consecutive years. Fruit with the lower values had higher incidence of bitter pit
cv Cox's Orange Pippin			45		96	Minimum level for recommending fruit for controlled atmosphere storage. Below this level bitter pit is common
Pyrus communis (pear)	Fruit	4 Orchards	60	76	97	Values of 60 and 67 mg kg^{-1} fresh weight in fruit from different orchards linked with high incidence of internal breakdown and cork spot

Note: Values in fresh matter, unless shown to contrary.

TABLE 5.2
Adequate Calcium Concentration in Tissues of Principal Field Crops

Crop Species	Plant Part and Growth Stage	Adequate Ca Conc. (g kg^{-1})
Wheat	Whole tops at heading	2–5
Barley	Whole tops at heading	3–12
Rice	Whole tops 100 days after sowing	2.5–4
Corn	Whole tops at 30 to 45 days after emergence	9–16
Corn	Ear leaf blade at silking	2.1–5
Sorghum	Whole tops at seedling	9–13
Sorghum	Whole tops at early vegetative	1.5–9
Sorghum	3rd blade below panicle at bloom	2–6
Soybean	Upper fully developed trifoliate prior to pod set	3.6–20
Dry bean	Upper fully developed trifoliate at early flowering	15–25
Cowpea	Petiole of uppermost mature leaf blade at early flowering	7.2–10

Source: Adapted from Fageria et al. (1997).

TABLE 5.3

Shoot Dry Weight, Grain Yield, and Uptake of Ca^{2+} by Principal Field Crops

Crop Species	Shoot Dry Wt. (kg ha^{-1})	Grain Yield (kg ha^{-1})	Ca^{2+} Uptake in Shoot (kg ha^{-1})	Ca^{2+} Uptake in Grain (kg ha^{-1})	Total (kg ha^{-1})
Upland rice	6642	4794	27	2	29
Lowland rice	8093	5000	20	4	24
Lowland rice	9423	6389	26	5	31
Corn	13670	8148	34	8	42
Dry bean	2200	3409	22	9	31
Dry bean	1773	1674	21	5	26
Soybean	2901	1323	48	5	53
Soybean	3244	3102	41	12	53

Source: Fageria and Baligar (2001); Fageria (2004); Fageria and Santos (2008); Fageria et al. (2007).

TABLE 5.5

Calcium Harvest Index in Principal Field Crops

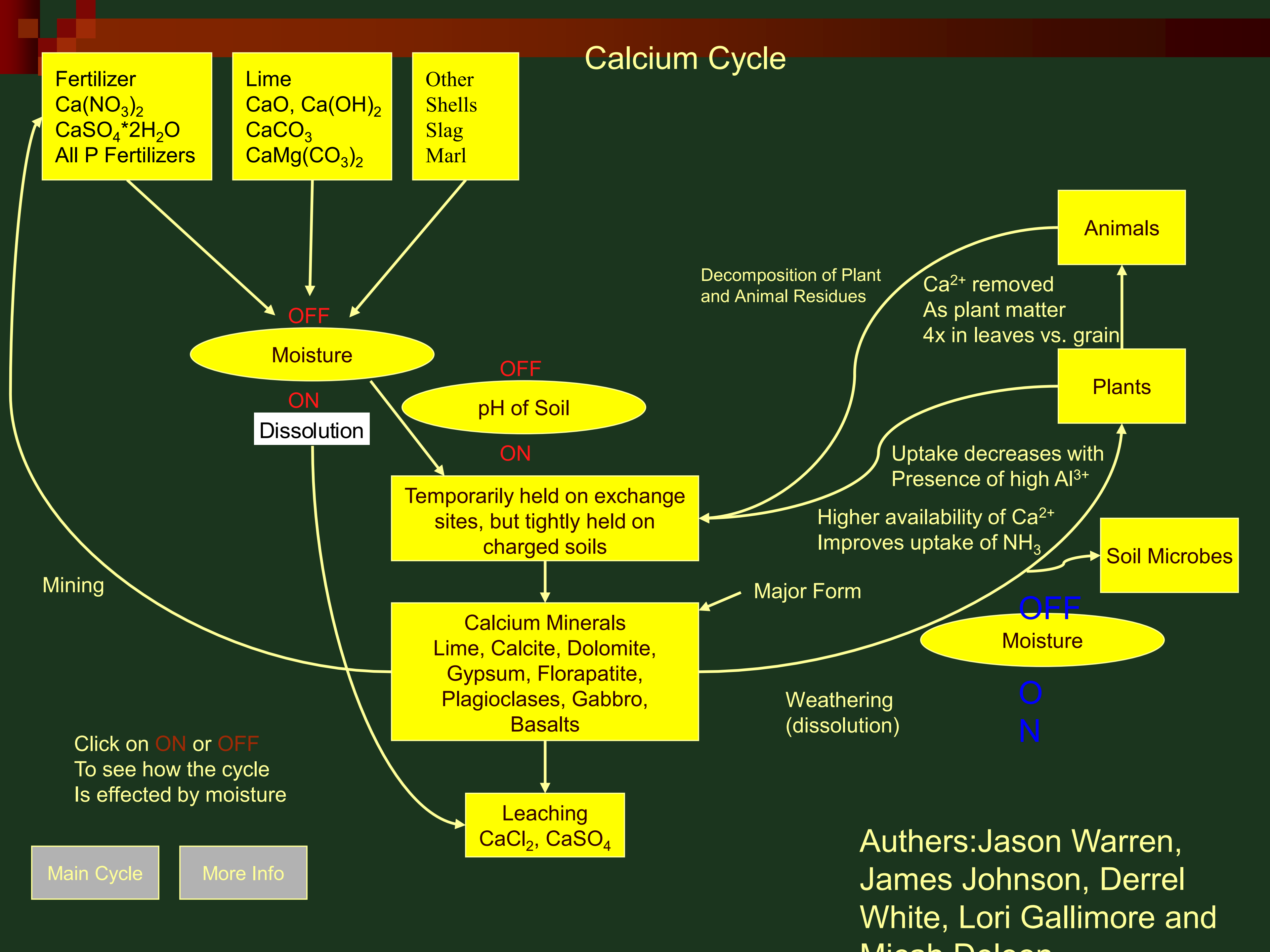
Crop Species	Ca Harvest Index (%)
Upland rice	7
Lowland rice	17
Lowland rice	16
Corn	19
Dry bean	29
Dry bean	19
Soybean	23

Note: Calcium harvest index (%) = (Ca uptake in grain/Ca uptake in grain plus straw) × 100.

8.3 Ca Cycles

- Input: soil Ca sources
- Output: Soil Ca loss
- Process: Ca behaviour in soil

8.3 Ca cycles



Calcium Cycle
Fertilizer
Ca(NO3)2
CaSO4*2H2O
All P Fertilizers
Lime
CaO, Ca(OH)2
CaCO3
CaMg(CO3)2
Other
Shells
Slag
Marl
OFF
Moisture
ON
Dissolution
OFF
pH of Soil
ON
Temporarily held on exchange sites, but tightly held on charged soils
Calcium Minerals
Lime, Calcite, Dolomite, Gypsum, Florapatite, Plagioclases, Gabbro, Basalts
Leaching
CaCl2, CaSO4
Mining
Decomposition of Plant and Animal Residues
Animals
Ca2+ removed
As plant matter
4x in leaves vs. grain
Plants
Uptake decreases with
Presence of high Al3+
Higher availability of Ca2+
Improves uptake of NH3
Soil Microbes
Major Form
OFF
Moisture
ON
Weathering
(dissolution)
Click on ON or OFF
To see how the cycle
Is effected by moisture
Main Cycle
More Info
Authers:Jason Warren, James Johnson, Derrel White, Lori Gallimore and Micah Dolson

8.3 Ca cycles

Dalam studi kesuburan tanah, siklus Ca ditinjau dari 3 aspek yaitu: input ke-, output dari- dan proses dalam tanah.

