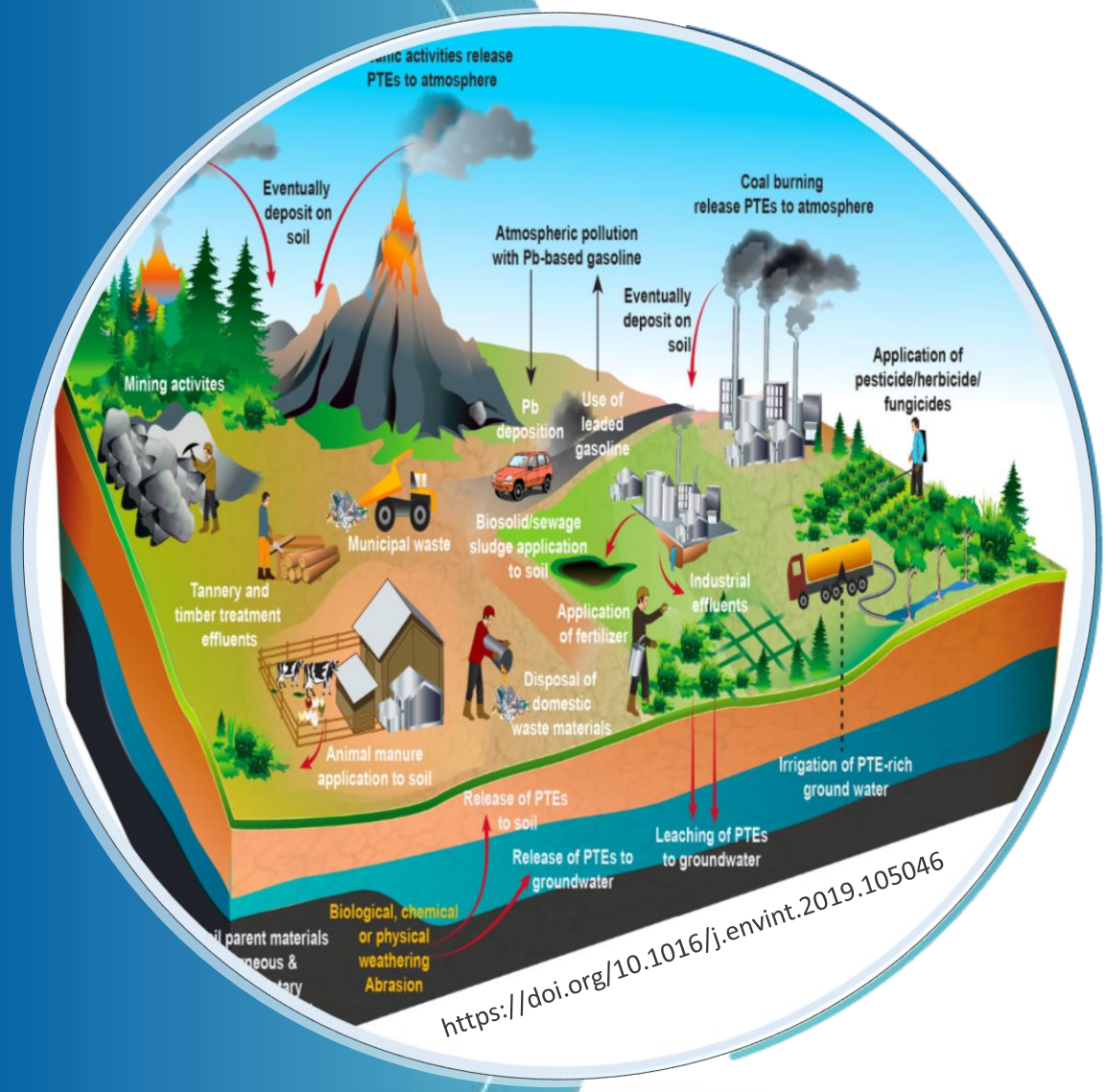


PROAGRO LECTORIUM

Potentially Toxic Elements (PTEs) in Soil-Plant Systems and Their Impact on Food Safety

Focus on Tropical Agroecosystems

Luiz Roberto Guimarães Guilherme, Ph.D.

Professor, Federal University of Lavras (UFLA), School of Agriculture (ESAL), Soil Science Department (DCS)

Research Fellow (CNPq), Member of the Brazilian Academy of Sciences (ABC)

Coordinator of the National Institute of Science and Technology INCT - Soil and Food Security

Lavras (Minas Gerais), Brazil

Outline

- Rationale
  - Critical concepts: Food Security *vs* Soil Security
  - Soil pollution is a growing threat to food safety
- Potentially toxic elements (PTEs) in agroecosystems
  - Sources
  - Fate (availability, mobility)
  - Transfer into food web / humans
- Brazil as a showcase
  - Ensuring food security in a tropical agroecosystem while promoting sustainable agricultural practices and judicious fertilizer management
- Final remarks

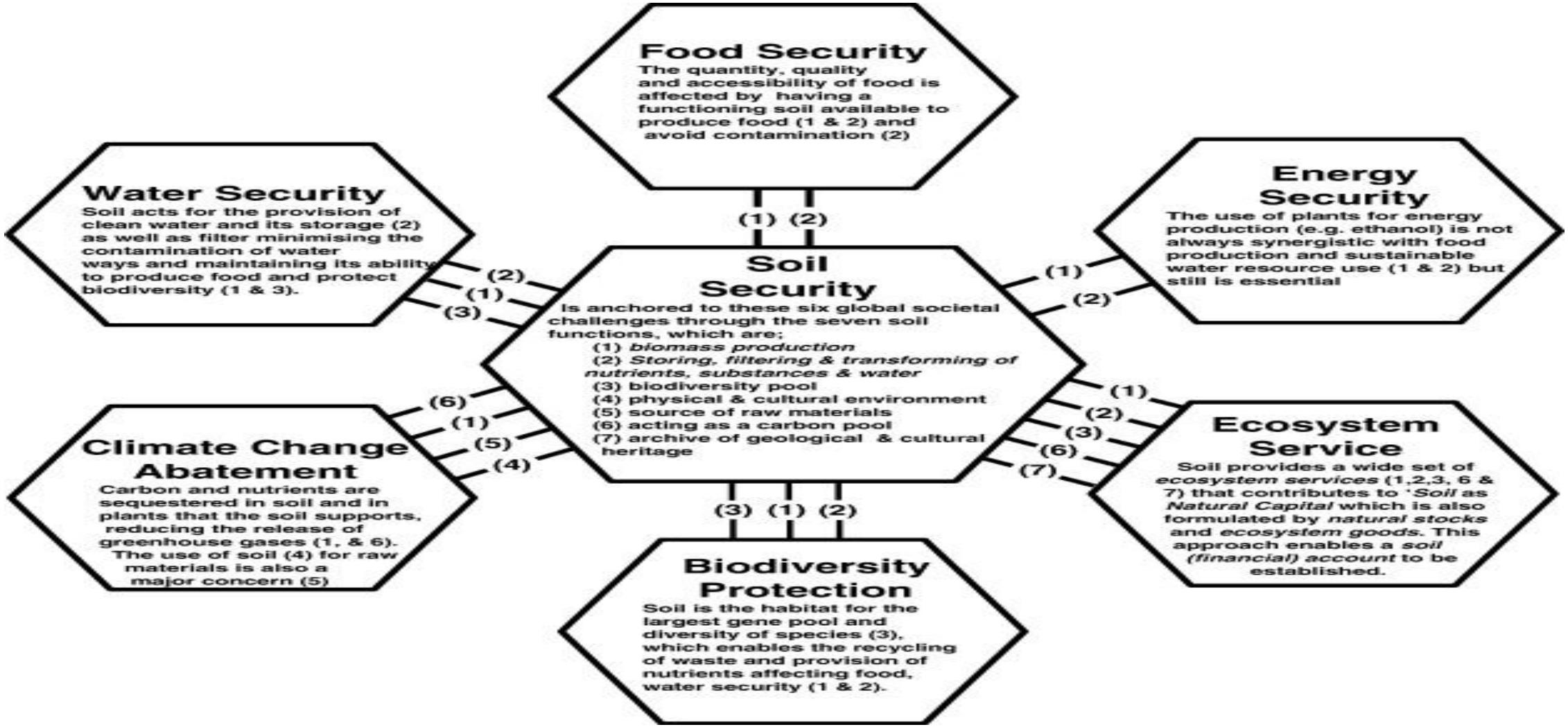
Rationale

Critical concepts:
Food Security *vs* Soil Security

Soil pollution is a growing threat to food safety

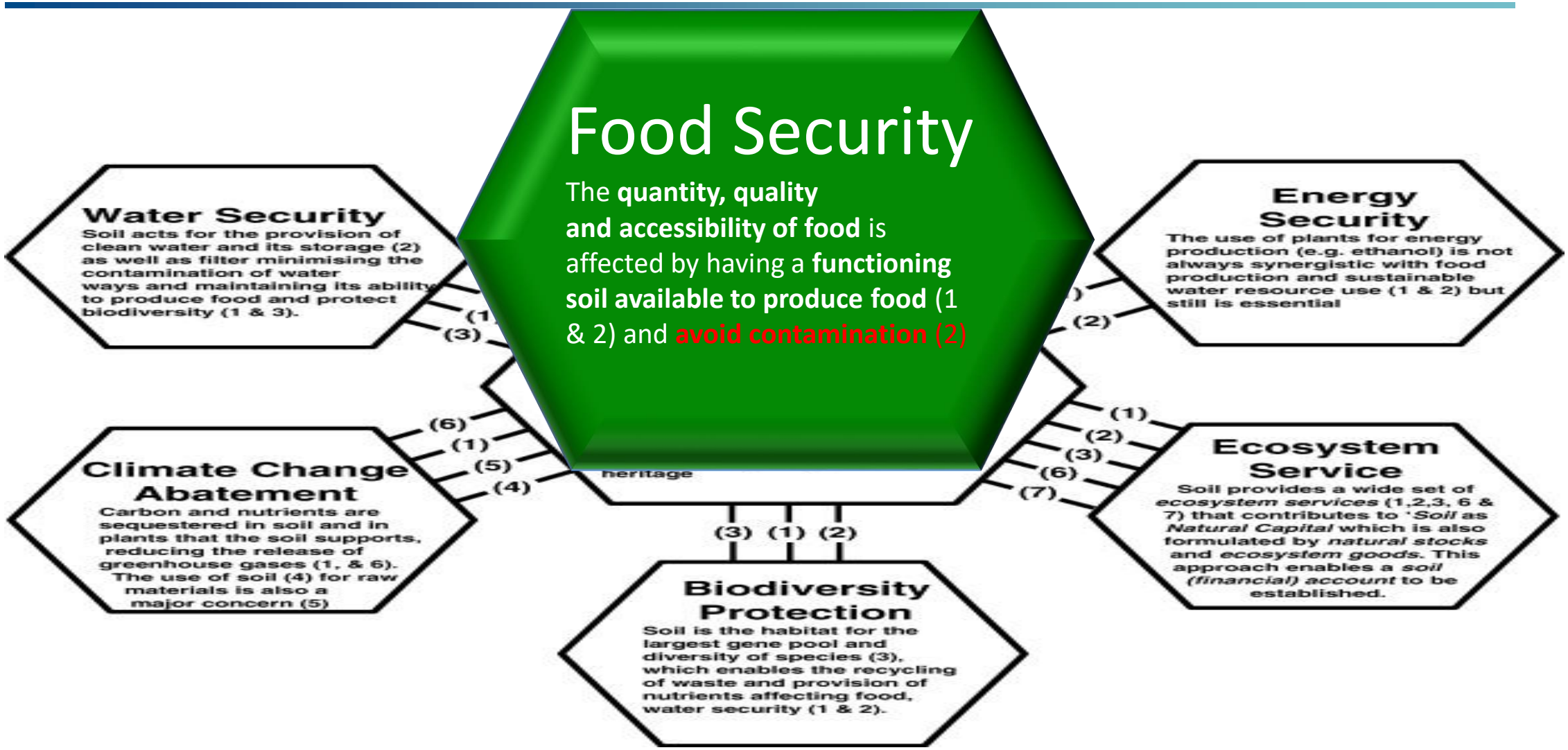
PROAGRO LECTORIUM

Food Security: a major societal challenge that depends on Soil Security *(Soil Functions)*



https://doi.org/10.1016/j.geoderma.2013.08.013

Food Security: a major societal challenge that depends on Soil Security *(Soil Functions)*



