Soil Fertility Management in Tropical Agriculture

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Importance of smallholder farming

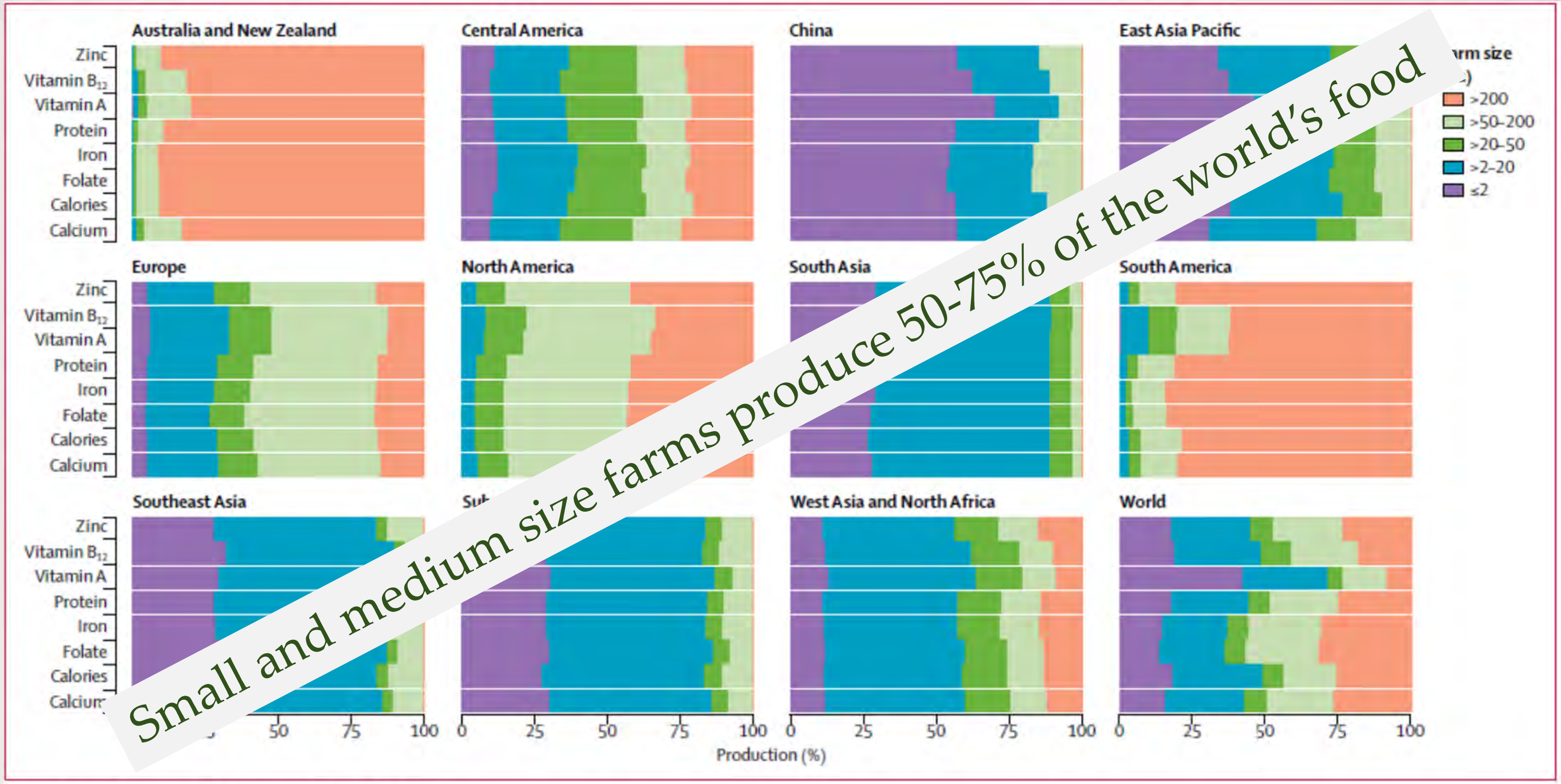


Figure 3: Distribution of nutrient production by farm size

Herrero et al., Lancet Planet Health 2017; 1: e33–42

Malawi

Kenya

Haiti

China

Senegal

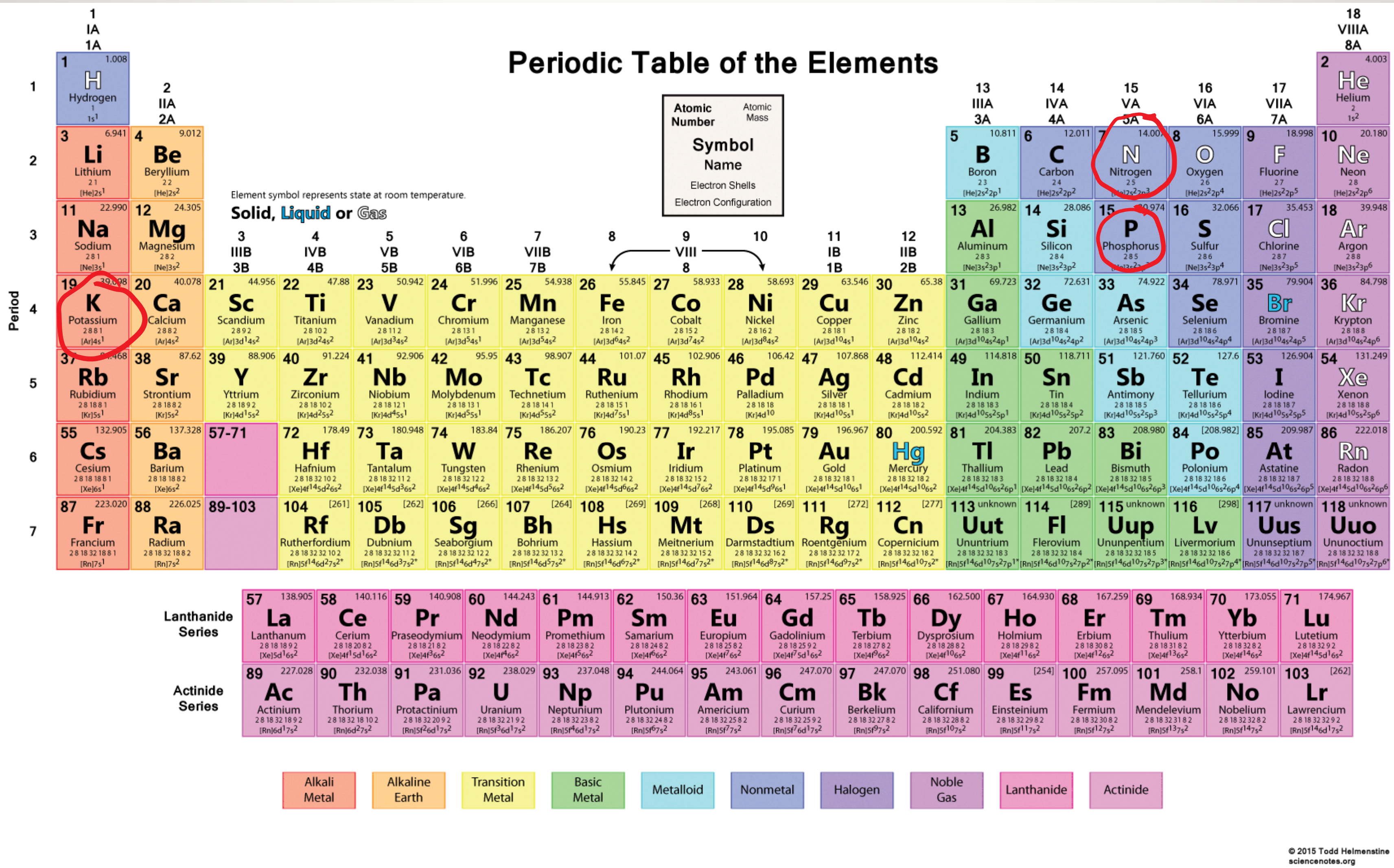
SOIL

IS NOT

DIRT!

Topics

- Essential nutrients for plant growth
- Formation and fertility of tropical soils
- Nutrient balance for crop production
- Improving soil fertility in smallholder farming



