2022 CCFEA Forum

肥料当前面临的挑战:从教育到应用

Current Challenges in Fertilizers: from Education to Application

May 19-21, 2022 (Beijing Time）

CONFERENCE AGENDA

Date: May 19—21, 2022 (Beijing Time)

Supported by:

International Scientific Centre of fertilizers (CIEC)
College of Resources and Environmental Sciences, NJAU
Jiangsu Provincial Key Lab for Organic Solid Waste Utilization
Jin Shanbao College, NJAU

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2022CCFEA Chairs

Prof. Lanzhu Ji

President of International Scientific Center for Fertilizers (CIEC), CAS, Shenyang, China.

Prof. Jianwen Zou

Dean of College of Resources and Environmental Sciences, Nanjing Agricultural University, Nanjing, China.

ABOUT 2022CCFEA

CIEC is the oldest scientific organization solemnly dedicated to fertilization. CIEC provides annual events to present and discuss scientific issues of fertilizer research on an international platform. With the support from CIEC, College of Resources and Environmental Sciences at Nanjing Agricultural University, and Jiangsu Provincial Key Lab for Organic Solid Waste Utilization, it is our pleasure to invite the leading experts in the field of fertilizers to present great lectures. The aim of 2022CCFEA is to light the advances of technology and products regarding fertilizers, to students (in particular for undergraduates) and young scholars.

The college of Resources and Environmental Sciences was inaugurated in 1996 on the basis of the Department of Soil Science and Agro-chemistry at NJAU. The college has the #1 ranked discipline in the field of soil science and plant nutrition, in China. It enrolls about 200 undergraduates and 250 graduate students each year. The college is performing the cutting edge of research in agricultural sciences, life sciences, and environmental sciences.

The primary topics of 2022CCFEA are as follows:

- The critical problems facing fertilizer use in the world including the necessity of fertilizer application and the side-effects caused by excessive application.
- How to improve the current education of fertilizer in higher education. Under the severe pandemic, we will vigorously guide college students to be involved in agriculture.

CONFERENCE AGENDA

Chairs: Prof. Lanzhu Ji, Prof. Jianwen Zou

Time	Schedule	Voov Meeting
May 19, 2022		
14:00-18:00	Registration and Pre-test	**685-9932-1314** **Code: 1201**
May 20, 2022		
17:30-18:00	Prof. Lanzhu Ji, President of CIEC	Conveners： Lanzhu Ji Zhen Li Meeting #： **685-9932-1314** **Code: 1201**
18:00-18:06	Prof. Feng Hu, Vice President of Nanjing Agricultural University	
18:06-18:10	Prof. Xuhui Zhang, Deputy Dean of College of Resources and Environmental Sciences, NJAU	
18:10-19:00	Invited: Prof. Qirong Shen, Academician of Chinese Academy of Engineering (Bio-organic Fertilizer)	
19:00-19:50	Invited: Prof. Ewald Schnug, Honorary-President of CIEC (Phosphate)	
19:50-20:40	Invited: Prof. Maria del Carmen Rivas, Soil Science Institute. National Institute of Agriculture Technology- INTA- Argentina (N, P, S)	
20:40-20:45	Flash talk: Xinyi Ke, Nanjing Agricultural University (Microorganism-Mineral-Fertilizer)	
20:45-20:50	Flash talk: Hongyi Yang, Nanjing Agricultural University (Fertilizer Management)	
May 21, 2022		
8:50-9:00	Prof. Jianwen Zou, Dean of College of Resources & Environ. Sci., Nanjing Agricultural University	Convener： Jianwen Zou Meeting #： **685-9932-1314** **Code: 1201**
9:00-9:50	Invited: Prof. Yuanliang Shi, Shenyang Institute of Applied Ecology, Chinese Academy of Sciences (New Type Fertilizer)	
9:50-10:20	Invited: Alejandro Galiano & Lina He, Tradecorp. Inc, Rovensa Group (Biostimulants)	
10:20-11:00	Invited: Prof. Shiwei Guo, Nanjing Agricultural University (Micronutrient Fertilizer)	
11:00-11:40	Invited: Prof. Manqiang Liu, Nanjing Agricultural University (Green Manure)	
11:40-12:30	Invited: Prof. Min Zhang, Shandong Agricultural University (SRFs)	
12:30-12:40	Rong Li, Deputy Dean, Closing Ceremony	

Chairs

Prof. Lanzhu Ji

Prof. Lanzhu Ji, professor in Ecology and Entomology, Institute of Applied Ecology, Chinese Academy of Sciences. He is mainly engaged in forest insect ecology, taxonomy, forest ecosystem health and management, and has presided over major and key projects of Knowledge Innovation Project of Chinese Academy of Sciences. He is also actively involved in multiple projects supported by National Science and Technology, State Forestry Administration, and National Natural Science Foundation of China.

Prof. Jianwen Zou

Prof. Jianwen Zou, dean of the College of Resources and Environmental Sciences, Nanjing Agricultural University. He has won the National Excellent Doctoral Dissertation award, the second prize of Natural Science of the Ministry of Education, the Science and Technology Award of Jiangsu Province, and the Science and Technology Innovation Team Award of the Ministry of Agriculture. As a distinguished professor in ecology, focusing on carbon & nitrogen processes and global change in the land surface. His excellent research has been published in Ecology Letters, Global Change Biology, EST, etc.

Invited Speakers

Prof. Qirong Shen

Prof. Qirong Shen, academician of Chinese Academy of Engineering, is currently director of the Academic Committee of Nanjing Agricultural University. He has been engaging in the research soil microorganisms and development of organic fertilizers for over forty years. Prof. Shen has made outstanding contributions to the development of China's organic fertilizer industry. Based on the application of bioorganic fertilizer and the corresponding technologies, the prevention and control of soil-borne diseases has been achieved.

Prof. Ewald Schnug

Prof. Ewald Schnug is honorary doctor of the Romanian Academy of Agricultural Sciences, and also is visiting professor at the Institute of Applied Ecology Chinese Academy of Sciences in Shenyang, China. He worked as director of the Institute for Crop and Soil Science at the Federal Research Centre for Cultivated Plants (JKI) and extraordinary Professor at the Technical University in Braunschweig, Germany. In addition, he was Honorary President of The International Scientific Center for Fertilizers (CIEC).

Prof. Dra. Maria Rivas

Prof. Dra. Maria Rivas is an agricultural engineer, PhD in Natural Resources from the Techniche Universität Braunschweig, Germany and professor of risks in agricultural work at the career of health and safety at Faculty of exact and natural sciences. Buenos Aires University. She is currently a researcher in the Soil Quality, Health and Technology Working Group of the Soil Institute of the Natural Resources Research Center (CIRN) of the National Institute of Agricultural Technology - Argentina.

Invited Speakers

Prof. Yuanliang Shi

Prof. Yuanliang Shi, professor at Shenyang Institute of Applied Ecology, Chinese Academy of Sciences, is a well-known soil and fertilizer expert. His research interests include study on soil microdomain ecosystem and its regulation, development and manufacture of new fertilizers, including stabilized fertilizers and fertilizer additives, mechanical activation technology, and phosphorus activators. He has published three books and more than 60 articles. He also owned10 authorized invention patents. He received Second Class Prize of the National Scientific and Technological Progress Award.

Lina He

Lina He, Tradecorp China Business director. She worked in Spanish-speaking countries and the Argentine consulate for many years. Since 2018, she has been working in Tradecorp (Rovensa Group), responsible for the development of the entire Tradecorp China business, and constantly deepening and promoting the concept of Tradecorp's sustainable development of agriculture, at the conference and fair such as CAC, CNCIC, New AG, etc.

Alejandro Navarro Galiano

Alejandro Navarro Galiano, R&D projects technician in Tradecorp (Rovensa Group. Tradecorp dedicated to the field of fertilisation and biostimulation of crops in agriculture.

Invited Speakers

Prof. Min Zhang

Prof. Min Zhang, director of faculty committee and professor of College of Resources and Environment, Shandong Agricultural University. He also works as the deputy director of National Engineering and Technology Research Center of Slow and Controlled Release Fertilizer. His research covers the fields of design of new fertilizers and utilization of soil resources, showing excellence in both theory and technology. He received Second Class Prize of the National Scientific and Technological Progress Award.

Prof. Shiwei Guo

Prof. Shiwei Guo, professor at Nanjing Agricultural University and member of the Expert Guidance Group of Scientific Fertilization of the Ministry of Agriculture and Rural Affairs. He received Ph.D. degree in agriculture from Kiel University, Germany. He is mainly engaged in the research of plant nutrition physiology, crop fertilization theory and practice, plant nutrition and ecological health. Prof. Guo has published more than 100 papers in academic journals. He received Excellent Science and Technology Award from Natural Resources Society of China .

Prof. Manqiang Liu

Prof. Manqiang Liu, professor at the College of Resources and Environmental Sciences, Nanjing Agricultural University. His research interests include the response, driving factors, ecological functions and ecological management of soil biodiversity under global change. Based on natural solutions (e.g., green manure) and functional trait approaches, he utilizes soil animal resources and cover crops (green manure) to enhance the self-regulation capacity of ecosystems, improve resource utilization efficiency and reduce external inputs, and develop climate-change smart agriculture.

Flash talk speakers

Xinyi Ke

Ms. Xinyi Ke is a junior student from College of Resources and Environmental Science, Nanjing Agricultural University. She won the silver prize in the 7th China International College Students ‘Internet+’ Innovation and Entrepreneurship Competition, based on the research and development of Microorganism-Mineral-Fertilizer system.

Hongyi Yang

Mr. Hongyi Yang is a graduate student from College of Agriculture, Nanjing Agricultural University. He won the silver prize in the 7th China International College Students ‘Internet+’ Innovation and Entrepreneurship Competition, based on smart application of multiple fertilizers to rice paddy.

Conveners

Prof. Feng Hu

Prof. Feng Hu, vice president of Nanjing Agricultural University, doubles as vice chairman of Chinese Soil Society, vice chairman of Jiangsu Ecological Society, and vice chairman of Jiangsu Ecological Civilization Research and Promotion Association. His main research fields are soil ecology, restoration ecology and integrated management of water and soil resources. He has published more than 90 papers in academic journals, and won multiple prizes in science and technology, at the national and provincial levels.

Prof. Rong Li

Prof. Rong Li, deputy dean of the College of Resources and Environmental Sciences, Nanjing Agricultural University. He is mainly engaged in the research of solid waste resources (organic fertilizer, bio-organic fertilizer and biological matrix), soil microbial ecology, microbial and plant nutrition. He received the first prize of Shennong China Science and Technology Award from the Ministry of Agriculture and the first prize of Technological Invention Award from the Ministry of Education.

Prof. Xuhui Zhang

Prof. Xuhui Zhang, deputy dean of the College of Resources and Environmental Sciences, Nanjing Agricultural University. At present, he is mainly engaged in soil science. He obtained excellent comprehensive evaluation of teaching quality for many times. He received the 2017 Excellent Teaching Quality Award of Nanjing Agricultural University, the second prize of Jiangsu Teaching Achievement and second prize of the Science and Technology Progress Award from the Ministry of Education.

120th Anniversary of Nanjing Agricultural University, 20th May 2022

Uranium – one of the hidden dangers and treasures in phosphates

Prof. mult. Dr. mult. Ewald Schnug

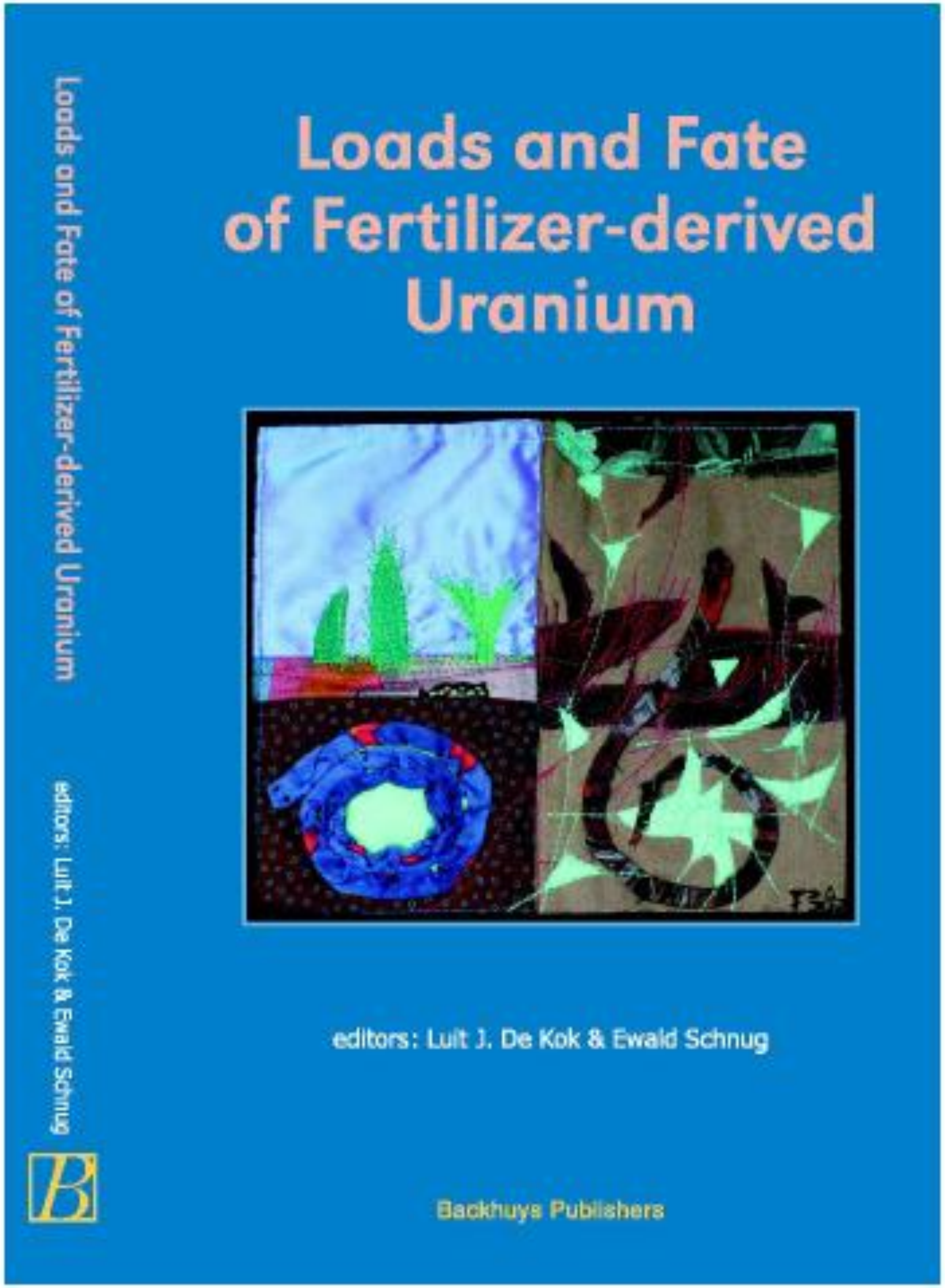
Technical University Braunschweig – Faculty 2 Life Sciences,
Pockelsstraße 14, D-38106 Braunschweig, Germany

Dir. & Prof. Dr. Silvia Haneklaus

Institute for Crop and Soil Science, Julius-Kuehn-Institute
Bundesallee 69, D-38116 Braunschweig, Germany

Technische Universität Braunschweig

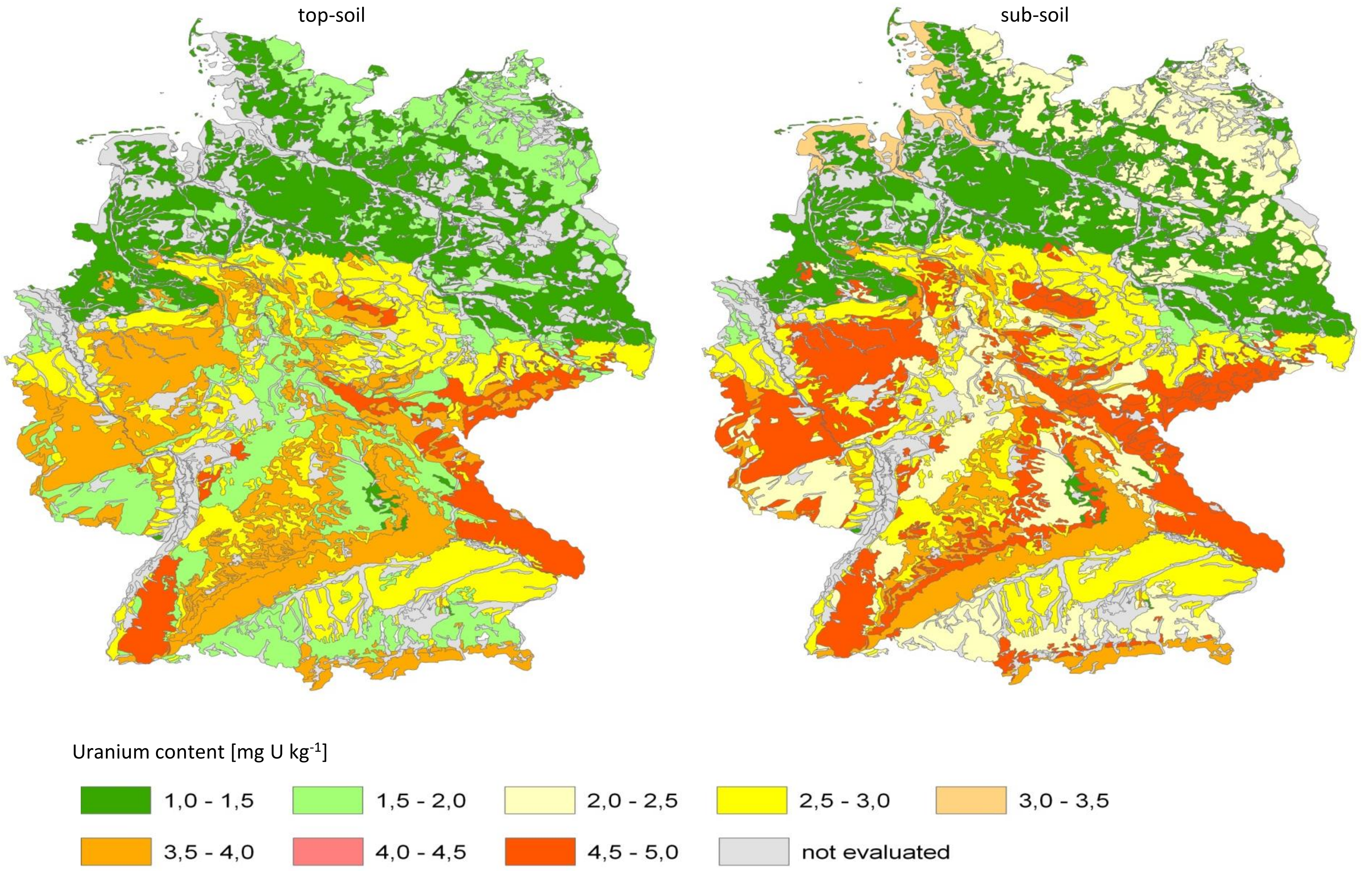
JKI Julius Kühn-Institut



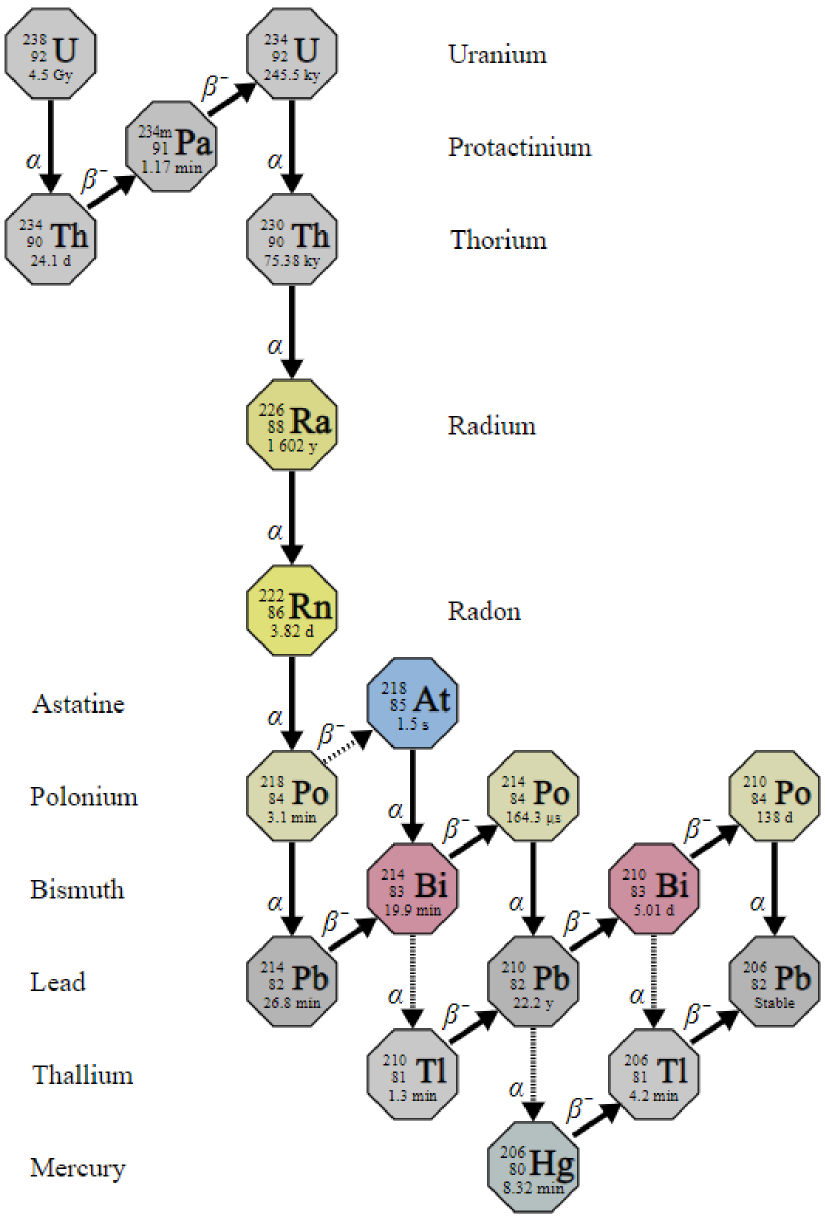
Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM)

TENORM stands for ’Technologically Enhanced Naturally Occurring Radioactive Materials’ that has been concentrated or exposed to the accessible environment as a result of human activities such as manufacturing, mineral extraction, or water processing” (EPA 2022).