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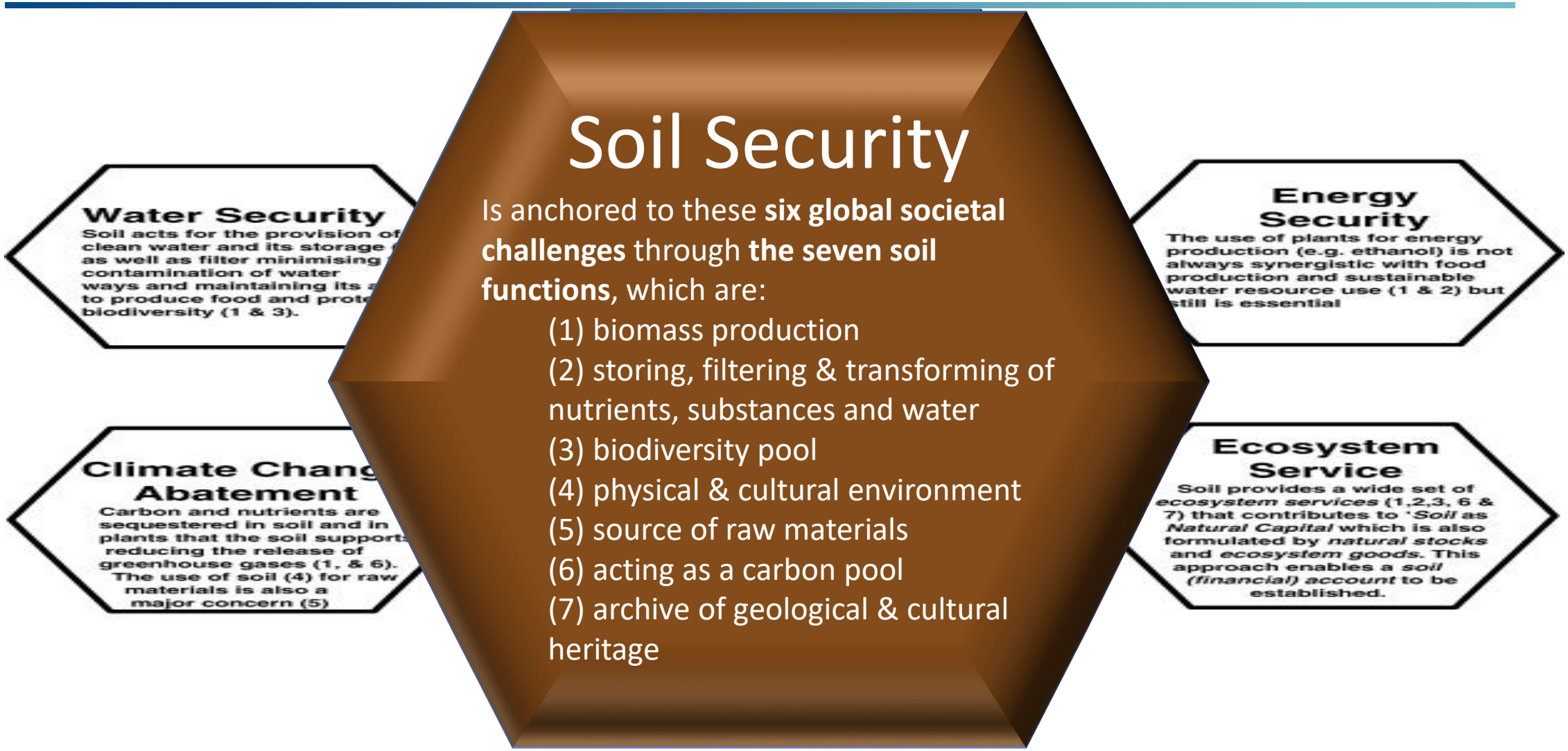
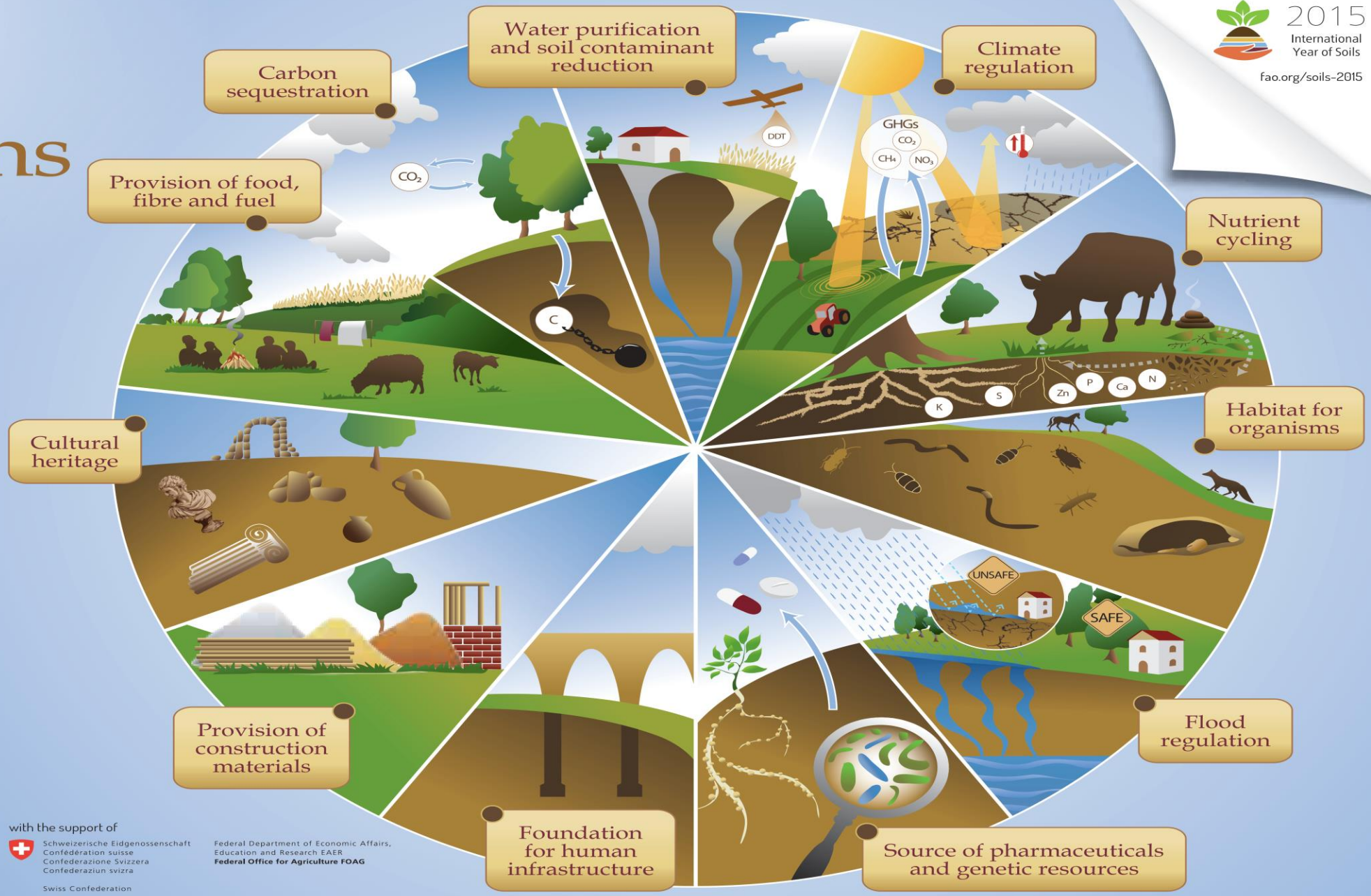
Food Security: a major societal challenge that depends on Soil Security *(Soil Functions)*



https://doi.org/10.1016/j.geoderma.2013.08.013

Soil functions

Soils deliver ecosystem services that enable life on Earth



2015 International Year of Soils

fao.org/soils-2015

Food and Agriculture Organization of the United Nations

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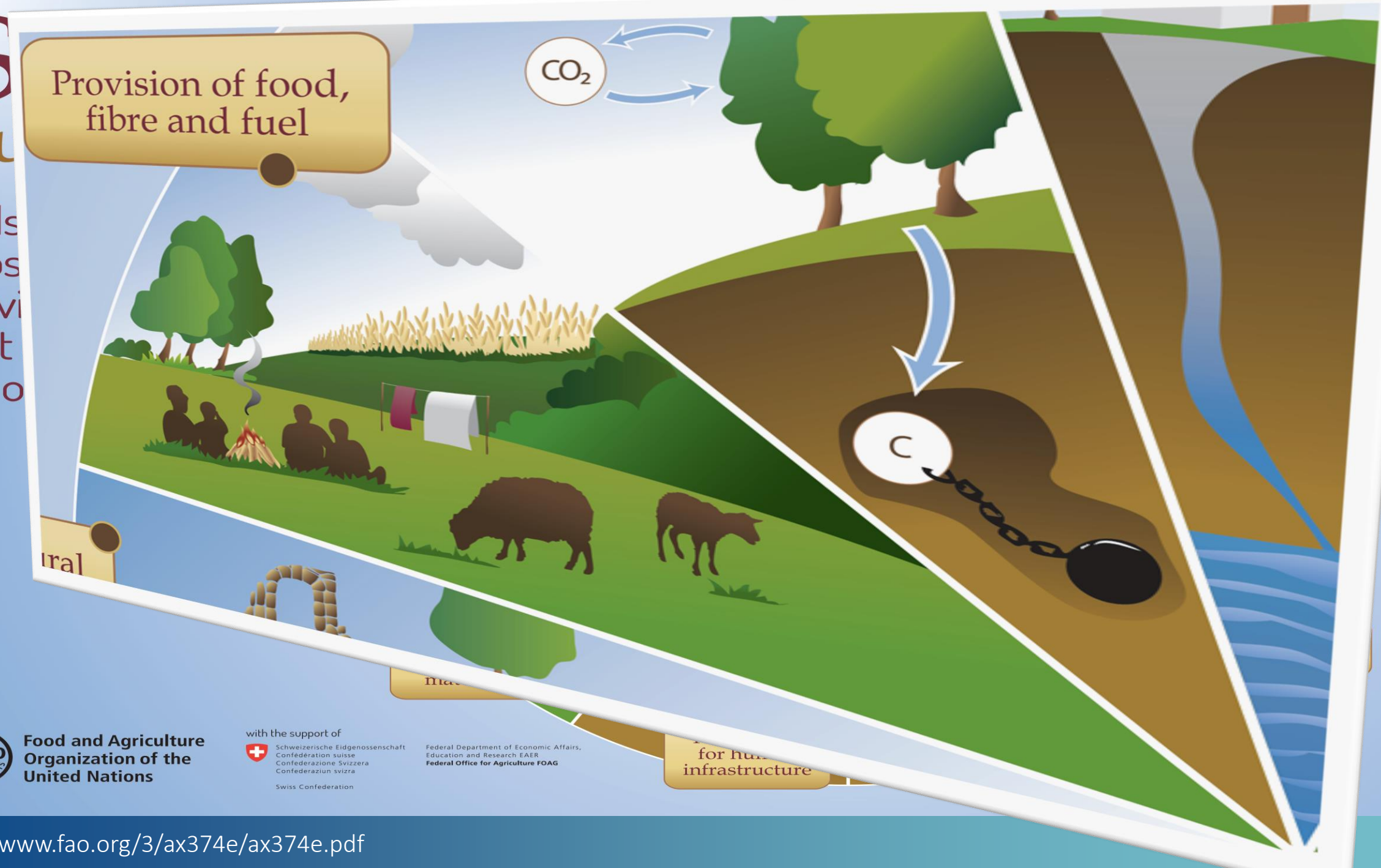
Federal Department of Economic Affairs, Education and Research EAER
Federal Office for Agriculture FOAG

https://www.fao.org/3/ax374e/ax374e.pdf



https://www.fao.org/3/ax374e/ax374e.pdf

The five dimensions of FOOD SECURITY

(1) food sufficiency (quantity)

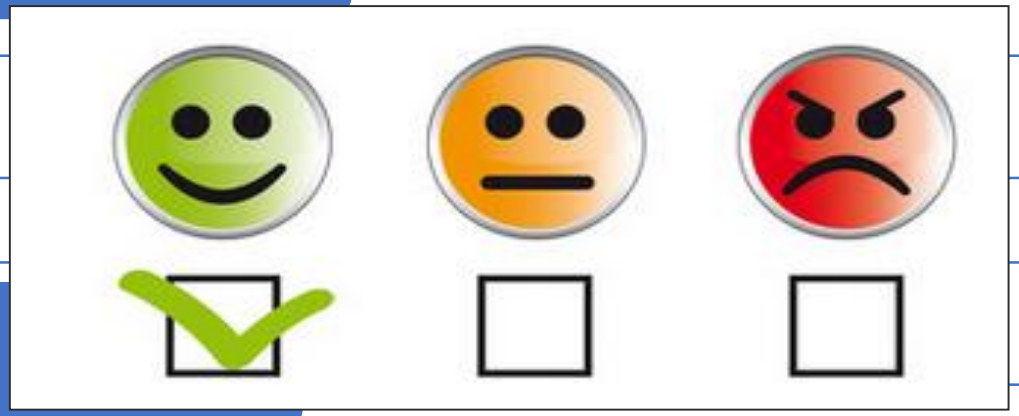
(2) nutrient adequacy (quality)

(3) cultural acceptability

(4) safety

(5) certainty and stability

How good we are?



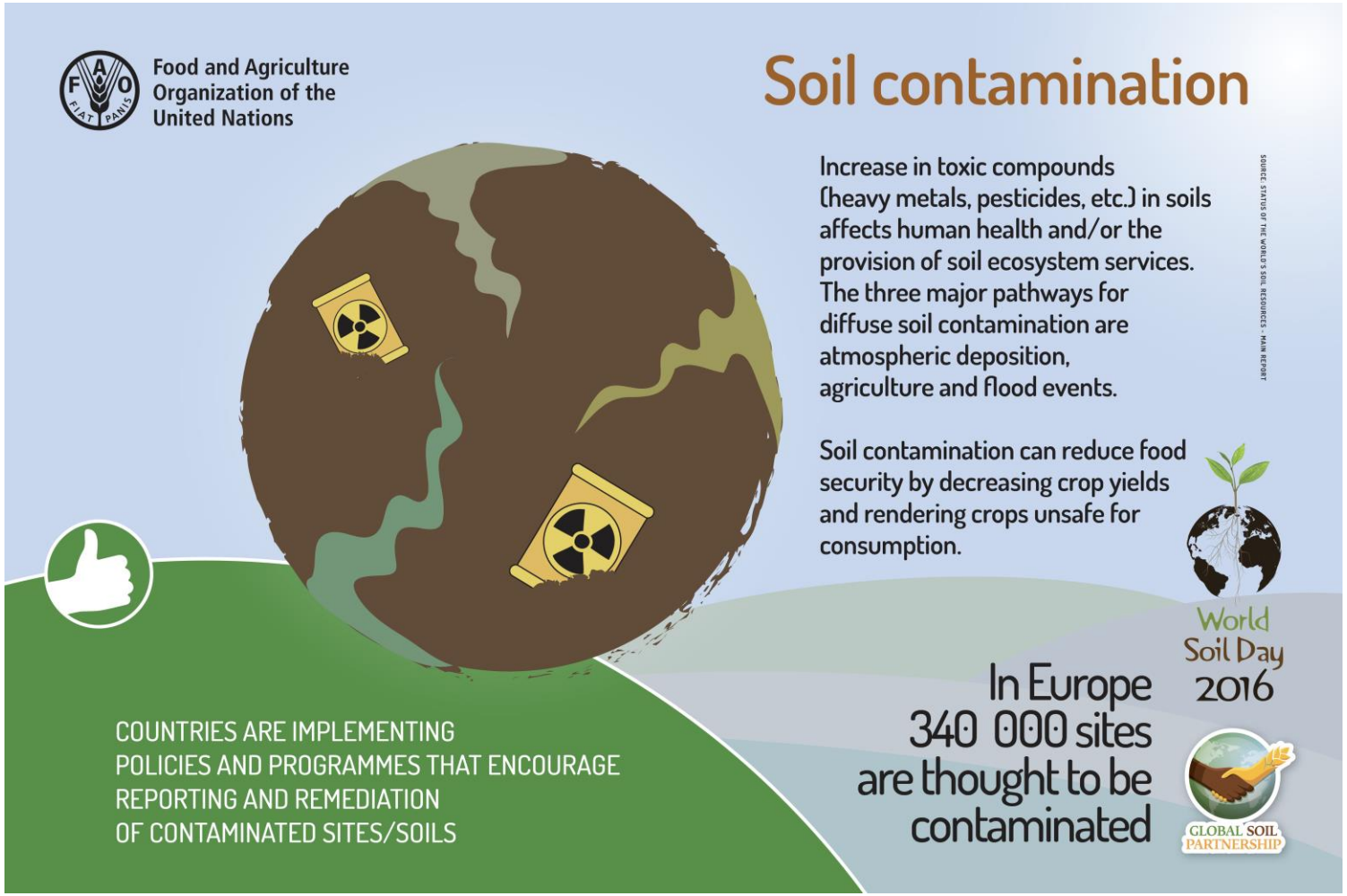
https://doi.org/10.1016/j.gfs.2013.05.002

https://www.fao.org/global-soil-partnership/about/why-the-partnership/en/

"Soils are under increasing pressure of intensification and competing uses for cropping, forestry, pasture and urbanization. The demands of a growing population for food, feed and fibre are estimated to result in a 60 percent increase by 2050. These pressures combined with unsustainable land uses and management practices, as well as climate extremes, cause land degradation. Soil preservation and sustainable land management have therefore become essential for reversing the trend of soil degradation and ensuring food security and a sustainable future."