Periodic Table of the Elements
Atomic Number
Atomic Mass
Symbol
Name
Electron Shells
Electron Configuration
Element symbol represents state at room temperature.
Solid, Liquid or Gas
Period
1 IA 1A
2 IIA 2A
3 IIIB 3B
4 IVB 4B
5 VB 5B
6 VIB 6B
7 VIIB 7B
8
9 VIII 8
10
11 IB 1B
12 IIB 2B
13 IIIA 3A
14 IVA 4A
15 VA 5A
16 VIA 6A
17 VIIA 7A
18 VIIIA 8A
1 H Hydrogen 1.008
2 He Helium 4.003
3 Li Lithium 6.941
4 Be Beryllium 9.012
5 B Boron 10.811
6 C Carbon 12.011
7 N Nitrogen 14.007
8 O Oxygen 15.999
9 F Fluorine 18.998
10 Ne Neon 20.180
11 Na Sodium 22.990
12 Mg Magnesium 24.305
13 Al Aluminum 26.982
14 Si Silicon 28.086
15 P Phosphorus 30.974
16 S Sulfur 32.066
17 Cl Chlorine 35.453
18 Ar Argon 39.948
19 K Potassium 39.098
20 Ca Calcium 40.078
21 Sc Scandium 44.956
22 Ti Titanium 47.88
23 V Vanadium 50.942
24 Cr Chromium 51.996
25 Mn Manganese 54.938
26 Fe Iron 55.845
27 Co Cobalt 58.933
28 Ni Nickel 58.693
29 Cu Copper 63.546
30 Zn Zinc 65.38
31 Ga Gallium 69.723
32 Ge Germanium 72.631
33 As Arsenic 74.922
34 Se Selenium 78.971
35 Br Bromine 79.904
36 Kr Krypton 84.798
37 Rb Rubidium 84.468
38 Sr Strontium 87.62
39 Y Yttrium 88.906
40 Zr Zirconium 91.224
41 Nb Niobium 92.906
42 Mo Molybdenum 95.95
43 Tc Technetium 98.907
44 Ru Ruthenium 101.07
45 Rh Rhodium 102.906
46 Pd Palladium 106.42
47 Ag Silver 107.868
48 Cd Cadmium 112.414
49 In Indium 114.818
50 Sn Tin 118.711
51 Sb Antimony 121.760
52 Te Tellurium 127.6
53 I Iodine 126.904
54 Xe Xenon 131.249
55 Cs Cesium 132.905
56 Ba Barium 137.328
57-71
72 Hf Hafnium 178.49
73 Ta Tantalum 180.948
74 W Tungsten 183.84
75 Re Rhenium 186.207
76 Os Osmium 190.23
77 Ir Iridium 192.217
78 Pt Platinum 195.085
79 Au Gold 196.967
80 Hg Mercury 200.592
81 Tl Thallium 204.383
82 Pb Lead 207.2
83 Bi Bismuth 208.980
84 Po Polonium [208.982]
85 At Astatine 209.987
86 Rn Radon 222.018
87 Fr Francium 223.020
88 Ra Radium 226.025
89-103
104 Rf Rutherfordium [261]
105 Db Dubnium [262]
106 Sg Seaborgium [266]
107 Bh Bohrium [264]
108 Hs Hassium [269]
109 Mt Meitnerium [268]
110 Ds Darmstadtium [269]
111 Rg Roentgenium [272]
112 Cn Copernicium [277]
113 Uut Ununtrium unknown
114 Fl Flerovium [289]
115 Uup Ununpentium unknown
116 Lv Livermorium [298]
117 Uus Ununseptium unknown
118 Uuo Ununoctium unknown
Lanthanide Series
57 La Lanthanum 138.905
58 Ce Cerium 140.116
59 Pr Praseodymium 140.908
60 Nd Neodymium 144.243
61 Pm Promethium 144.913
62 Sm Samarium 150.36
63 Eu Europium 151.964
64 Gd Gadolinium 157.25
65 Tb Terbium 158.925
66 Dy Dysprosium 162.500
67 Ho Holmium 164.930
68 Er Erbium 167.259
69 Tm Thulium 168.934
70 Yb Ytterbium 173.055
71 Lu Lutetium 174.967
Actinide Series
89 Ac Actinium 227.028
90 Th Thorium 232.038
91 Pa Protactinium 231.036
92 U Uranium 238.029
93 Np Neptunium 237.048
94 Pu Plutonium 244.064
95 Am Americium 243.061
96 Cm Curium 247.070
97 Bk Berkelium 247.070
98 Cf Californium 251.080
99 Es Einsteinium [254]
100 Fm Fermium 257.095
101 Md Mendelevium 258.1
102 No Nobelium 259.101
103 Lr Lawrencium [262]
Alkali Metal
Alkaline Earth
Transition Metal
Basic Metal
Metalloid
Nonmetal
Halogen
Noble Gas
Lanthanide
Actinide
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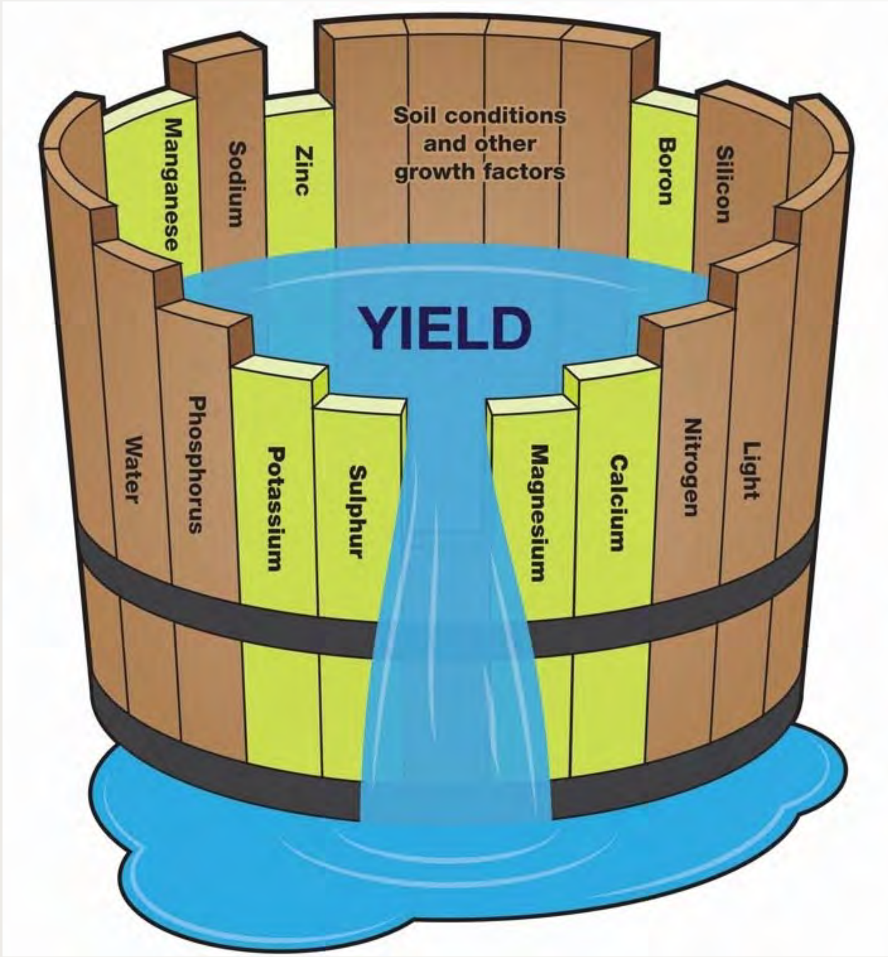
sciencenotes.org

Plant-essential Nutrients

- "Macronutrients" are absorbed by plants in the largest amounts
  - C, H, O come from the atmosphere and water
  - N, P, K, Ca, Mg, S
- "Micronutrients" are absorbed in smaller amounts
  - Fe, Mn, Cu, Zn, Mo, Ni, B, Cl
  - A few other elements are required by some but not all plants (example: Si)
- Essential nutrients function in specific plant processes and can't be substituted

Liebig's "law of the minimum"



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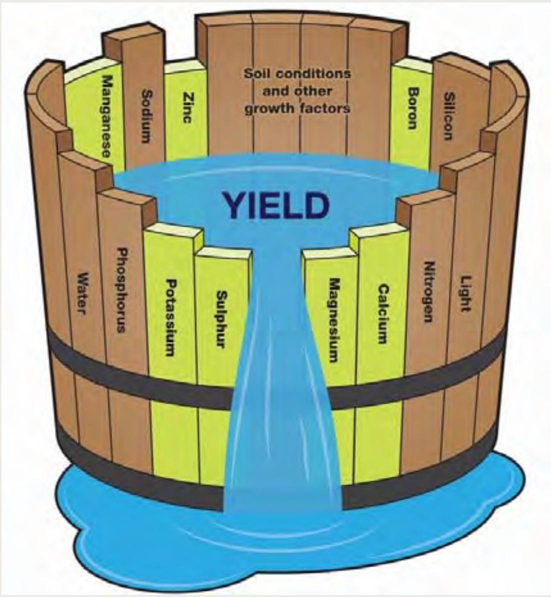
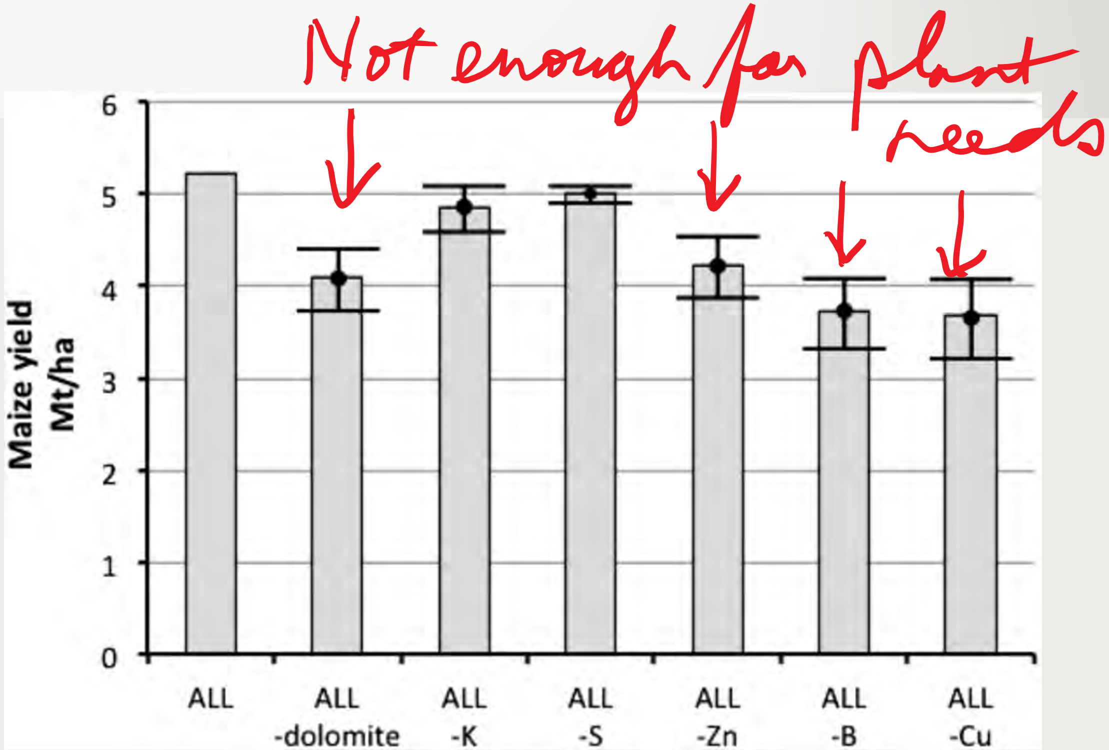




B. Vanlauwe et al., SOIL, 1, 491–508, 2015
www.soil-journal.net/1/491/2015/
Research in Burundi

Nutrient Sources

- Weathering of naturally-occurring soil minerals
  - Most tropical soils are highly weathered and have low amounts of nutrient-bearing minerals (esp. P, K, Ca, Mg)
  - Nutrient release through soil mineral weathering is not a sustainable nutrient source!
- Nitrogen fixation from legume crops or cover crops
  - Biomass must stay on the soil for maximum N benefit
- Crop residues, manures, composts, etc.
- Fertilizers