INPUT

1. Residu tanaman
2. Pupuk Ca
3. Kotoran hewan/binatang
4. Deposisi udara
5. Pelapukan batuan ber Ca

8.3 Ca cycles

- Output:

1. Terangkut panen
2. Run off dan erosi
3. Pencucian

8.3 Ca cycles

- Process:

1. Ca organik mengalami dekomposisi
2. Ca anorganik:

   a. Diambil tanaman dan biota tanah

   b. Diikat oleh komponen tanah: liat, logam (Al, Fe, Zn… Ca, .. Dll)

8.4. SOIL Ca RESOURCES

1. Pant Residue
2. Ca fertilizer
3. Animal manure/residue
4. Ash (Abu TKKS)
5. Atmosferic Depostion
6. Rock P weathering

Table 9.6 Summary of Compounds Formed from the Reaction of Phosphate Fertilizers with Soils or Soil Constituents (Continued)

Compound	Mineral name	Compound	Mineral name
$Ca_{10}(PO_4)_6(OH)_2$	Hydroxyapatite	$Ca(NH_4)_2P_2O_7 \cdot H_2O$	—
$Ca_{10}(PO_4)_6F_2$	Fluorapatite	$Ca_3(NH_4)_2(P_2O_7)_2 \cdot 6H_2O$	—
$CaAlH(PO_4)_2 \cdot 6H_2O$	—	$Ca_5(NH_4)_2(P_2O_7)_3 \cdot 6H_2O$	—
$CaAl_6H_4(PO_4)_3 \cdot 20H_2O$	—	$CaNH_4HP_2O_7$	—
$CaNH_4PO_4 \cdot H_2O$	—	$Ca_2NH_4H_3(P_2O_7)_2 \cdot 3H_2O$	—
$Ca(NH_4)_2(HPO_4)_2 \cdot H_2O$	—	$CaK_2P_2O_7$	—
$Ca_2NH_4H_7(PO_4)_4 \cdot 2H_2O$	NH_4-Flatt's salt	$Ca_3K_2(P_2O_7)_2 \cdot 2H_2O$	—
$Ca_2(NH_4)_2(HPO_4)_3 \cdot 2H_2O$	—	$Ca_6K_2(P_2O_7)_3 \cdot 6H_2O$	—
$CaKPO_4 \cdot H_2O$	—	$Ca_2KH_3(P_2O_7)_2 \cdot 3H_2O$	—
$CaK_3H(PO_4)_2$	—	$CaNa_2P_2O_7 \cdot 4H_2O$	—
$Ca_2KH_7(PO_4)_4 \cdot 2H_2O$	K-Flatt's salt	$Fe(NH_4)_2P_2O_7 \cdot 2H_2O$	—
$CaFe_2H_4(PO_4)_4 \cdot 5H_2O$	—	$Mg(NH_4)_2P_2O_7 \cdot 4H_2O$	—
$CaFe_2H_4(PO_4)_4 \cdot 8H_2O$	—	$Mg(NH_4)_6(P_2O_7)_2 \cdot 6H_2O$	—
$Ca_3Mg_3(PO_4)_4$	—	$Mg(NH_4)_2H_4(P_2O_7)_2 \cdot 2H_2O$	—
$FePO_4 \cdot 2H_2O$	Strengite	$Ca(NH_4)_3P_3O_{10} \cdot 2H_2O$	—

From Sample et al., 1986. *The Role of Phosphorus in Agriculture*, Khasawneth, F.E., Sample, E.C., and Kamprath, E.J., Eds., p. 284. With permission of American Society of Agronomy.

SOIL Ca LOSS

1. Run off and erosion
2. Leaching
3. Removal by crop harvest

2. Leaching

Table 12.1 Estimated Annual Ca and Mg Drainage Losses from a Sandy, Loam Soil in Orchard Lysimeters at Summerland, B.C.

Vegetation	1978	1979	1980
Calcium (kg ha^{-1} yr^{-1})			
Grass[a] cover	259	117	367
No grass	1045	275	578
Magnesium (kg ha^{-1} yr^{-1})			
Grass cover	82	35	136
No grass	293	71	194
Precipitation and irrigation (mm)			
Precipitation	330	240	320
Irrigation[b]	670	690	860

[a] Kentucky bluegrass (*Poa pratensis*).

[b] Irrigation water generally contained 28×10^{-6} kg Ca L^{-1}, and 9×10^{-6} kg Mg L^{-1}.

Adapted from Nielsen and Stevenson (1983).

8.5. SOIL Ca

TABLE 5.3

Calcium Concentration, Cation Exchange Capacity and pH of Top Layers of Some Representative Soils

Soil	Soil Order	Ca^{2+} Concentration (mmol kg^{-1})	CEC ($cmol_c$ kg^{-1})	pH
Typic Cryoboralf, Colorado, 0–18 cm depth	Alfisol	30.5	13.3	5.9
Typic Gypsiorthid, Texas, 5–13 cm depth	Aridisol	100.0	21.6	7.9
Typic Ustipsamment, Kansas, 0–13 cm depth	Entisol	9.5	52.0	6.6
Typic Dystrochrept, West Virginia, 5–18 cm depth	Inceptisol	5.0	11.4	4.9
Typic Argiustoll, Kansas, 0–15 cm depth	Mollisol	73.5	23.8	6.6
Typic Acrustox, Brazil, 0–10 cm depth (low CEC below 65 cm)	Oxisol	2.1	20.5	5.0
Typic Haplorthod, New Hampshire, 0–20 cm depth	Spodosol	14.5	25.7	4.9
Typic Umbraquult, North Carolina, 0–15 cm depth	Ultisol	2.0	26.2	3.9
Typic Chromoxerert, California, 0–10 cm depth	Vertisol	84.0	24.6	7.8

Source: Data from USDA, *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*. Agricultural Handbook Number 436. Washington, DC: USDA, 1975.

8.5. SOIL Ca

- **Content present in soils:**
  - Tropical soils: 0.1-0.3%
  - Temperate soils: 0.7-1.5%
  - Calcareous soils: >3.0%
  - Largely dependent on parent material of soil and rainfall

8.5. SOIL Ca

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)

				Exchangeable cations ($cmol_c\ kg^{-1}$)					
Treatment	Depth (m)	pH H_2O	OC ($g\ kg^{-1}$)	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.