Uranium is a natural occuring radiactive element (NORM) in rocks and soils



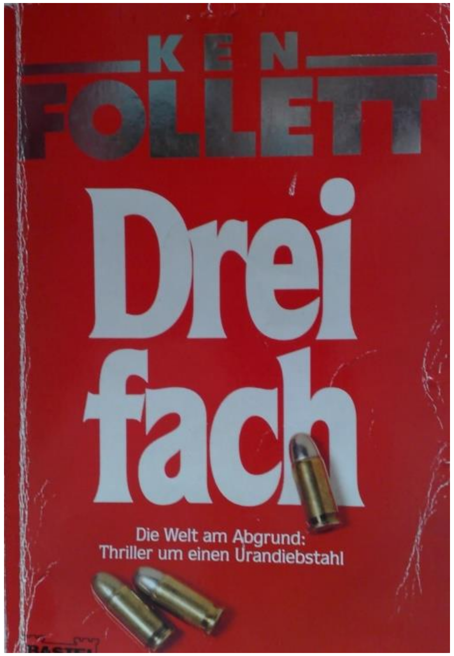
90 percentile values (classified) of U contents (mg/kg) in top-soils (left figure) and sub-soils (right figure) in Germany
source: Utermann and Fuchs, 2008)



Uranium is a radiotoxic α – particle emitter

… with some.even more dangerous daughter-nuclides!

“There is no safe level for radioactivity. Who talks this mistakes radioactivity with water in a swimmimg pool; at one meter depth you are safe, at three meter depth the nonswimmer drowns. In reality you can compare radiation with speed limits on roads – thirty miles per houre are safer than eighty, but not as safe than twenty and complete safe one is only one dont use a car at all.“



The physicist from the Weizmann-Institute in
Ken Follet´s “Triple“ Fine Blend, N.V. 1979.

(Es gibt keine sichere Strahlungsmenge. Wer so redet verwechselt Strahlung mit Wasser in einem Swimmingpool; wenn dieses einen Meter tief ist, ist man sicher, wenn es drei Meter tief ist, ertrinkt der Nichtschwimmer. In Wirklichkeit sind Strahlungsmengen eher mit Geschwindigkeitsbegrenzungen auf der Strasse zu vergleichen – dreißig Meilen pro Stunde sind sicherer als achtzig, aber nicht so sicher wie zwanzig und völlig sicher ist man nur, wenn man gar nicht erst ins Auto steigt.“

Der Physiker aus dem Weizmann-Institut in Kenn Follets „Triple“ Fine Blend, N.V. 1979)

Uranium is a biochemical toxin…….

MAC values for heavy metals regulated in the German Ordinance for Soil Protection, for uranium and for well known toxic substances (source: TRGS 900)

	Cd	Cr	As, Co, Hg, Pb	**U**	Ni, Sb, V	Cu, Zn
MAC-value (mg/m^3)	0,015	0,05	0,1	**0,25***	0,5	1,0
Comparable substances			Christoballite 0,15		Warfarine Bromine 0,7	CaCN, Cl 1,5, Cyanide 5

* In the workplace, NIOSH/OSHA (National Institute for Occupational Safety and Health) has set a Recommended Exposure Limit (REL) and a Permissible Exposure Limit (PEL) of 0.05 mg/m^3 for uranium dust, while the NRC (Nuclear Regulatory Commission) has an occupational limit of 0.2 mg/m^3

http://www.atsdr.cdc.gov/toxprofiles/phs150.html (Agency for Toxic Substances and Disease Registry, ATSDR)

Uranium accummulates in biological tissue

KIDNEY: Busby 2007: Uranium builds up in humans and living systems due to its high affinity for tissue components, DNA and nervous system components. The graph below is from the Royal Society Report. It shows that a continuous daily ingestion of 1μg will result in kidney concentration of 12μg/l. At this concentration DNA will be saturated with UO_2^{++}.

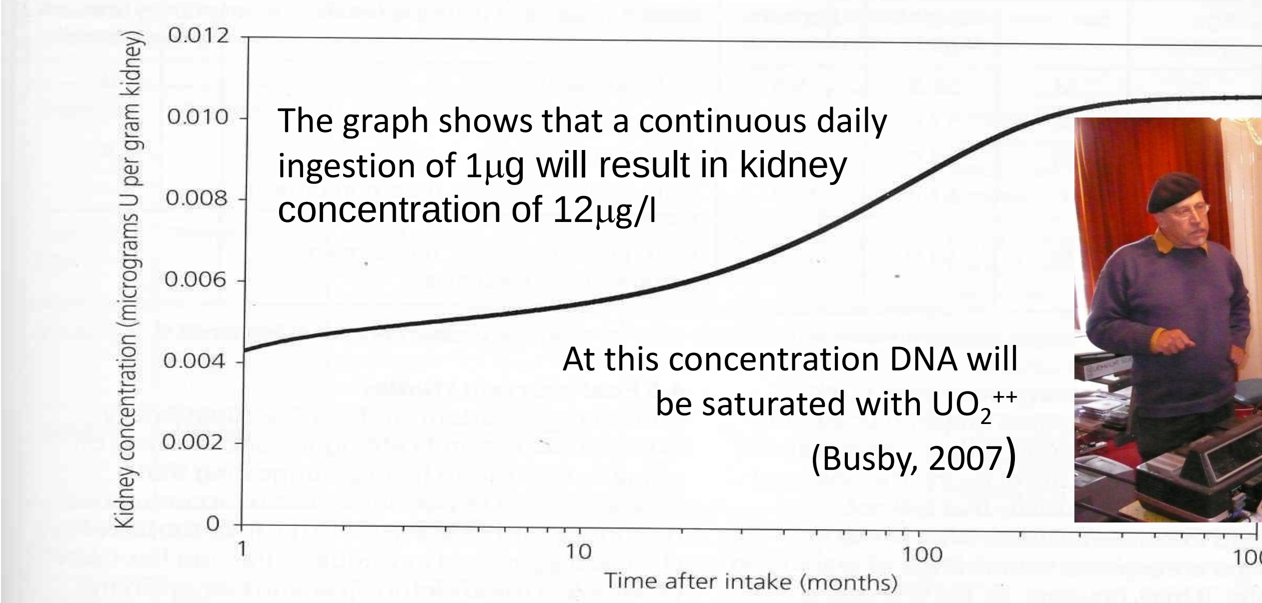
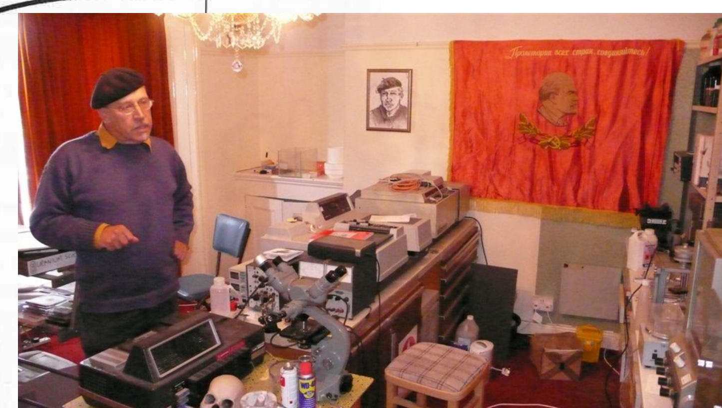


Figure 2. Predicted concentration of uranium in the kidney from the constant uptake into the blood of 1μg uranium per day.

Chris Busby´s lab in Aberystwyth



HAIR: Sela et al. (2006): U in hair (μg/g) = 0.038 * x U in drinking water (μg/g) + 0.2 ; R^2= 78%

Basics of biochemical U-toxicity

Uranium is a long-known nephrotoxin. The most remarkable damage of U coming along with low and medium contaminations is cancer. More recently, U has been proven to mimic the effect of estrogen (i.e. accelerated vaginal opening) at drinking water levels, which are considered as being "safe" by authorities (Raymond-Whish *et al*. 2007). In addition, Envirhom (2005) showed that the brain is a target for U toxicity. Its sensitivity seems to be similar to that of kidneys (Envirhom 2005).

(collected from Schnug et al., 2008)

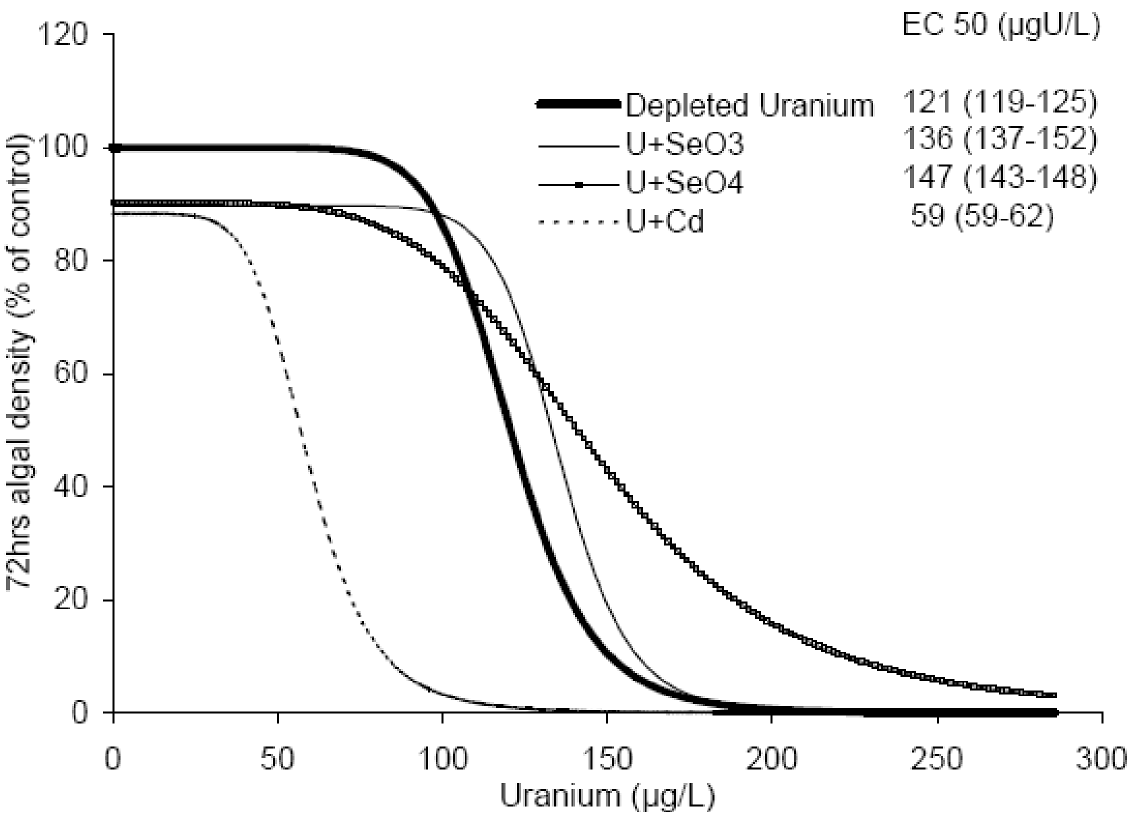
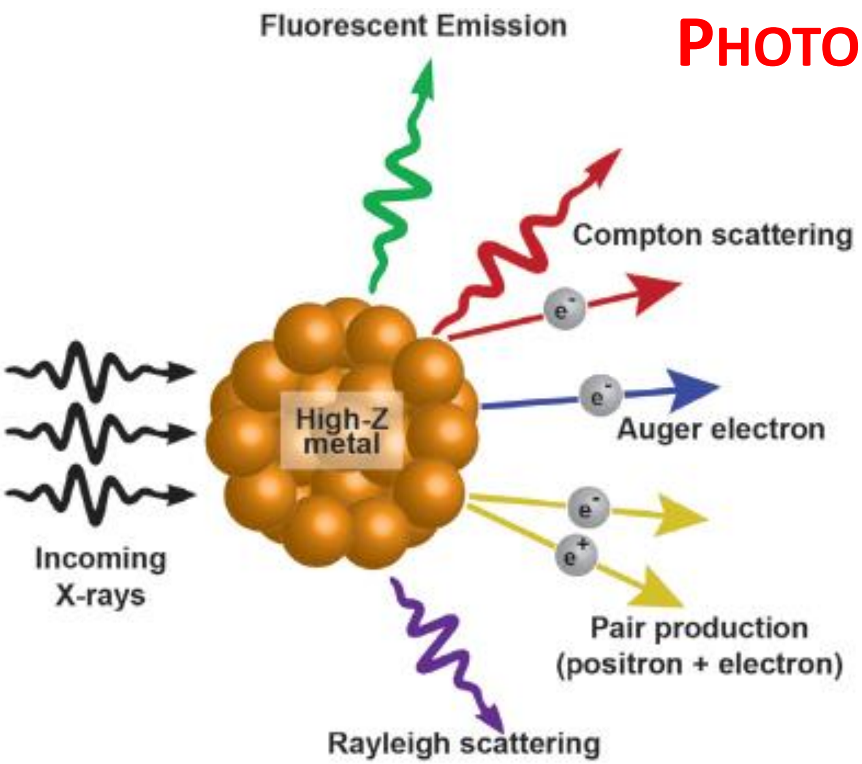


Figure 29 Effect of depleted uranium, alone or in mixture with selenium or cadmium, on the 72hrs-growth inhibition of the green algae *Chlamydomonas reinhardtii* at pH=5, modified HSM medium (measurement of algae density by fluorescence in microplates). Selenium and cadmium are added to provoke an effect of 10% (*i.e.* 60, 0.96 and 42 µg/L of selenite, selenate and cadmium are added, respectively). EC50 of uranium are given with their 95% confidence interval, estimated by a non parametric bootstrap simulation (n=500) from the fit of raw data (10 conditions + control, n=3).

The toxicity of uranium is synergistically enhanced by Cd

(source: Henner, 2008)

Neither chemical nor radiological toxicity toxicity of uranium alone explain the overall dangers of uranium for living organisms!



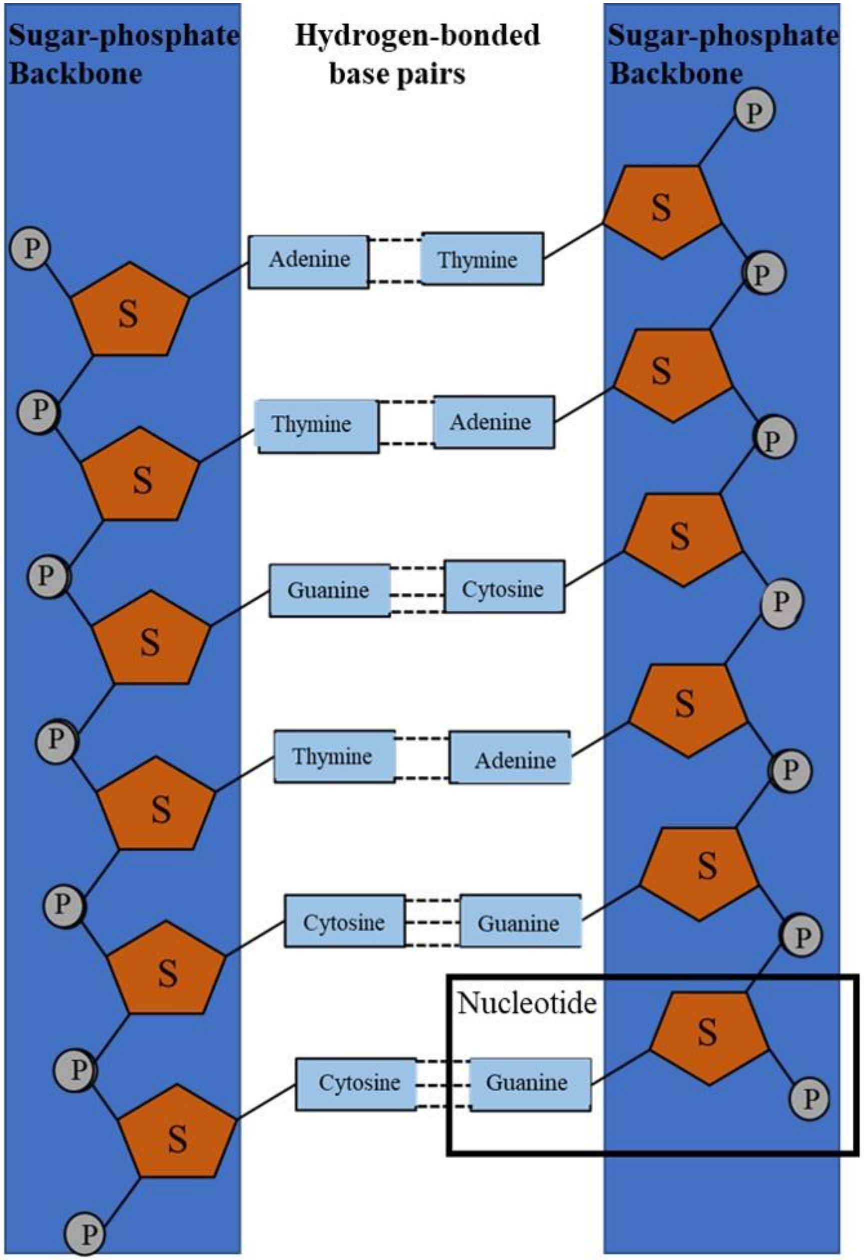
Interaction of X-rays with high-Z material nanoparticles

(Kwatra et al. 2013: Tanslational Cancer Research, 2(4), doi: 10.3978/j.issn.2218-676X.2013.08.06)

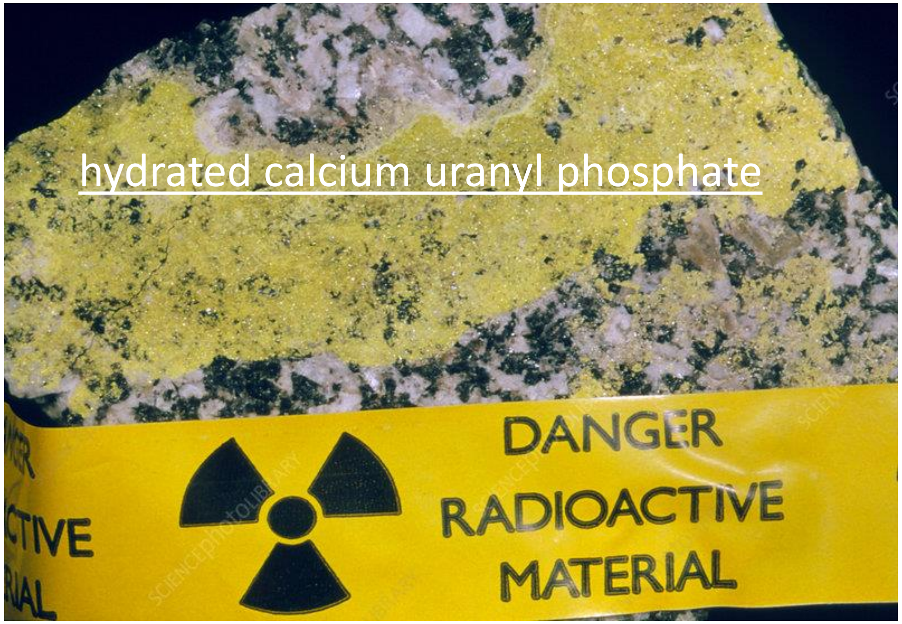
PHOTOELECTRON CONVERSION

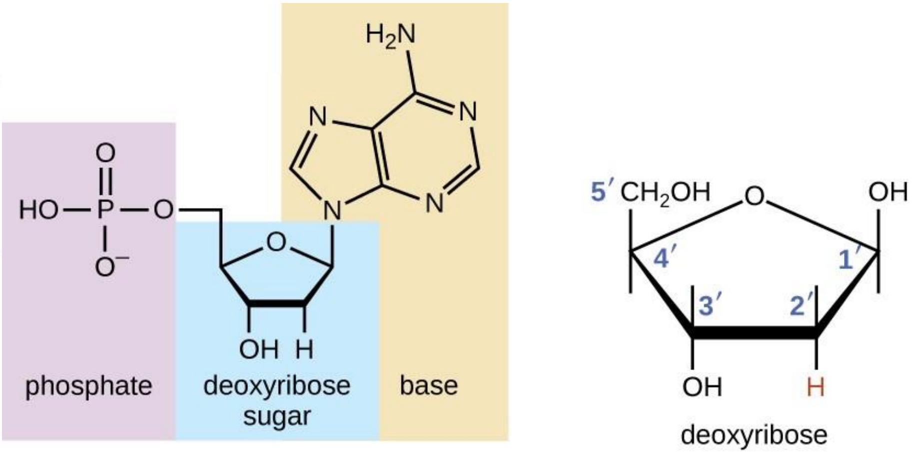
Elements of high atomic number Z exhibit phantom or secondary radiotoxicity though absorption of natural background gamma and X-rays and re-emission of photoelectrons … this means that U (Z=92) bound to the DNA has over 55,000 times more absorption of natural background gamma radiation than the DNA.