Plant available nutrients

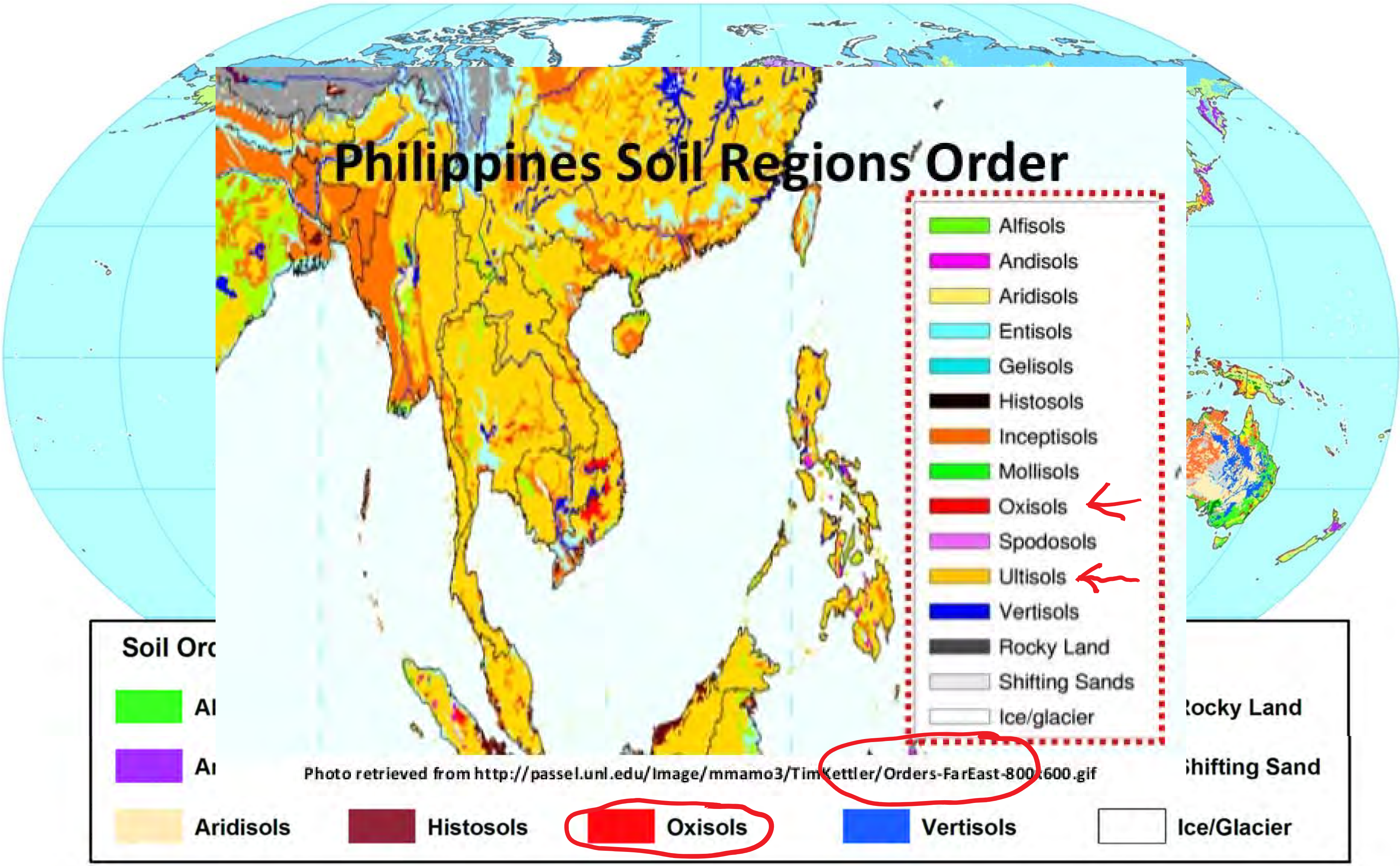
- Nutrients contained in soil minerals or organic materials may not be available to plants. For some nutrients, only a tiny fraction is available.
- Plant available nutrients are nutrients soluble in water and accessible for uptake by plant roots.
- Plant available nutrients may be low because soils are nutrient-depleted. This is why we use fertilizers.
- Other factors—drought, soil pH, salinity may also limit nutrient availability

The Five Soil-Forming Factors

- Parent Material (rocks)
- Climate
  - temperature, precipitation
- Organisms
  - Plants, microorganisms, animals, humans
- Topography (slope, aspect, elevation)
- Time

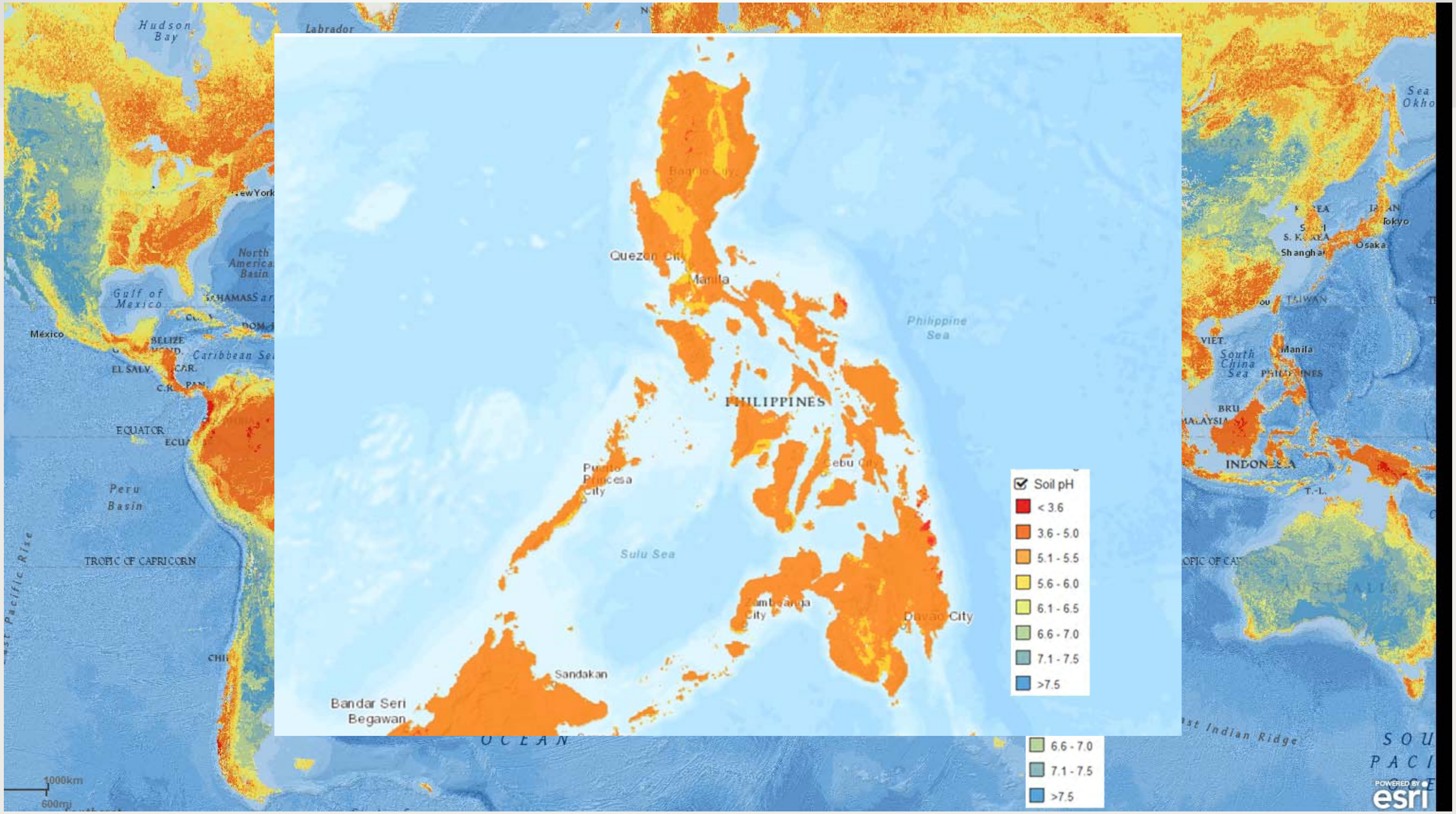




Ultisols commonly occur in moist subtropical climates. Highly leached, acid soils, often yellow-orange in color. Oxisols are most highly weathered soils, formed in humid tropical-subtropical climates. Acid, yellow-orange