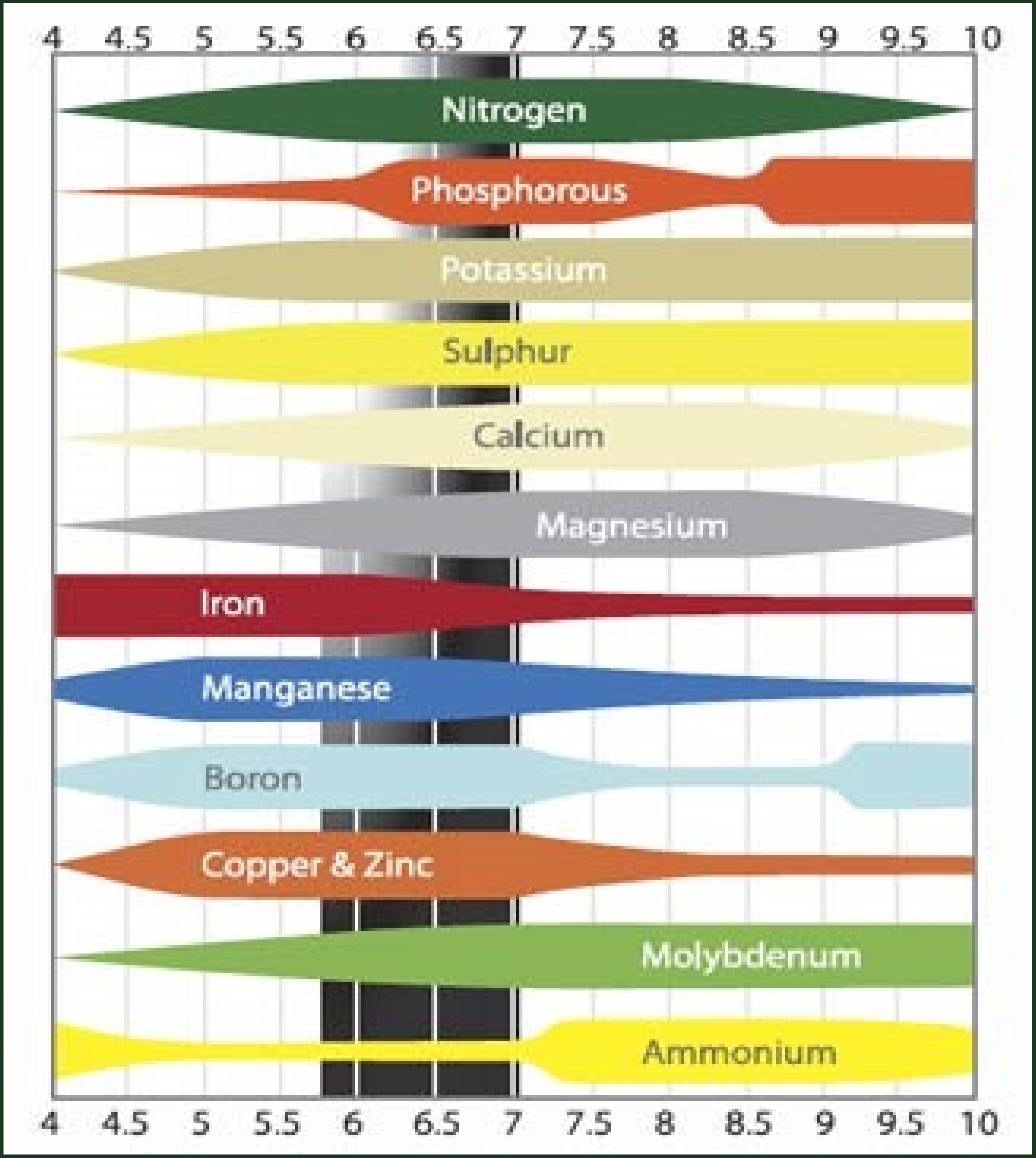
8.6. SOIL Ca AVAILABILITY

8.6.1 Factors affecting Soil Ca availability

Release of Ca^{2+} or Mg^{2+} from the exchange complex and their availability to crop plants depends upon the following factors; a number of these are interdependent:

1. Total Ca or Mg supply
2. Type of clay minerals present
3. Cation exchange capacity (CEC) of soil
4. Percentage saturation of CEC with Ca^{2+} or Mg^{2+}
5. Soil pH
6. Ratio of Ca^{2+} or Mg^{2+} to other cations in soil solution

Soil pH



4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
Nitrogen
Phosphorous
Potassium
Sulphur
Calcium
Magnesium
Iron
Manganese
Boron
Copper & Zinc
Molybdenum
Ammonium

Soil pH

- **Effect of pH on availability:**
  Depends on mineral
- **Sources of Calcium:**
  - Lime (CaO) ($Ca(OH)_2$), Calcite ($CaCO_3$), Dolomite ($CaMg(CO_3)_2$, Gypsum ($CaSO_4 \cdot 2H_2O$), any Phosphorus fertilizer, Anorthite ($CaAl_2Si_2O_3$), biotite, apatite, augite & hornblende.

OM DECOMPOSITION & MINERALISATION

- Organic matter decomposition & mineralisation determine by:

  a. OM quality

  b. Decomposer

  c. Environment

8.7. AGRONOMIC ROLE OF Ca

5.5.1 Effect of Ca on growth and production

TABLE 5.1
Influence of Soil pH on Root Growth of Wheat and Dry Bean Grown on Brazilian Oxisol

Soil pH in H_2O	Root Dry Weight of Wheat (g $plant^{-1}$)	Root Dry Weight of Dry Bean (g $plant^{-1}$)
4.1	1.21	0.48
4.7	2.51	0.89
5.3	2.95	1.17
5.9	2.97	1.35
6.6	2.75	1.18
7.0	2.77	0.95

Regression Analysis

Soil pH (X) vs. root dry wt. of wheat (Y) = $-14.5996 + 5.9145X - 0.4937X^2$, $R^2 = 0.9323^*$

Soil pH (X) vs. root dry wt. of dry bean (Y) = $-7.8220 + 3.0959X - 0.2627X^2$, $R^2 = 0.9856^{**}$

*, **Significant at the 5 and 1% probability level, respectively.

Source: Adapted from Fageria and Zimmermann (1998).