Uranium binds with Phosphate



DNA

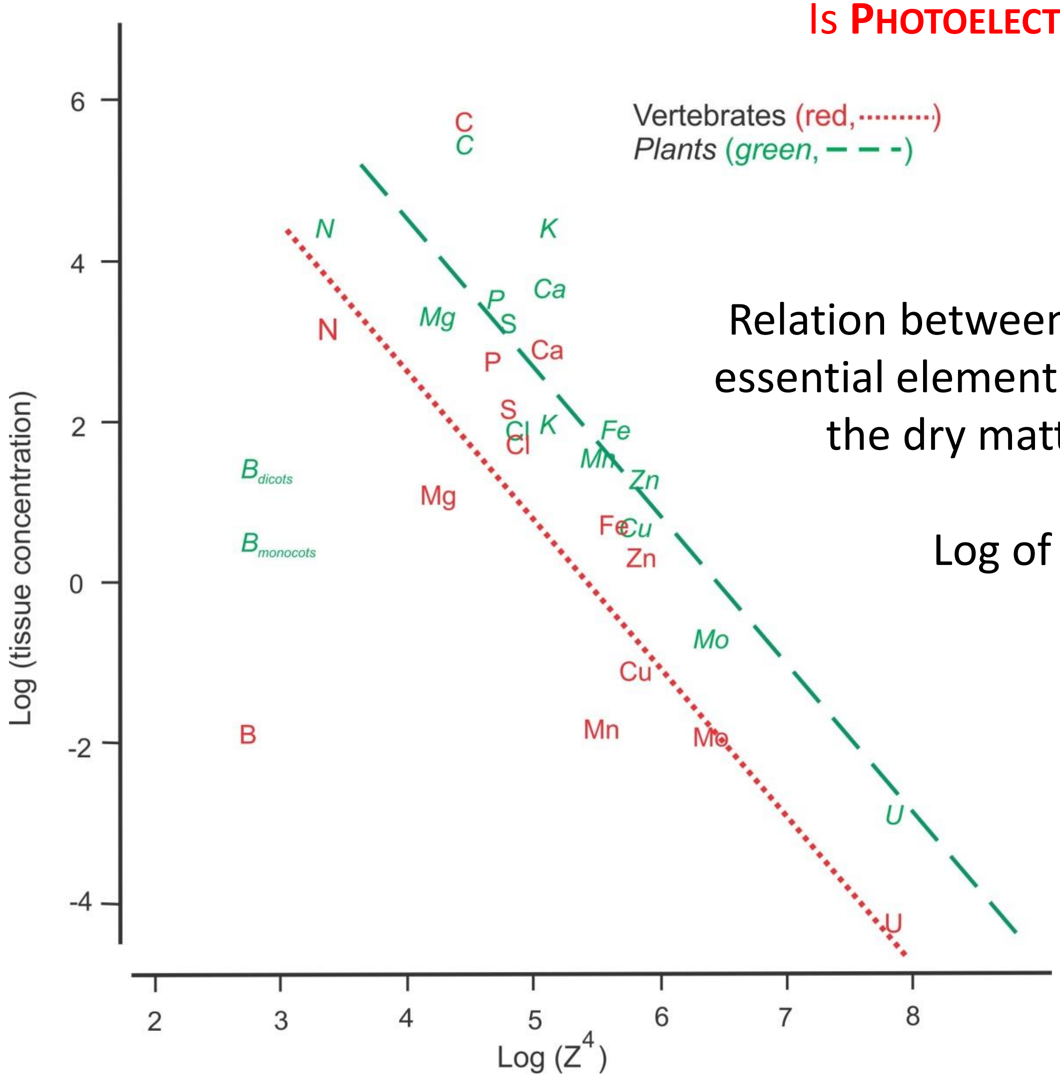




(a) (b)

Uranium combines radiological-and chemical toxicity through the secondary electron effect

Is **Photoelectron Conversion** the reason why life avoids heavy elements ?



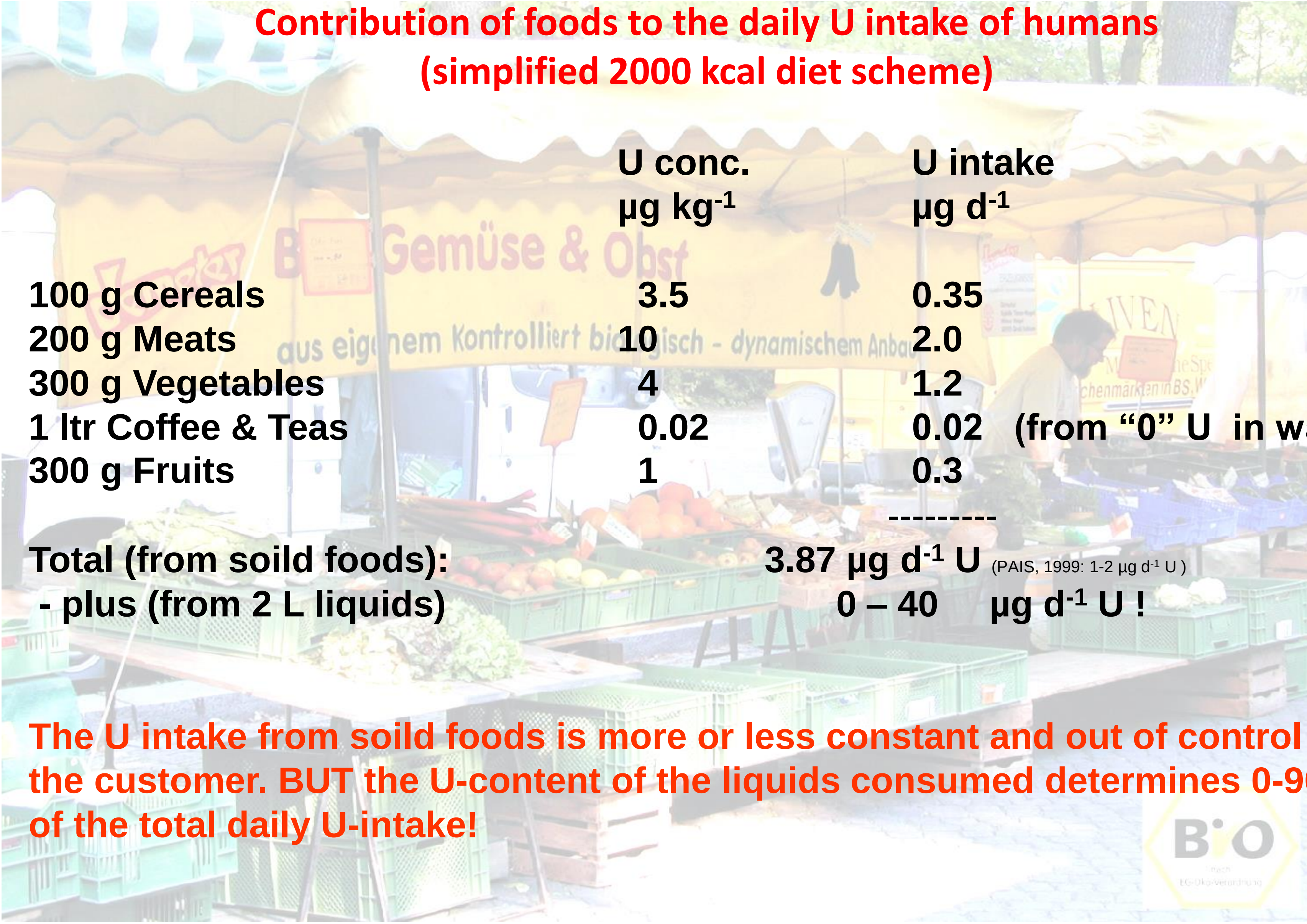
Relation between the Log of typical physiological essential element and uranium concentrations in the dry matter of vertebrate (red) and plant (green) tissue versus the Log of the biquadratic atomic number.

.... $-1.65X+9.65$; $R^2=71\%$ (without B)

- - - - $-1.60X+10.7$; $R^2=72\%$ (without B)

Compiled from Busby and Schnug, 2008 and Busby, 2019

The Uranium balance of humans



Contribution of foods to the daily U intake of humans (simplified 2000 kcal diet scheme)

	U conc. $\mu g\ kg^{-1}$	U intake $\mu g\ d^{-1}$
100 g Cereals	**3.5**	**0.35**
200 g Meats	**10**	**2.0**
300 g Vegetables	**4**	**1.2**
1 ltr Coffee & Teas	**0.02**	**0.02 (from "0" U in water)**
300 g Fruits	**1**	**0.3**

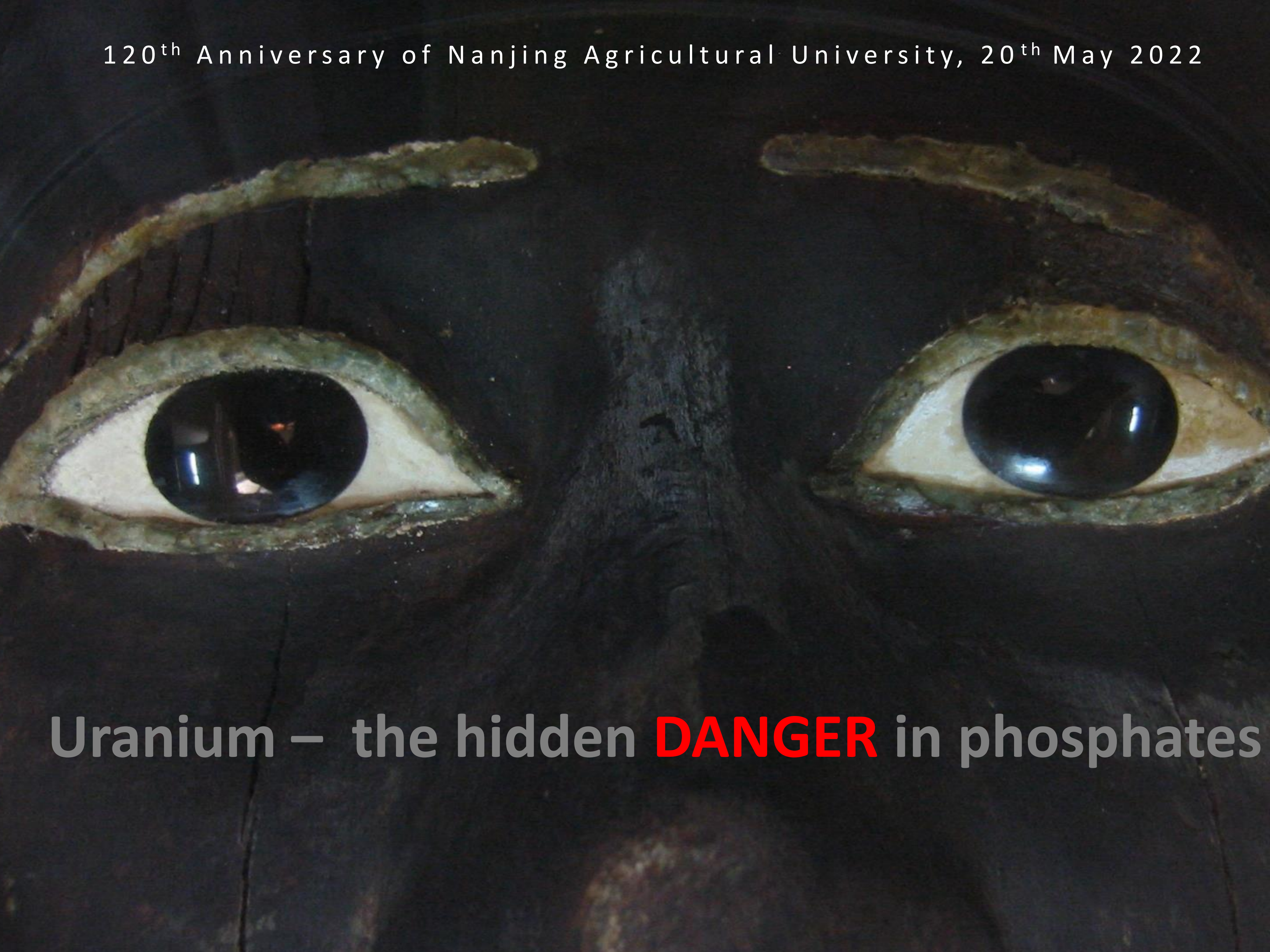
Total (from soild foods):		**3.87 $\mu g\ d^{-1}$ U** (PAIS, 1999: 1-2 $\mu g\ d^{-1}$ U)
- plus (from 2 L liquids)		**0 – 40 $\mu g\ d^{-1}$ U !**

The U intake from soild foods is more or less constant and out of control of the customer. BUT the U-content of the liquids consumed determines 0-90% of the total daily U-intake!

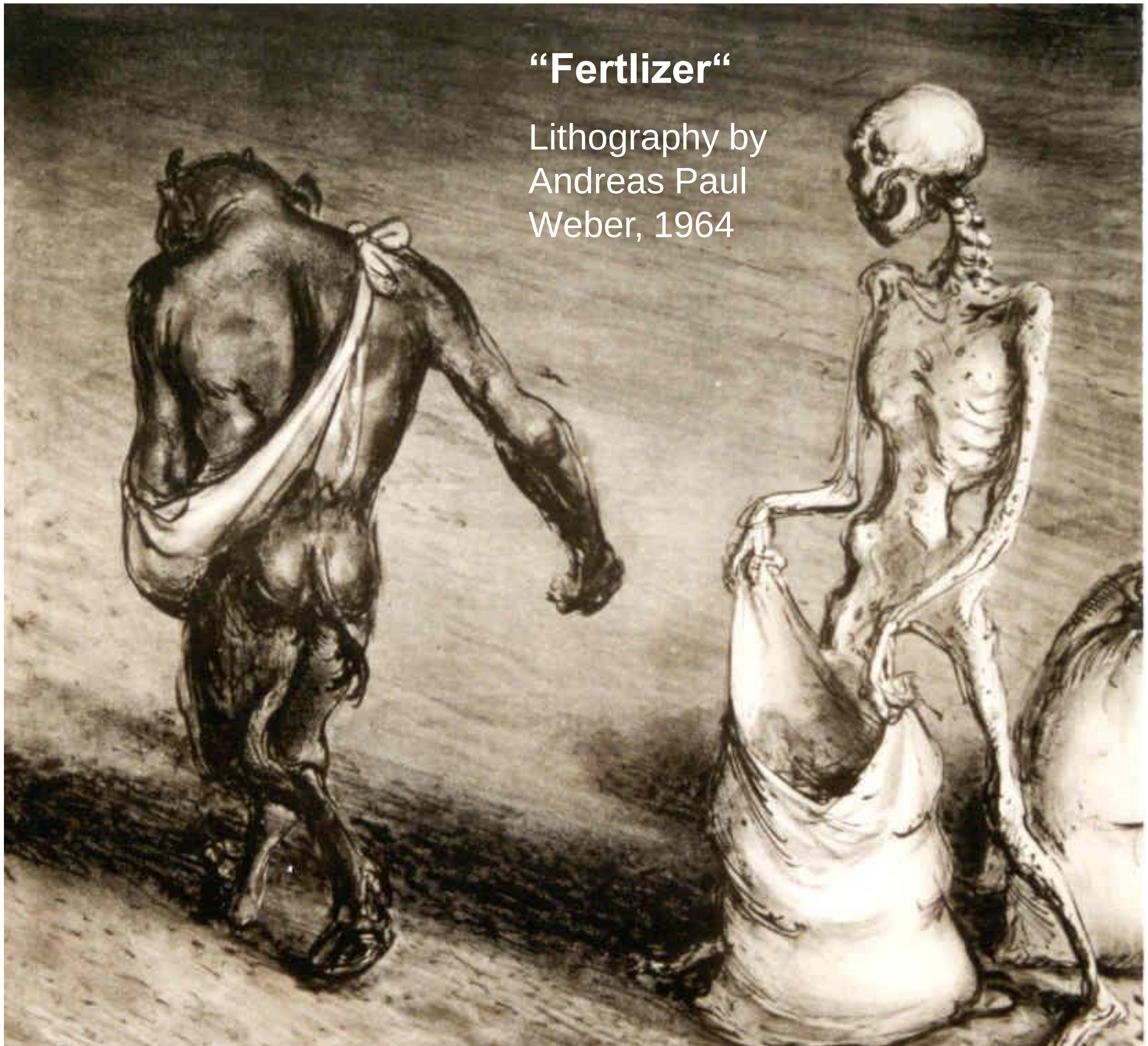
Choosing the right drinking water source has the strongest influence on the daily U intake humans

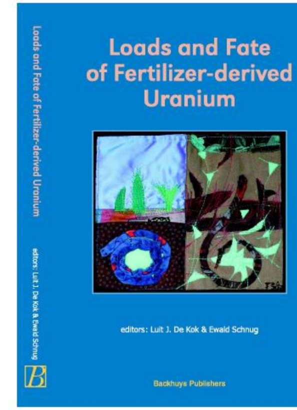
Consumed water type	Abbreviation	U (µg/d)
Tap water	1 - TW	3.34
German bottled mineral water	2 - GBW	6.16
World bottled mineral water	3 - WBW	7.08
Dietary style		
Standard	I	1.31
Vegetarian, ovo-lacto	II	1.43
Vegan	III	2.02
Carnivore	IV	1.63
Personal intake strategy	**Formula**	
Maximum reduction potential (%) of daily intake	(A/B*100)-100	**-67**
Maximum increase potential (%) of daily intake	(B/A*100)-100	**+200**

Mean U exposure estimates for different water consumer types in different dietary group types (Hassoun, 2011).


120th Anniversary of Nanjing Agricultural University, 20th May 2022
Uranium – the hidden DANGER in phosphates

TENORM :t he dark side of P-fertilization...





Mineral P-fertilizers contain on an average 259 mg Uran per kg P_2O_5

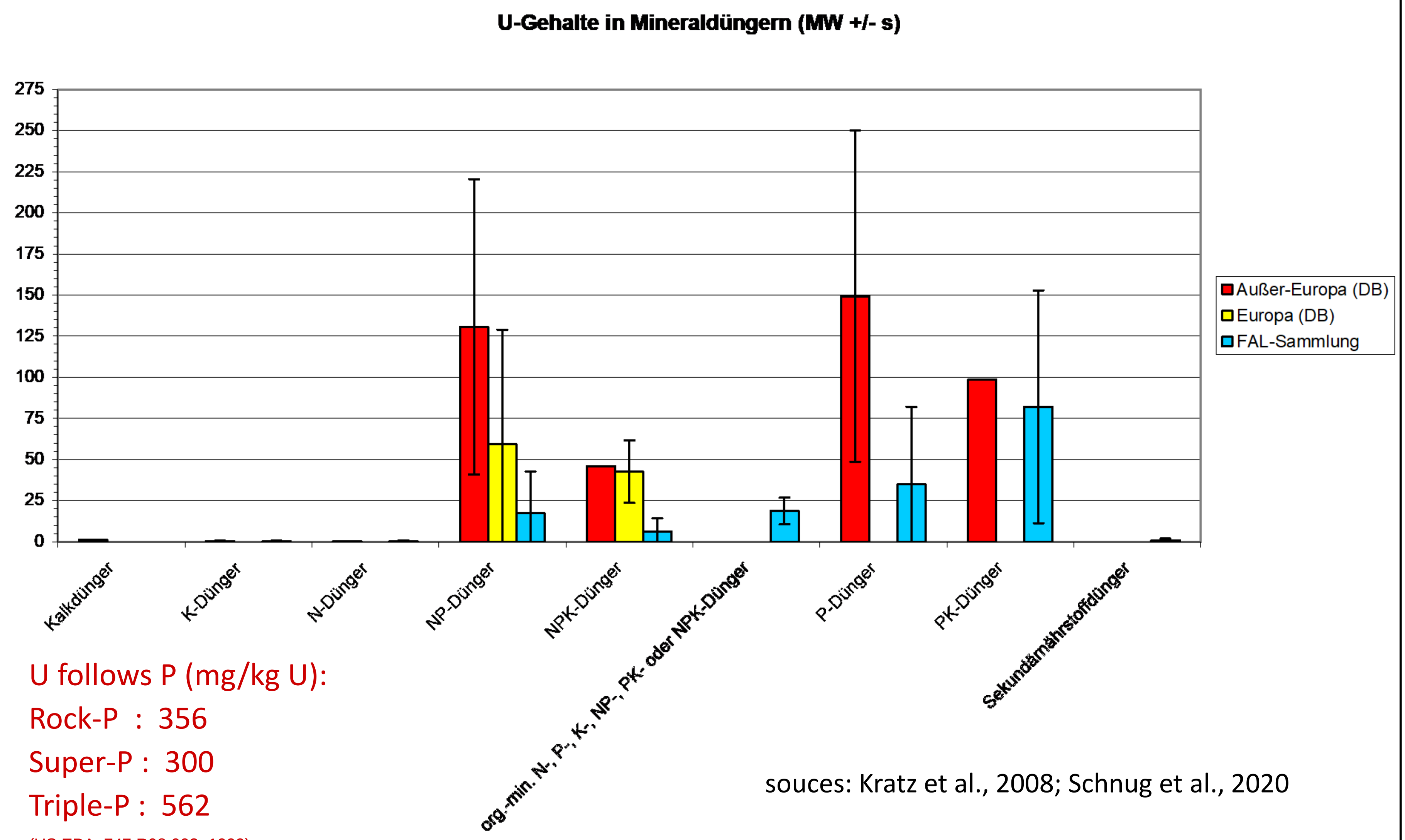
Uranium and Cadmium concentrations in fertilizers (mg/kg U)

Tab. 1: P_2O_5, Cd and U content in fertilizers with P_2O_5-content > 5%, traded in Germany in 2007 (n=78).

		P_2O_5 (%)	Cd (mg/kg)	U (mg/kg)	mg Cd per kg P_2O_5	mg U per kg P_2O_5
Mean		22.8	12.0	61.3	47	283
Median		17.0	7.40	39.8	50	264
Minimum		5.00	0.11	0.73	0.24	6.39
Maximum		49.0	34.8	206	107	1713
Percentil	25	10.8	2.89	11.7	18.0	79.8
	50	17.0	7.40	39.8	49.9	264
	75	40.0	20.2	87.4	67.1	402

U concentration of P-fertilizers traded in Germany has not changed over time

Uranium concentrations in fertilizers (mg/kg U)



U follows P (mg/kg U):

Rock-P : 356

Super-P : 300

Triple-P : 562

(US EPA, 747 R98.003, 1999)

souces: Kratz et al., 2008; Schnug et al., 2020

Uranium loads to agricultural soils

U balances in agroecosystems:
Comparison of various calculation models

		U **loads** (g/ha*a) mean	U **loads** (g/ha*a) range	U **uptake** by plants (g/ha*a)
Model 1: GAP (22 kg P/ha*a)	Mineral fertilization	**15**	7 - 23	**<0.35**
	Organic fertilization	**2.8**	2.3 - 3.2	
Model 2: German model regions	Mineral fertilization	**10**	7 - 15	
	Manure-based fertilization	**7**	2.8 - 16	
Model 3: based on official P field balances for Germany	Combined mineral and organic fertilization (1996 - 2005)	**6**	7.6 - 4.4	**0.15**

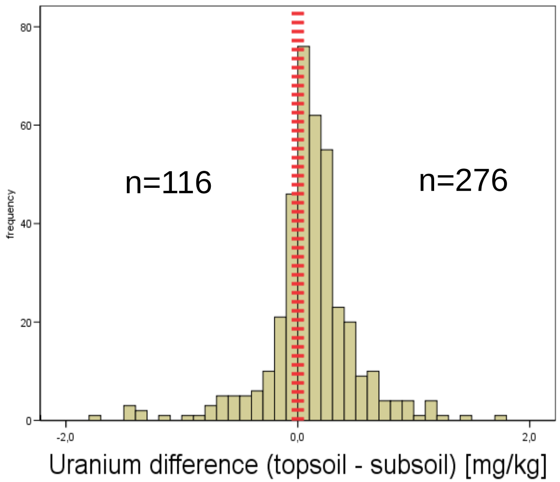
GAP = “Good Agricultural Practice“

source: Kratz et al., 2008

Evidence for U accumulation in agricultural soils

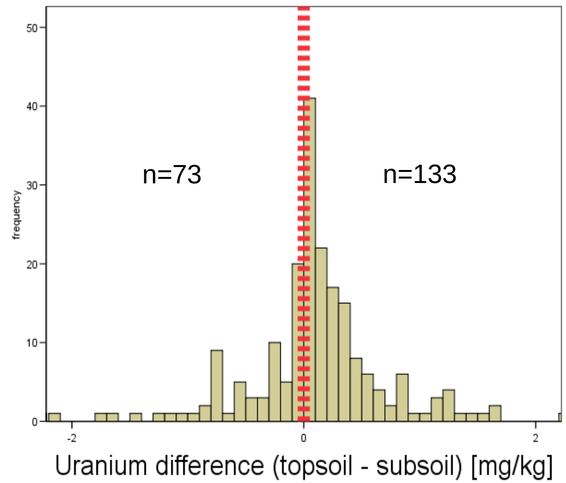
German soils (Utermann and Fuchs 2008)

soils under arable land



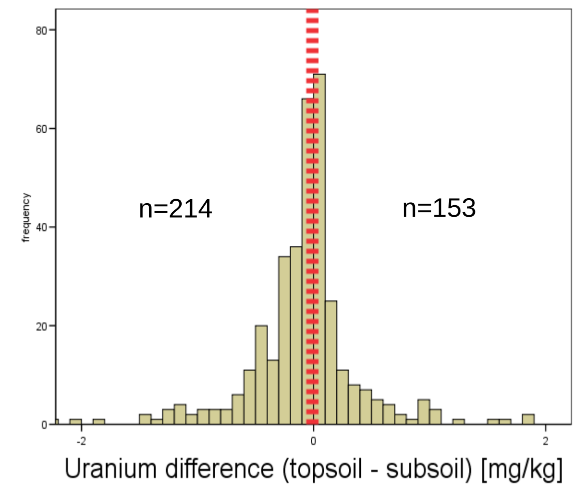
Median: 0.11 mg/kg

soils under pasture



Median: 0.09 mg/kg

soils under forest



Median: -0.04 mg/kg

“expected“ from P-balance: 0.32 mg/kgU
found:
Utermann & Fuchs (2008): + 0.15 mg/kg U
Rogasik et al. (2008): + 0.15 mg/kg U
Huhle et al. (2008): + 0.20 mg/kg U
“missing“ : 0.15 mg/kg U

50% of all U applied with fertilizers to agricultural land remains in top soil layers

Evidence for agricultural influence on U in ground and drinking water

Uranium and nitrate concentrations in neighbouring shallow (7-9m) and deep (70-90m) wells of two waterworks in southern Germany (2008 data).