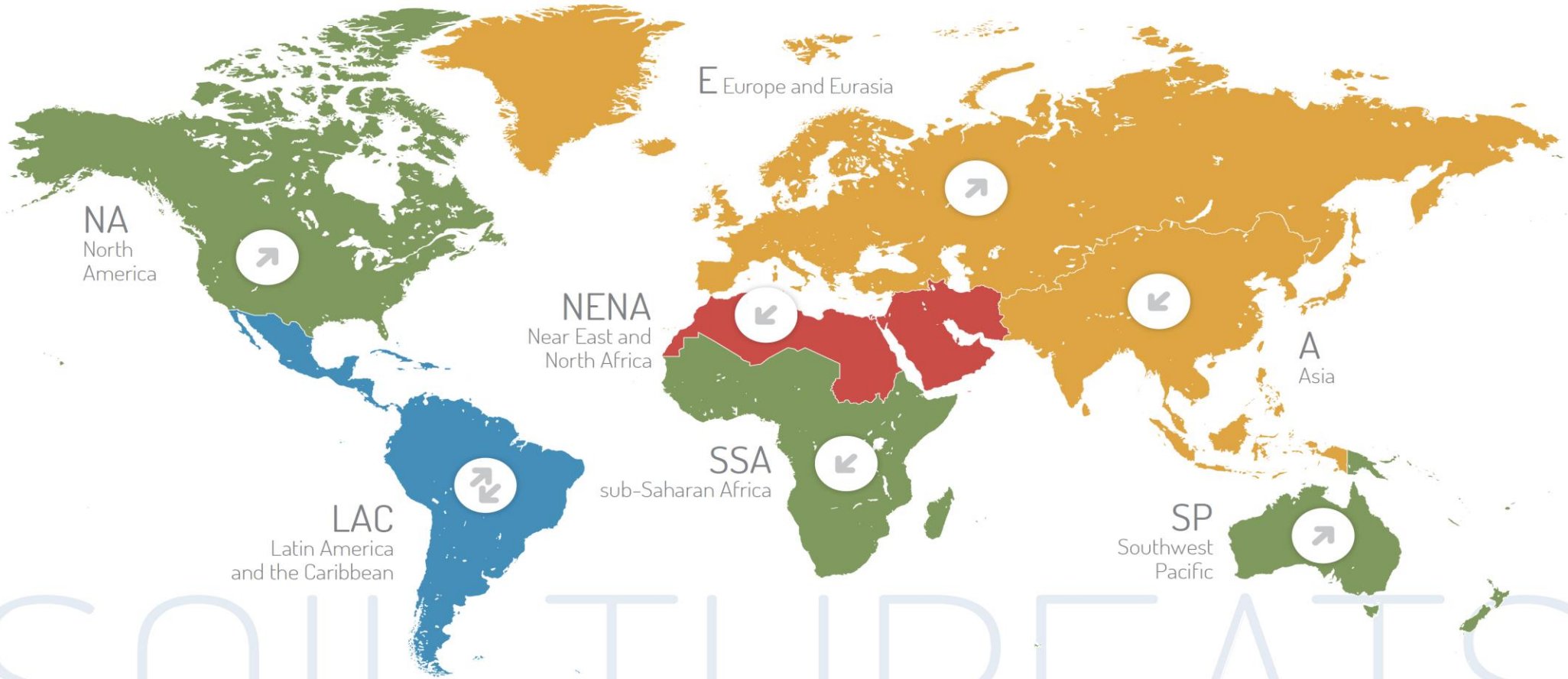
https://www.fao.org/global-soil-partnership/about/why-the-partnership/en/

Soil contamination



- *The **increase in toxic compounds** (**heavy metals**, **pesticides**, etc.) in soils affects **human health** and/or the provision of **soil ecosystem services**.*
- *Soil contamination can **reduce food security** by **decreasing agricultural yields** and rendering **crops unsafe for consumption**.*
- *The **three main pathways for** diffuse soil pollution are **atmospheric deposition, agriculture, and flooding**.*

https://openknowledge.fao.org/server/api/core/bitstreams/68f57bce-b094-4f53-9aee-a8ce24af8cb9/content



SOIL THREATS

Soil contamination

N/1/11.16

Condition

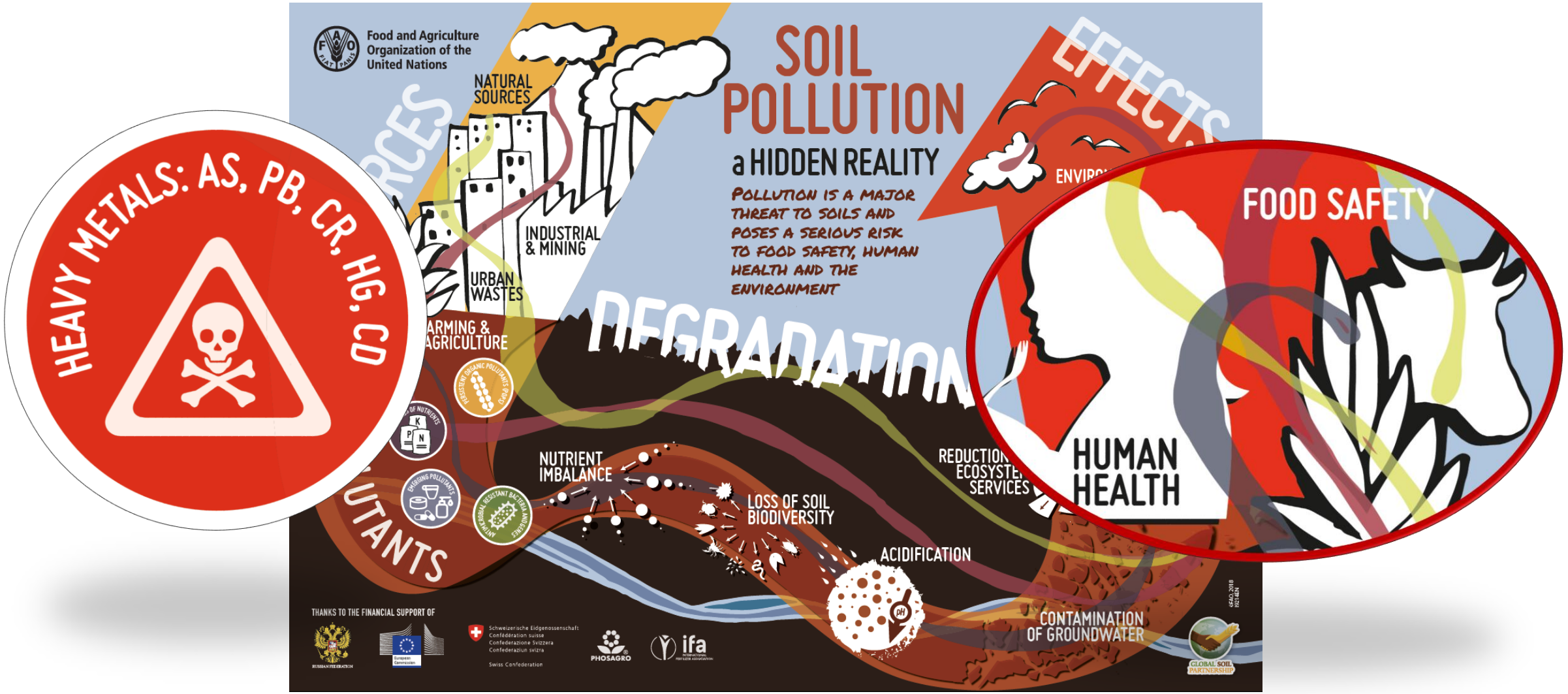
Very poor | Poor | Fair | Good

Trend

Improving | Deteriorating | Variable | Stable

https://openknowledge.fao.org/server/api/core/bitstreams/68f57bce-b094-4f53-9aee-a8ce24af8cb9/content

Is Soil Pollution a threat to Food Security? The case of “heavy metals”



https://openknowledge.fao.org/bitstreams/ef256f1a-6775-4ea2-8880-f310105feadc/download

Potentially toxic elements (PTEs) in agroecosystems

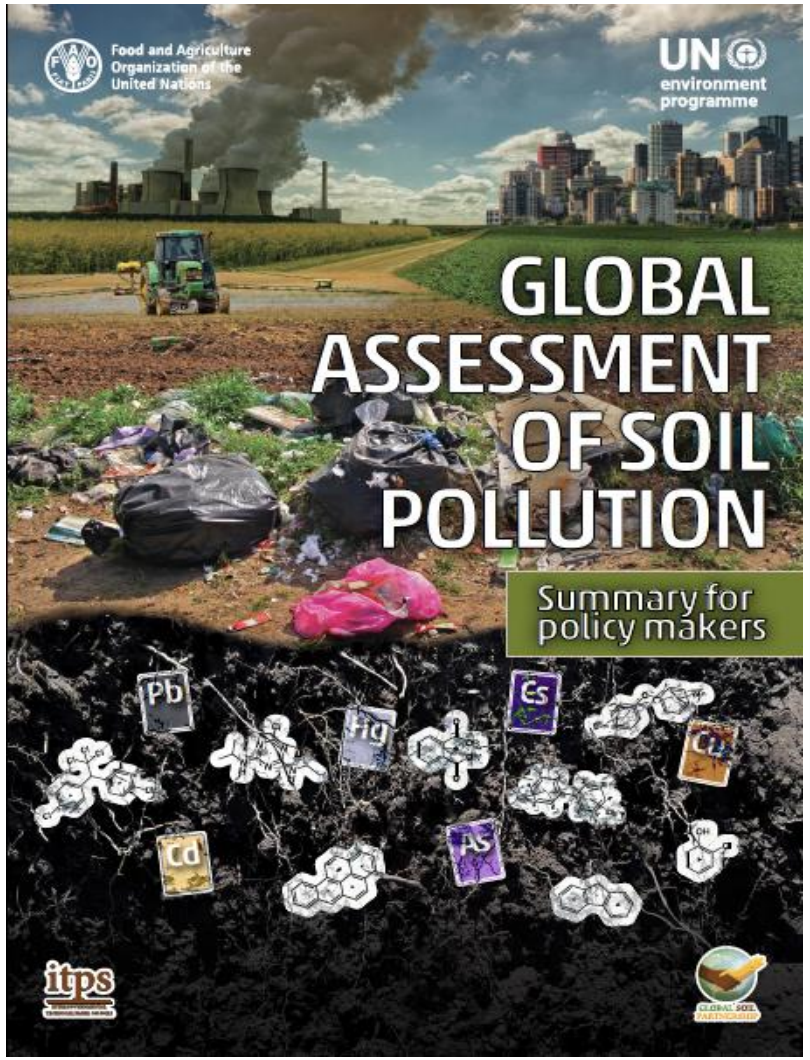
Sources

Fate (availability, mobility)

Transfer into food web / humans

PROAGRO LECTORIUM

Soil Pollution as a threat to Food Security



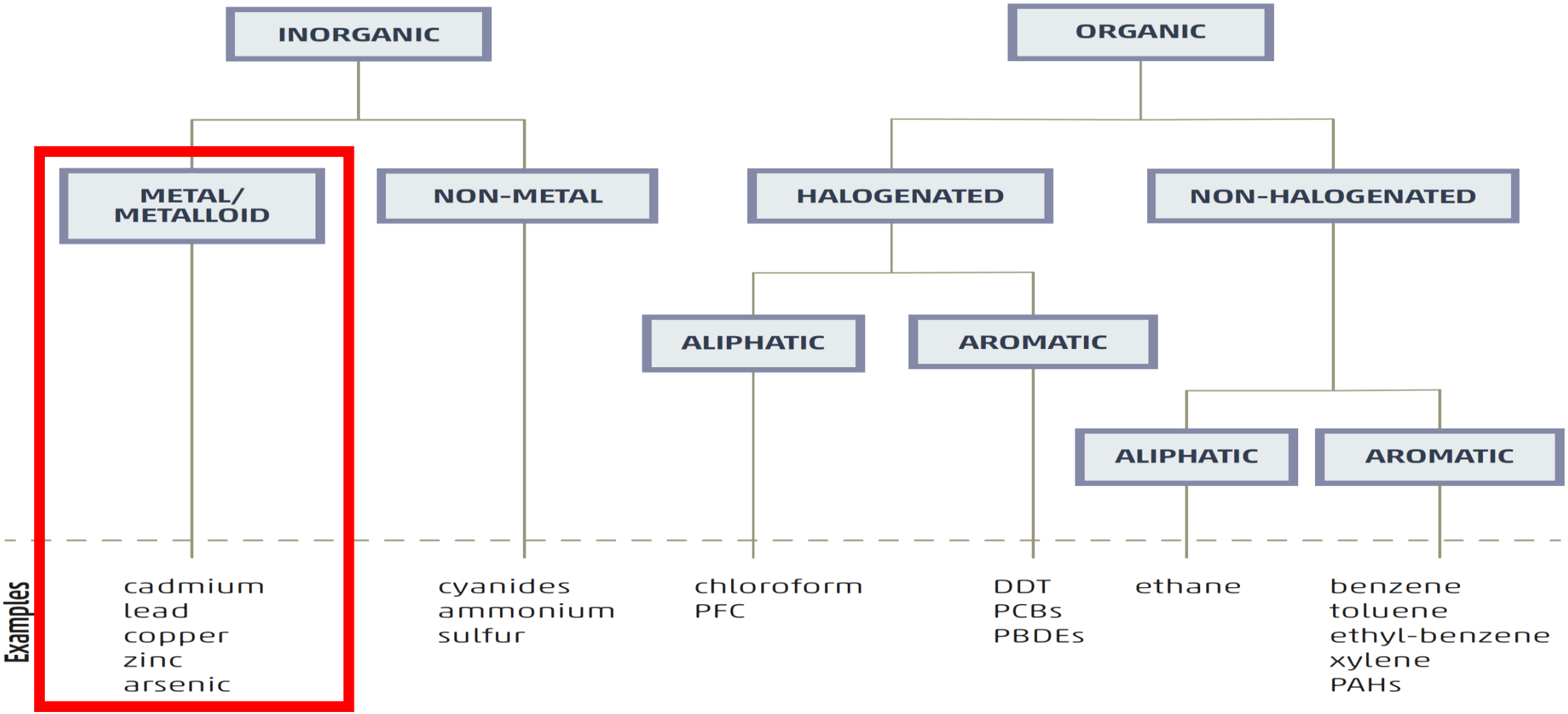
The case of **"heavy metals"** or **"trace elements"** or **"potentially toxic elements"**

Trace elements [2]

The term "trace elements" refers to a group of ubiquitous elements that normally occur at very low levels in the environment and which can be toxic to organisms. Trace elements include heavy metals (that is, those metals with high atomic mass) such as lead (Pb), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), mercury (Hg), tin (Sn), nickel (Ni) and zinc (Zn). Non-metals that are regarded as trace elements include arsenic (As), antimony (Sb) and selenium (Se).