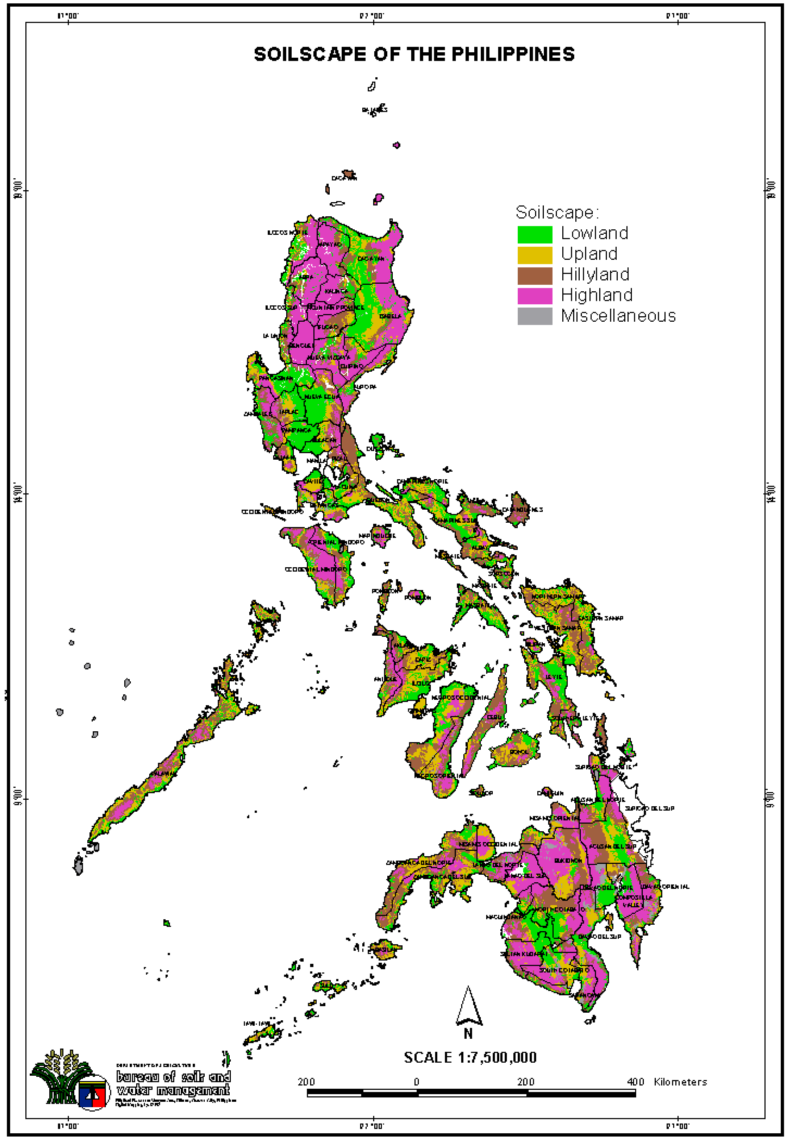
pH of Tropical Soils



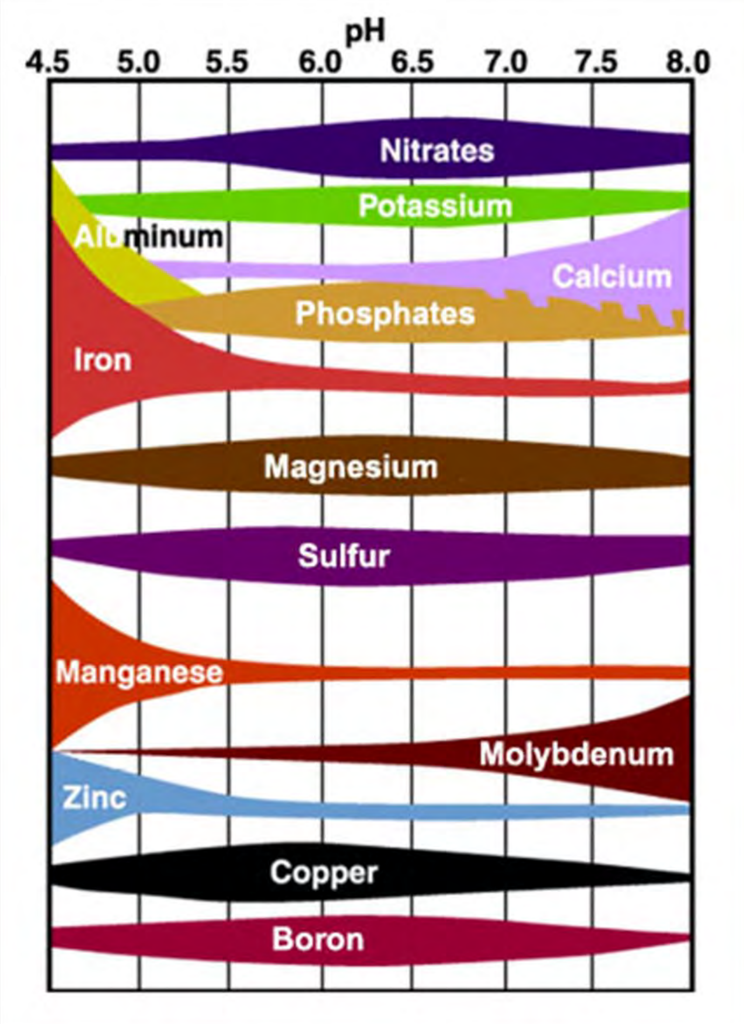
Global Agroclimatology Mapping, Virginia Tech

Local Resources

- http://bswm.da.gov.ph/



Soil pH and Nutrient Availability



http://www.traylorchemical.com

Nitrogen

- The nutrient most often limiting to plant growth
- In soils, N exists mostly in soil organic matter and crop residues. This is one reason that it is so important to conserve and increase soil OM!
- N can be added to soils naturally through N fixation (bacterial process) with legumes used as crops, cover crops, and intercrops.

Adding Nitrogen to Soils with Legumes

Cover crops

Intercropping with legumes

Phosphorus

- Phosphorus, among the most common elements found in the Earth’s crust, was dubbed “life’s bottleneck” by science writer Isaac Asimov. “[L]ife can multiply until all the phosphorus is gone, and then there is an inexorable halt which nothing can prevent. We may be able to substitute nuclear power for coal, and plastics for wood, and yeast for meat, and friendliness for isolation—but for phosphorus there is neither substitute nor replacement.”
- There is NO phosphorus equivalent to N fixation!

Phosphorus deficiency

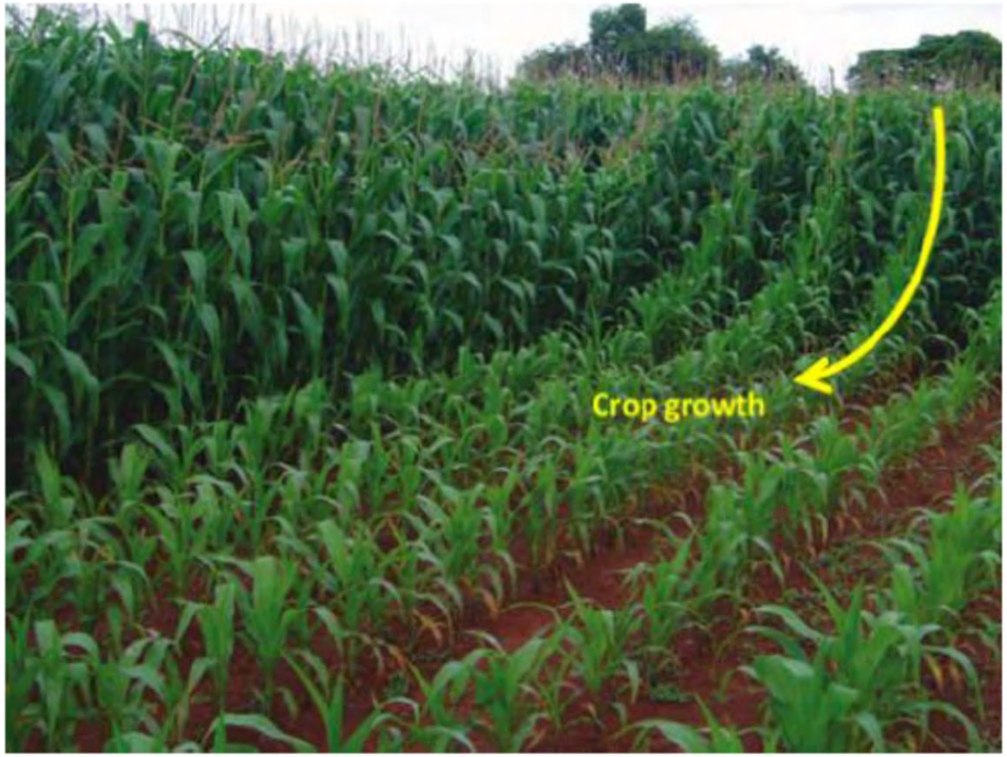
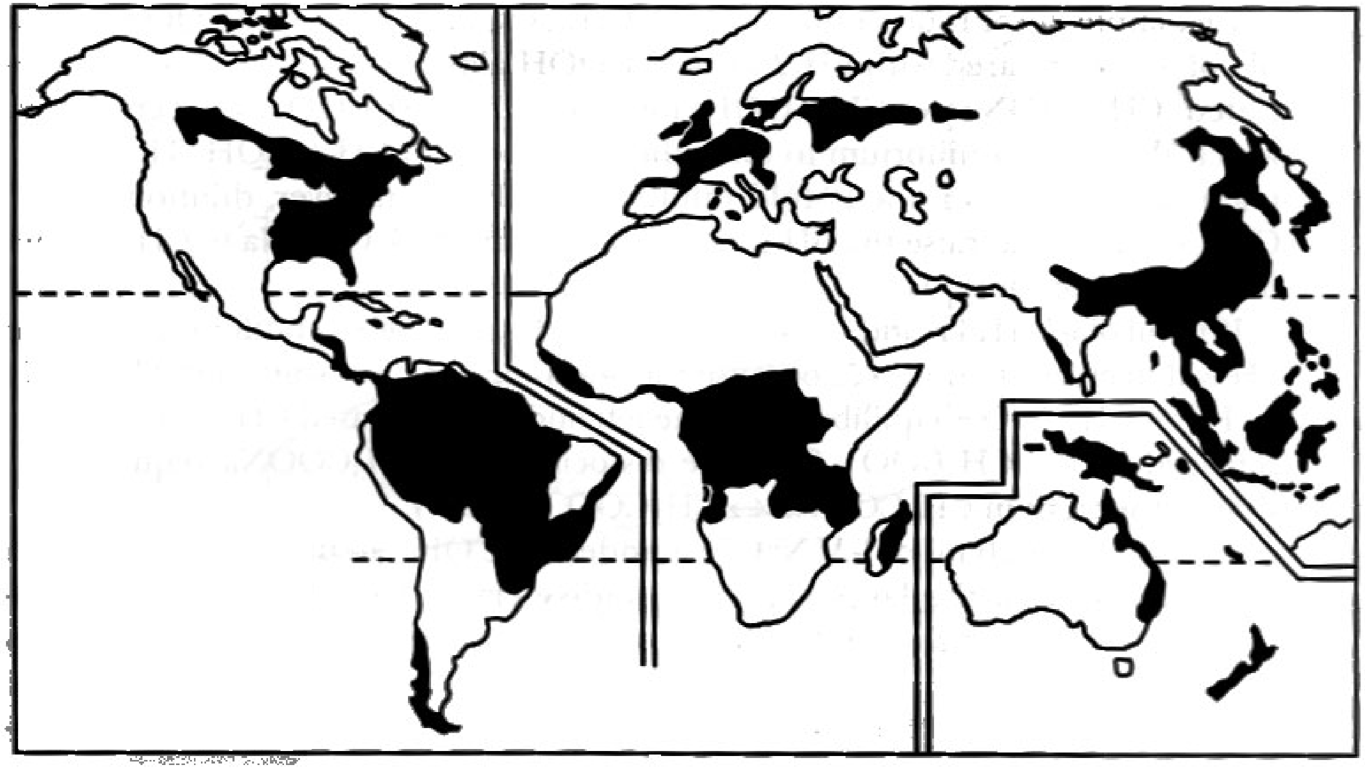