Location	Well type	U (µg/L)	NO_3 (mg/L)
Straubing	shallow	2.8	40.0
	deep	< 0.2	2.8
Rehlingen	shallow	10	22.0
	deep	1.6	8.2

source: Schnug et al.2022

At an annual application rate of 9 g/ha U applied with 22 kg/ha P a steady state concentration of 22 µg/L U is expected in the percolating water.

(source: Jaques et al., 2008)

Uranium from P fertilization accumulates in agricultural soils and is leached into grundwaters:

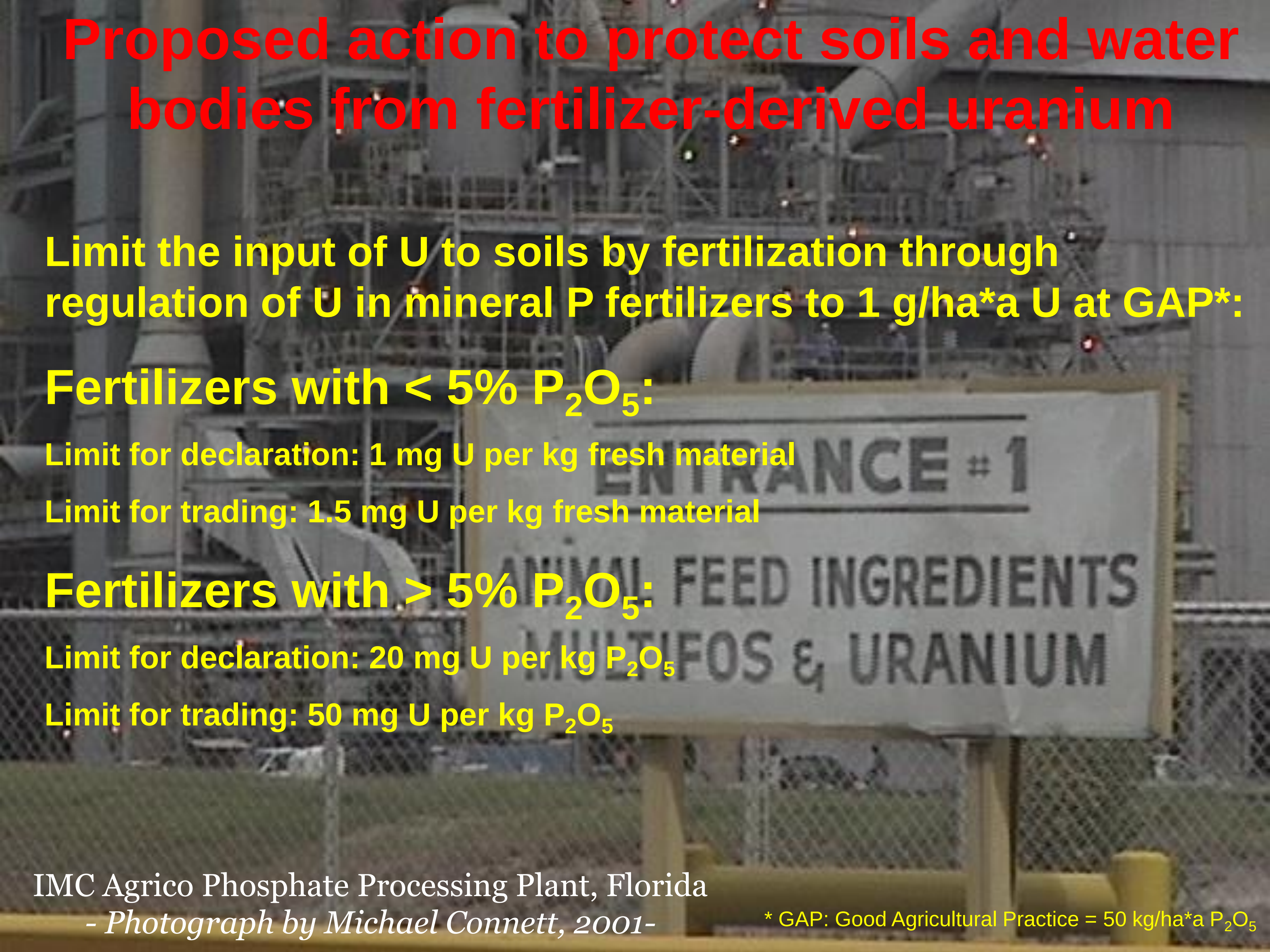
Differences in water U concentrations from agricultural land compared to forest land in Germany found by:

Huhle et al. (2008): + 1.73 µg/L U

Birke and Fuchs (2008): + 0.77 µg/L U

At least 25% of all drinking water wells in Northern Germany are already contaminated with significant amounts of U from fertilization (Smidt et al. 2011).

Proposed action to protect soils and water bodies from fertilizer-derived uranium



Limit the input of U to soils by fertilization through regulation of U in mineral P fertilizers to 1 g/ha*a U at GAP*:

Fertilizers with < 5% P_2O_5:

Limit for declaration: 1 mg U per kg fresh material

Limit for trading: 1.5 mg U per kg fresh material

Fertilizers with > 5% P_2O_5:

Limit for declaration: 20 mg U per kg P_2O_5

Limit for trading: 50 mg U per kg P_2O_5

IMC Agrico Phosphate Processing Plant, Florida
- Photograph by Michael Connett, 2001-

* GAP: Good Agricultural Practice = 50 kg/ha*a P_2O_5

What if U in P fertilizers will be regulated ?

Table 1. P_2O_5, Cd and U concentration in fertilizers with a P_2O_5 content, traded in Germany

Reference	n	P_2O_5 (%)	Cd (mg/kg)	U (mg/kg)	mg Cd per kg P_2O_5	mg U per kg P_2O_5
Kratz et al. (2011)	78	22.8	12.0	61.3	47.1	283
Dittrich & Klose (2008)	193	25.8	9.43	63.3	37.0	245
Leiterer & Ludewig (2011/12) *	16	8.20	1.47	25.7	17.2	274
Klein (2013) *	16	6.42	1.16	8.00	18.0	126

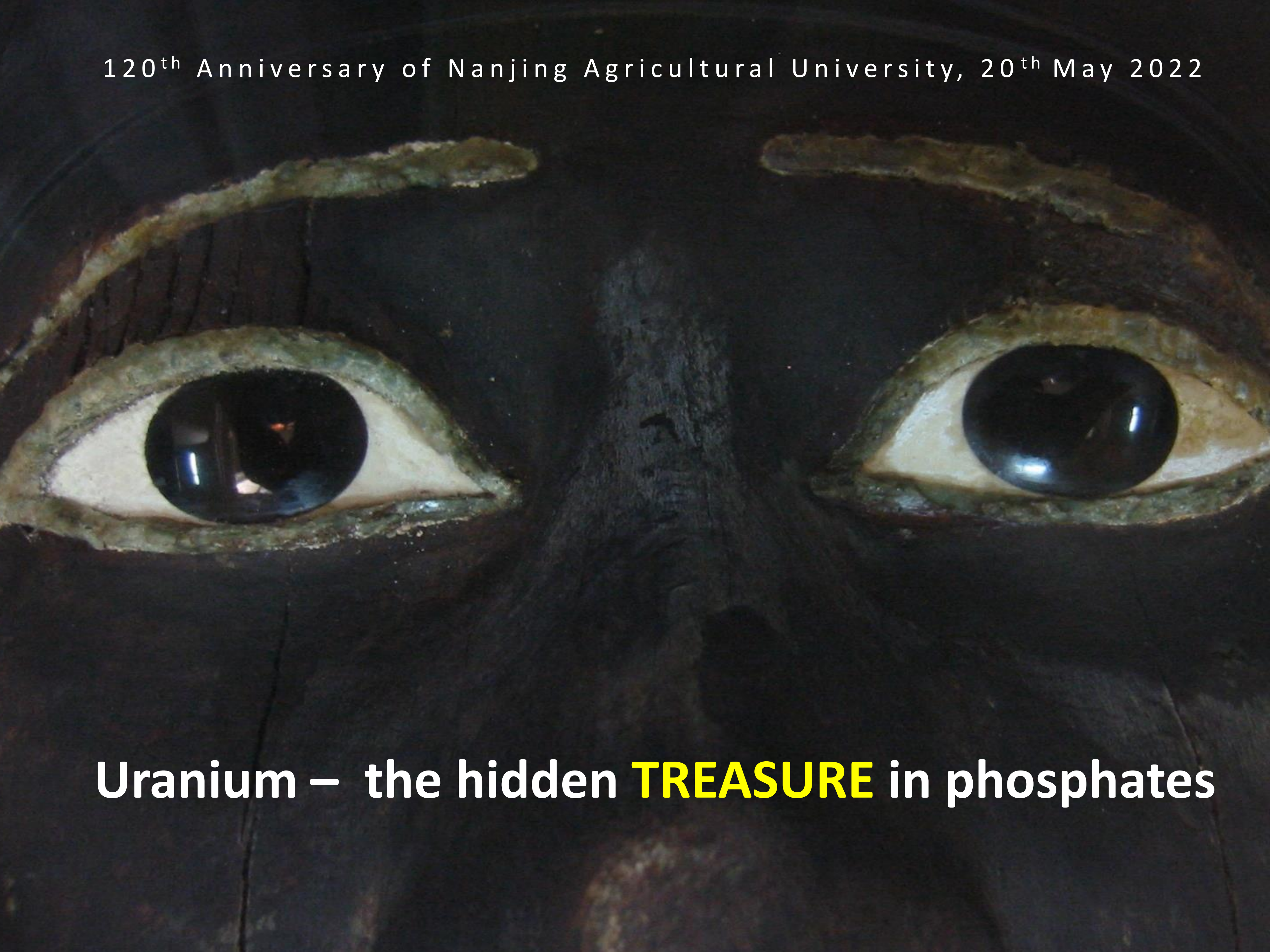
* fertilizer type "organic mineralic"

If the critical values given above would have been applied to this samples 30% would have had to show a declaration of the Cd content and a 15% of would have been banned from trading because of exceeding Cd concentrations. In case of U on for 25% of them a declaration for U concentration would have been required and nearly 50% of them would be not marketable.

BUT:

Whereto with the uranium in mineral P-fertilizers?

120th Anniversary of Nanjing Agricultural University, 20th May 2022



Uranium – the hidden TREASURE in phosphates

Energetical and ecological characteristic of energy sources

Energy source	Energy density in MJ/kg	Electricity produced in kWh/kg	CO_2 Emission in g/kWh	Landuse in ha/1,000MW
1 kg Firewood	12	1	1851	5,333,333
1 kg Coal	33	3	1000	
1 kg Oil	46	4	814	
1 kg Natural gas	54	5	480	
1 kg U (0.7% ^{235}U)	600,000	50,000	32	768
1 kg LEU (3.5% ^{235}U)	3,456,000	288,000		
Solar			27	12,961
Wind			24	51,842
1 kg Water (pot. at 100m dam height)	0.00008	0.001	22	125,000

Sources:
http://www.physik.uni-muenchen.de/lehre/vorlesungen/wise_06_07/ep1/vorlesung/skript26_5_2.pdf
http://www.xemplar.ca/de/about_uranium.php
http://www.co2-emissionen-vergleichen.de/Stromerzeugung/CO2-Vergleich-Stromerzeugung.html
Deal. J. (2010) “Night with a futurist”. Webinar of the The DaVinci Institute. PO Box 270315. Louisville. CO 80027. USA. January 10, .2010.

Facts of rock phosphate valorization

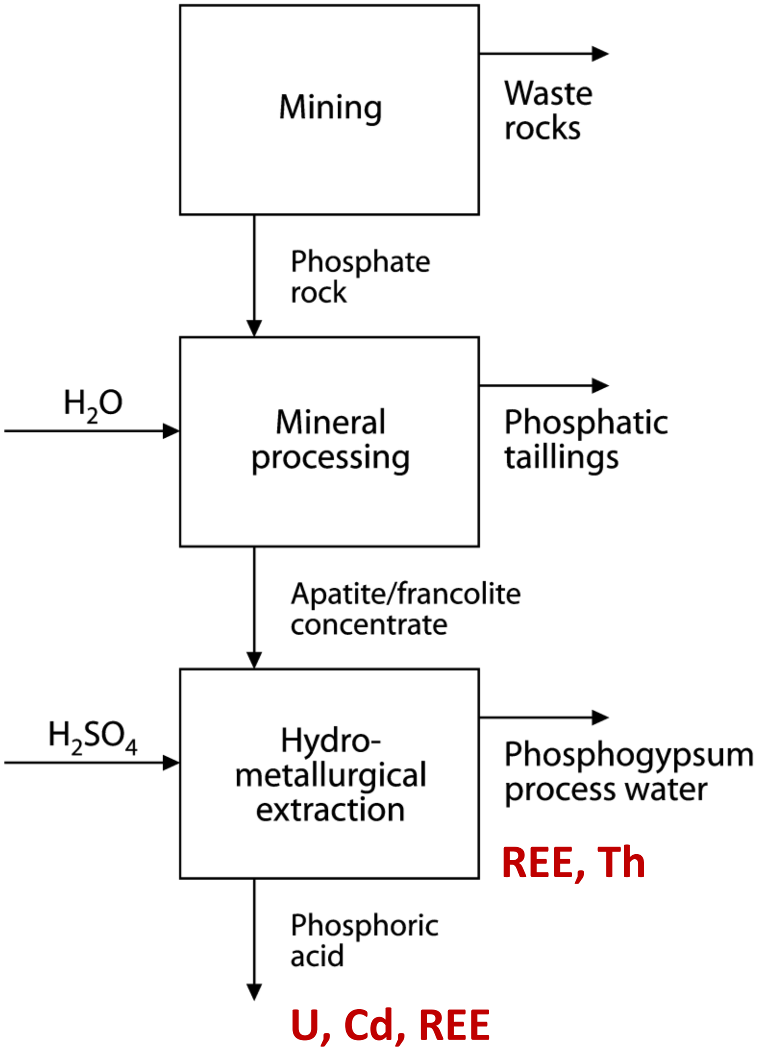
Trace elements transfer to waste- and product-streams

Behaviour of trace elements

U, Cd, REE – Phosphoric acid

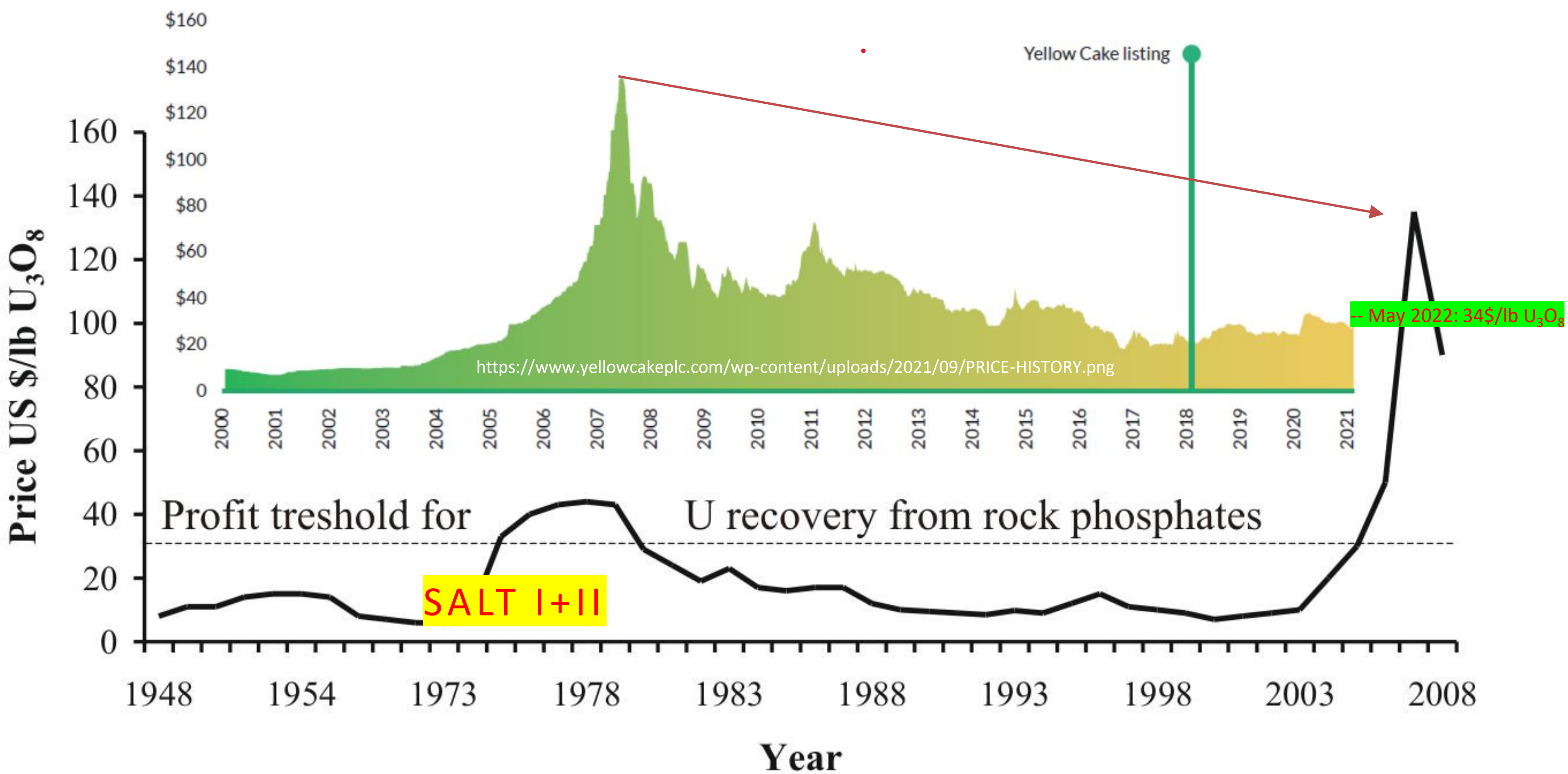
REE, Th – Phosphogypsum

Extraction possible using acid/organic solvent leaching & ion exchange technology



Source: Valkov et al. (2014), Cánovas et al. (2018), Wu et al. (2018)

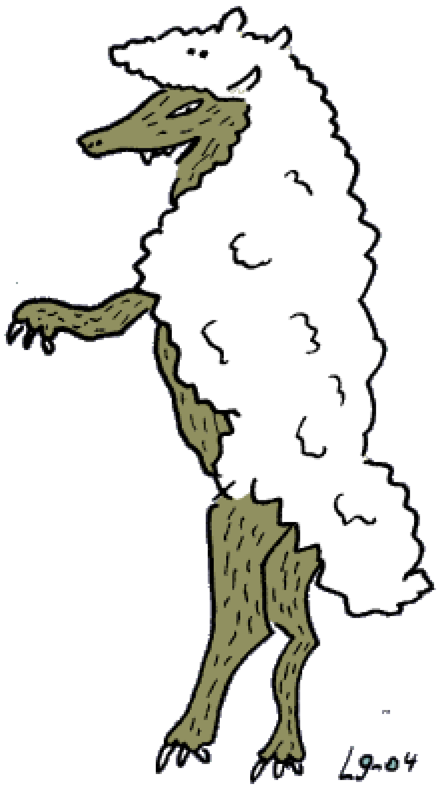
Worldmarket prices for Uranium (1955-2022)



SALT: Strategic Arms Limitation Talks: Nixon and Soviet General Secretary Leonid Brezhnev signed the ABM Treaty and interim SALT agreement on **May 26, 1972**, in Moscow. For the first time during the Cold War, the United States and Soviet Union had agreed to limit the number of nuclear missiles in their arsenals.