8.7. AGRONOMIC ROLE OF Ca

5.5.1 Effect of Ca on growth and production

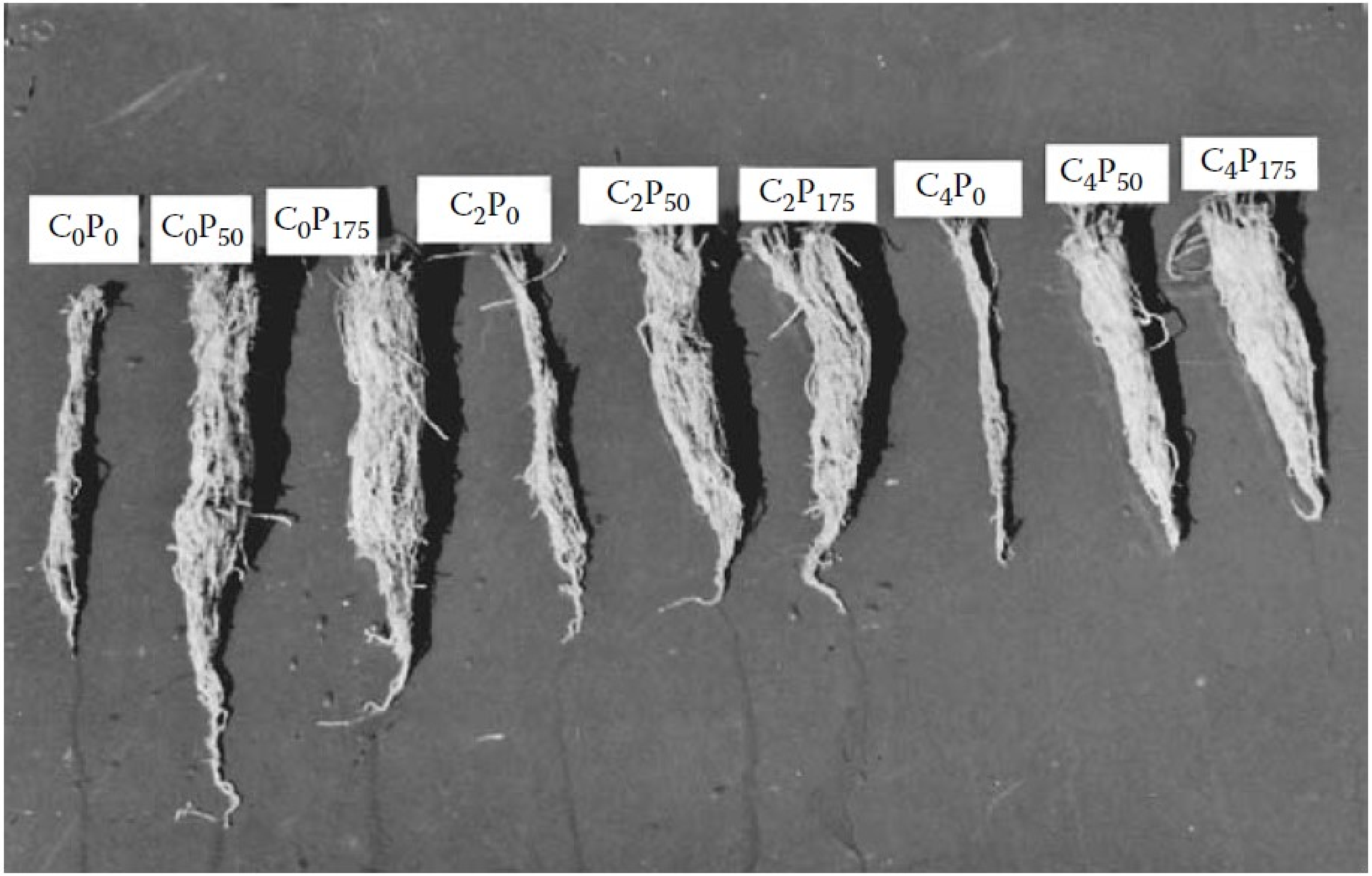


FIGURE 5.3 Root growth of rice at three lime rates and three P levels. Lime rates were 0, 2, and 4 g kg^{-1} of soil and P levels were 0, 50, and 175 mg kg^{-1} of soil.

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)

TABLE 5.6

Shoot Dry Weight of Upland Rice Dry Bean and Corn under Different Lime and P Rates

Lime Rate ($g\ kg^{-1}$)	P Rate ($mg\ kg^{-1}$)	Upland Rice Shoot Dry Wt. ($g\ pot^{-1}$)	Dry Bean Shoot Dry Wt. ($g\ pot^{-1}$)	Corn Shoot Dry Wt. ($g\ pot^{-1}$)
0	0	0.72	1.25	1.10
0	50	15.08	8.30	4.93
0	175	18.63	10.60	8.73
2	0	0.73	1.30	1.43
2	50	15.23	9.00	7.13
2	175	13.23	10.60	11.47
4	0	0.33	1.70	1.10
4	50	10.20	10.50	6.60
4	175	13.20	12.00	9.93

Source: Adapted from Fageria et al. (1995).

TABLE 5.8
Soil pH, Ca, Mg, and Al Contents as Influenced by Liming in Brazilian Oxisol

Lime Rate (Mg ha^{-1})	pH in H_2O	Ca^{2+} ($cmol_c\ kg^{-1}$)	Mg^{2+} ($cmol_c\ kg^{-1}$)	Al^{3+} ($cmol_c\ kg^{-1}$)
18 Days after Sowing of Upland Rice				
0	5.0	1.07	0.38	0.62
3	5.3	1.33	0.72	0.28
6	5.6	1.90	0.99	0.13
9	5.9	2.18	1.32	0.10
12	6.0	2.51	1.49	0.08
67 Days after Sowing of Upland Rice				
0	5.0	1.17	0.33	0.52
3	5.4	1.60	1.09	0.26
6	5.6	2.09	1.53	0.12
9	5.8	2.52	1.78	0.07
12	6.0	2.91	2.35	0.04

Regression Analysis across Two Sampling Dates

Lime rate (X) vs. pH (Y) = $5.0085 + 0.1309X - 0.0039X^2$, $R^2 = 0.9920$**

Lime rate (X) vs. Ca (Y) = $1.1180 + 0.1353X$, $R^2 = 0.9940$**

Lime rate (X) vs. Mg (Y) = $0.4480 + 0.1253X$, $R^2 = 0.9860$**

Lime rate (X) vs. Al (Y) = $0.554 - 0.1009X + 0.0051X^2$, 0.9870**

* Significant at the 1% probability level.

Source: Adapted from Fageria et al. (1991).

5.5. AGRONOMIC ROLE OF Ca

5.5.1 Effect of Ca on growth and production

Table 12.2 Effect of Various Gypsum Amendments on Pod Yields and Grades in Peanut on Lakeland Soil in Georgia

Gypsum materials	Pod yield[a] (Mg ha^{-1})	SMK[b] (%)
Crystalline	4.48 a[c]	70 a
Fine powder (wet)	4.38 ab	69 a
Coarse powder	4.11 abc	68 a
Fine powder (dry)	3.86 abc	68 a
Granular 1	3.46 abc	70 a
Granular 2	3.30 bc	68 a
Pelleted	3.10 c	67 a
Control (no gypsum)	3.03 c	61 b

[a] Adjusted to 7% moisture.

[b] Sound, mature kernels.

[c] The means followed by same letter are not significantly different at $p = 0.10$.

Adapted from Alva et al. (1989).

5.5. AGRONOMIC ROLE OF Ca

5.5.1 Effect of Ca on growth and production

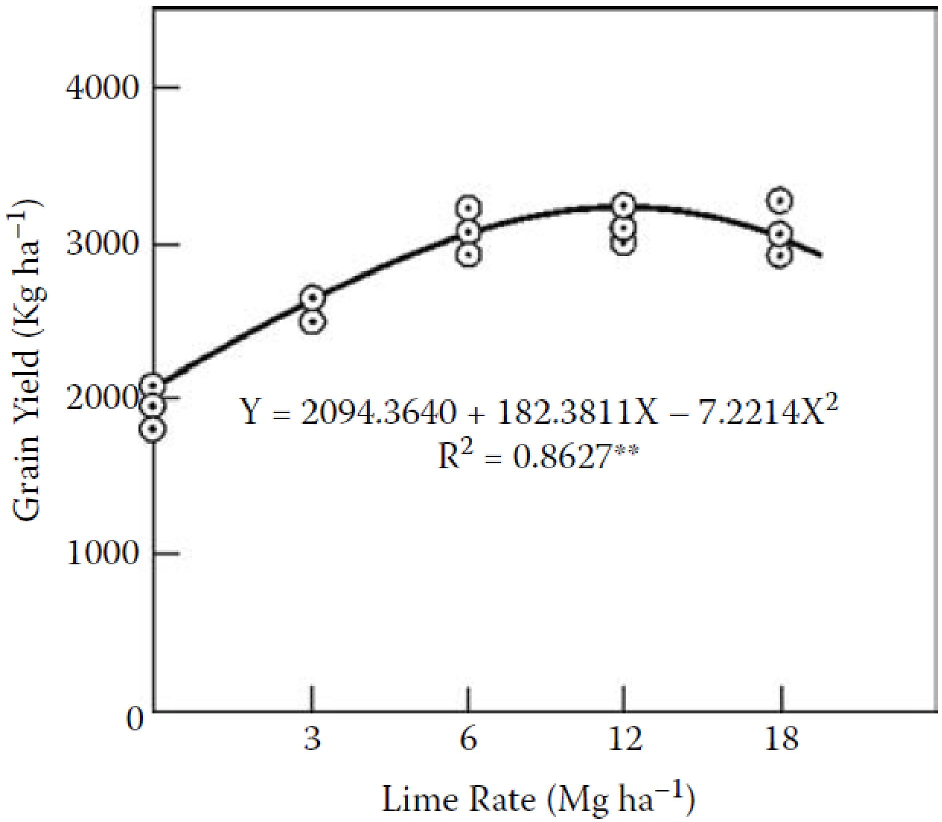


FIGURE 5.4 Relationship between lime rate and grain yield of soybean grown on Brazilian Oxisol. Values are averages of 3-year field trial.