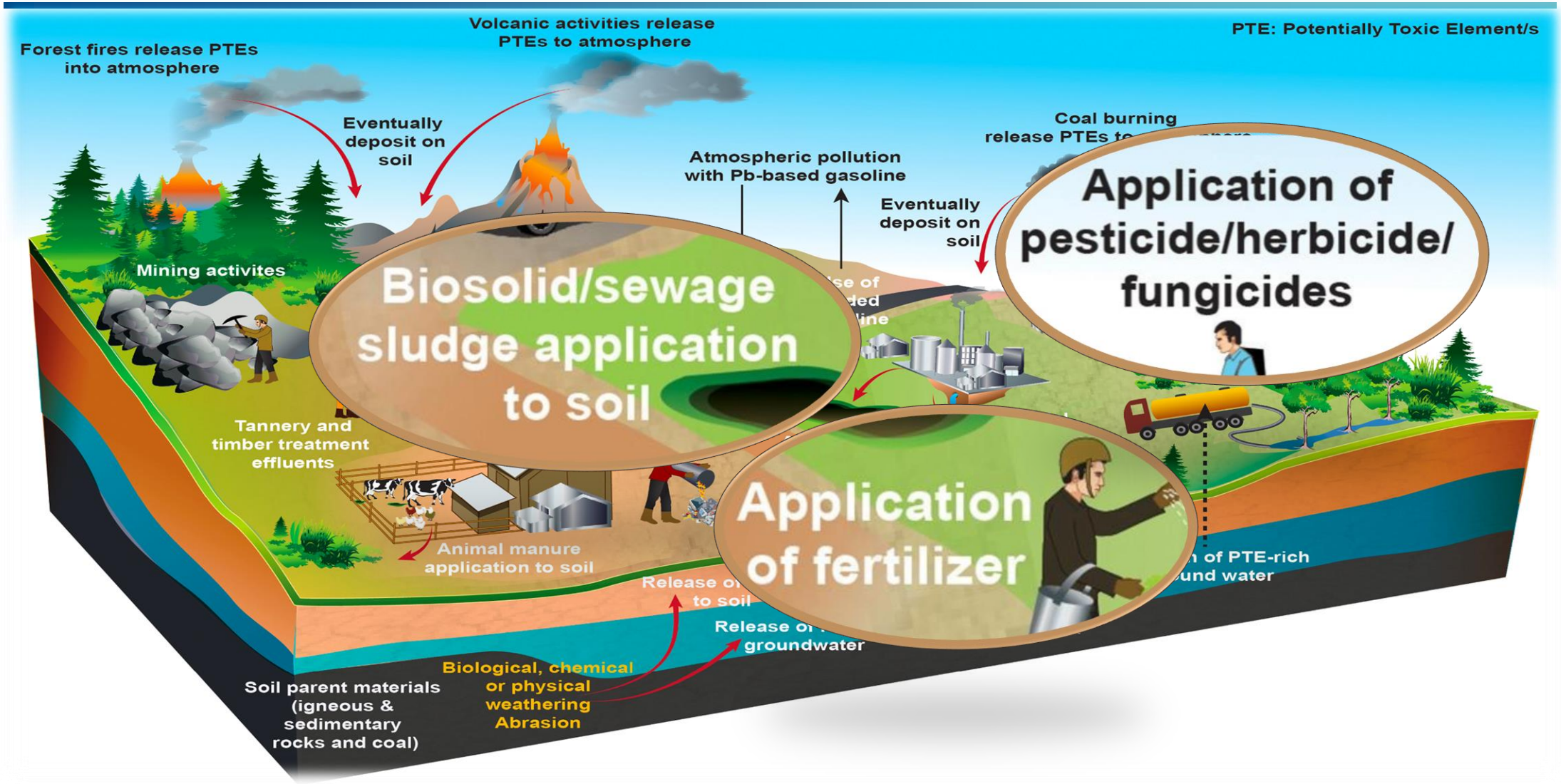
https://doi.org/10.4060/cb4827en

Systematic categorization of major soil contaminants



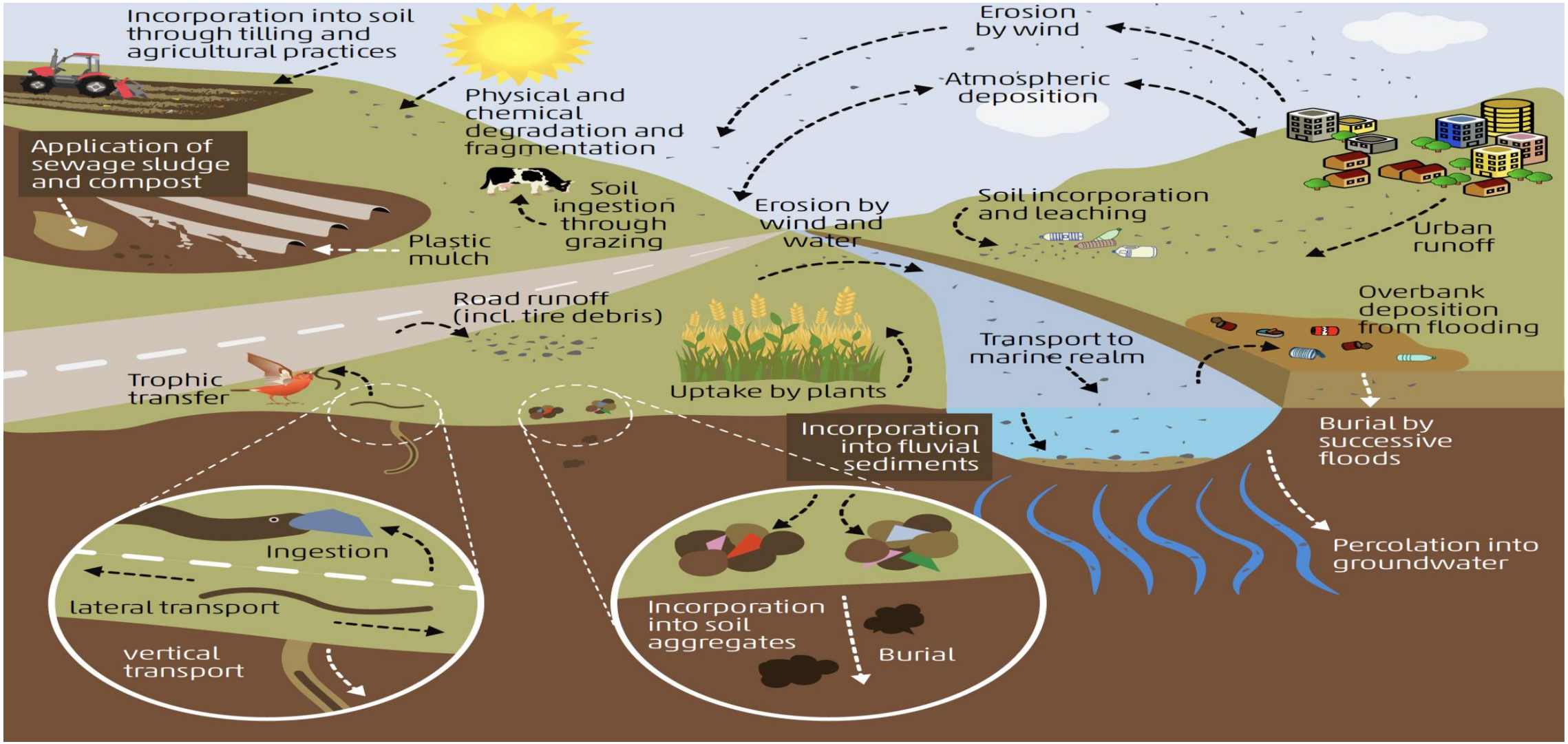
https://doi.org/10.4060/cb4894en

Potentially toxic element (PTE) sources in soil ecosystems



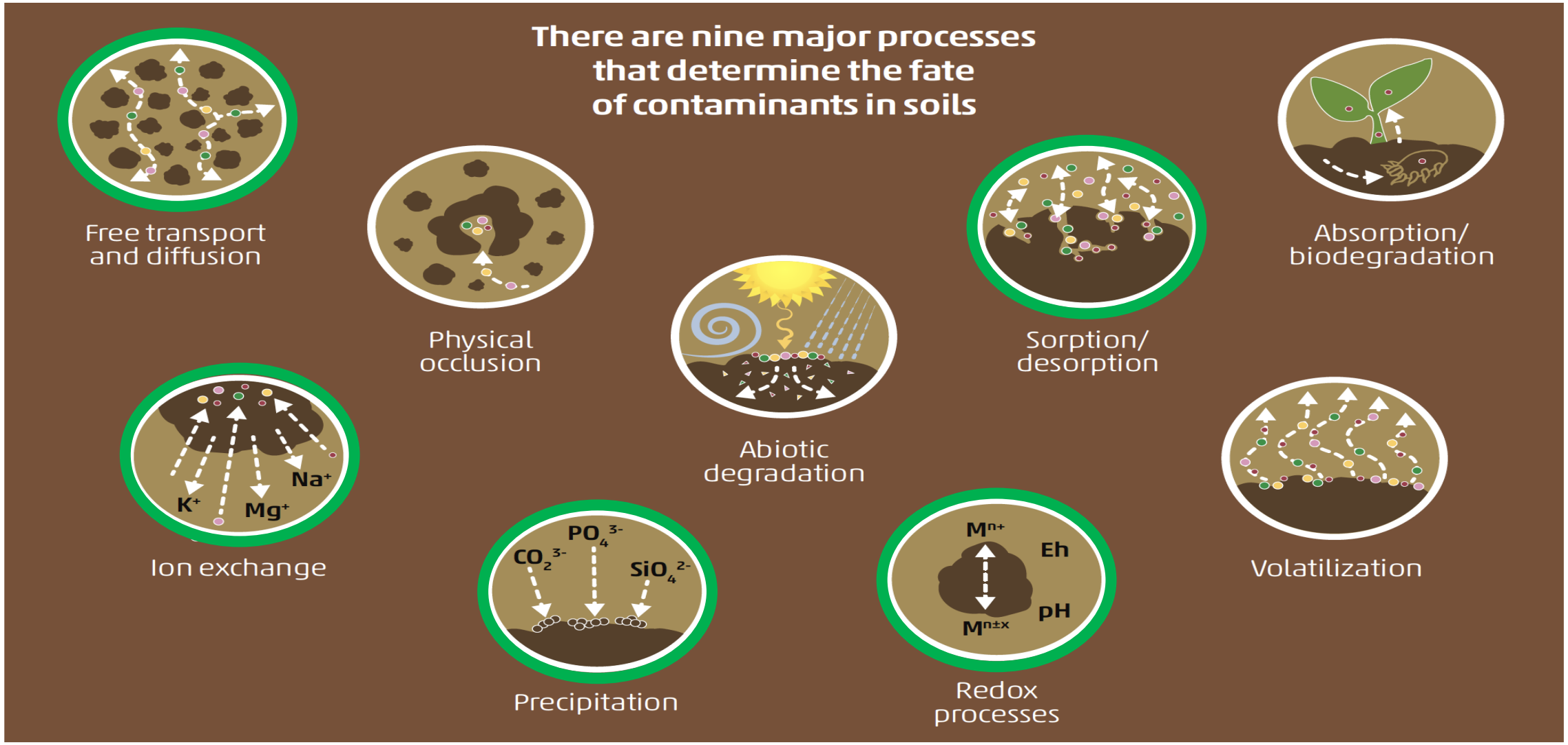
https://doi.org/10.1016/j.envint.2019.105046

Contaminants in soils: routes of entrance



https://doi.org/10.4060/cb4894en

Contaminants in soils: fate



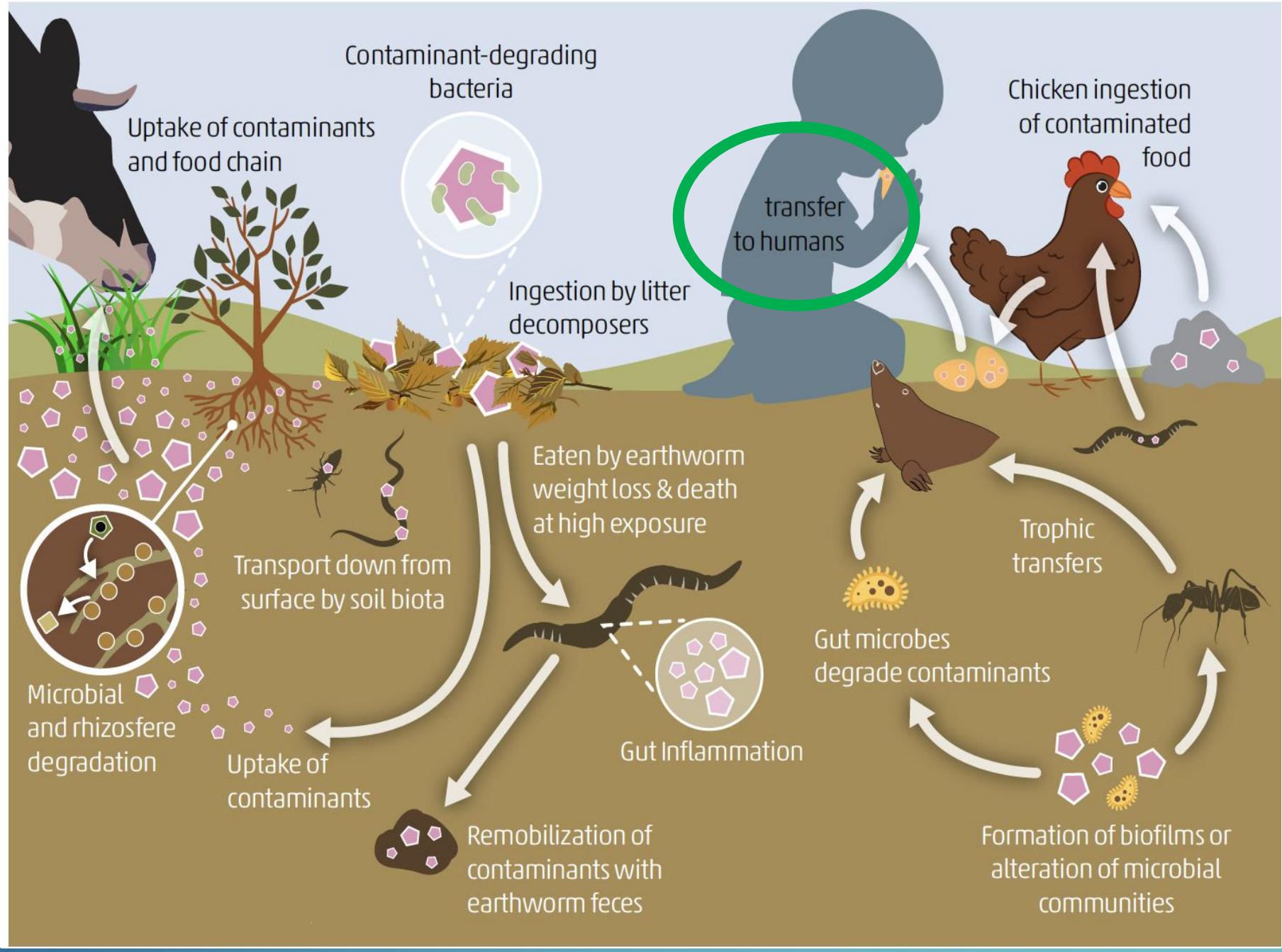
https://doi.org/10.4060/cb4894en

Chemical behaviors of selected PTEs in soils

- **Arsenic (As):** **Oxidation states**: +3, +5; **Sorption:** Mainly sorbed to Fe(oxy)hydroxides through inner-sphere bidentate and monodentate surface complexes; **Speciation:** In natural waters, soils, and sediments, the As species of interest are arsenate oxyanions, As(V); arsenite oxyanions, As(III); monomethylarsonic acid, As(III); and dimethylarsinic acid, As(I). However, under natural environmental conditions, arsenic exists mainly in two species, arsenite (As (III)), which is mainly present under anaerobic conditions and arsenate (As(V)), which is mainly present under aerobic conditions; **Others:** Shares chemical similarity with P; therefore, phosphates increase As mobility in soils.
- **Cadmium (Cd):** **Sorption:** Forms inner-sphere complexes on surfaces, bound to organic matter (OM) at pH < 6.5 and to Fe oxides at pH > 6.5. Forms complexes with inorganic ligands or dissolved OM. Association with soil components: A great part of Cd is bound to humic acid. Cadmium carbonates might be found as a major Cd species in some soils, whereas a small amount of Cd sulfide might be found in other soils; **Mobility and bioavailability**: Cd is highly mobile and thus is readily available for plant uptake. It has a long biological half-life in the human body (15–20 yrs); **Others:** Forms precipitates in reduced soils containing S as CdS (solubility <0.1 µg/L).
- **Chromium (Cr):** **Oxidation states:** +3, +6; Geochemical fractions: Residual and crystalline Fe oxide fractions are the Cr dominant fractions in most soils; **Speciation:** Can exist in several oxidation states ranging from the metallic form, Cr(0), to Cr(VI). The most stable oxidation states of Cr in the environment are Cr(III) and Cr(VI). The insoluble $Cr(OH)_3$ or Cr(III) is sorbed to soil colloids; $Cr(H_2O)_3^{6+}$ in strongly acidic soils. Cr(VI) is typically associated with oxygen as CrO_4^{2-} and $Cr_2O_7^{2-}$; **Others:** Cr(III) is less mobile and less toxic than Cr(VI) and is mainly found bound to OM.