“Who pays the bill?“

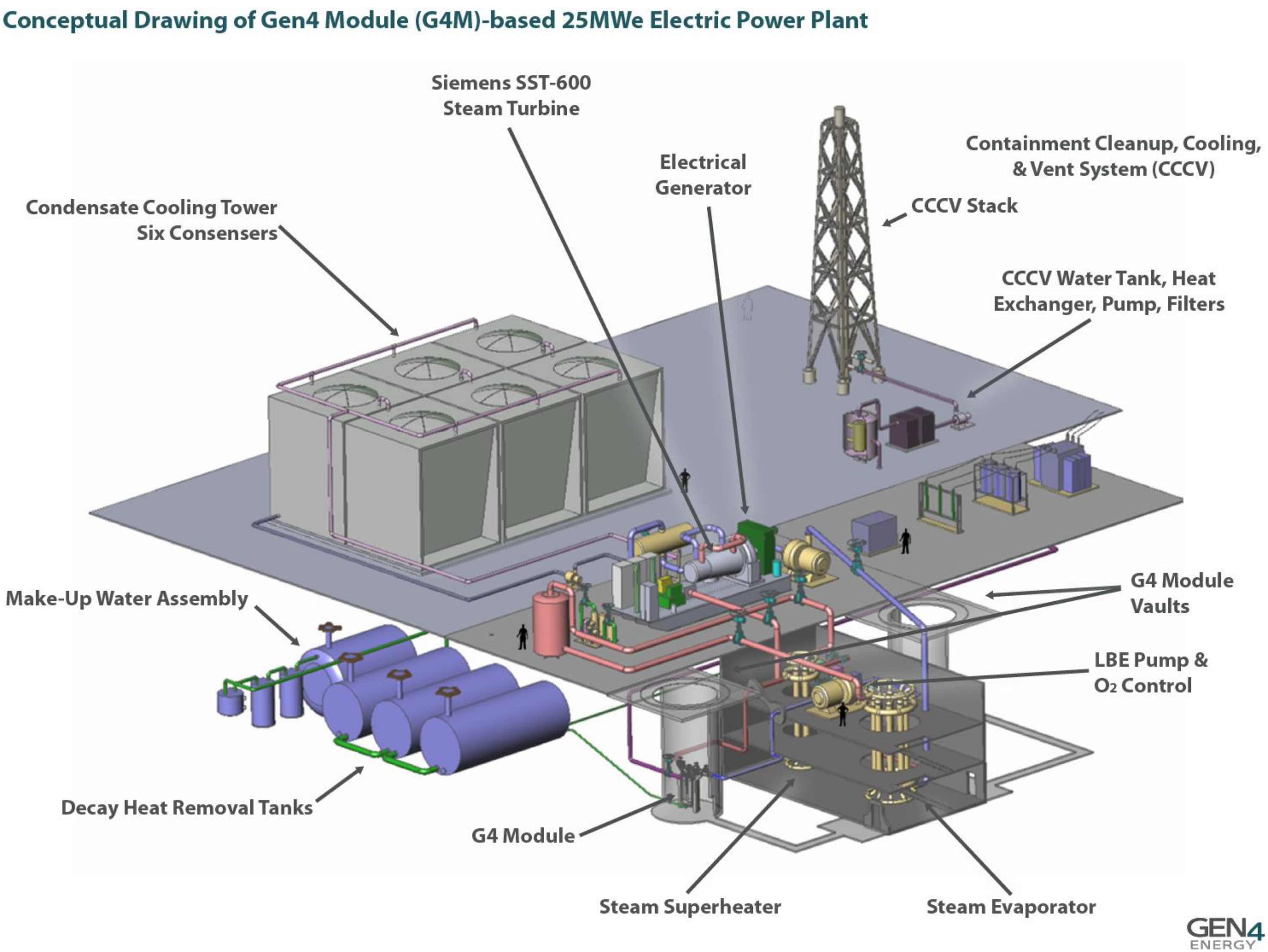
On an average during the last 10 years in Germany alone 177 T uranium were spend every year with mineral P-fertilizers....



披着羊皮的狼

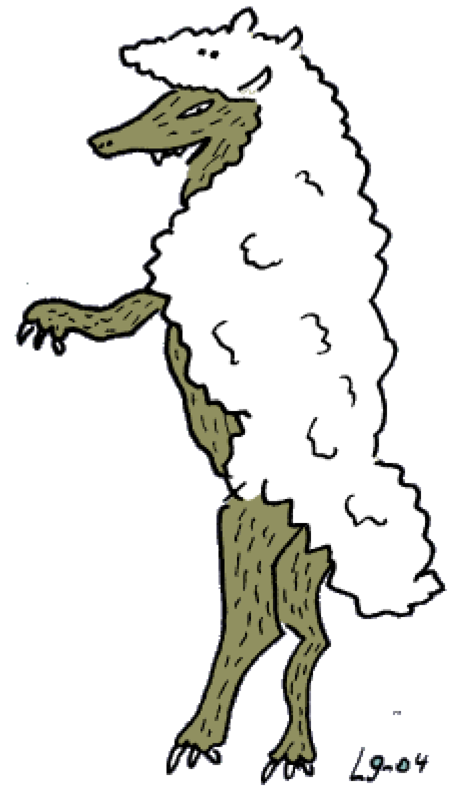
To compare: in the German repository for nuclear waste “Bergwerk ASSE II“ are stocked “only“ in total 102 T U (equivalent to approx. 201 T natural U) !!!!!!!!!!!!!!!!!!!!

Safe Nuclear Power The Gen4 Module has incorporated advanced safety features like LBE (Lead-bismuth eutectic) coolant, an underground vault, and decay heat removal.



… which contained enough energy to supply 2.5 Million average sized German housholds and equals the energy of firewood harvested from 5,935,000 ha forest.

(thats more than 50% of Germanys entire forest area!)



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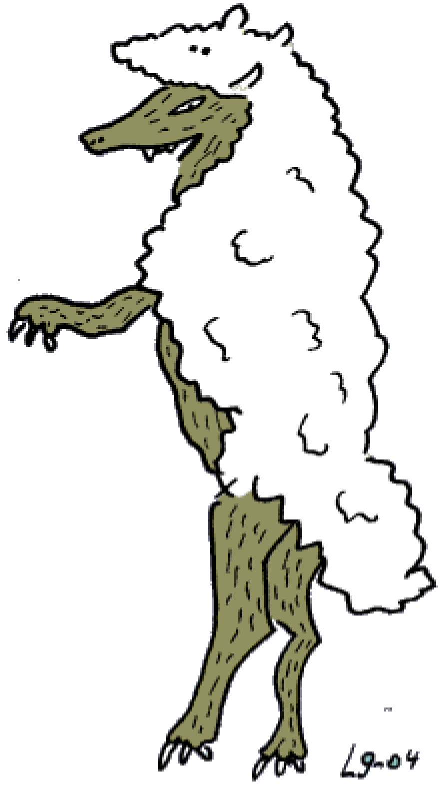
From 10 g U (corresponding to a P-fertilization of 22 kg/ha P according to GAP) 500 kW of energy can be produced. Compared to the same amount of energy derived from coal this saves a total of 500 kg CO_2. At an actual CO_2–tax of 0.25€/kg this equals a value of 125 €/ha.

The monetary value of 10 g U (as yellow cake) amounts actually (07.4.2022) 2 €, the costs of the 22 kg P (2€/kg) = 46 €/ha

If farmers would be rewarded for the CO_2 saved by buying U depleted P-fertilizers they should receive at least 123€/ha)



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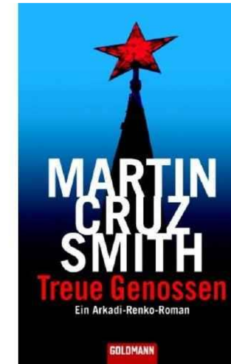
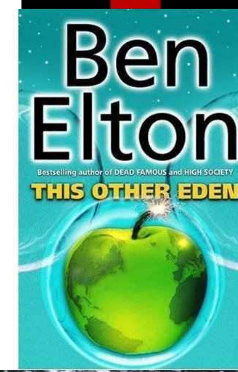
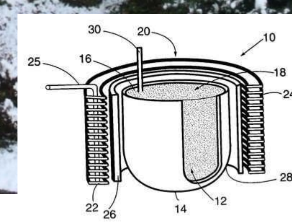
Uranium retrieved from mineral P-fertilizers –

An unconventional contribution of agriculture to climate protection ?!?!?!

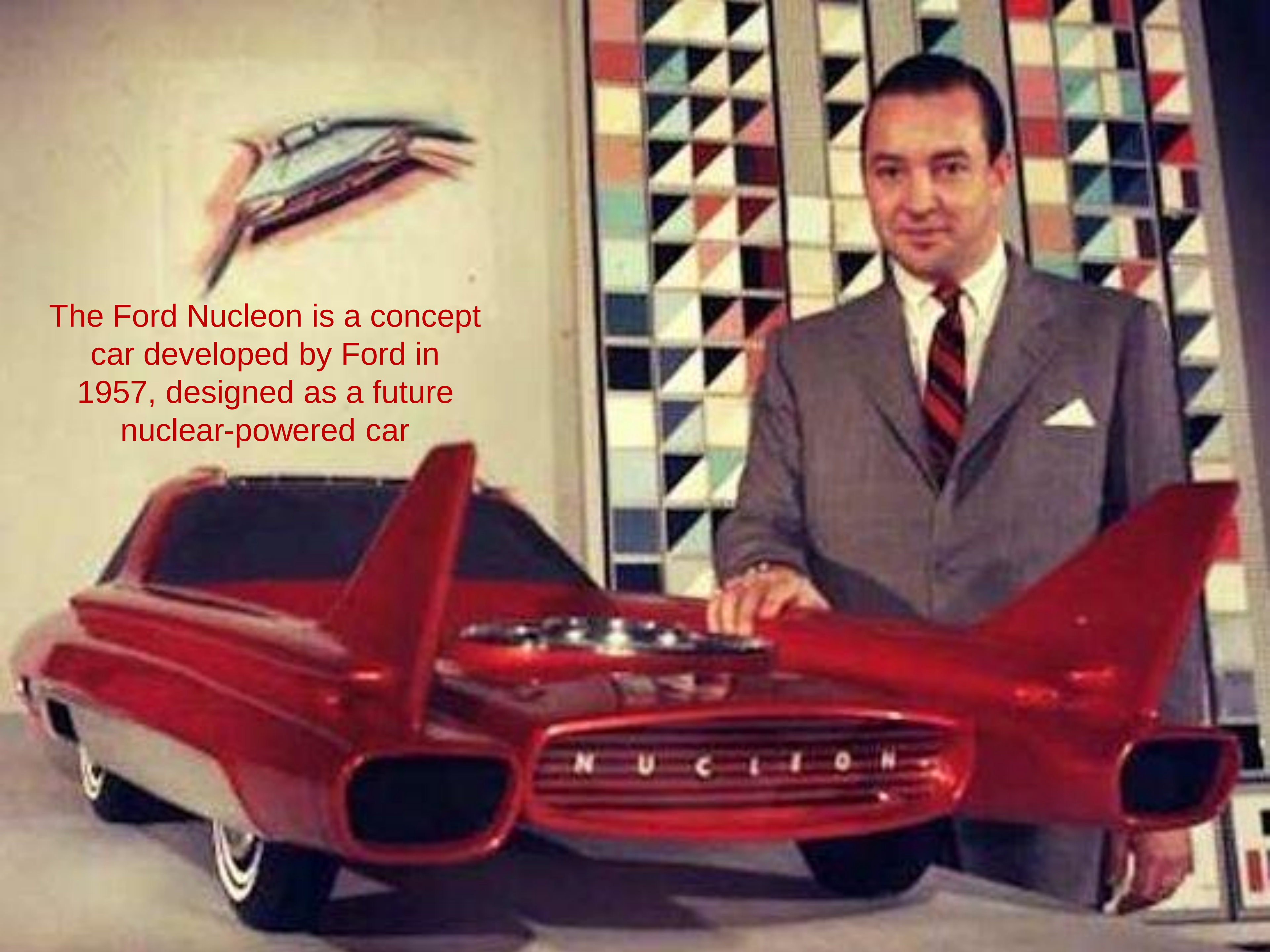
Goslar, Neue Strasse 21

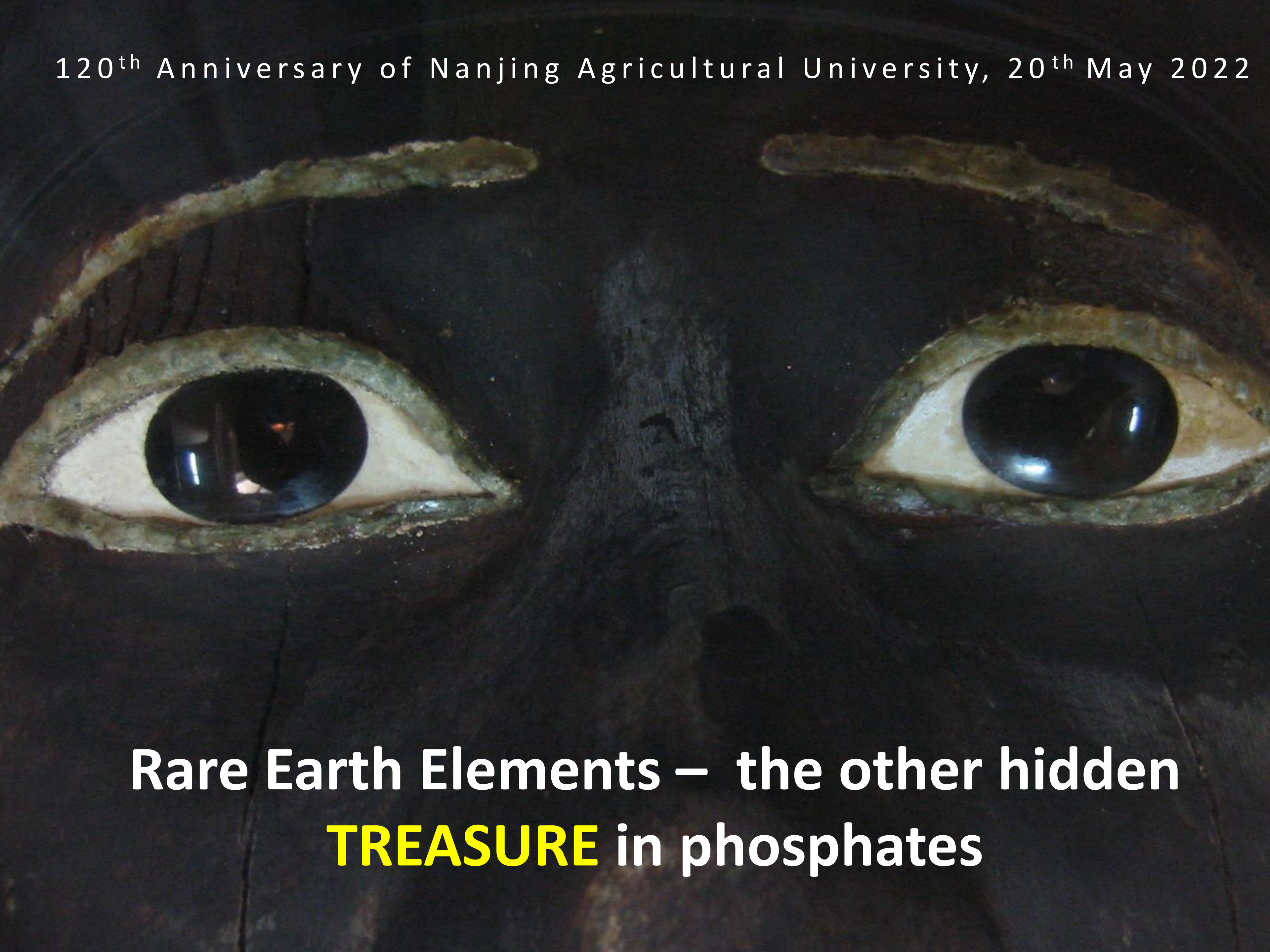






Hyperion Nuclear Unit


The Ford Nucleon is a concept car developed by Ford in 1957, designed as a future nuclear-powered car
NUCLEON



120th Anniversary of Nanjing Agricultural University, 20th May 2022

Rare Earth Elements – the other hidden TREASURE in phosphates

Facts of rock phosphate valorization

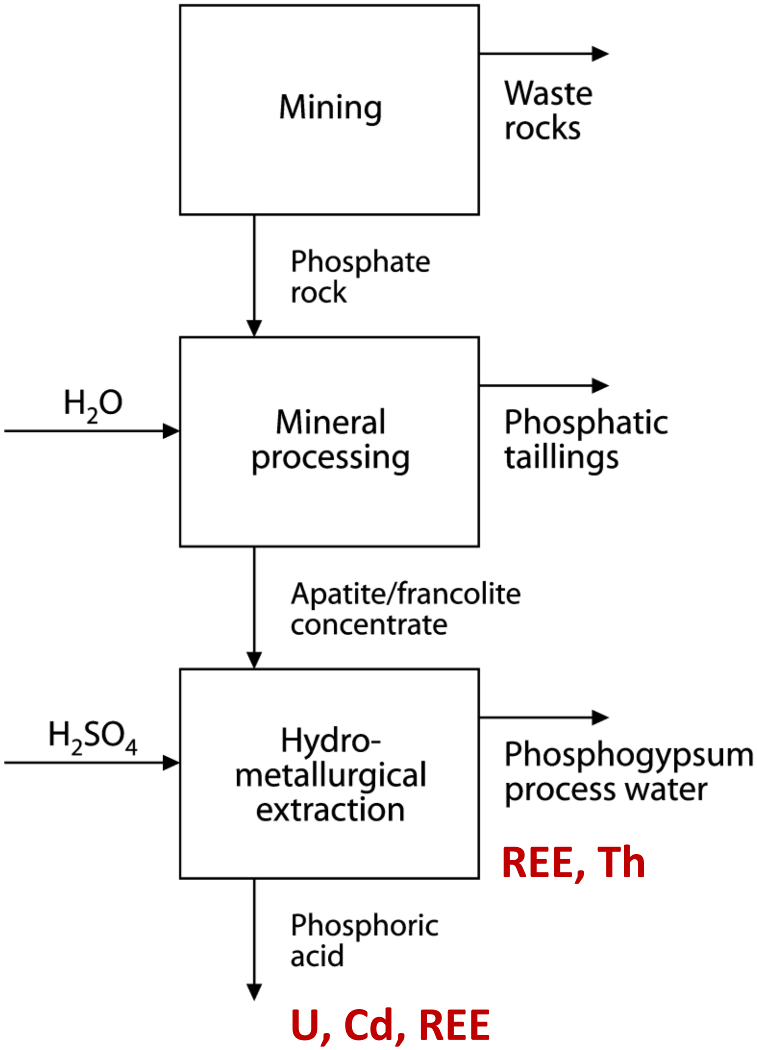
Trace elements transfer to waste- and product-streams

Behaviour of trace elements

U, Cd, REE – Phosphoric acid

REE, Th – Phosphogypsum

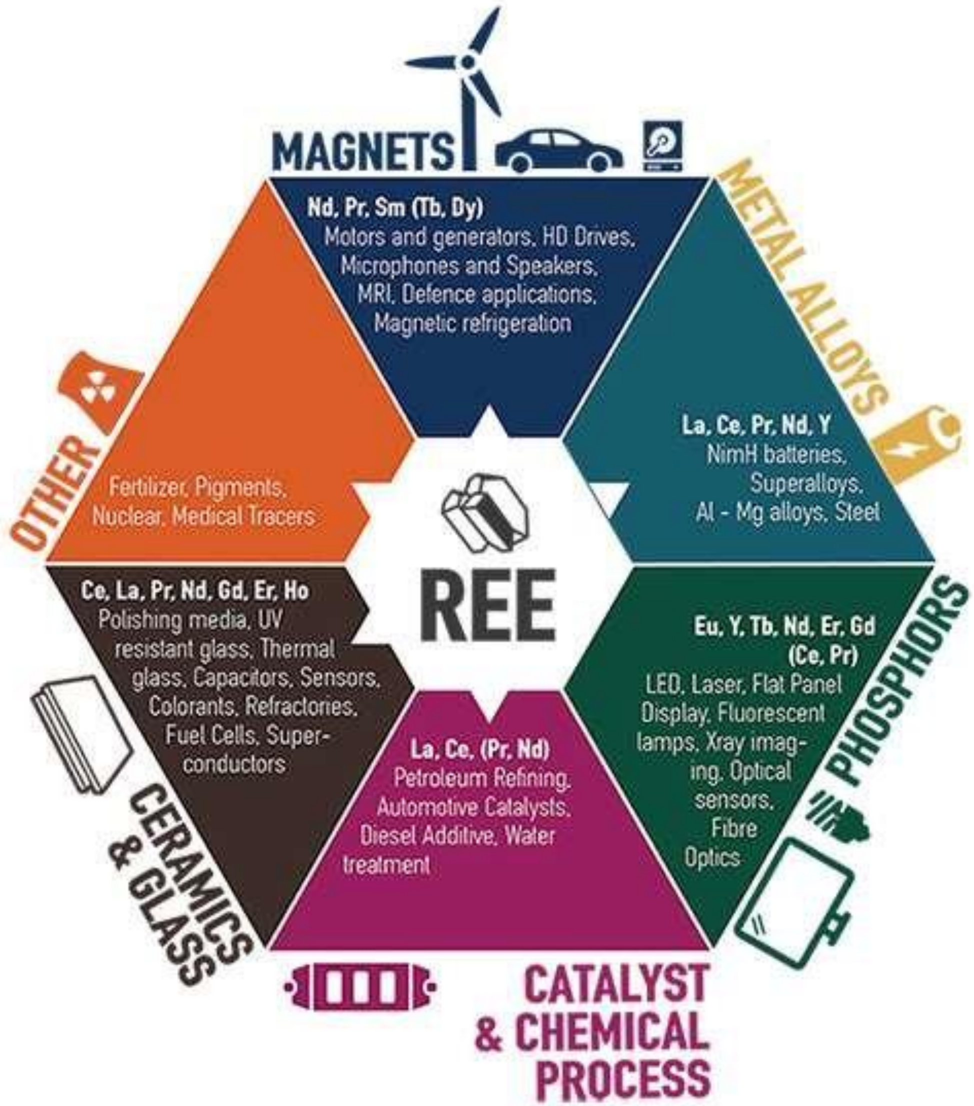
Extraction possible using acid/organic solvent leaching & ion exchange technology



Source: Valkov et al. (2014), Cánovas et al. (2018), Wu et al. (2018)

Geometric mean and coefficients of variation (cv) and Clarke values of Lanthanides (REE) and Actinides in 22 igneous and 128 sedimentary rock phosphates from worldwide (Schnug et al. 2022)

Element	Igneous rock phosphates		Sedimentary rock phosphates		Clarke value Significance[1]
	mean (mg/kg)	cv (%)	mean (mg/kg)	cv (%)	(mg/kg)
Lanthanides					
Ce	198	141	40.3	145	2.5 **
Dy	19.7	87	6.41	76	3.9 ***
Er	10.0	75	4.31	78	3.2 **
Eu	7.23	119	1.62	114	2.7 ***
Gd	31.9	120	7.39	97	4.0 ***
Ho	3.63	77	1.41	129	4.3 ***
La	122	155	36.3	94	2.2 **
Lu	0.690	69	0.513	86	2.7 ns
Nd	151	132	30.1	127	2.8 ***
Pr	34.1	134	7.03	126	2.9 ***
Sm	30.4	128	6.12	120	2.4 ***
Tb	4.16	108	1.11	82	3.0 ***
Tm	0.96	65	0.546	81	2.6 ns
Yb	5.47	67	3.36	84	3.1 ns
Actinides					
Th	5.08	219	2.75	92	2.7**
U	7.56	119	59.6	69	4.7***
Significance levels between igneous and sedimentary: ns = >0.05, * = <0.05, ** = <0.01, *** = < 0.001					



metallic state

oxidized state

Rare Earth Elements usage in various technologies (http://www.eurare.eu/RareEarthElements.html)

Uranium and REE´s in world P-resources are idden treasures their exploitation resulting in

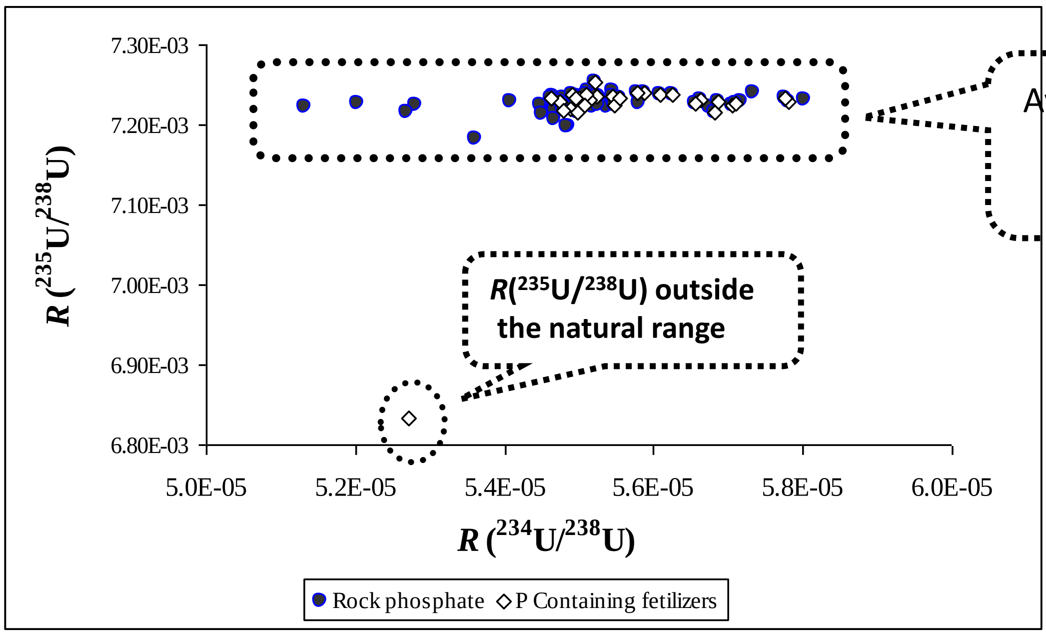
- Cleaner fertilizers
- Cleaner soils
- Cleaner waters
- Cleaner atmosphere
- Increased profitability of fertilizer manufacturing

World U resources actually last for approx. 50 more years;
U in rock-P can feed the nuclear energy cycle for 350 years (Hu et al., 2008)

Thank you for your attention!