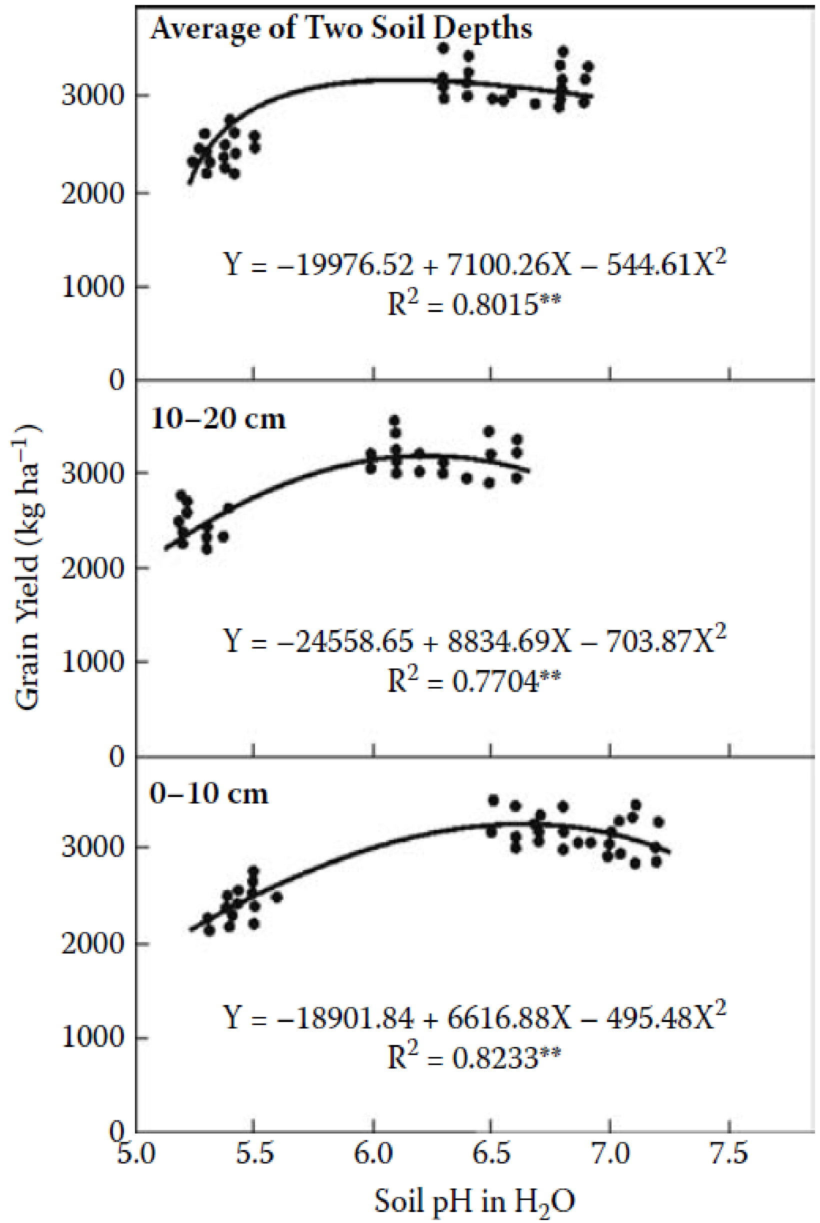


FIGURE 5.5 Relationship between soil pH and grain yield of dry bean. Values are averages of five field trails conducted for 3 years (Fageria, 2008).

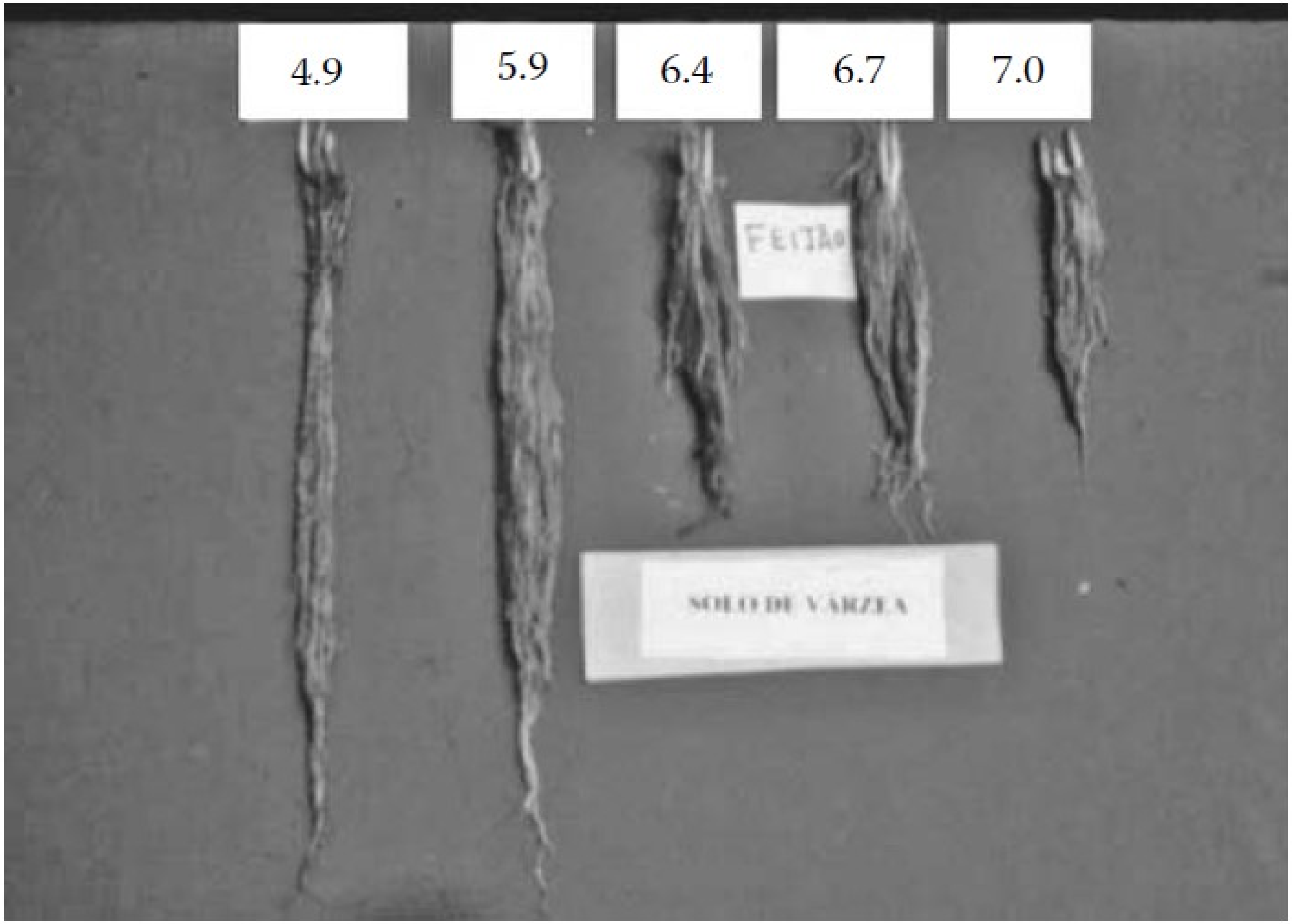


FIGURE 5.6 Influence of soil pH on root growth of dry bean.