Figure 7. Effect of bad P_2O_5 supply (foreground) on crop development of forage maize.

https://livestocksystems.ilri.org/2016/01/27/manure-manual/

Soils low in K



Common fertility properties of cropped tropical soils

- Acid pH of 5.5 or below and aluminum toxicity
- Low soil organic matter and N
- Low plant-available P (except where manures have been added)
- Low plant available K
- Low available B and Cl (except near coastlines)
- High availability of some micronutrients

Nutrient Balance for Crop Production

Nutrient Removal in Crop Harvest (kg/ha nutrient per t/ha grain yield)

Crop	N	P	K
Maize	12	3	4
Beans	50	6	13
Millet	28	4	7
Sorghum	13	3	5
Rice	13	3	3
Peanuts	35	3	7
Wheat	19	4	4
Banana (25 ton/ha)	45	6	110

Nutrient Removal in Residue Harvest (kg/ha nutrient per t/ha grain yield)

Crop	N	P	K
Maize	8	1	17
Millet	14	2	17
Sorghum	13	3	5
Rice	8	1	17
Peanuts	16	2	10
Wheat	12	1	17

Examples—nutrient removal

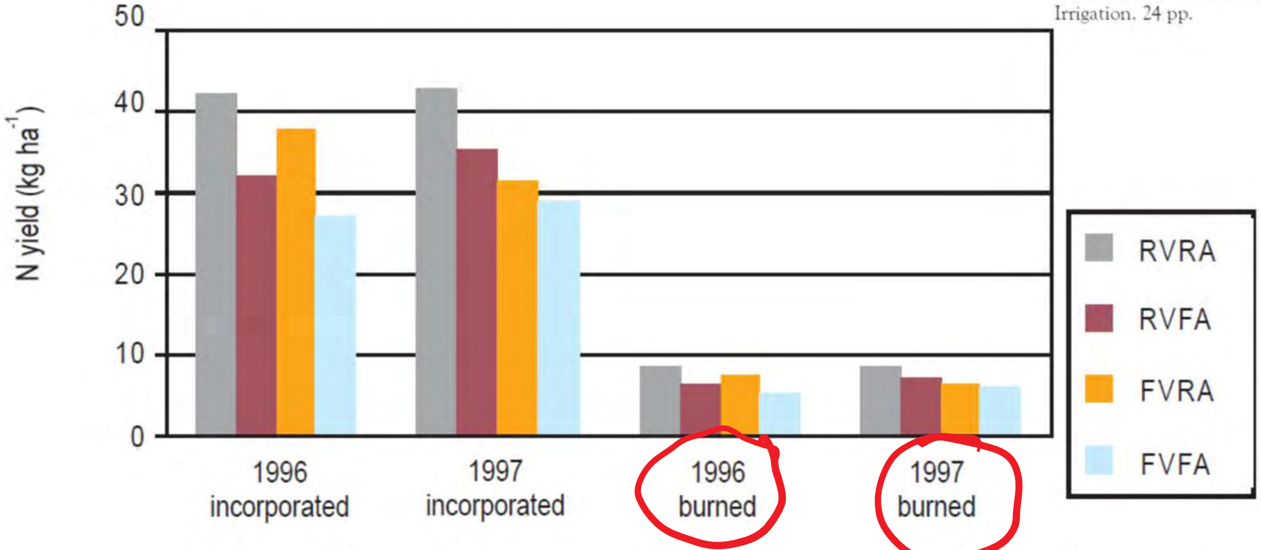
- Sub-Saharan Africa: Millet with 1.5 t/ha yield
  - 42 kg/ha N, 5 kg/ha P, 10 kg/ha K removed in grain
  - 21 kg/ha N, 3 kg/ha P, 25 kg/ha K removed in harvested residue
- SE Asia: Rice with 3.0 t/ha yield
  - 39 kg/ha N, 9 kg/ha P, 9 kg/ha K removed in grain
  - 24 kg/ha N, 3 kg/ha P, 51 kg/ha K removed in harvested (or burned) residue
- South America: Potato with 13 t/ha yield
  - 39 kg/ha N, 9 kg/ha P, 70 kg/ha K removed in tubers
  - 26 kg/ha N, 6 kg/ha P, 39 kg/ha K removed in residue
- Sub-Saharan Africa: Peanut with 1.0 t/ha yield
  - 35 kg/ha N, 3 kg/ha P, 7 kg/ha K removed in nuts/shells
  - 16 kg/ha N, 2 kg/ha P, 10 kg/ha K removed in harvested residue

Source: IPNI Nutrient Calculator, https://www.ipni.net/app/calculator/home

Residue conservation for nutrient benefit

Figure 5. Effect of variety, agronomy, and residue management on nitrogen contribution from groundnut residues.

Citation: ICRISAT/MAI. 2000. Cost-effective soil fertility management options for smallholder farmers in Malawi. PO Box 776, Bulawayo, Zimbabwe: ICRISAT; and Lilongwe, Malawi: Ministry of Agriculture and Irrigation. 24 pp.



RVRA = Researcher variety researcher agronomy, RVFA = Researcher variety farmer agronomy, FVRA = Farmer variety researcher agronomy etc.

Varieties: improved variety CG 7, local variety Chalimbana. Agronomic practices: number of weedings, plant population density.

The biggest factor in N benefit in both years was not variety or agronomy, but residue management, i.e. whether residues were burned or incorporated.

Nutrient additions and losses

- Plant available nutrients are naturally lost from soils by…
  - Chemical weathering by rainfall
  - Erosion (soil loss)
  - Crop harvest and livestock grazing
- Plant available nutrients are naturally added to soils by…
  - Nitrogen fixation with legumes
  - Conservation of crop residues. [remember that these nutrients came from the soil to begin with—recycling rather than addition]
  - Manure or compost additions

The nutrient "bottom line"

- Soils used for crop production experience net loss of plant available nutrients unless…
  - Legumes are part of a crop rotation (only effective for N)
  - Manures or other organic materials are IMPORTED from outside the field
  - Fertilizers are added
- Nutrient replacement is essential for sustainable crop production!
- Although soils differ in native fertility, there are NO soils that can support sustainable crop yields indefinitely without nutrient addition.

Nutrient depletion most severe in Africa

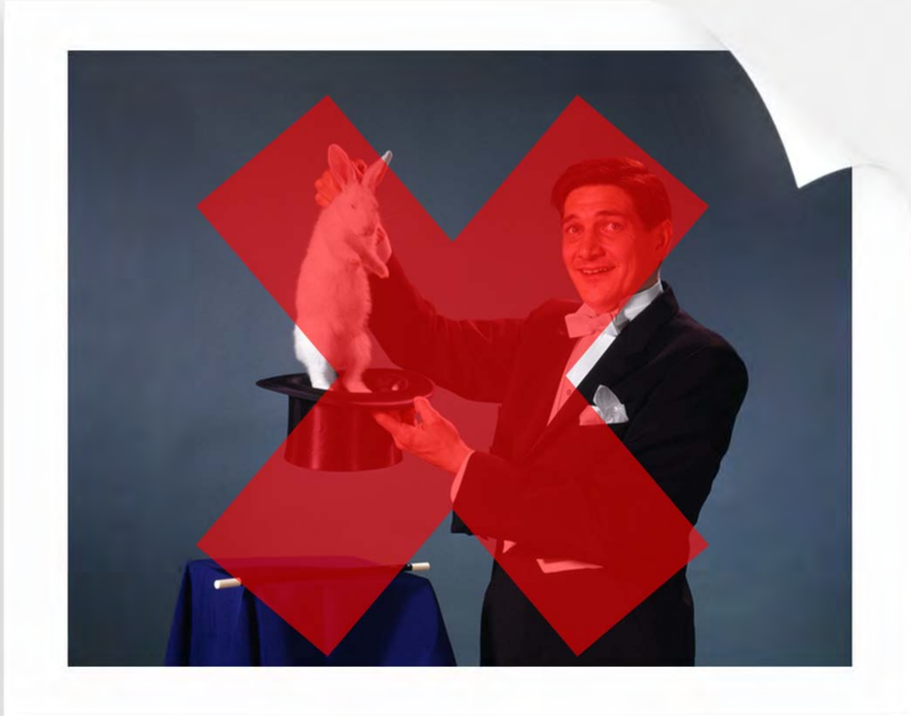
- Annual nutrient depletion rates on cultivated lands during the past 30 years in 37 African countries:
  - 22 kg/ha of nitrogen (N),
  - 2.5 kg of phosphorus (P),
  - and 15 kg/ha of potassium (K)
- An annual loss equivalent to U.S. $4 billion in fertilizer

Soil Fertility and Hunger in Africa, Pedro A. Sanchez (March 15, 2002), *Science* 295 (5562),

Improving soil fertility in smallholder farming

- There is no magic!

  (Walang magic!)



Building soil fertility in smallholder farming

- Avoiding nutrient losses
  - Reduce soil erosion with continuous soil cover
  - Return the highest possible amount of crop residue to soil
- Add nutrients to soil
  - Maximize N fixation with legumes in crop rotation, as cover crops and green manures (keep residues on soil!)
  - Intercropping with legume crops, trees, forbs
  - Return manures and ashes to soils
  - Fertilize using the right rate, time, place, and source (4R)
- Minimize other limitations to crop growth such as acidity, salinity, etc.
- “Conservation Agriculture”

Protect the soil! Keep it covered!