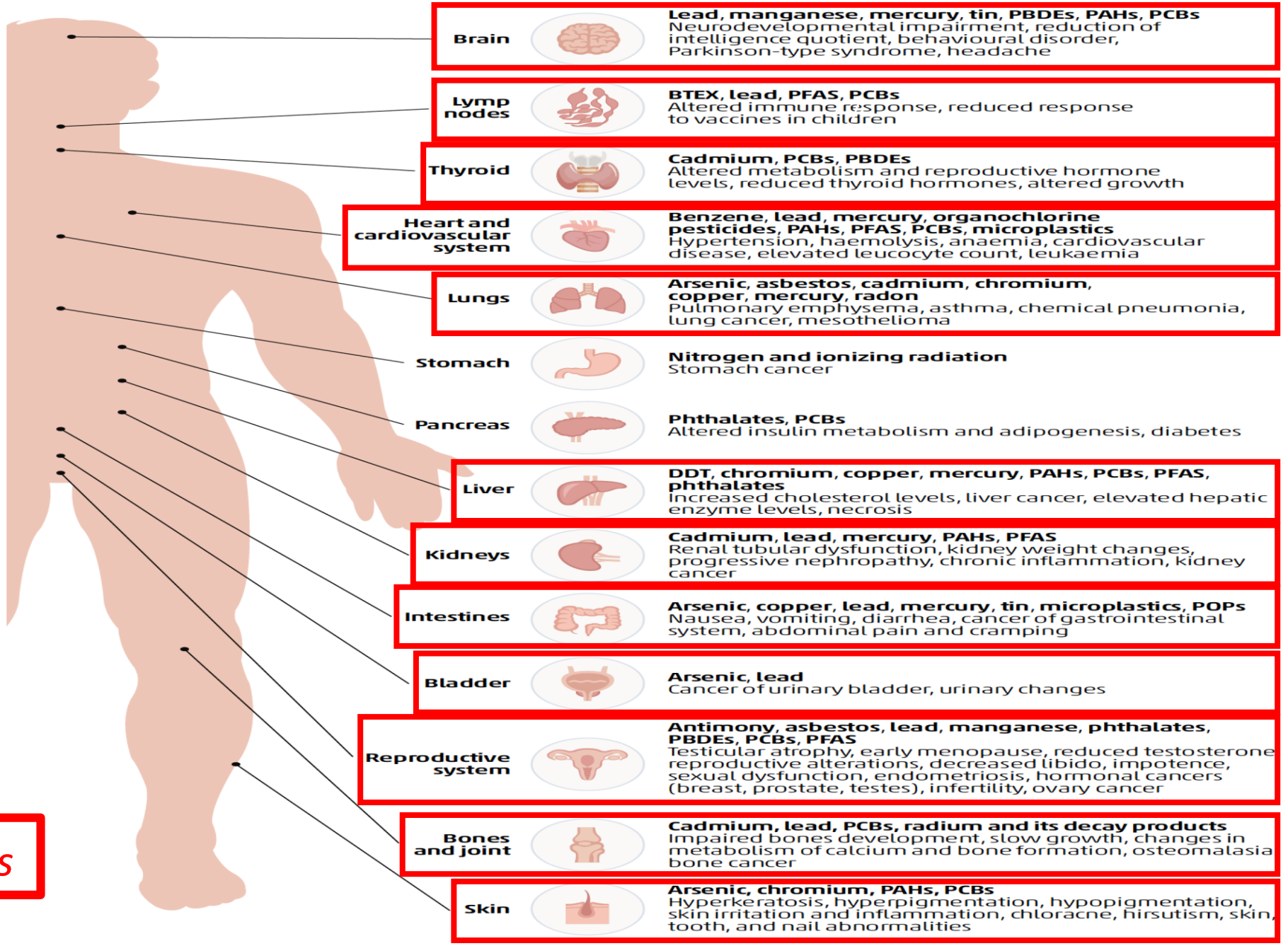
https://doi.org/10.1016/j.envint.2019.105046

Contaminants' transfer into the terrestrial food web from the soil to pastures and crops, which are ingested by wildlife, livestock and humans, and from the soil to invertebrates, ingested by birds and poultry and ultimately **transferred to humans**



https://doi.org/10.4060/cb4894en

Main **effects of soil contaminants** on human health, indicating the **organs or systems affected** and the contaminants causing them

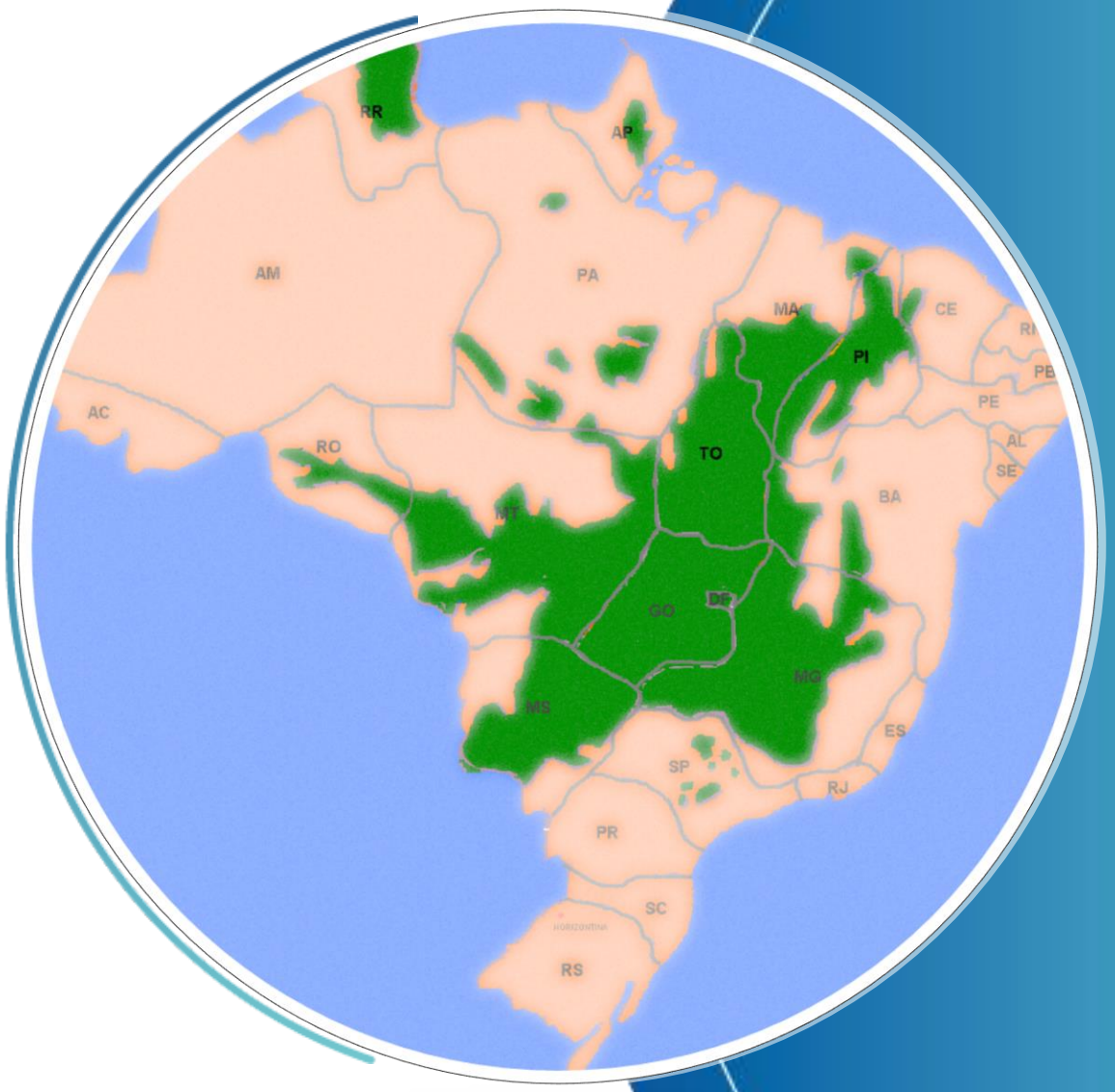


organs affected by PTEs

https://doi.org/10.4060/cb4894en

Brazil as a showcase

Ensuring food security in a tropical agroecosystem while promoting sustainable agricultural practices and judicious fertilizer management



PROAGRO LECTORIUM

Our great challenge: how to feed - with QUALITY and SAFETY - nearly 10 billion people in 2050?

HOW TO FEED THE WORLD 2050

HIGH-LEVEL EXPERT FORUM

Rome 12–13 October 2009

Global agriculture towards 2050

THE CHALLENGE

Agriculture in the 21st century faces multiple challenges: it has to produce more food and fibre to feed a growing population with a smaller rural labour force, more feedstocks for a potentially huge bioenergy market, contribute to overall development in the many agriculture-dependent developing countries, adopt more efficient and sustainable production methods and adapt to climate change.

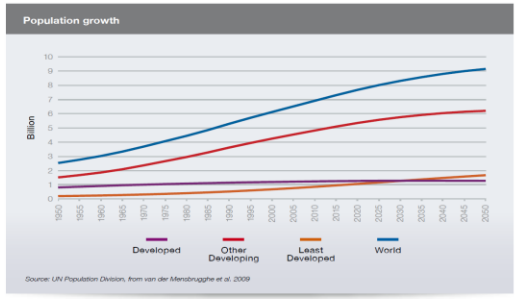
FOOD DEMAND AND PRODUCTION

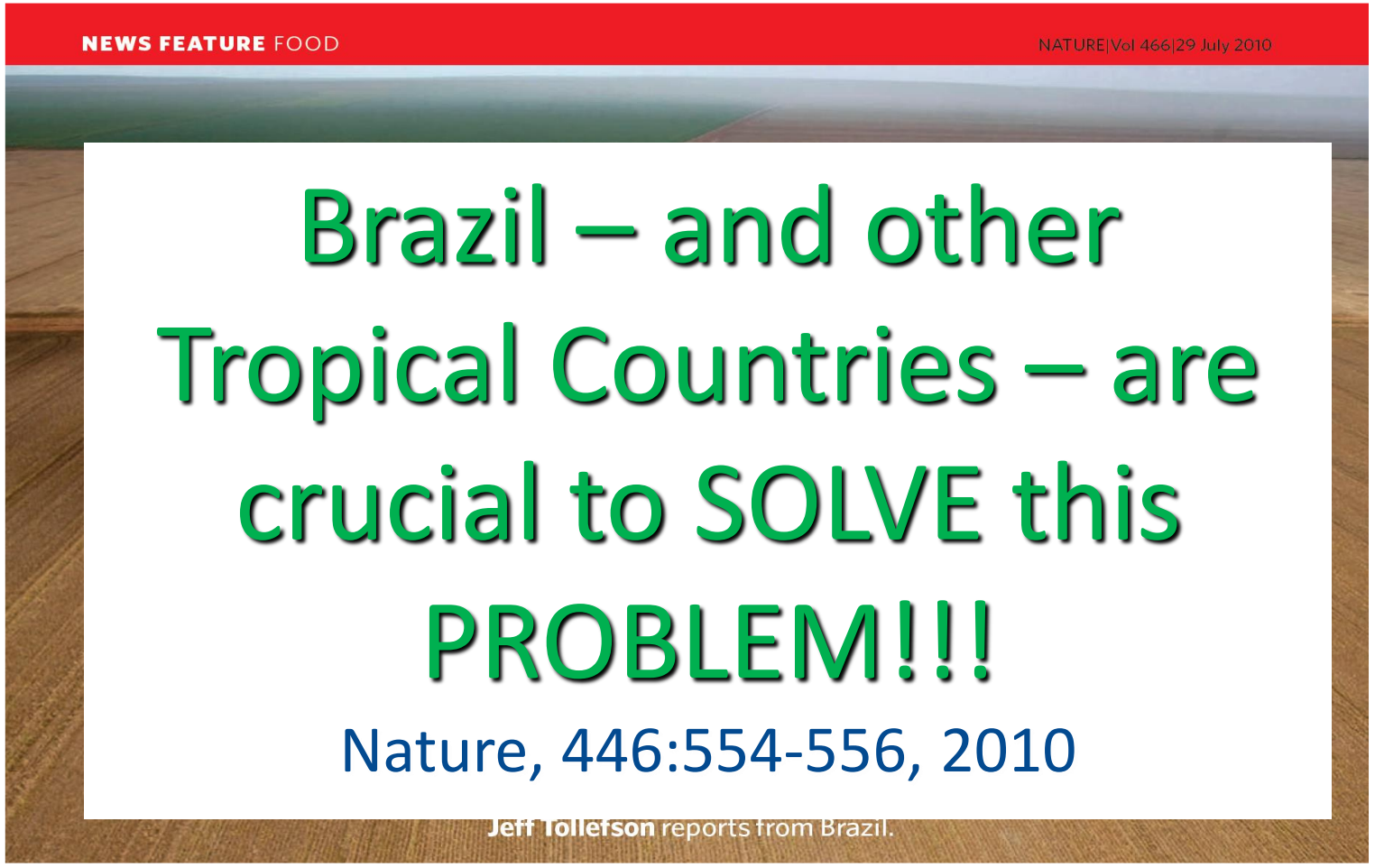
World population is expected to grow by over a third, or 2.3 billion people, between 2009 and 2050. This is a much slower rate of growth than the one seen in the past four decades during which it grew by 3.3 billion people, or more than 90 percent. Nearly all of this growth is forecast to take place in the developing countries. Among the latter group, sub-Saharan Africa's population would grow the fastest (+114 percent) and East and Southeast Asia's the slowest (+13 percent). Urbanization is foreseen to continue at an accelerating pace with urban areas to account for 70 percent of world population in 2050 (up from 49 percent at present) and rural population, after peaking sometime in the next decade, actually declining.