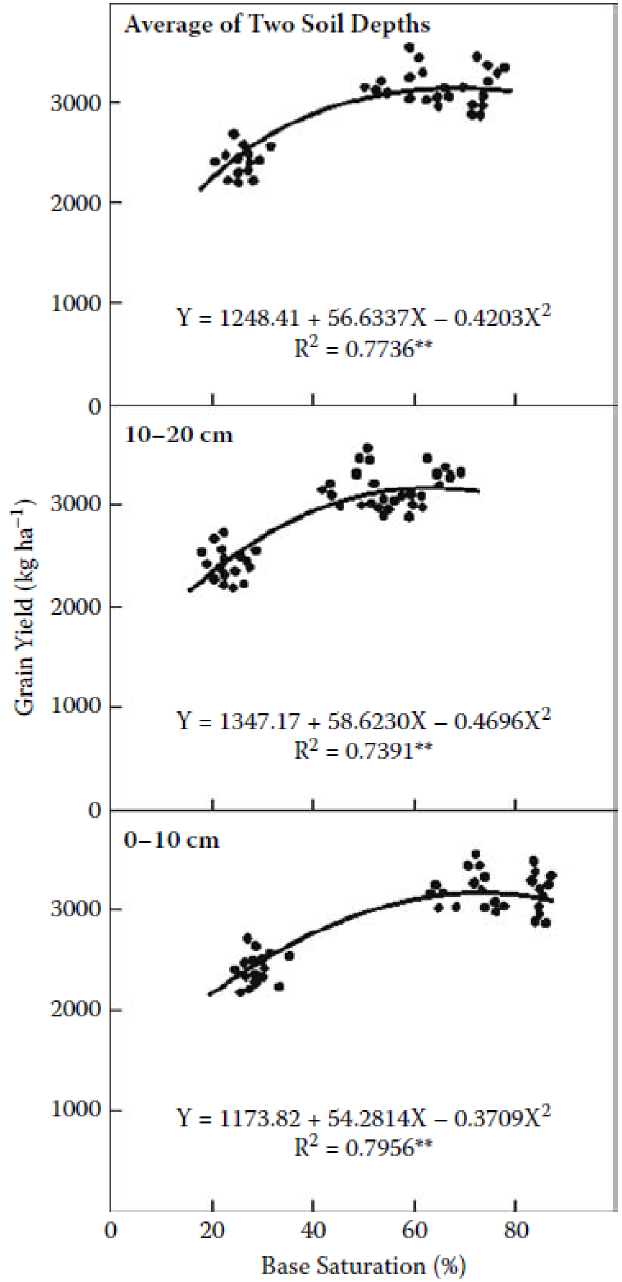


FIGURE 5.7 Relationship between base saturation and grain yield of dry bean. Values are averages of five field trails conducted for 3 years (Fageria, 2008).

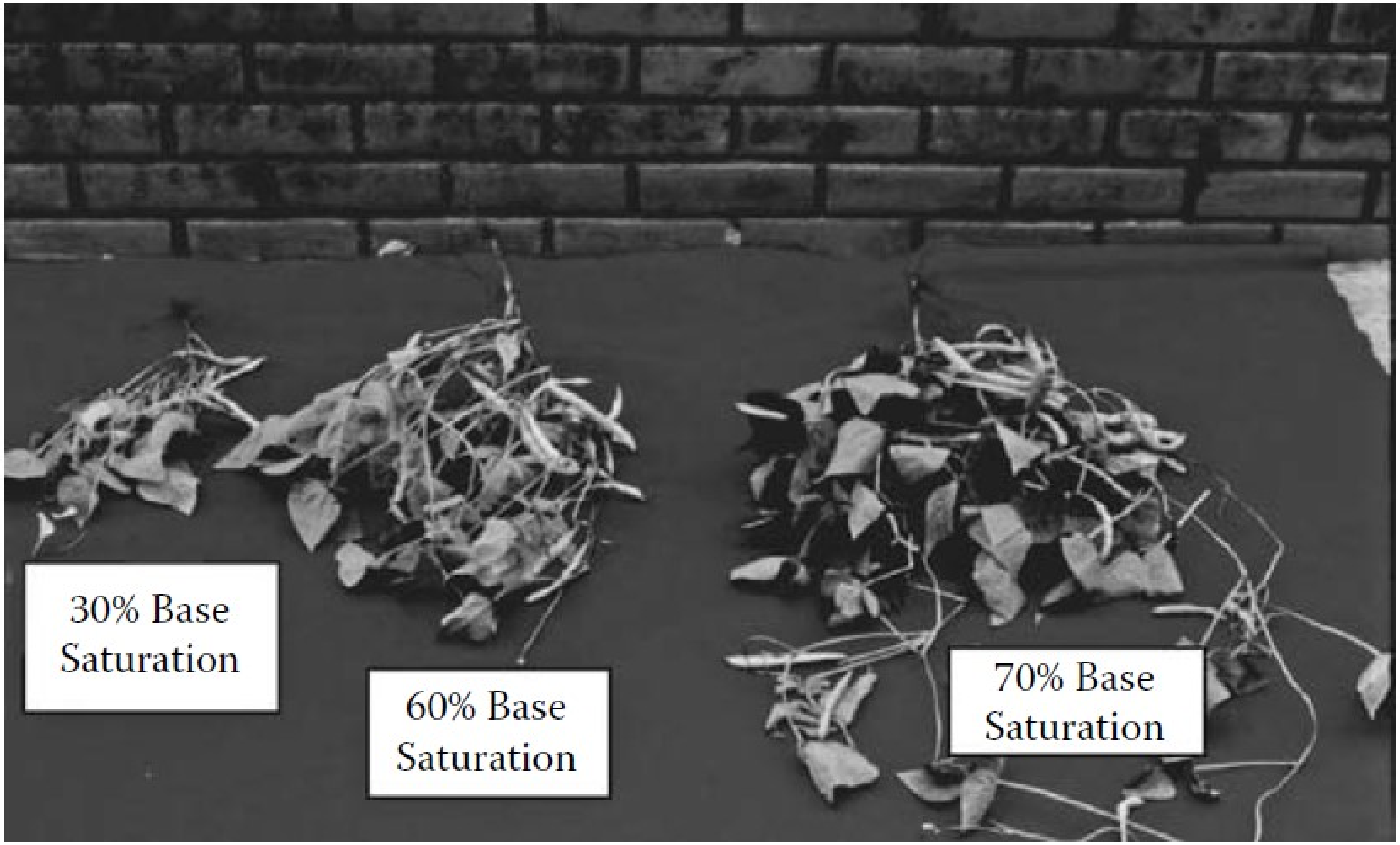


FIGURE 5.8 Dry bean plant growth at 30% base saturation (left), 60% base saturation (middle), and 70% base saturation (right) grown on a Brazilian Oxisol.