Building soil fertility in smallholder farming

- Avoiding nutrient losses
  - Reduce soil erosion with continuous soil cover
  - Return the highest possible amount of crop residue to soil
- Add nutrients to soil
  - Maximize N fixation with legumes in crop rotation, and as cover crops (keep residues on soil!)
  - Intercropping with legume crops, trees, forbs
  - Return manures and ashes to soils; add compost
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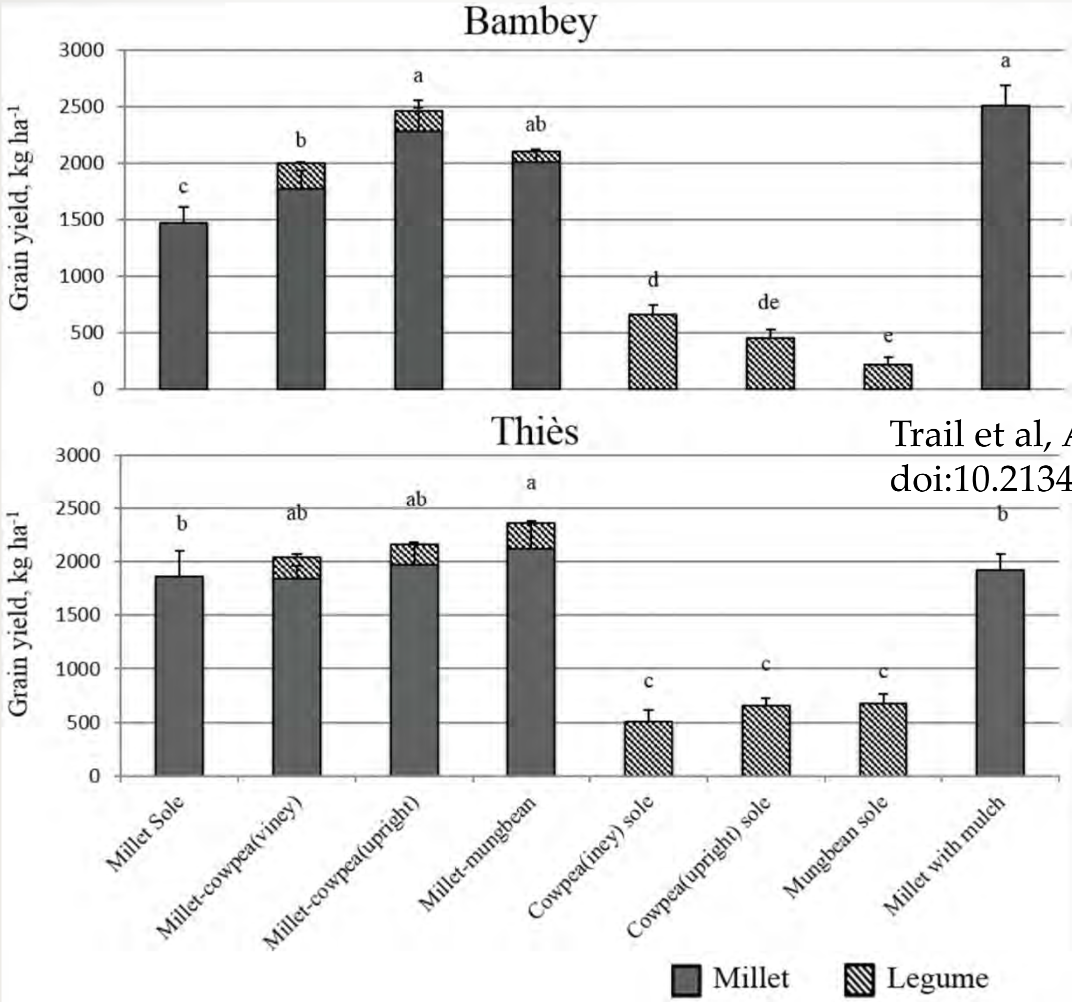
Intercropping increased grain yields…

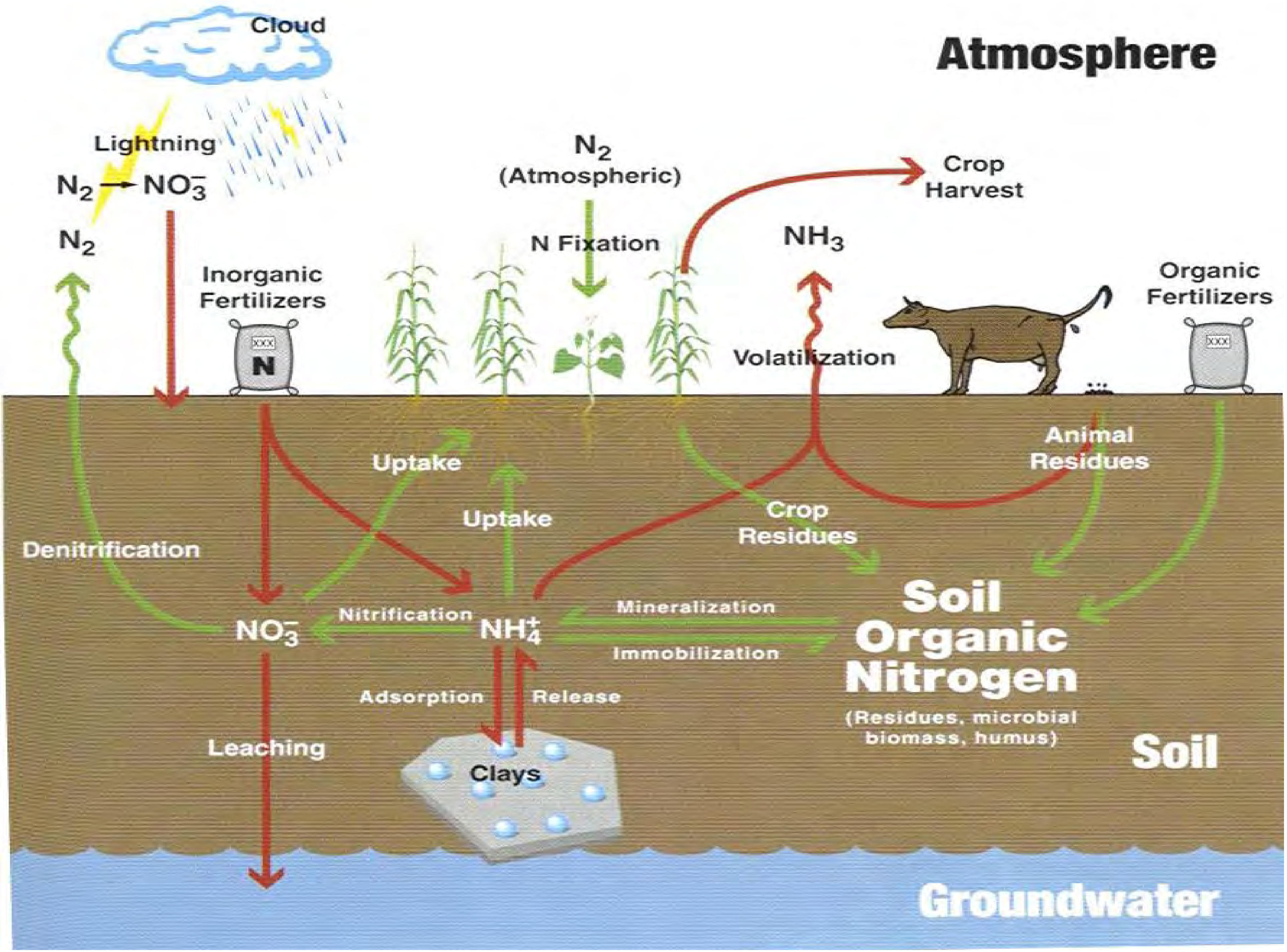


Trail et al, Agron. J. 108:1742–1752 (2016)
doi:10.2134/agronj2015.0422

The “four rights” approach for plant nutrients

- Apply at the right **AMOUNT** as established through soil and plant testing and recommendations, realistic yield goals, yield history, etc.
- Apply at the right **TIME** as established through knowledge of when plant nutrient demand is highest
- Apply at the right **PLACE** so that plant roots can access nutrients. Depends on crop, tillage, etc.
- Apply using the right **SOURCE** to maximize availability and minimize losses

Good reference is 4R Plant Nutrient Management in African Agriculture, http://ssa.ipni.net/ipniweb/region/africa.nsf


Cloud
Atmosphere
Lightning
$N_2 \rightarrow NO_3^-$
N_2
N_2
(Atmospheric)
Crop
Harvest
N Fixation
NH_3
Inorganic
Fertilizers
N
Organic
Fertilizers
Volatilization
Animal
Residues
Uptake
Uptake
Crop
Residues
Denitrification
Soil
Organic
Nitrogen
(Residues, microbial
biomass, humus)
NO_3^-
Nitrification
NH_4^+
Mineralization
Immobilization
Adsorption
Release
Leaching
Clays
Soil
Groundwater