At the same time, per capita incomes in 2050 are projected to be a multiple of today's levels. There is a consensus among analysts that recent trends whereby the economies of developing countries have been growing significantly faster that the developed ones is likely to continue in the future. Relative inequality in per capita incomes would be reduced considerably by 2050. However, absolute differences would remain pronounced and could even increase further, given the current huge gaps in absolute per capita incomes. Moreover, inter-country and inter-regional inequalities within the present-day developing world would tend to become more pronounced.

The projected global economic growth of about 2.9 percent annually would lead to a significant reduction or even near elimination of absolute "economic" poverty in the developing countries (persons living on less than US$1.25/day in 2005 prices). Nevertheless, even in 2050 the world will still be far from solving the problem of economic deprivation and malnutrition of significant parts of the population: the US$1.25/day poverty line is simply too low. On less stringent criteria, deprivation and undernutrition will remain widespread, though significantly less than today.

These trends mean that market demand for food would continue to grow. Demand for cereals, for both food and animal feed uses is projected to reach some 3 billion tonnes by 2050, up from today's nearly 2.1 billion tonnes. The advent of biofuels





Brazil – and other Tropical Countries – are crucial to SOLVE this PROBLEM!!!

Nature, 446:554-556, 2010

www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf

Brazil: The land of the 4Fs...

Food

Feed

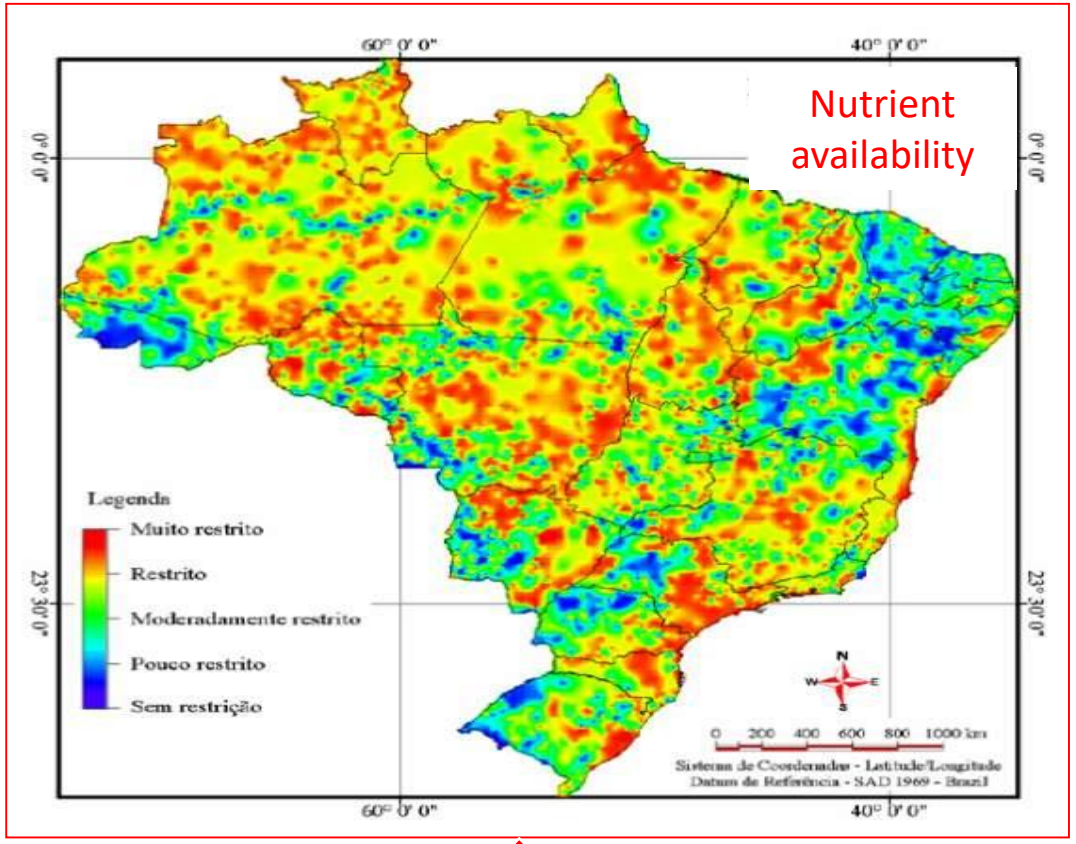
Fiber

Fuel

For that, we need another F, which is Fertilizer

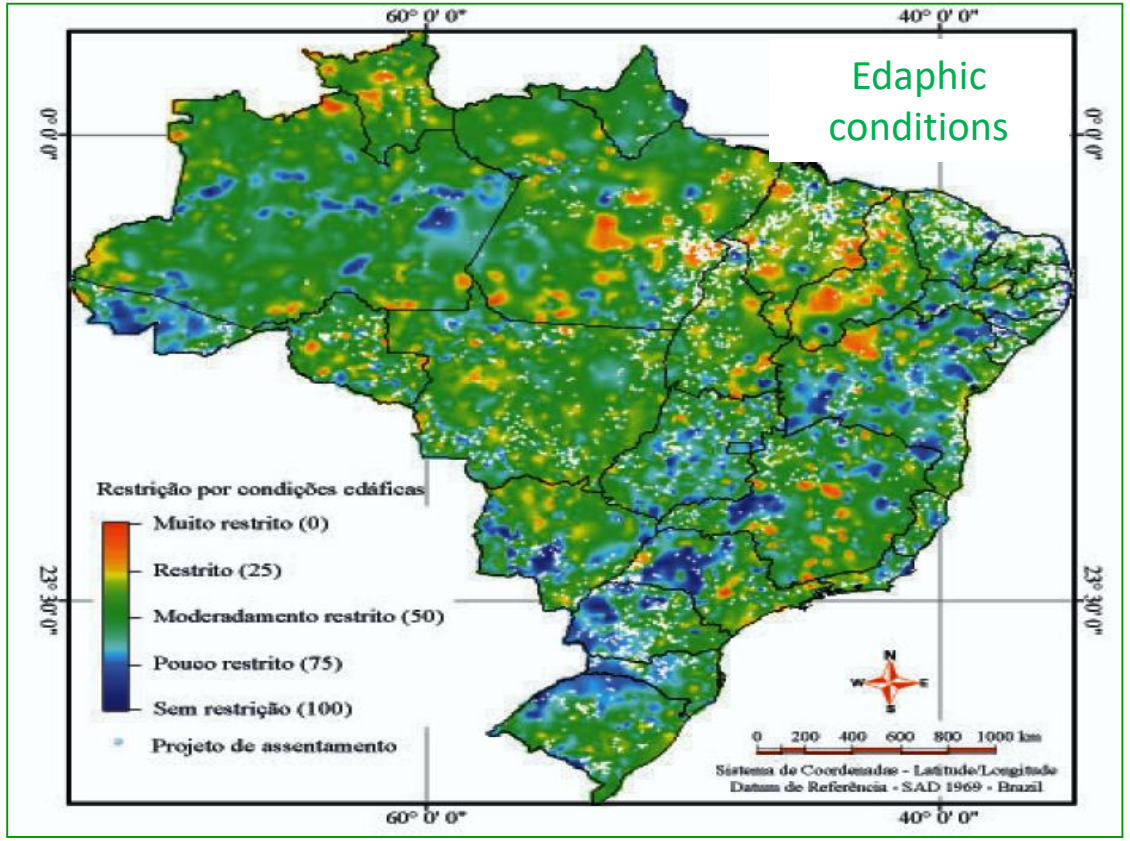
(Plant nutrients…)

Brazil: Tropical country *(weathered soils)*



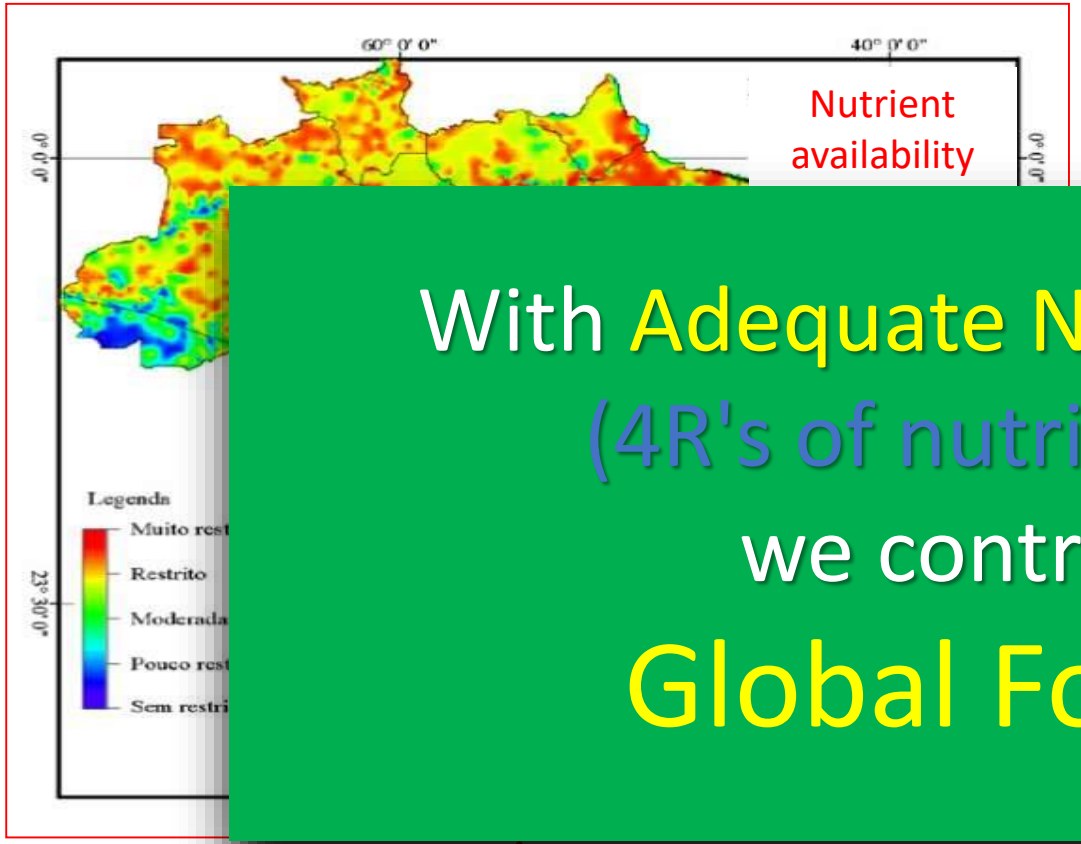
Many soil fertility constraints, e.g., high phosphorus (P) adsorption capacity, but…