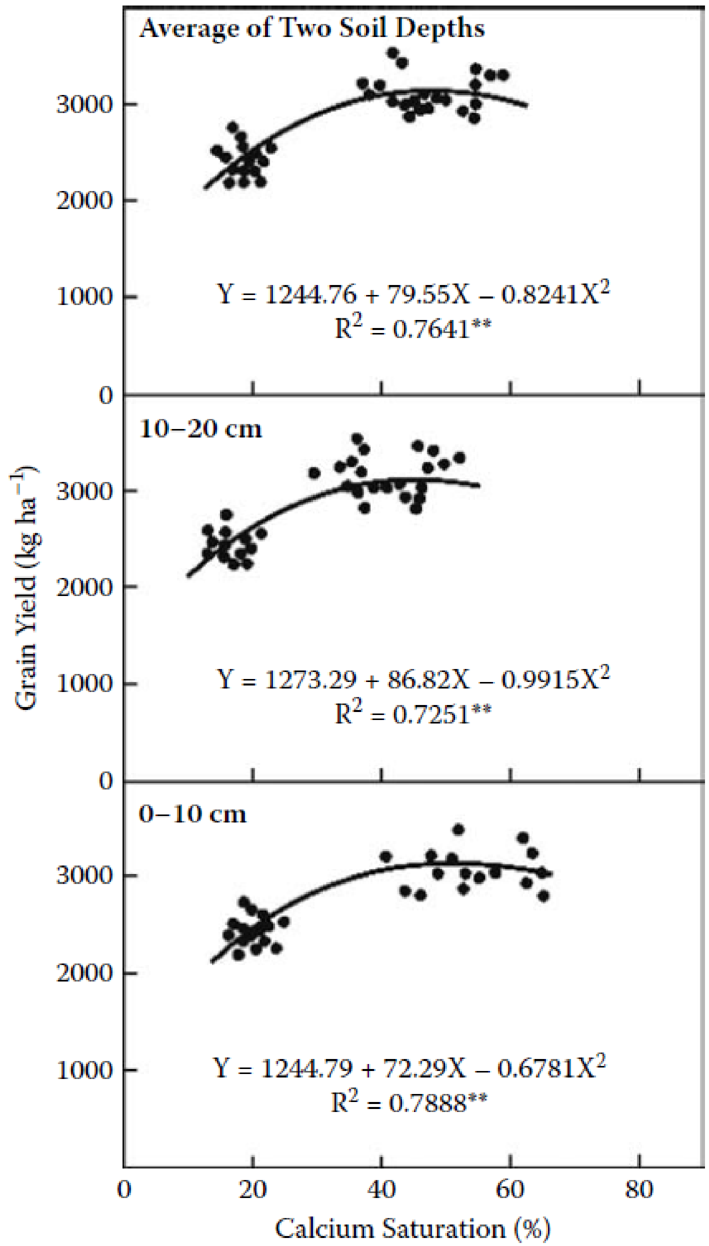


FIGURE 5.9 Relationship between calcium saturation and grain yield of dry bean. Values are averages of five field trails conducted for 3 years (Fageria, 2008).

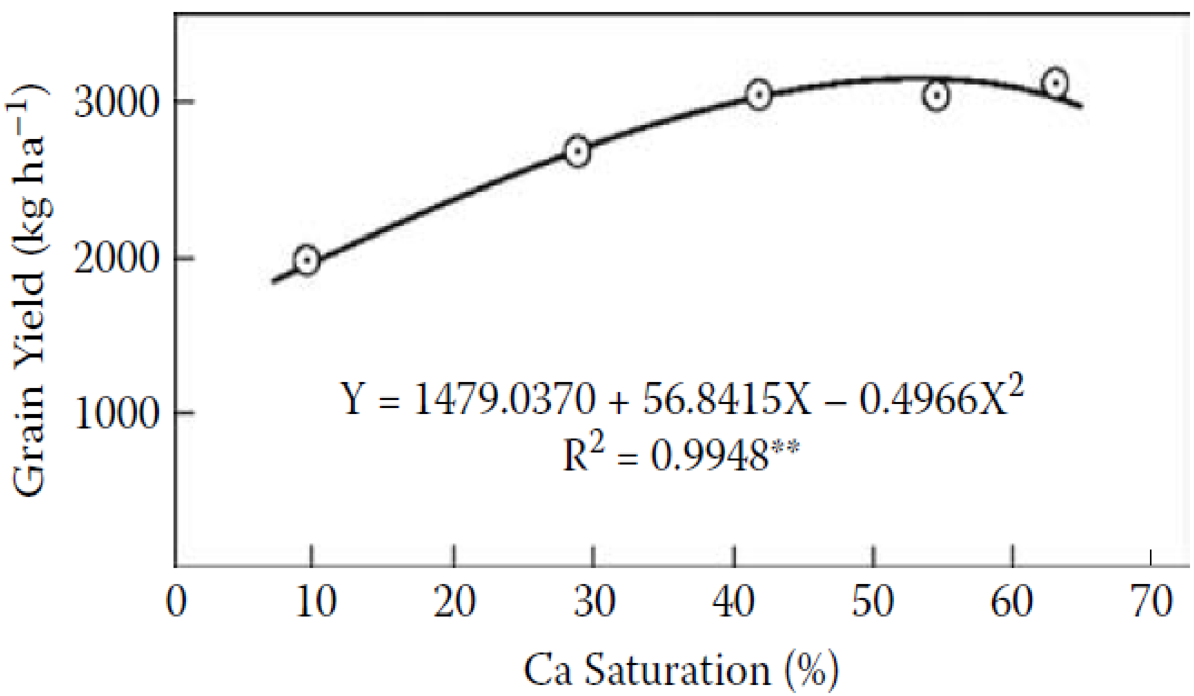


FIGURE 5.10 Relationship between calcium saturation and grain yield of soybean.