Soil pH and Phosphorus Availability

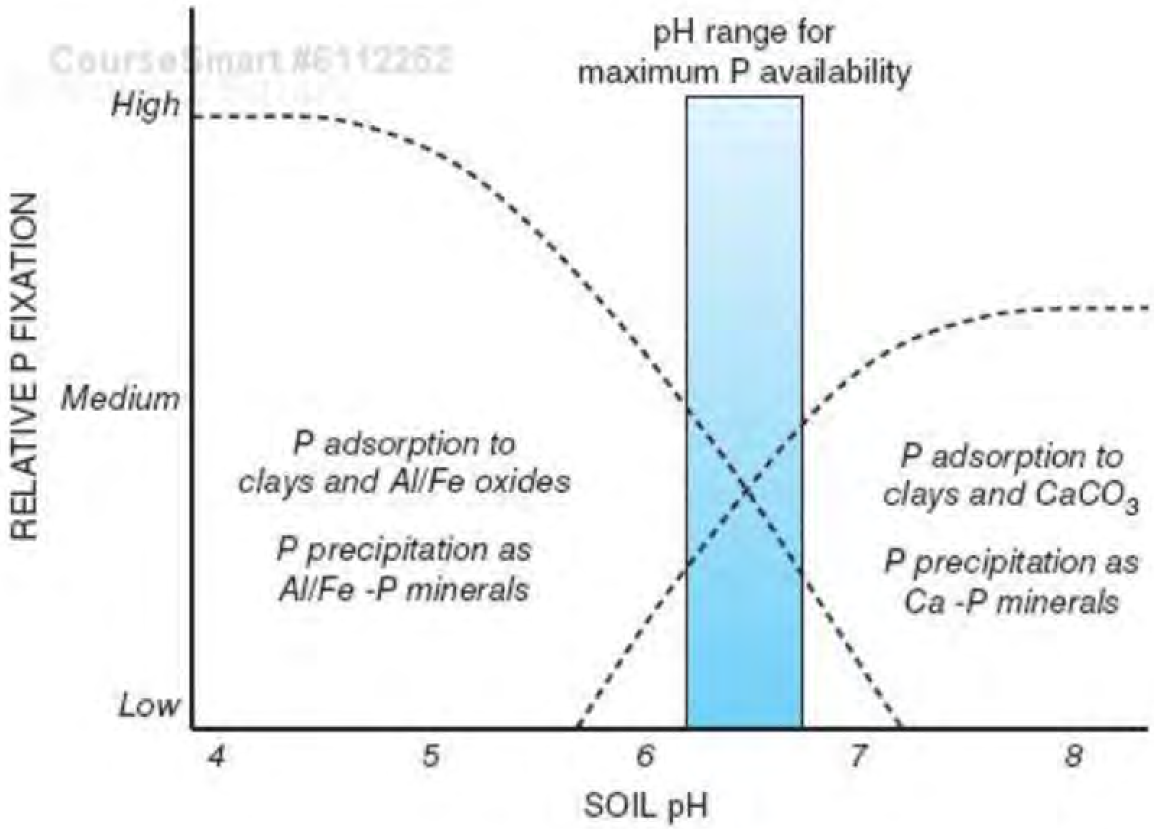


Figure 5-11 *Relative effect of soil pH on P adsorption and precipitation.*

P availability from fertilizers decreases with time

Table 5-11
Influence of Soil Type on Residual Fertilizer P Availability

		% P Available After 6 Months	
Soil Type	# of Soils	*Mean*	*Range*
Calcareous	56	45	11–72
Slightly weathered	80	47	7–74
Moderately weathered	27	32	6–51
Highly weathered	40	27	14–54

Note: Resin extractable P measured 6 months after P application.

Source: Sharpley, 1991, Soil Sci. Soc. Am. J., *55:1038.*

What is a Fertilizer?

- A fertilizer is anything capable of providing plant-available nutrients
- Most fertilizers are synthetic (chemical) salts composed of plant nutrients
- Fertilizer sources:
  - N fertilizers from N in the atmosphere
  - P fertilizers are mined, treated to increase solubility
  - K fertilizers are mined and purified
- Organics can also be fertilizers

Fertilizers

- Chemical or synthetic:
  - Not harmful to soils or soil organisms when used properly!
  - Supply nutrients directly in the forms that plants use
  - Although access and affordability can be a problem, chemical fertilizers are highly concentrated nutrient sources
- Organic:
  - Any organic material can be a fertilizer
  - Organic fertilizers provide soil organic matter also
  - Organic fertilizers contain mostly "slow-release" nutrients (N, P)
  - It is challenging to find enough organics to supply sustainable levels of nutrient addition for crop production, except on small scales

Manure as N source

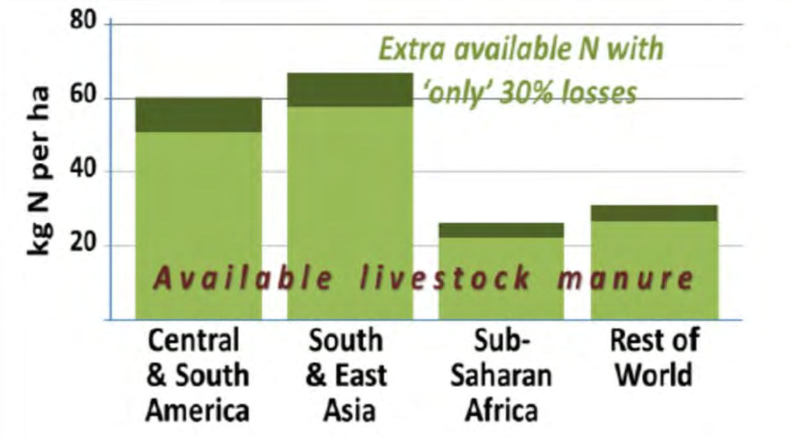


Figure 4. Available N from manure per ha grassland and arable crops and the N gain (dark topping) if losses are reduced from 40 to 30 %.

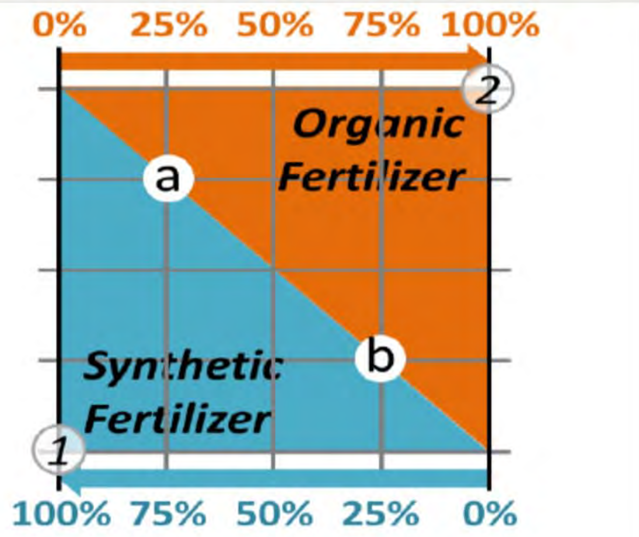
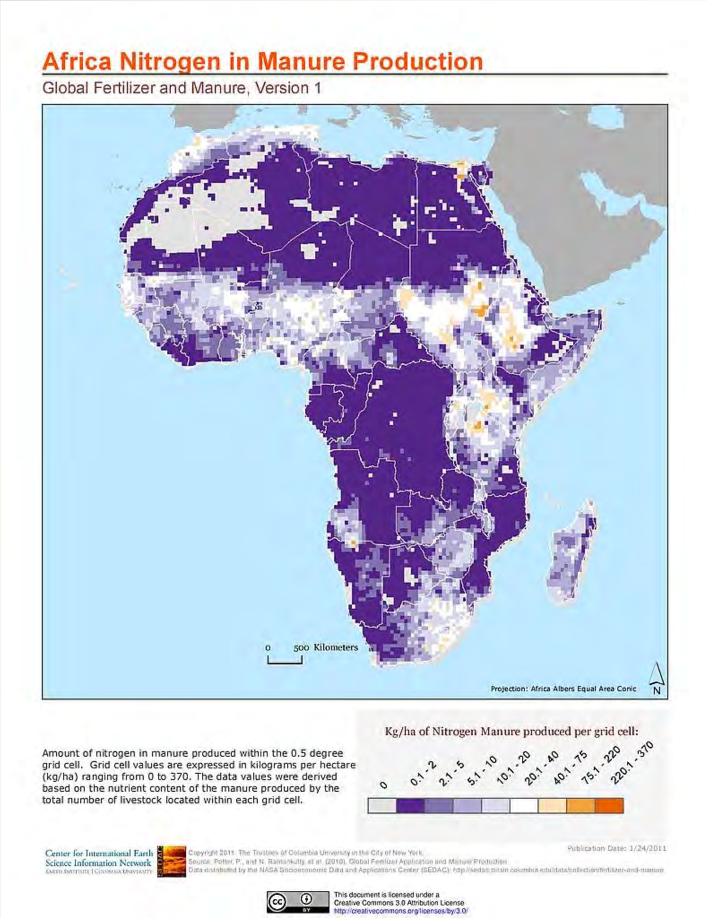
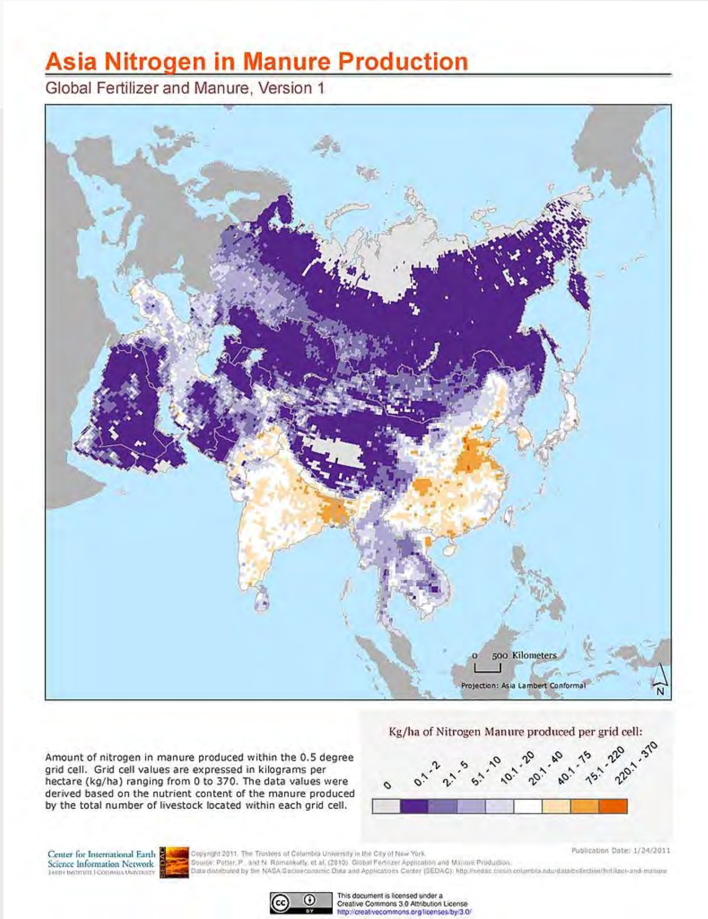


Figure 5. Organic fertilizer replacing synthetic fertilizers (read direction: bottom to up).