Uranium isotopes in P fertilizers

$R(^{235}U/^{238}U)$ as a tool to detect contamination with anthropogenic U – DU in fertilizer



Average of $R(^{235}U/^{238}U)$ = 0.720%, ranging from 0.718 to 0.725%.

Fig. 23: $R(^{235}U/^{238}U)$ and $R(^{234}U/^{238}U)$ in different RP, P- fertilizers

Dimona ?

source: Sattouf et al. (2008)

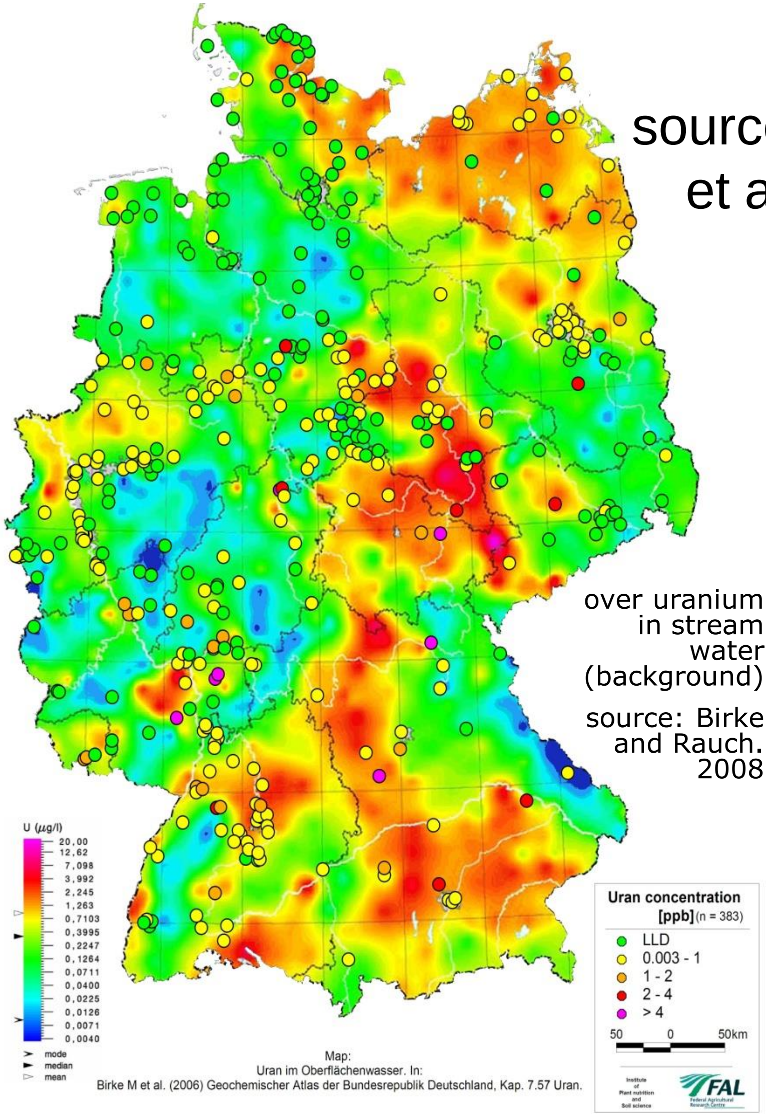
U concentration factor $(CF)_{soil/plant}$ in comparison to other selected heavy metals

V	Cr	As, Co, Hg, Pb, **U**	Sb	Ni	Cd	Cu	Zn
0.02	0.03	0.05	0.1	0.2	0.25	0.3	1

(Baes et al., 1984; Kloke et al., 1994; Lamas, 2005; Lübben & Sauerbeck, 1991; Rivas, 2005; Schick et al., 2008; Schönbuchner, 2002)

Plants are not the primary entry of U from soils into the food chain!

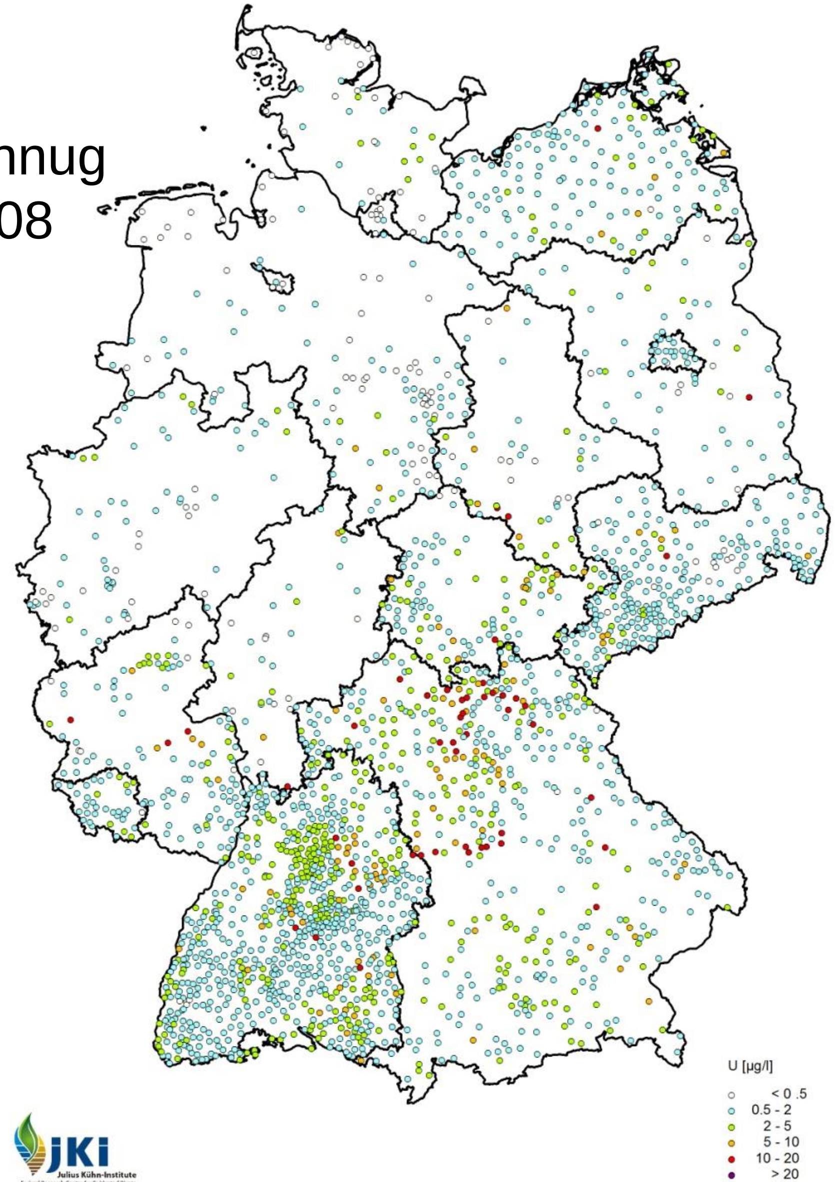
Uranium in tap water (circles)



over uranium in stream water (background)

source: Birke and Rauch. 2008

source: Schnug et al., 2008



U in German tap waters

County	Area km²	Area %	Population (millions)	Population %	N	Samples per 1000 inhabitants	km² per sample	% < 0.2 µg/L U*	% < 2.0 µg/L U*	% < 10.0 µg/L U*
HE	21.114	5.9	5.90	7.3	33	179	640	25.0	66.2	100.0
TH	16.251	4.5	2.54	3.2	304	8	53	0.8	81.2	100.0
RP	19.486	5.4	3.88	4.8	120	32	162	32.7	83.7	91.9
ST	20.443	5.7	2.80	3.5	66	42	310	57.7	88.6	95.8
BW	35.751	10.0	10.00	12.4	1.263	8	28	13.6	88.8	99.1
Germany	**358.921**	**100.0**	**80.61**	**100.0**	**3.555**	**23**	**100**	**38.1**	**92.6**	**99.4**
BY	70.553	19.7	11.60	14.4	579	20	122	19.1	94.7	98.4
MV	23.170	6.5	1.85	2.3	482	4	48	13.0	95.2	99.8
SN	18.338	5.1	4.60	5.7	329	14	56	53.2	95.5	98.6
SH	15.731	4.4	2.70	3.3	50	54	315	52.4	98.2	100.0
SL	2.570	0.7	1.08	1.3	38	28	68	66.5	98.8	100.0
NI	47.343	13.2	7.48	9.3	123	61	385	73.6	98.8	100.0
NRW	37.070	10.3	17.69	21.9	71	249	522	50.5	98.9	100.0
BB	29.053	8.1	2.67	3.3	64	42	454	70.0	99.8	100.0
BE	889	0.2	3.45	4.3	18	192	49	49.8	100.0	100.0
HB	404	0.1	0.68	0.8	6	113	67	84.0	100.0	100.0

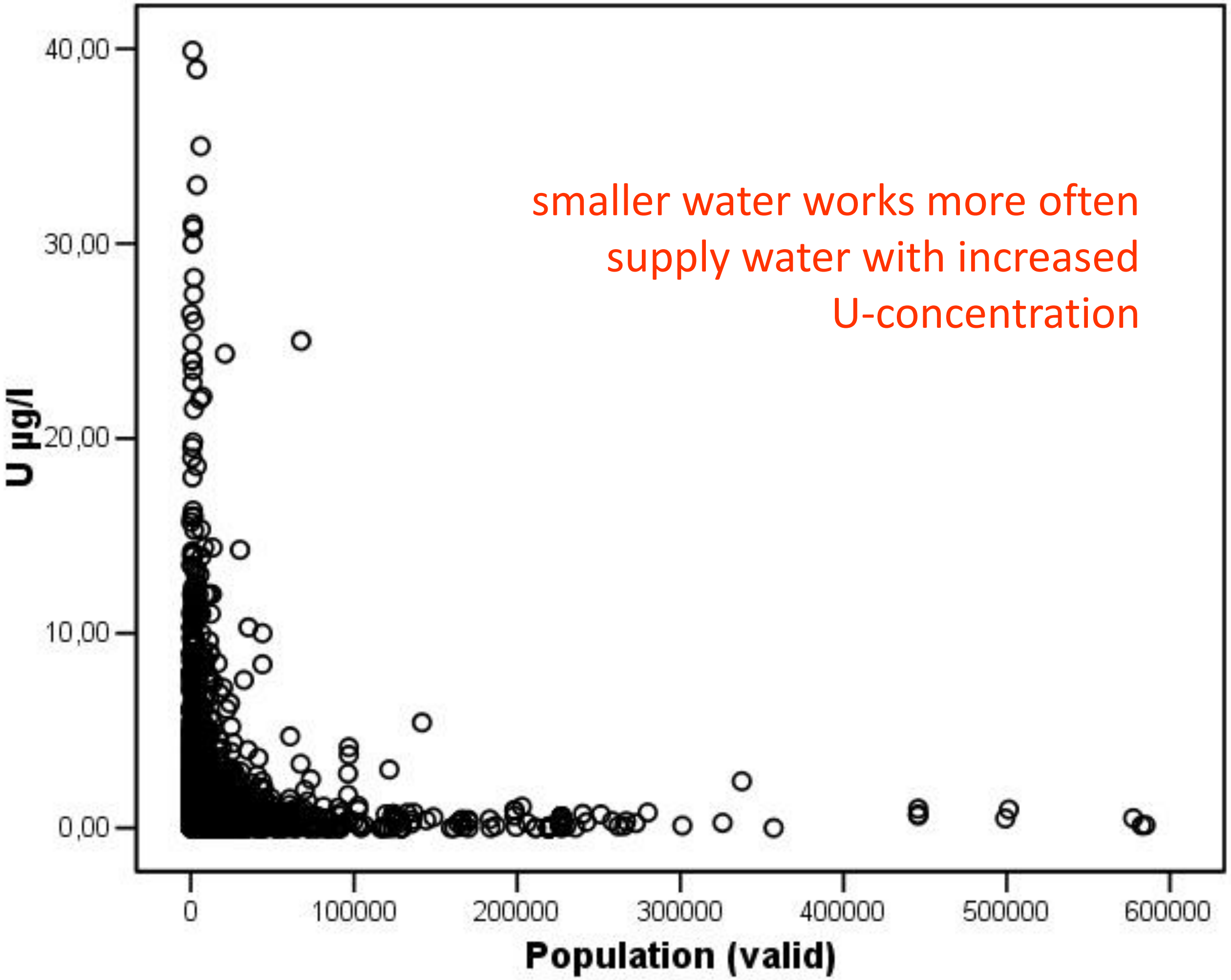
* Percentage of population with access to tap water of the assigned U-concentration


Finally .....

.... more than 45,000 pieces of plastic debris float on every square mile of ocean..... *


... (nearly) everything ends up in our water .....

* (Botham, N. (2005) The world´s greatest book of useless information. John Blake Publ. London, UK



U in tap water as a function of the area supplied by the waterworks (data from 2006-2008)

Tab. 2: Uranium and nitrate concentrations in neighbouring shallow (7-9m) and deep (70-90m) wells of two waterworks in southern Germany (2008 data).

Location	Well type	U (µg/L)	NO_3 (mg/L)
Straubing	shallow	2.8	40.0
	deep	< 0.2	2.8
Rehlingen	shallow	10	22.0
	deep	1.6	8.2

Evidence for agricultural influence on U in water!

Differences in water U concentrations from agricultural land compared to forest land in Germany found by:

Huhle et al. (2008): + 1.73 µg/L U

Birke and Fuchs (2008): + 0.77 µg/L U

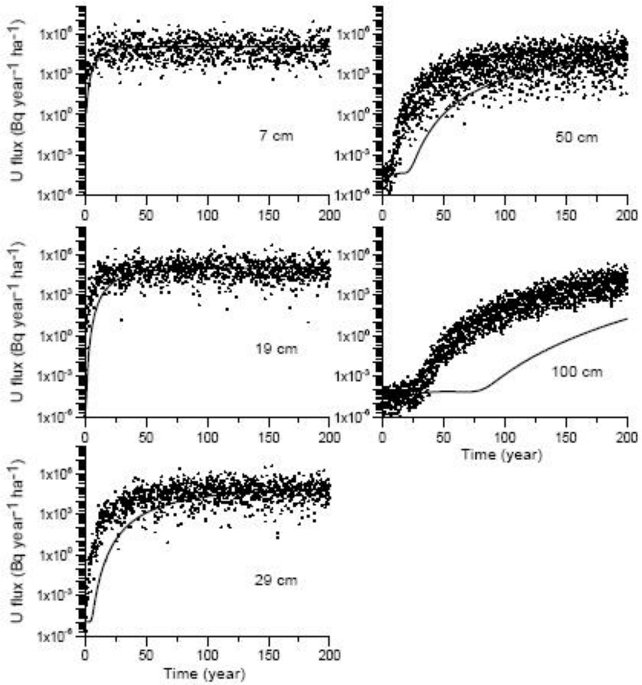


Figure 3. Downward U fluxes for the transient (dots) and steady-state (line) flow simulations at different depths.

Modelling uranium leaching from agricultural soils to groundwater as a criterion for comparison with complementary safety indicators[1]

Jacques D.[(1)], J. Šimůnek[(2)], D. Mallants[(1)], and M.Th. van Genuchten[(3)]
[(1)] Waste and Disposal Department, SCK•CEN, Boeretang 200, B-2400 Mol, Belgium
[(2)] University of California Riverside, Riverside, CA 92521, USA
[(3)] George E. Brown, Jr. Salinity Laboratory, 450 W Big Springs RD, Riverside, CA 92507, USA

[1] Published in: 29th Symposium on the Scientific Basis for Nuclear Waste Management, September 12-16, 2005, Ghent (Belgium)

At an annual application rate of
9 g/ha U applied with 22 kg/ha P
a steady state concentration of 22 µg/L U is
expected in the percolating water
(Jaques et al., 2008)

(e.g., after 200 years in figure 3). This comparison of fluxes serves to demonstrate that long-time continuous fertilization may pose a more serious radiological health effect than a degraded or even failing low-level nuclear waste repository of the type envisioned in Northern Belgium.

Whereto with the uraium in mineral P-fertilize

To compare: in the German repository for nuclear waste “Bergwerk ASSE II“ are stocked “only“ in total 102 T U (equivalent to approx. 201 T natural U) !!!!!!!!!!!!!!!!!!!!

Drinking waters show a wide range of U concentrations:

Element	Source	N	P5/P10	Mean	Median	P95	Maximum	CI-Median[e]
U in tap Water	PB-FAL[b]	4092	0.03/0.10	1.67	0.500	7.21	49.0	0.43-0.53
	UBA[a]	150	-.-/<0.001	0.66	0.169	3.16	19.4	0.15-0.19
	EFSA[c]	97	0.05/-.--	0.43	0.500	1.80	10.5	n.a.
	EFSA[cc]	4833	0.03/-.--	3.09	0.725	9.27	**93.0**	n.a.
U in bottled water	FAL-PB[d]	1154	0.00/0.00	3.45	0.300	8.43	474	0.21-0.32
	FAL-PB[dd]	775	0.00/0.00	3.92	0.300	10.0	**474**	0.21-0.32
	FAL-PB[ddd]	362	0.00/0.00	1.45	0.161	8.48	27.4	0.08-0.18
	EFSA[c]	1224	0.02/-.--	1.19	0.325	5.30	10.5	n.a.
	EFSA[cc]	2207	0.03/-.--	3.18	0.440	8.40	153	n.a.

Descriptive statistics for U concentrations (µg l^{-1}) in tap waters and mineral waters

Remarks:
[a] random sample, mean of 1029 measurements from 150 locations (Schulz et al. 2009)
[b] FAL-PB entire German tap water data base
[c] EFSA (2009) Germany only (see comments in text above!) [cc] EFSA (2009) entire database for EU
[d] FAL-PB world mineral waters; [dd] FAL-PB German and neighbouring EU countries; [ddd] FAL-PB
[e] 95%-confidence interval for median
f no significant correlation between independent sampled and analysed samples.
(Hassoun 2011)

The Waves of U recovery

1. Started in 1950s, ended early 1960s – Emphasis on Military Stockpiling
2. Started late 1970s, ended 1990s – Nuclear Power down after Chernobyl
3. 2010 – Nuclear Renaissance/ Era of Resource Conservation and Sustainability, Carbon Dioxide Mitigation. Nuclear down again after Fukushima
4. 2022 -Renewed Interest in Uranium Supply

   after Russia triggered war against Ukraine.

May 2022

Celebrating the 120th Anniversary of

南京大學
NANJING UNIVERSITY

CIRN Instituto de Suelos
INTA
Ministerio de Agricultura, Ganadería y Pesca
Argentina

Institute of Plant Nutrition and Soil Science

Maria del Carmen Rivas

Interactions between soil uranium contamination and fertilization with N, P and S on the uranium content and uptake of corn, sunflower and beans, and soil microbiological parameters

Published as: Landbauforschung Völkenrode Sonderheft 287

Braunschweig
Federal Agricultural Research Centre (FAL)
2005

My deepest thanks to my mentor, **Prof. Dr. Dr. Ewald Schung**.

Similarly, I would like to express my sincere thanks to
Prof. Dr. Silvia Haneklaus,
Prof. Dr. Jutta Rogasik and
Prof. Dr. Juergen Fleckestein (R.I.P)

I thank **all the colleagues of the former Institute of Plant Nutrition and Soil Science** (FAL), current JKI.