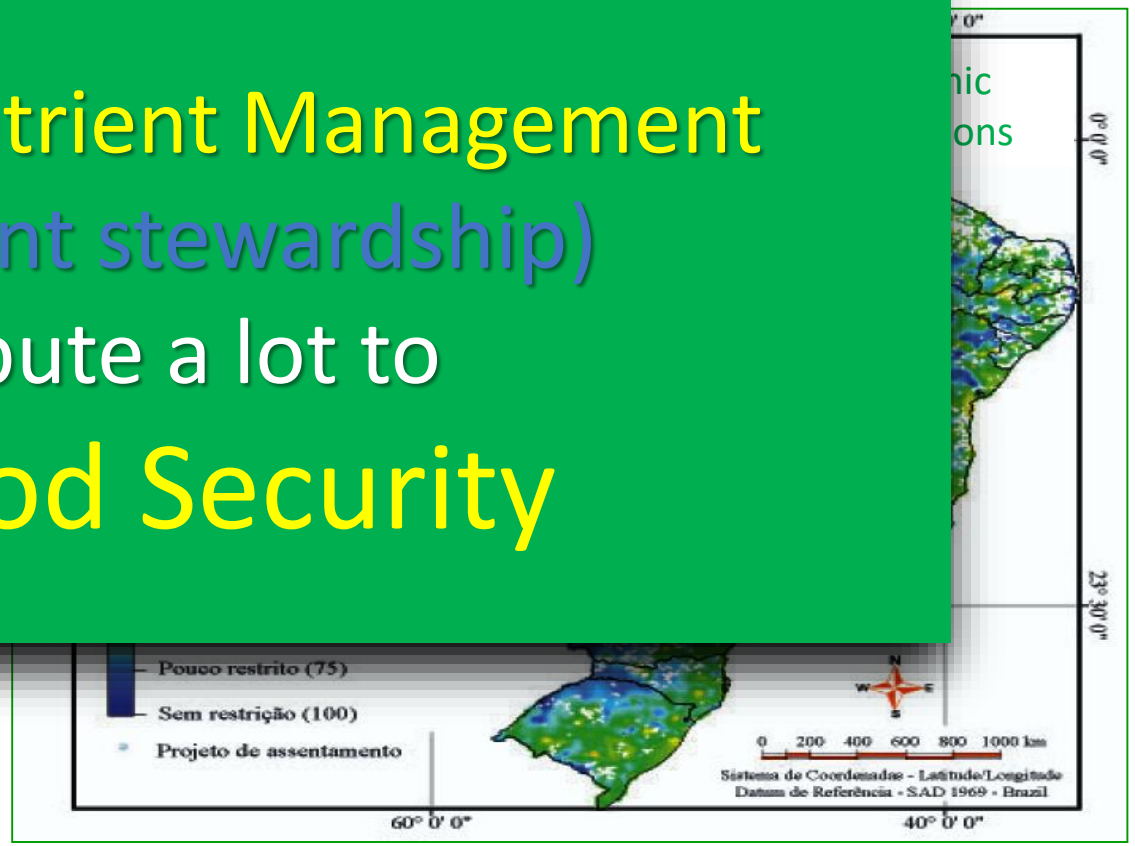
… Good edaphic conditions overall



Brazil: Tropical country *(weathered soils)*

… Good edaphic conditions overall

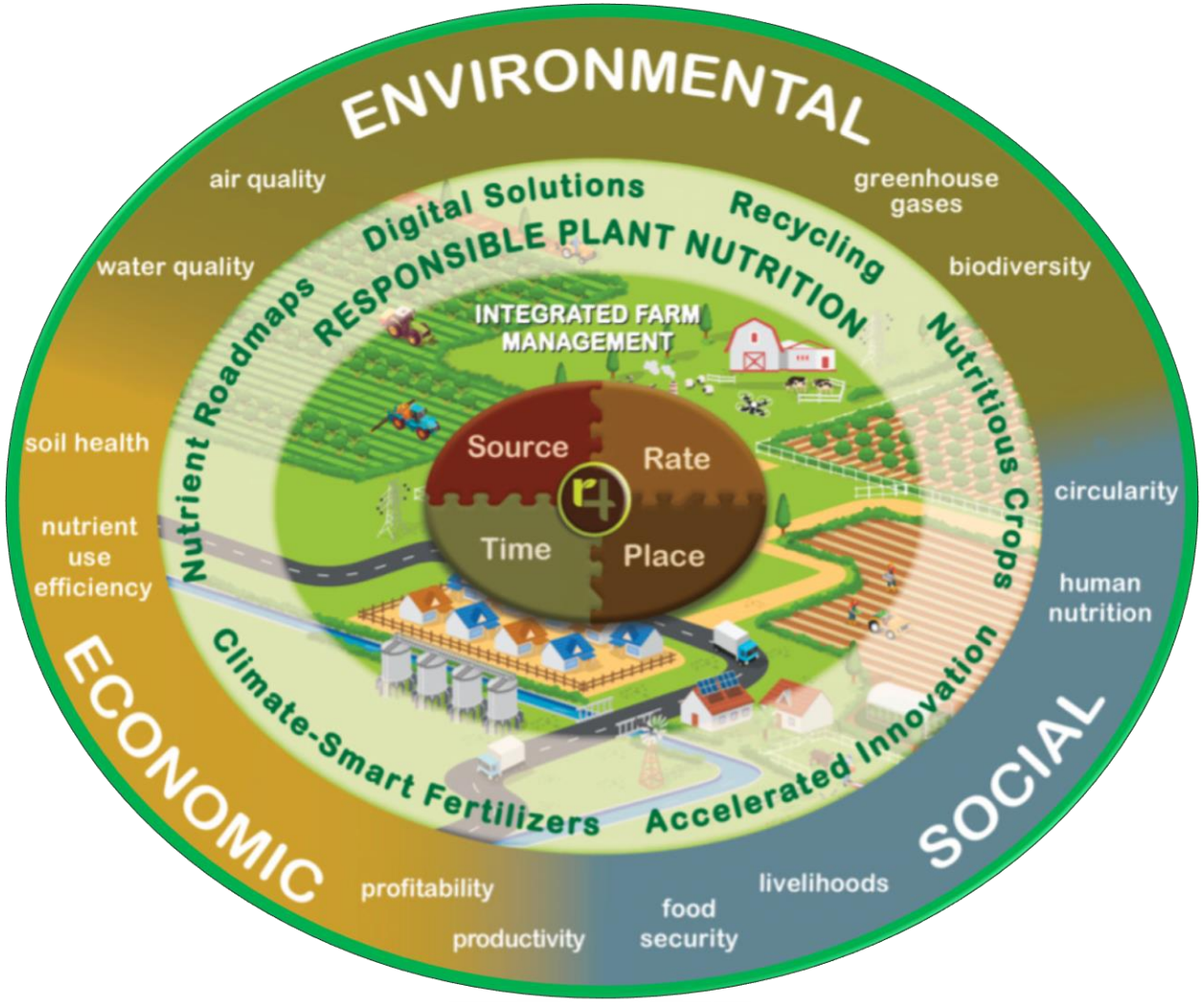


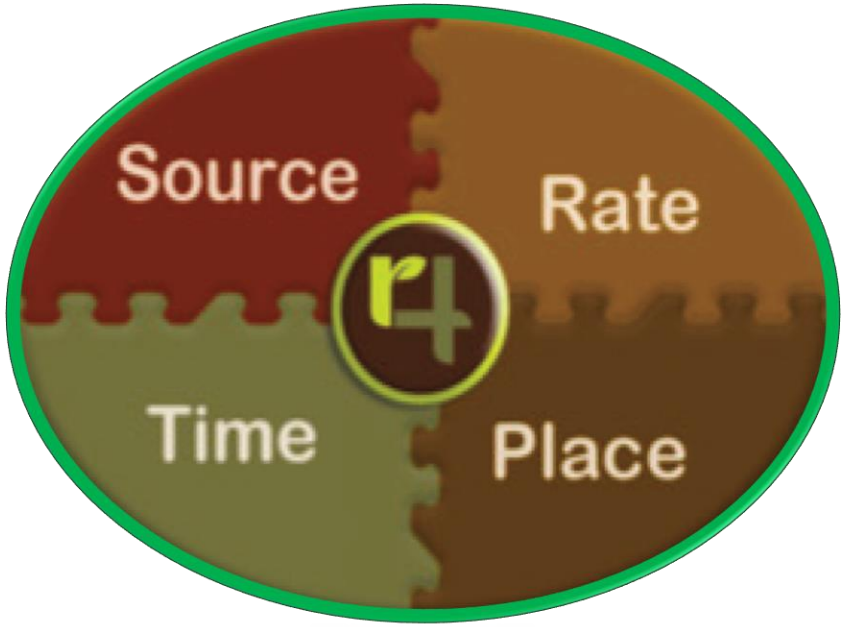


With Adequate Nutrient Management
(4R's of nutrient stewardship)
we contribute a lot to
Global Food Security

Many soil fertility constraints, e.g., high phosphorus (P) adsorption capacity, but…

The 4R's of nutrient stewardship

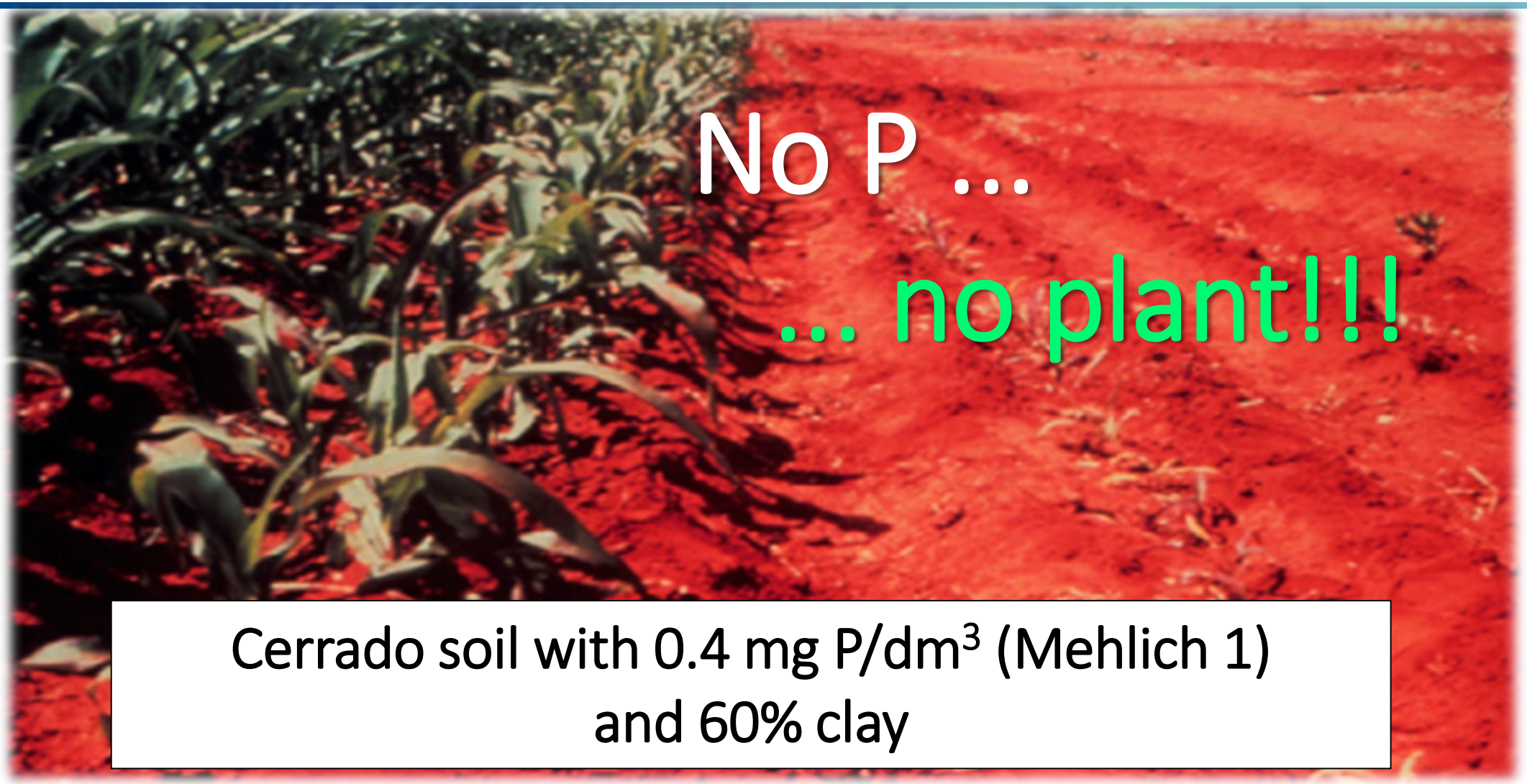




- **Right fertilizer source,** at the
- **Right rate,** at the
- **Right time,** and in the
- **Right place**

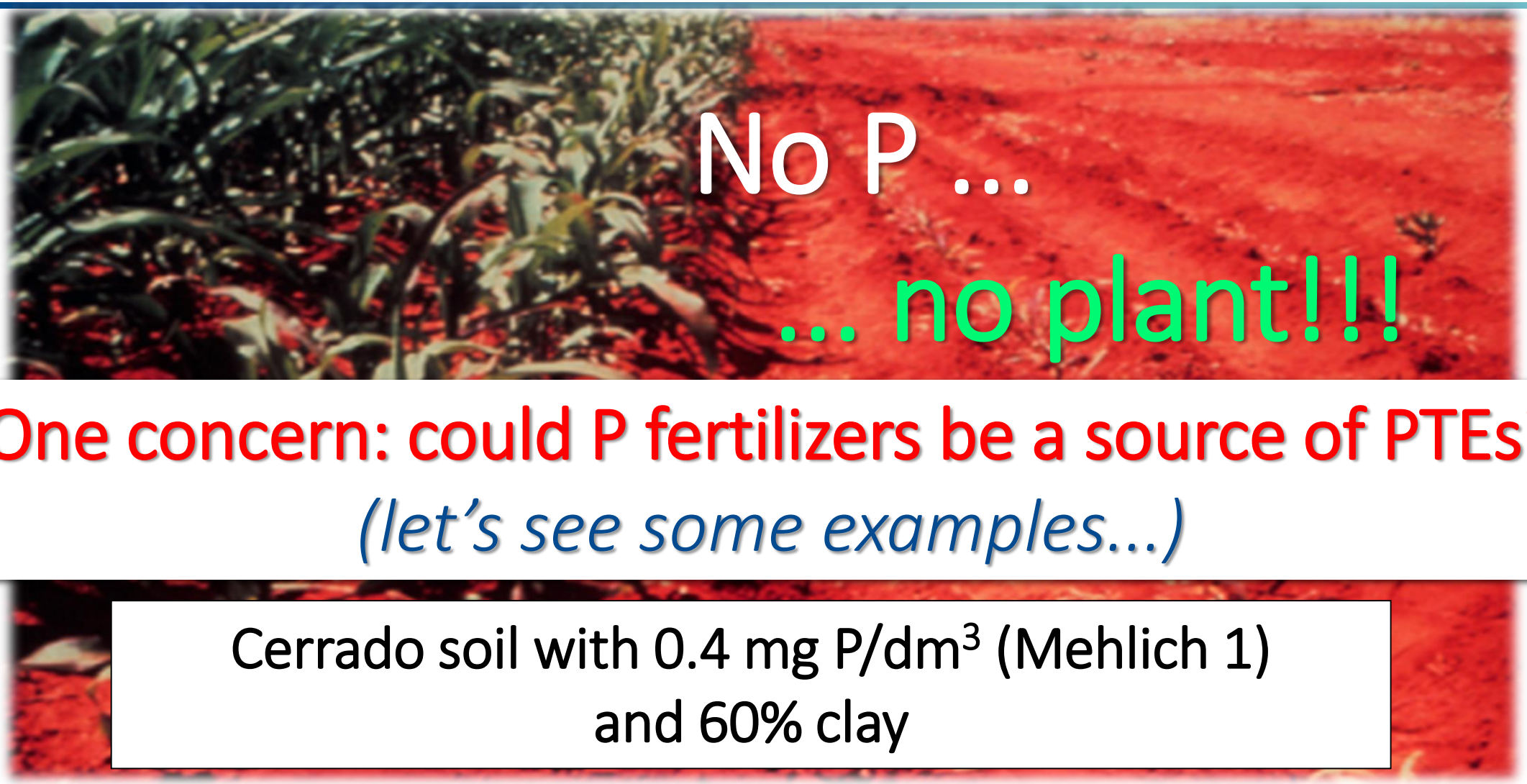
https://sprpn.org/issue-brief/furthering-4r-nutrient-stewardship/

Highly P Fixing Soils + Adequate P Fertilization = High Yields!



Cerrado soil with 0.4 mg P/dm^3 (Mehlich 1)
and 60% clay

Highly P Fixing Soils + Adequate P Fertilization = High Yields!

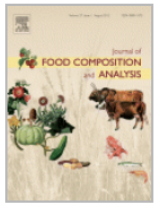


One concern: could P fertilizers be a source of PTEs?

(let's see some examples...)

Cerrado soil with 0.4 mg P/dm^3 (Mehlich 1)
and 60% clay

Journal of Food Composition and Analysis
Volume 27, Issue 1, August 2012, Pages 32-37



Original Research Article

Cadmium in potato and soybeans: Do phosphate fertilization and soil management systems play a role?

Ana Paula Branco Corguinha [a], Veridiana Cardozo Gonçalves [a], Guilherme Amaral de Souza [a], Willian Eduardo Amaral de Lima [a], Evanise Silva Penido [a], Cesar Augusto Brasil Pereira Pinto [b], Eros Artur Bohac Francisco [c], Luiz Roberto Guimarães Guilherme [a]

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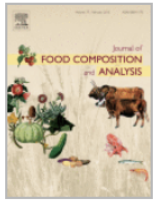
https://doi.org/10.1016/j.jfca.2012.05.001 Get rights and content

Highlights

- Cadmium (Cd) contents in potato and soybean in Brazil were studied.
- Cd content in potato varied among cultivars and areas, remained mainly in peel.
- Cd content in soybean independent of the cropping system.
- Cd in studied crops is within *Codex Alimentarius* limits, and not a risk to human health.
- Cd in crops in soils with high rate of P fertilization not a risk to human health.

Journal of Food Composition and Analysis
Volume 37, February 2015, Pages 143-150



Original Research Article

Assessing arsenic, cadmium, and lead contents in major crops in Brazil for food safety purposes

Ana Paula Branco Corguinha [a], Guilherme Amaral de Souza [a], Veridiana Cardoso Gonçalves [a], Camila de Andrade Carvalho [a], Willian Eduardo Amaral de Lima [a], Fábio Aurélio Dias Martins [b], Celso Hideto Yamanaka [c], Eros Artur Bohac Francisco [d], Luiz Roberto Guimarães Guilherme [a]

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https://doi.org/10.1016/j.jfca.2014.08.004

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Highlights

► We investigated arsenic, cadmium and lead contents in major crops in Brazil (rice, wheat, corn, soybeans, and potatoes).

► Arsenic and cadmium content in wheat varied among accessions.