Excellent resource: https://livestocksystems.ilri.org/2016/01/27/manure-manual/

Africa vs. Asia: N in manures





http://sedac.ciesin.columbia.edu/data/collection/ferman-v1/maps/gallery/search

Composition of organic fertilizers

	% Moisture	N	P	K	N/P Ratio
		(% of dry weight)			
Chicken	35	4.4	2.1	2.6	2.1
Cattle	80	1.9	0.7	2.0	2.7
Hog	72	2.1	0.8	1.2	2.6
Horse	63	1.4	0.4	1.0	3.5
Sheep	68	3.5	0.6	1.0	5.8
Municipal solid waste compost	40	1.2	0.3	0.4	4.0
Sewage sludge	80	4.5	2.0	0.3	2.25

Nutrient release from manures

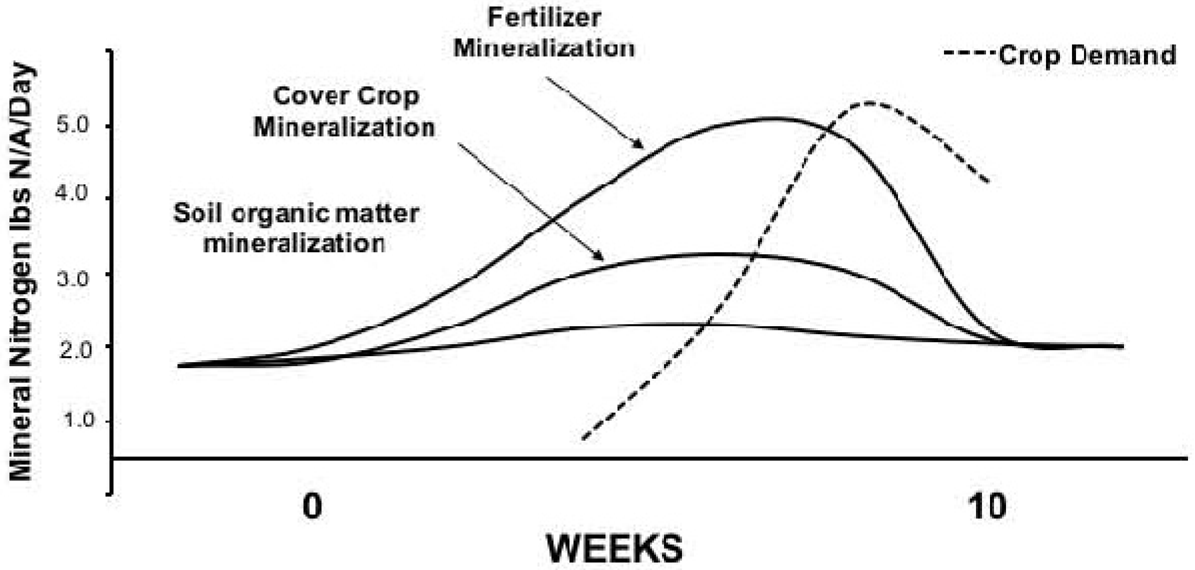
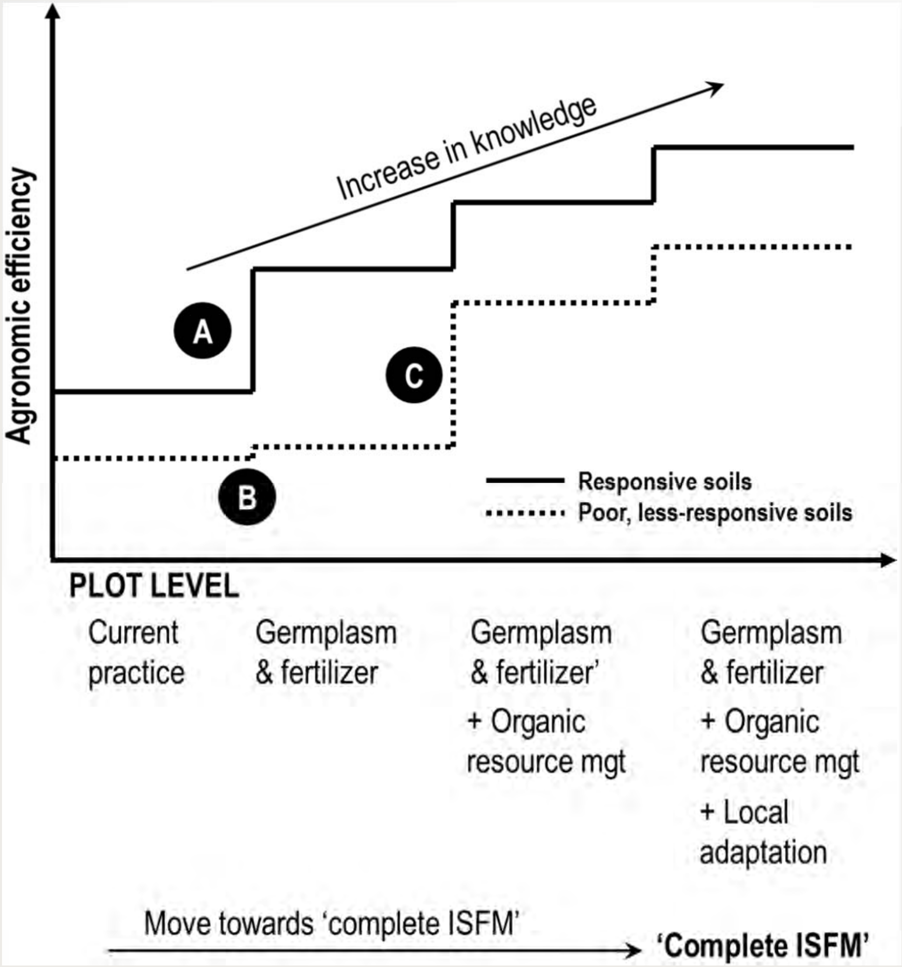


Figure 3. Theoretical depiction of N supplied to a crop from mineralization of soil organic matter, mineralization of crop residues and organic fertilizers

http://ucanr.edu/blogs/salinasvalleyagriculture//blogfiles/43248_original.jpg

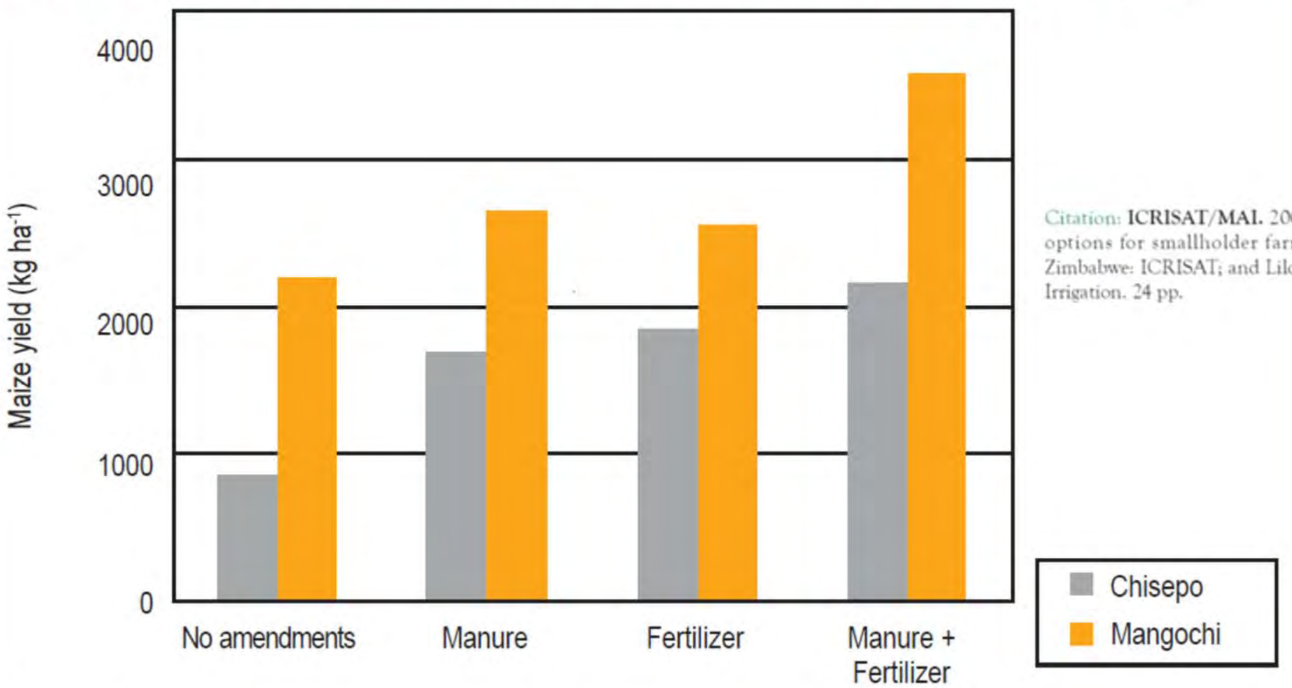
Integrated Soil Fertility Management



B. Vanlauwe et al., SOIL, 1, 491–508, 2015
www.soil-journal.net/1/491/2015/

Integrated soil fertility mgmt.-example

Figure 3. Maize grain yield response to small amounts of manure and fertilizer.



Goat manure 5 t ha^{-1}, targeted application of 2 handfuls per planting station. N fertilizer 17 kg ha^{-1}. Data averaged from 10 on-farm trials at Chisepo (Central Malawi) and Mangochi (Southern Malawi), 1998.

Citation: **ICRISAT/MAI.** 2000. Cost-effective soil fertility management options for smallholder farmers in Malawi. PO Box 776, Bulawayo, Zimbabwe: ICRISAT; and Lilongwe, Malawi: Ministry of Agriculture and Irrigation. 24 pp.

Closing points

- Small-medium farms produce 50-75% of the world's food
- All essential nutrients are important!
- Soils of the humid and subhumid tropics are usually nutrient-depleted and often acid
- Livestock grazing and crop production remove nutrients. They must be replaced for sustainability
- Active management is needed to avoid nutrient depletion. Phosphorus is particularly challenging
- Building soil fertility is hard work! But worth it!

If you have questions…

- Attend my workshop today or tomorrow
- Email to tlthompsonlbb@gmail.com