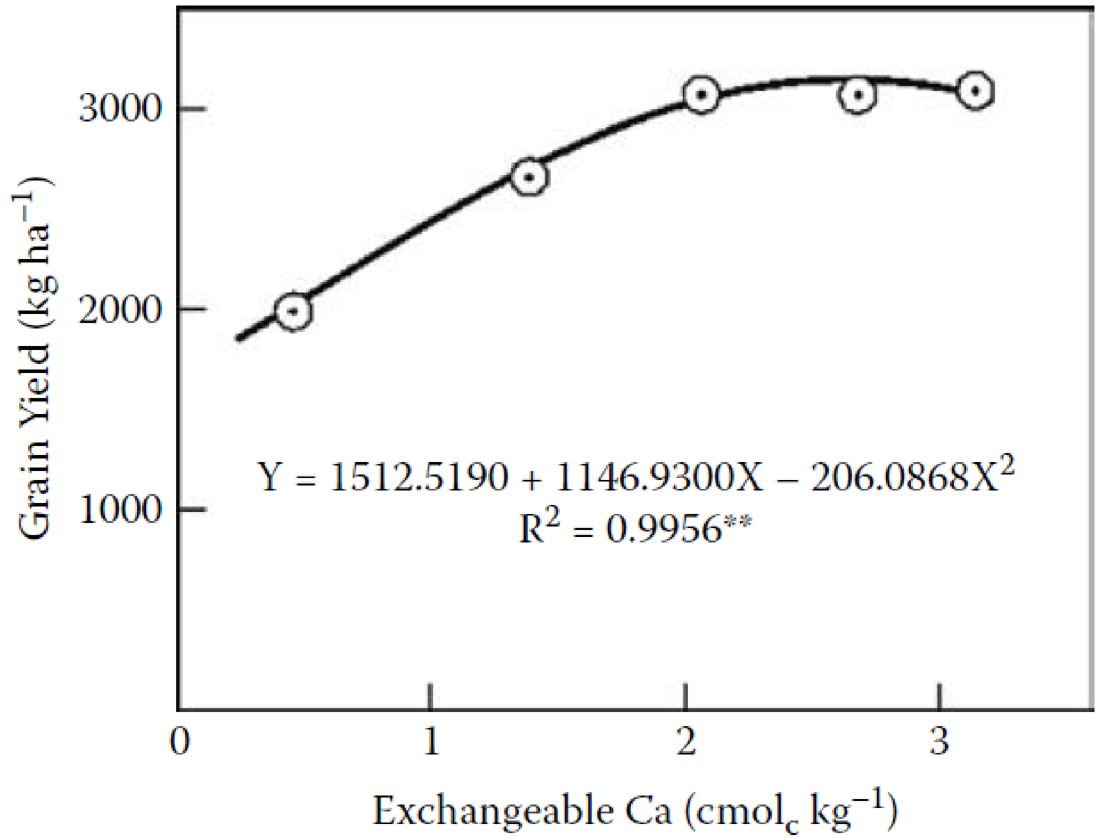


FIGURE 5.11 Relationship between exchangeable calcium content in the soil and grain yield of soybean.

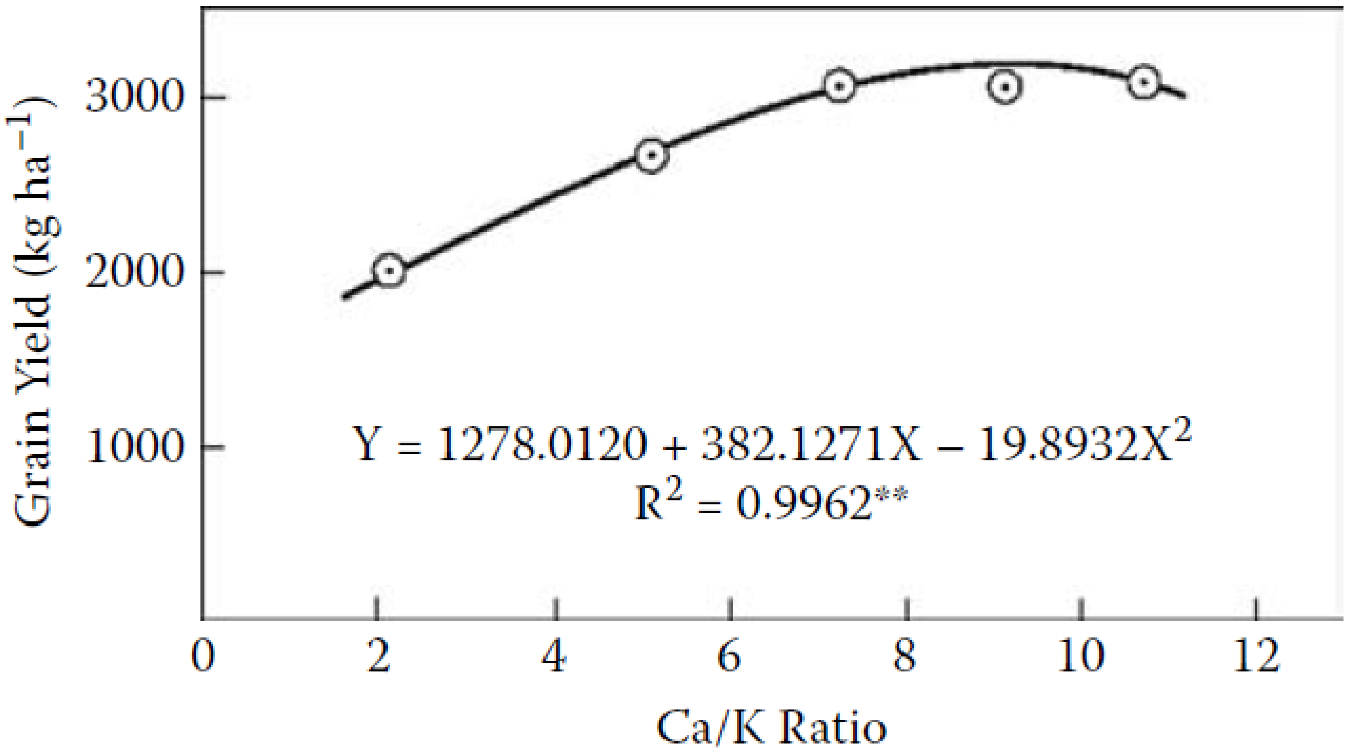


FIGURE 5.13 Relationship between Ca/K ratio and grain yield of soybean.

Ca Deficiency Symptom

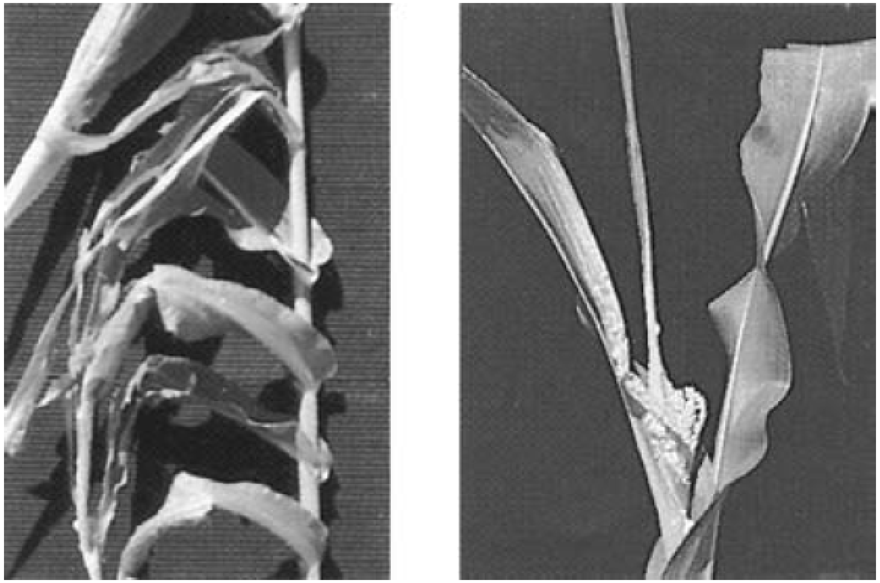


Figure 12.4. Calcium deficiency. The leaf tips stick to the next lower leaf, giving a ladderlike appearance (left). The young leaves of new plants are affected first. They are often distorted and small, the margins are irregular in form, and the leaves frequently show spotted necrotic areas. There may be dieback of the growing tip (right). Root growth is markedly impaired. (From *Corn Field Manual*, J.R. Simplot Company Minerals & Chemical Division, Pocatello, ID, ©1984. With permission.) See Plate 3 following p. 170.

Ca Deficiency Symptom

FIGURE 5.3 Calcium-deficient maize (*Zea mays* L.). The younger leaves which are still furled are yellow, but the lamina of the older, emerged leaf behind is green. (Photograph by Allen V. Barker.) (For a color presentation of this figure, see the accompanying compact disc.)

Ca Deficiency Symptom

FIGURE 5.4 Fruit of tomato (*Lycopersicon esculentum* Mill. cv Jack Hawkins) (Beefsteak type) showing blossom-end rot (BER). (Photograph by Philip S. Morley.) (For a color presentation of this figure, see the accompanying compact disc.)

8. CALSIUM MANAGEMENT

8.1 Decreasing Ca Losses

8.2 Increasing Ca uptake

8.3 Organic matter management

8.4. Management of Ca fertilization