► Trace elements contents for the studied crops do not pose a risk to human health.

Environmental Research
Volume 263, Part 2, 15 December 2024, 120171

Arsenic, cadmium, and chromium concentrations in contrasting phosphate fertilizers and their bioaccumulation by crops: Towards a green label?

Mariana Rocha de Carvalho [a], Thiago Adorno de Almeida [b], Gustavo Avelar Zorgdrager Van Opbergen [b], Fábio Henrique Alves Bispo [b], Lívia Botelho [b], Alexandre Boari de Lima [b], Paulo Eduardo Ribeiro Marchiori [a], Luiz Roberto Guimarães Guilherme [b]

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https://doi.org/10.1016/j.envres.2024.120171 Get rights and content

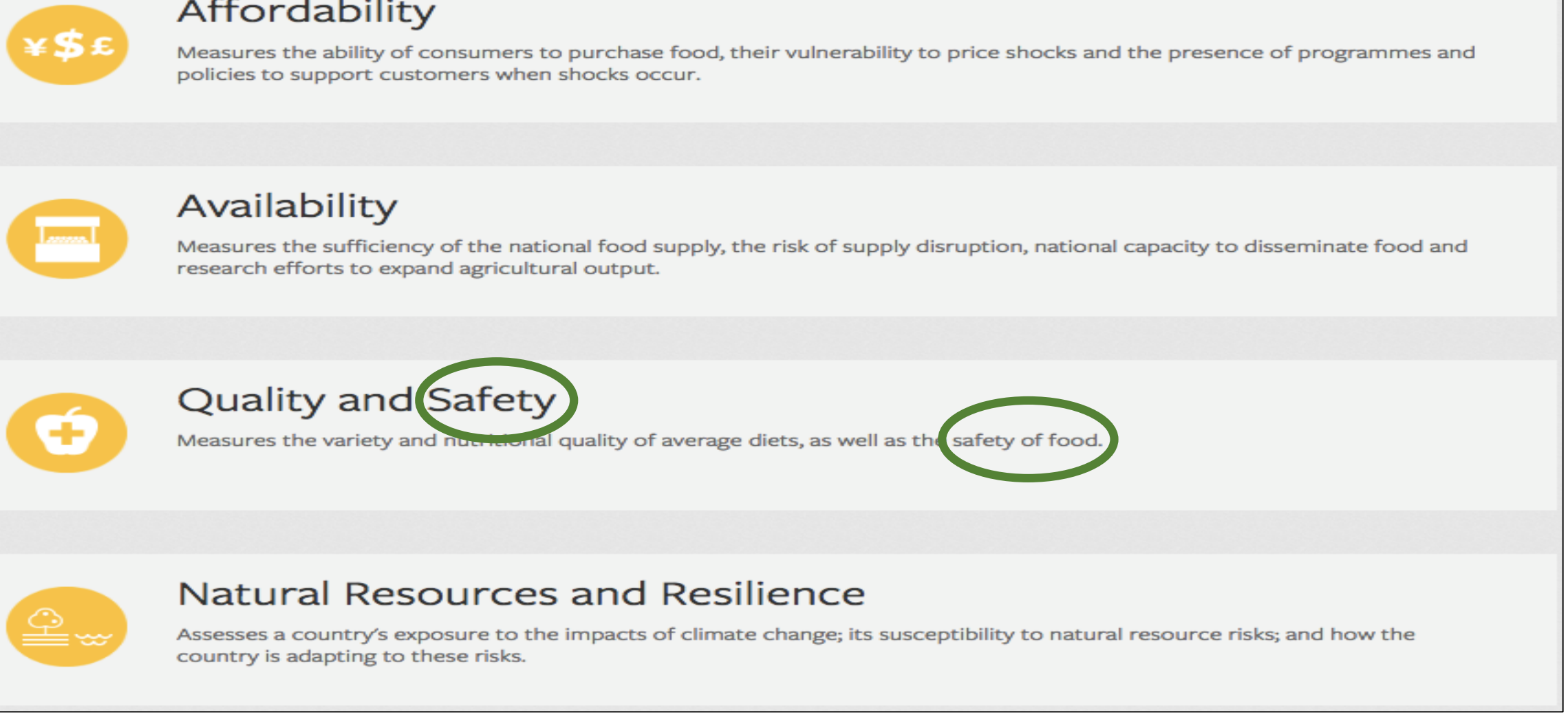
Highlights

- Phosphate fertilizers may represent sources of potentially toxic elements for agriculture.
- High-Cd P fertilizers increase Cd in xylem sap and its transfer from soil to plant tissues.
- Using low-Cd P fertilizers reduces Cd accumulation/transfer into the food chain.
- Potato crops have a high potential to accumulate Cd from P fertilizers.

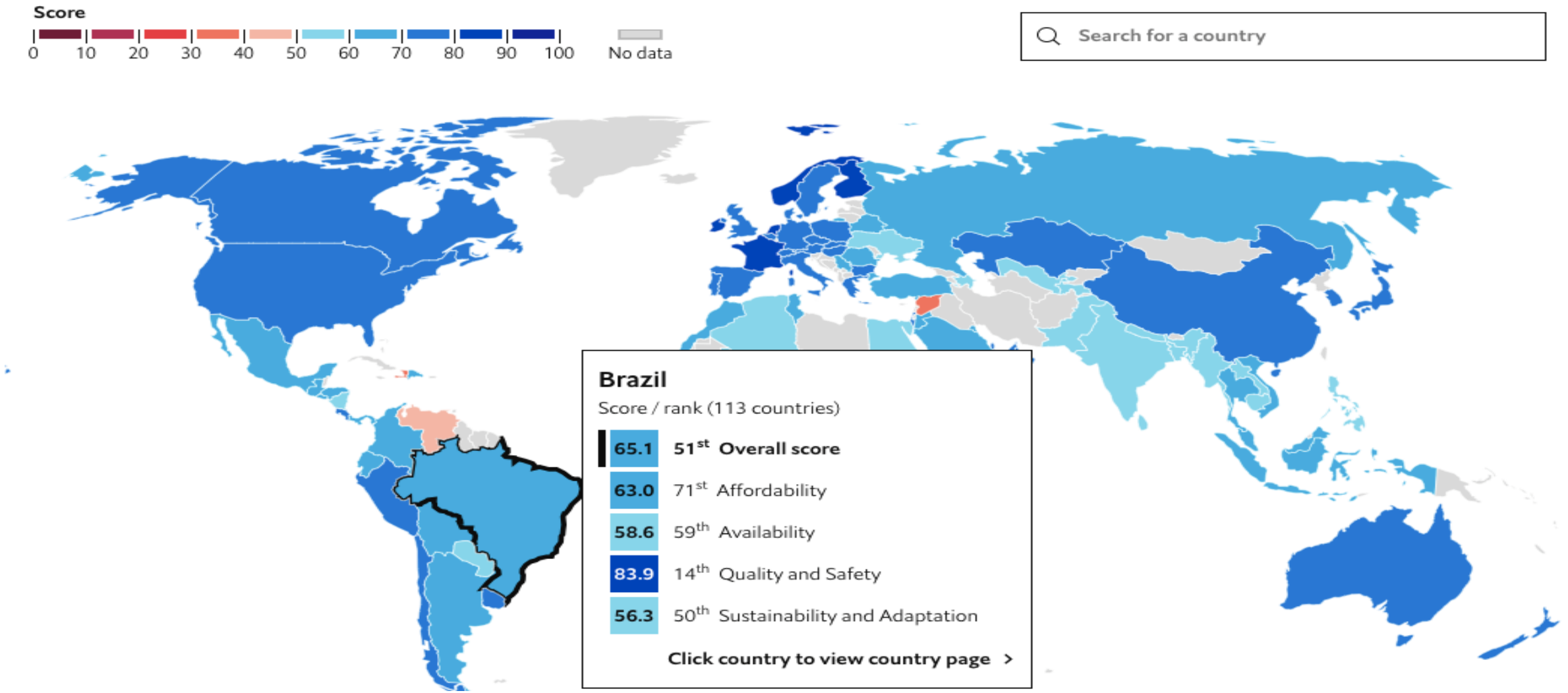
Final Remarks

PROAGRO LECTORIUM

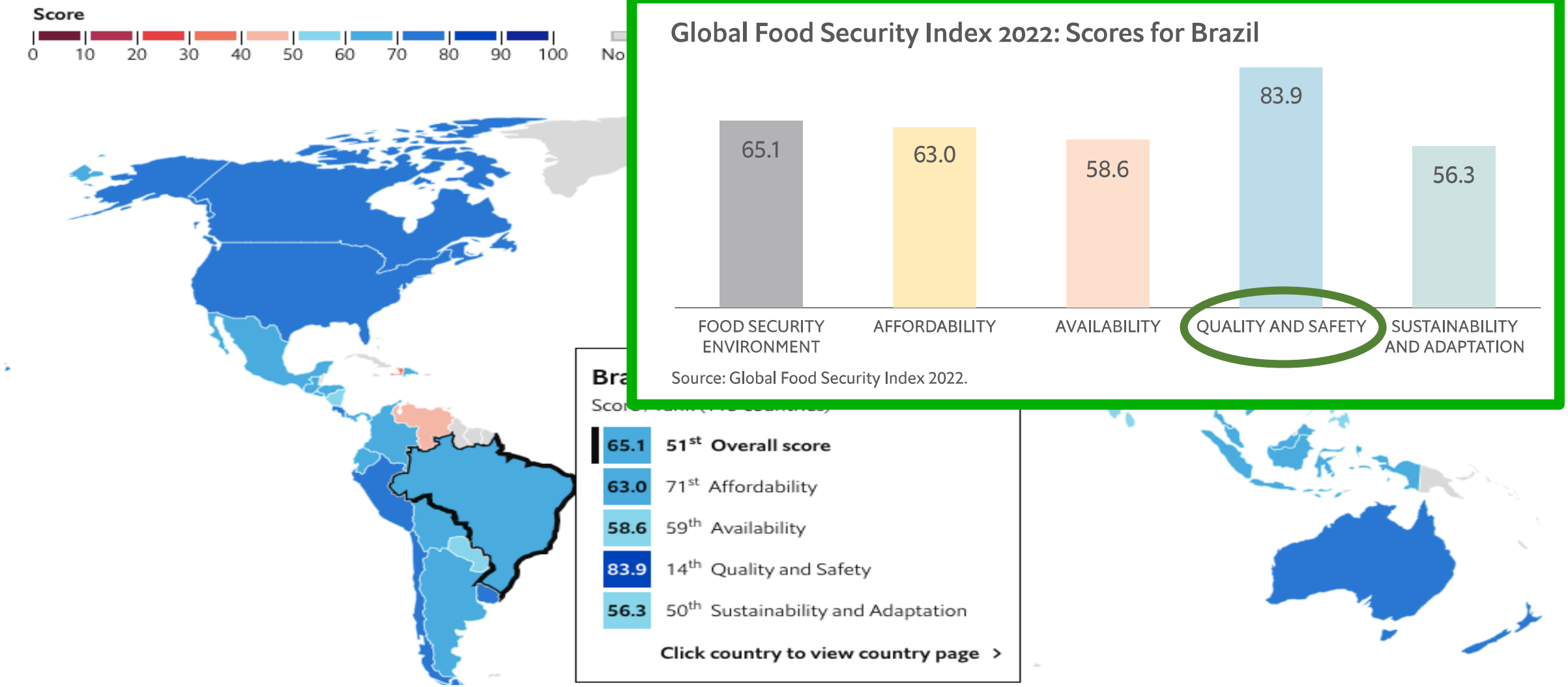
Global Food Security Index:
Components of the Food Security Index



Global Food Security Index: Brazil (2022)



Global Food Security Index: Brazil (2022)



Global Food Security Index: Brazil
Score 2022 & Variation from 2012 to 2022

	Score	Δ
FOOD SECURITY ENVIRONMENT	65.1	↑ +1.3

	Score	Δ
1 AFFORDABILITY	63.0	↓ -9.6
1.1 Change in average food costs	38.0	↓ -17.5
1.2 Proportion of population under global poverty line	95.6	↑ +8.2
1.3 Inequality-adjusted income index	44.2	↓ -2.7
1.4 Agricultural trade	66.8	↓ -5.1
1.5 Food safety net programmes	73.2	↓ -26.8

	Score	Δ
2 AVAILABILITY	58.6	↓ -2.7
2.1 Access to agricultural inputs	83.6	↑ +16.8
2.2 Agricultural research & development	55.4	↑ +29.6
2.3 Farm infrastructure	52.4	↑ +32.8
2.4 Volatility of agricultural production	95.2	↑ +10.2
2.5 Food loss	51.9	↓ -0.9
2.6 Supply chain infrastructure	35.8	↑ +0.6
2.7 Sufficiency of supply	38.7	↓ -45.6
2.8 Political and social barriers to access	64.4	↓ -2.4
2.9 Food security and access policy commitments	47.5	↓ -52.5

	Score	Δ
3 QUALITY AND SAFETY	83.9	↑ +9.8
3.1 Dietary diversity	60.5	↑ +1.9
3.2 Nutritional standards	100.0	↑ +52.4
3.3 Micronutrient availability	63.4	↓ -16.3
3.4 Protein quality	94.0	↑ +6.0
3.5 Food safety	99.7	↑ +3.6

	Score	Δ
4 SUSTAINABILITY AND ADAPTATION	56.3	↑ +11.6
4.1 Exposure	67.1	↔
4.2 Water	63.8	↔
4.3 Land	54.4	↑ +3.5
4.4 Oceans, rivers and lakes	38.1	↓ -4.4
4.5 Political commitment to adaptation	59.7	↑ +18.7
4.6 Disaster risk management	52.9	↑ +52.9

Very good (80–100) | Good (70–79.9) | Moderate (55–69.9) | Weak (40–54.9) | Very weak (0–39.9)

Source: Global Food Security Index 2022.

Worst indicator: **supply chain infrastructure** (item 2.6)

Best indicators: **nutritional standards** and **food safety** (items 3.2 and 3.5)

https://impact.economist.com/sustainability/project/food-security-index/explore-countries/brazil

Is Soil Pollution a threat to Food Security?

https://www.fao.org/about/meetings/global-symposium-on-soil-pollution/en/ & https://www.fao.org/3/ca0362en/CA0362EN.pdf

https://www.fao.org/about/meetings/global-symposium-on-soil-pollution/en/ & https://www.fao.org/3/ca0362en/CA0362EN.pdf

https://www.fao.org/about/meetings/global-symposium-on-soil-pollution/en/ & https://www.fao.org/3/ca0362en/CA0362EN.pdf

https://www.fao.org/about/meetings/global-symposium-on-soil-pollution/en/ & https://www.fao.org/3/ca0362en/CA0362EN.pdf

"From the perspective of achieving the SDGs, the ***prevention of soil pollution and the minimization and remediation of former pollution*** *were identified as a priority due to the serious implications of this* ***threat****, not only for* ***the health of our soils*** *but especially for human health, water and air quality,* ***food safety*** *and the conservation of ecosystems."*

https://www.fao.org/about/meetings/global-symposium-on-soil-pollution/en/ & https://www.fao.org/3/ca0362en/CA0362EN.pdf

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