Gratefully acknowledged is **Technische Universität Carolo-Wilhelmina of Braunschweig**

CIRN Instituto de Suelos

INTA

Ministerio de Agricultura, Ganadería y Pesca
Argentina

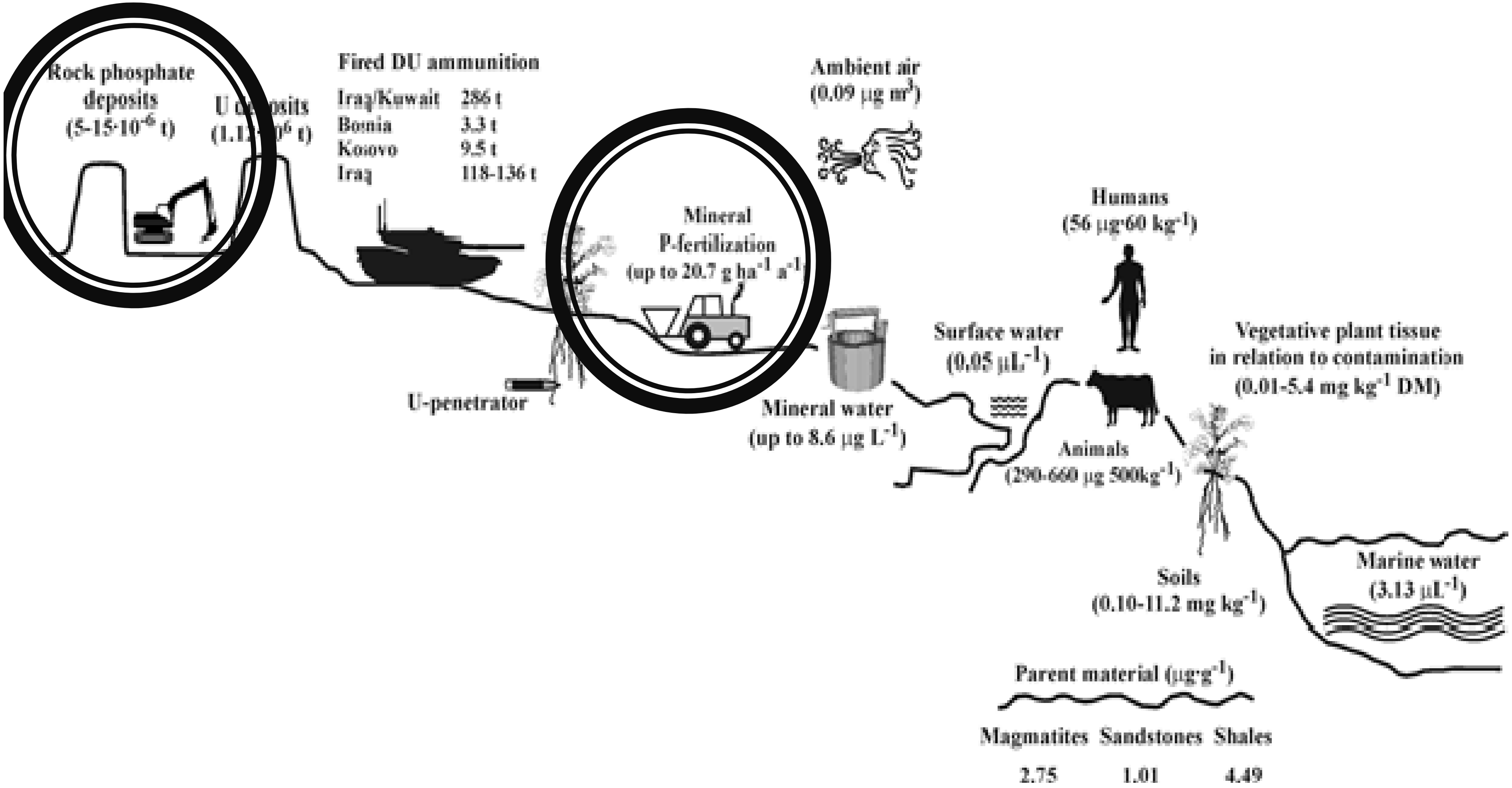
Interactions between soil uranium contamination and fertilization with N, P and S on the uranium content and uptake of corn, sunflower and beans.

Dra. Ing. Agr. Maria del Carmen Rivas.
rivas.mariadelcarmen@inta.gob.ar

CIRN Instituto de Suelos
INTA
Ministerio de Agricultura, Ganadería y Pesca
Argentina

Introduction

Anthropogenic input of uranium into the environment



"DU Trojan Horse of Nuclear War" Described by Moret (2004)

Iraq (1991)

Bosnia (1994-1995)

Kosovo (1999)

Iraq (2003)

Ukraine (2022)

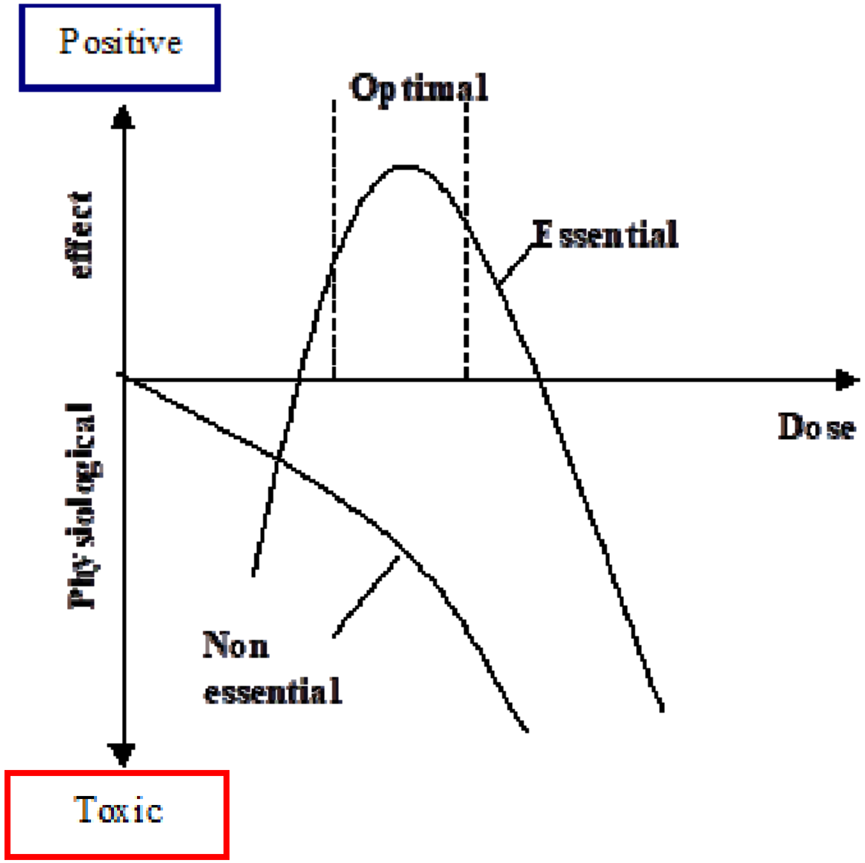
Dose - effect response

Heavy metals belong to the trace elements group.

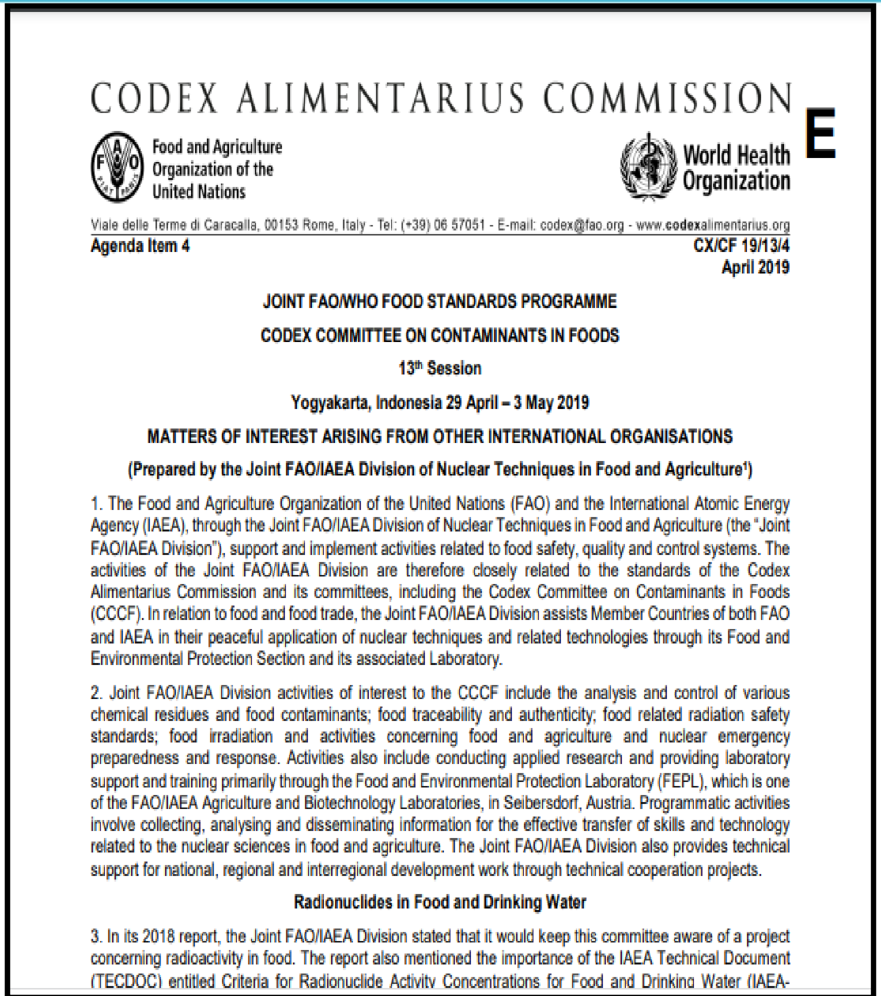
For plants, they can be classified as non-essential or essential.

Non-essential metals disturb the normal operational sequence of metabolic processes in the plant, even if present in smallest quantities.

They can act toxically, depending on the dose



CODEX 2019 radionuclides



CODEX ALIMENTARIUS COMMISSION

E

Food and Agriculture Organization of the United Nations

World Health Organization

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Agenda Item 4

CX/CF 19/13/4
April 2019

JOINT FAO/WHO FOOD STANDARDS PROGRAMME

CODEX COMMITTEE ON CONTAMINANTS IN FOODS

13th Session

Yogyakarta, Indonesia 29 April – 3 May 2019

MATTERS OF INTEREST ARISING FROM OTHER INTERNATIONAL ORGANISATIONS

(Prepared by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture[1])

1. The Food and Agriculture Organization of the United Nations (FAO) and the International Atomic Energy Agency (IAEA), through the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture (the "Joint FAO/IAEA Division"), support and implement activities related to food safety, quality and control systems. The activities of the Joint FAO/IAEA Division are therefore closely related to the standards of the Codex Alimentarius Commission and its committees, including the Codex Committee on Contaminants in Foods (CCCF). In relation to food and food trade, the Joint FAO/IAEA Division assists Member Countries of both FAO and IAEA in their peaceful application of nuclear techniques and related technologies through its Food and Environmental Protection Section and its associated Laboratory.

2. Joint FAO/IAEA Division activities of interest to the CCCF include the analysis and control of various chemical residues and food contaminants; food traceability and authenticity; food related radiation safety standards; food irradiation and activities concerning food and agriculture and nuclear emergency preparedness and response. Activities also include conducting applied research and providing laboratory support and training primarily through the Food and Environmental Protection Laboratory (FEPL), which is one of the FAO/IAEA Agriculture and Biotechnology Laboratories, in Seibersdorf, Austria. Programmatic activities involve collecting, analysing and disseminating information for the effective transfer of skills and technology related to the nuclear sciences in food and agriculture. The Joint FAO/IAEA Division also provides technical support for national, regional and interregional development work through technical cooperation projects.

Radionuclides in Food and Drinking Water

3. In its 2018 report, the Joint FAO/IAEA Division stated that it would keep this committee aware of a project concerning radioactivity in food. The report also mentioned the importance of the IAEA Technical Document (TECDOC) entitled Criteria for Radionuclide Activity Concentrations for Food and Drinking Water (IAEA-

"…to develop principles for harmonized guidance on radionuclide activity concentration values in food and drinking water"

While the WHO Drinking Water Guidelines provide guidance to national authorities in the case of drinking water, there is no equivalent international guidance for food.

*"There is **no intention to specify numerical limits for radioactivity in food in normal circumstances."***

CODEX 2021 radionuclides

“Naturally occurring radionuclides are found in many different foods and tend to give radiation doses higher than those provided by artificially produced radionuclides in situations not affected by a nuclear emergency situation in the past, but no specific safety problem for food, feed or drinking water due to the presence of naturally occurring radionuclides has been identified. ii. No problems in international trade have been identified due to the presence of naturally occurring radionuclides in food, feed and drinking water”

CODEX ALIMENTARIUS COMMISSION

Food and Agriculture Organization of the United Nations

World Health Organization

Viale delle Terme di Caracalla, 00153 Rome, Italy - Tel: (+39) 06 57051 - E-mail: codex@fao.org - www.codexalimentarius.org

Agenda Item 16

CX/CF 21/14/14
April 2021
ORIGINAL LANGUAGE ONLY

JOINT FAO/WHO FOOD STANDARDS PROGRAMME

CODEX COMMITTEE ON CONTAMINANTS IN FOODS

14th Session
(virtual)
3-7 and 13 May 2021

DISCUSSION PAPER ON THE RADIOACTIVITY IN FOOD AND FEED (INCLUDING DRINKING WATER) IN NON-EMERGENCY SITUATIONS

(Prepared by the Electronic Working Group chaired by the European Union and co-chaired by Japan)

BACKGROUND

1. Following discussions at the 13th Session of the Committee on Contaminants in Foods (CCCF13, 2019) the Committee agreed to establish an electronic working group (EWG) on radioactivity in food and feed (including drinking water) to produce a discussion paper for consideration at its next session, chaired by EU, co-chaired by Japan, working in English with the following terms of reference (REP19/CF, paras. 26-27):

   i. Provide factual information on the radioactivity of both human-made and natural origin that can be found in food (including drinking water) and feed in normal circumstances (i.e. not in an emergency exposure situation following a nuclear or radiological accident).

   the presence in normal circumstances of radioactivity in food

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Argentina

Toxical profile for uranium (2013)

“”Uranium from soil is not taken up by plants, but rather is adsorbed onto the roots. Thus, the highest levels of uranium are found in root vegetables, primarily unwashed potatoes…”

Toxicological profile for uranium.

U.S. Department of health and human services.

Agency for toxic substances and disease registry, 2013.

https://www.atsdr.cdc.gov/toxprofiles/tp150.pdf

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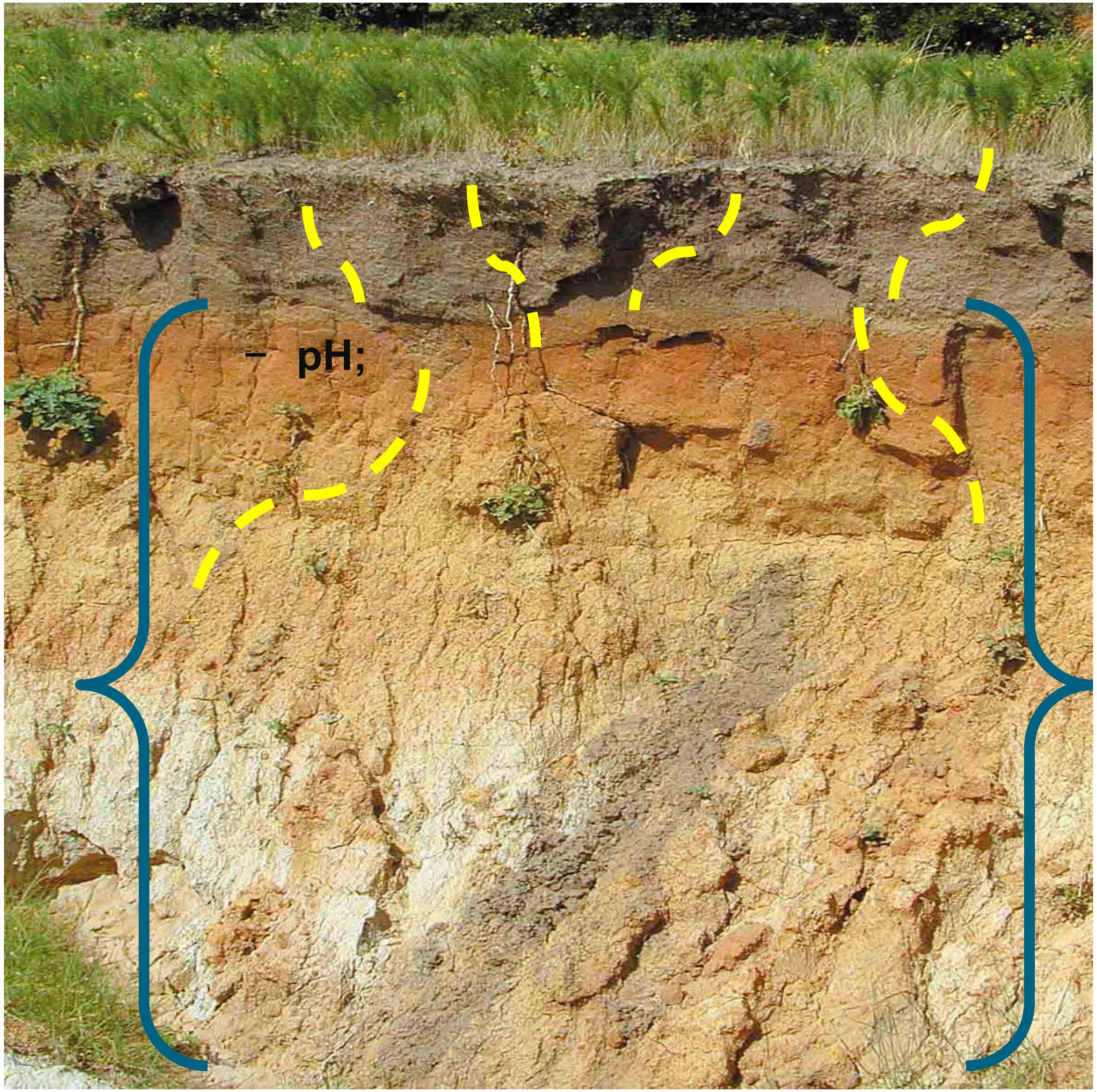
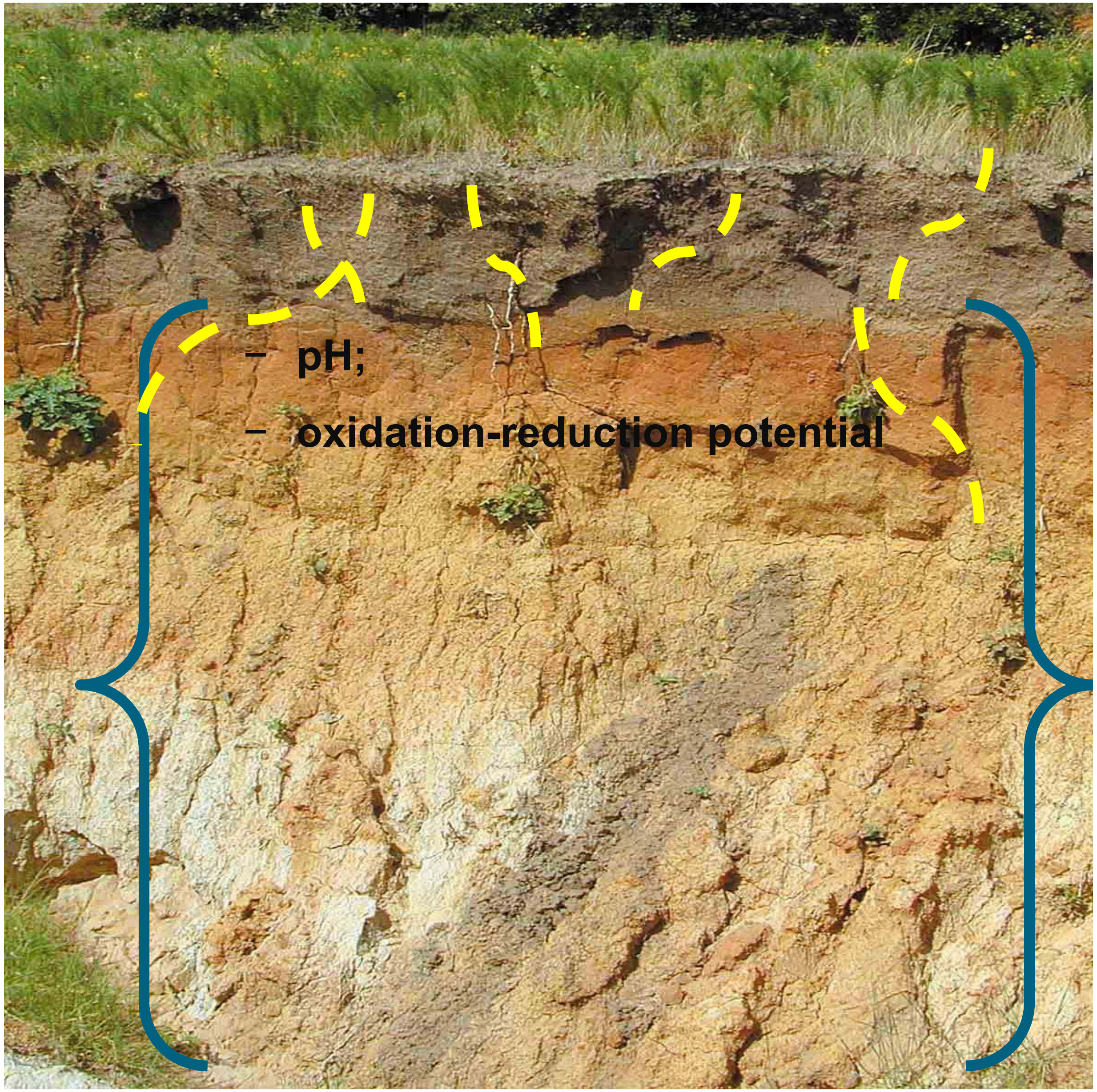
Uranium mobility in soil and its vertical transport (leaching)

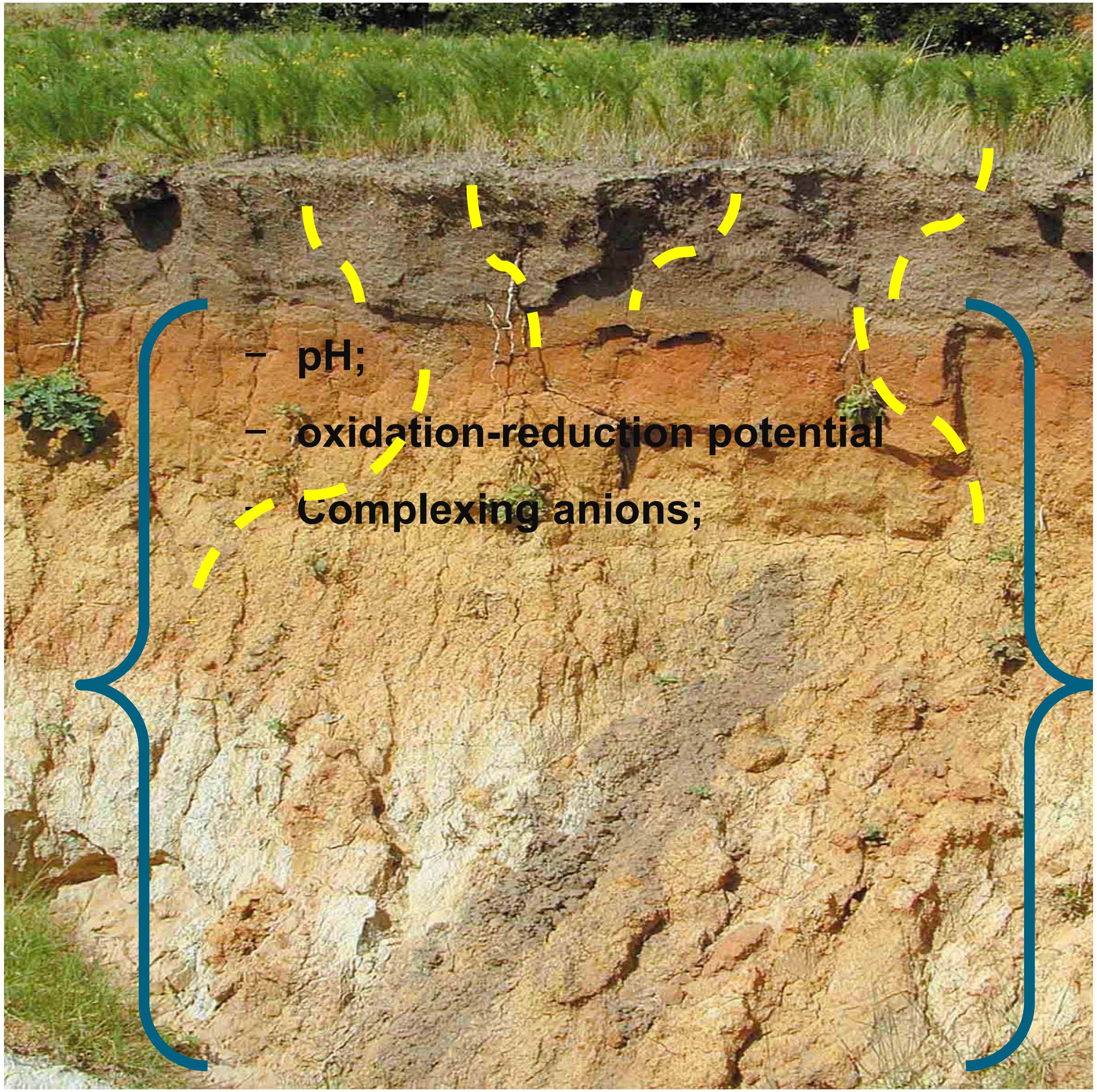


Uranium mobility in soil and its vertical transport (leaching)

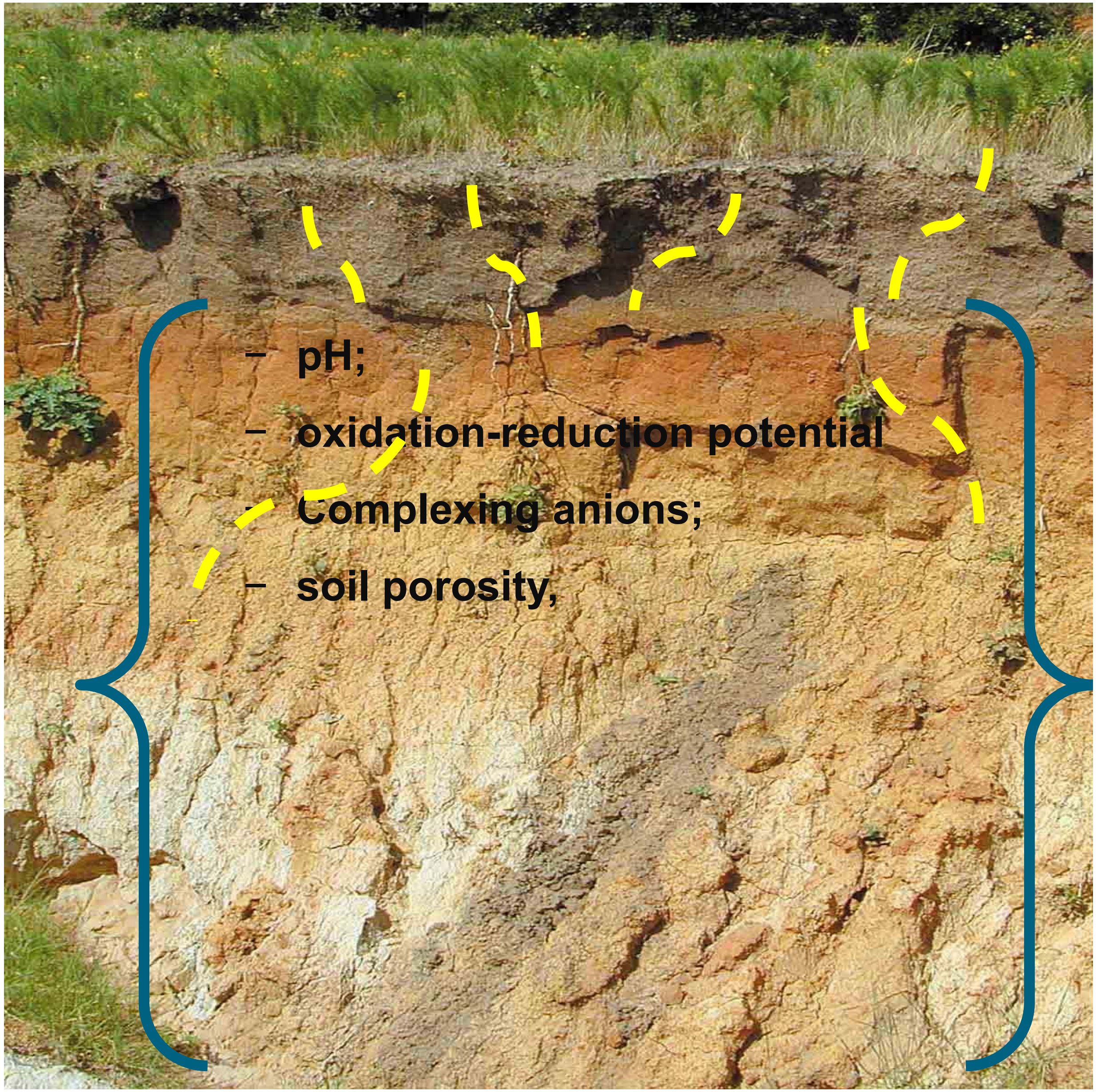


- pH;
- oxidation-reduction potential

Uranium mobility in soil and its vertical transport (leaching)

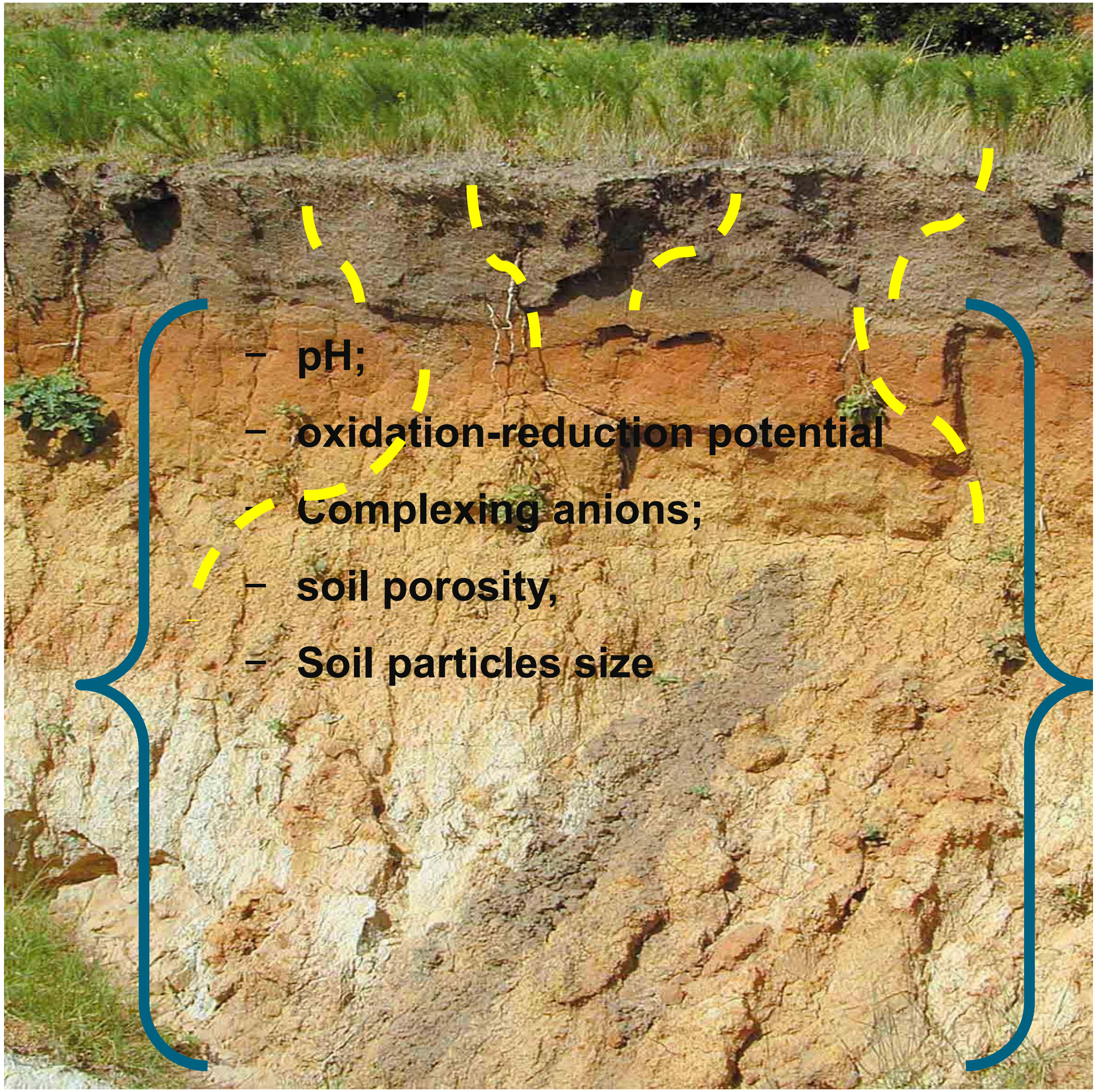


Uranium mobility in soil and its vertical transport (leaching)



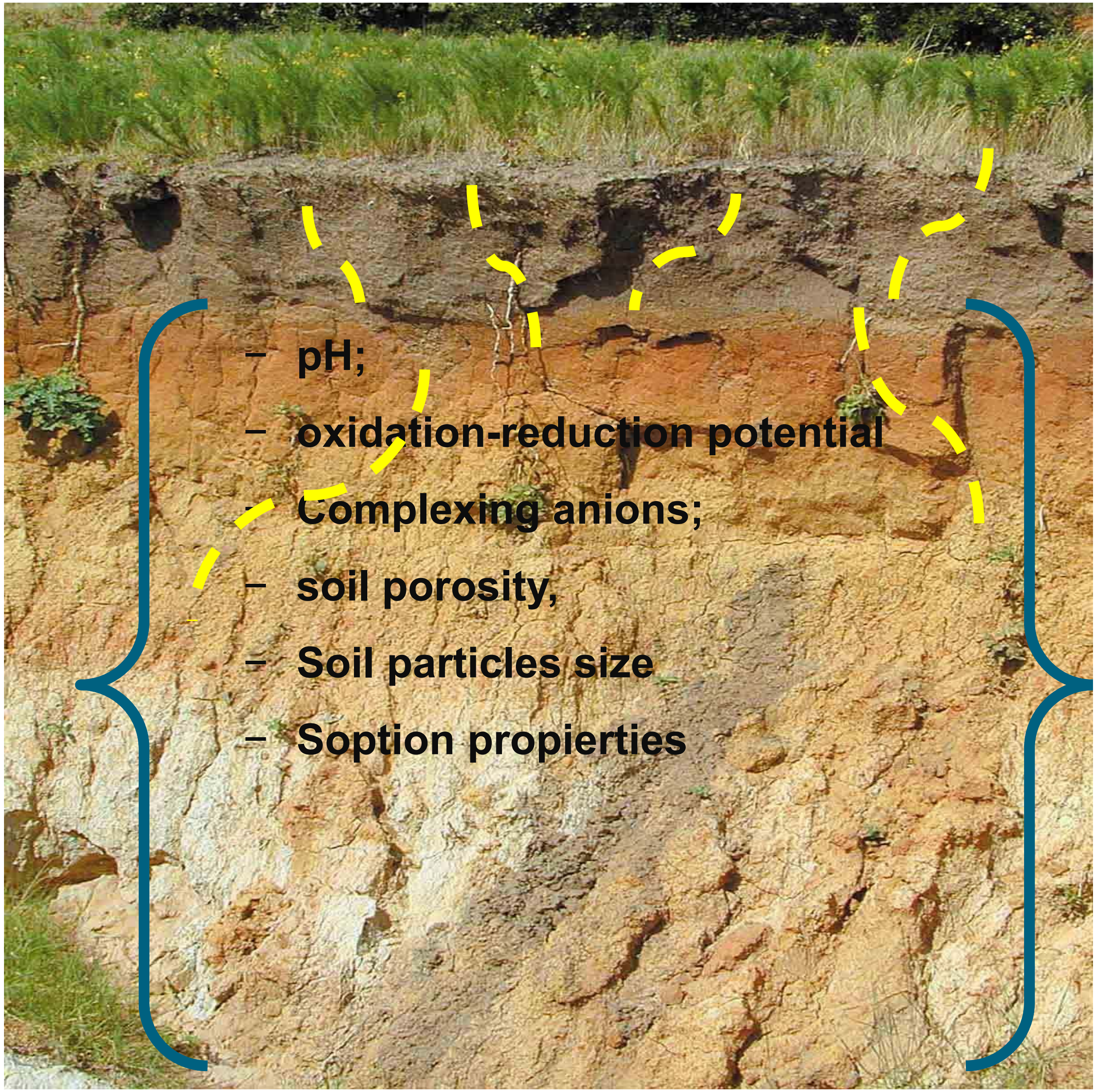
- pH;
- oxidation-reduction potential
- Complexing anions;
- soil porosity,

Uranium mobility in soil and its vertical transport (leaching)



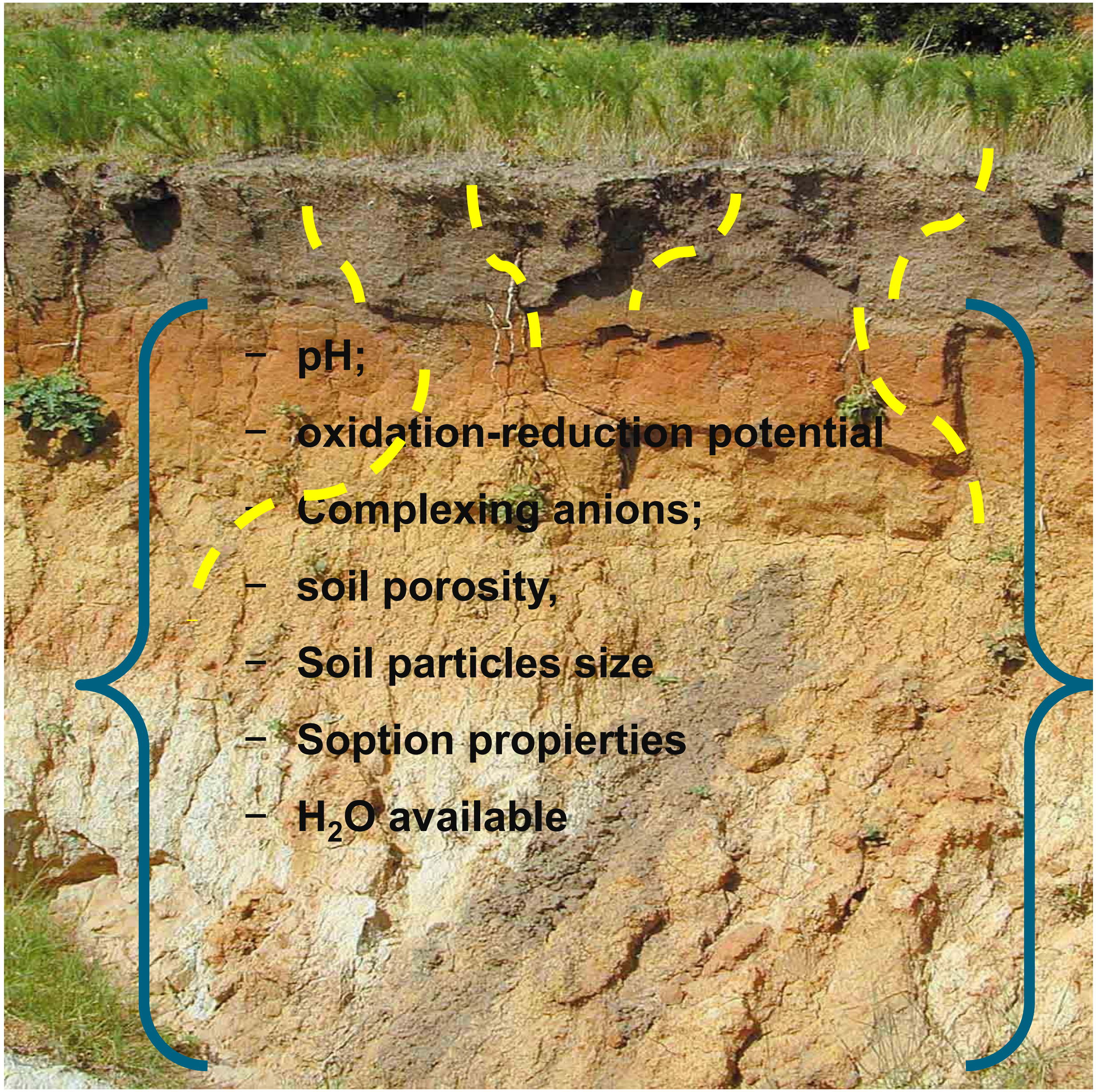
- pH;
- oxidation-reduction potential
- Complexing anions;
- soil porosity,
- Soil particles size

Uranium mobility in soil and its vertical transport (leaching)



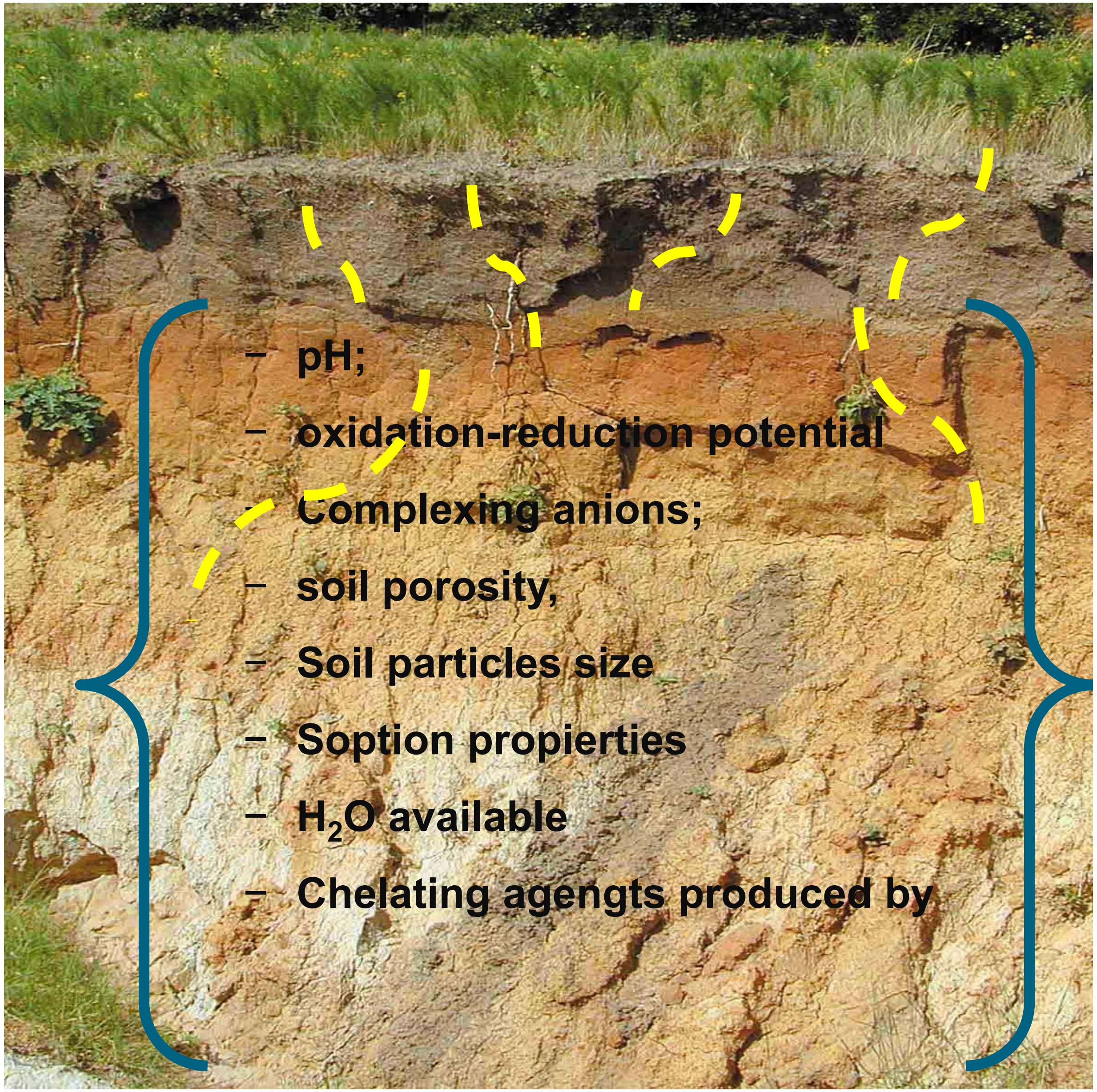
- **pH;**
- **oxidation-reduction potential**
- **Complexing anions;**
- **soil porosity,**
- **Soil particles size**
- **Soption propierties**

Uranium mobility in soil and its vertical transport (leaching)

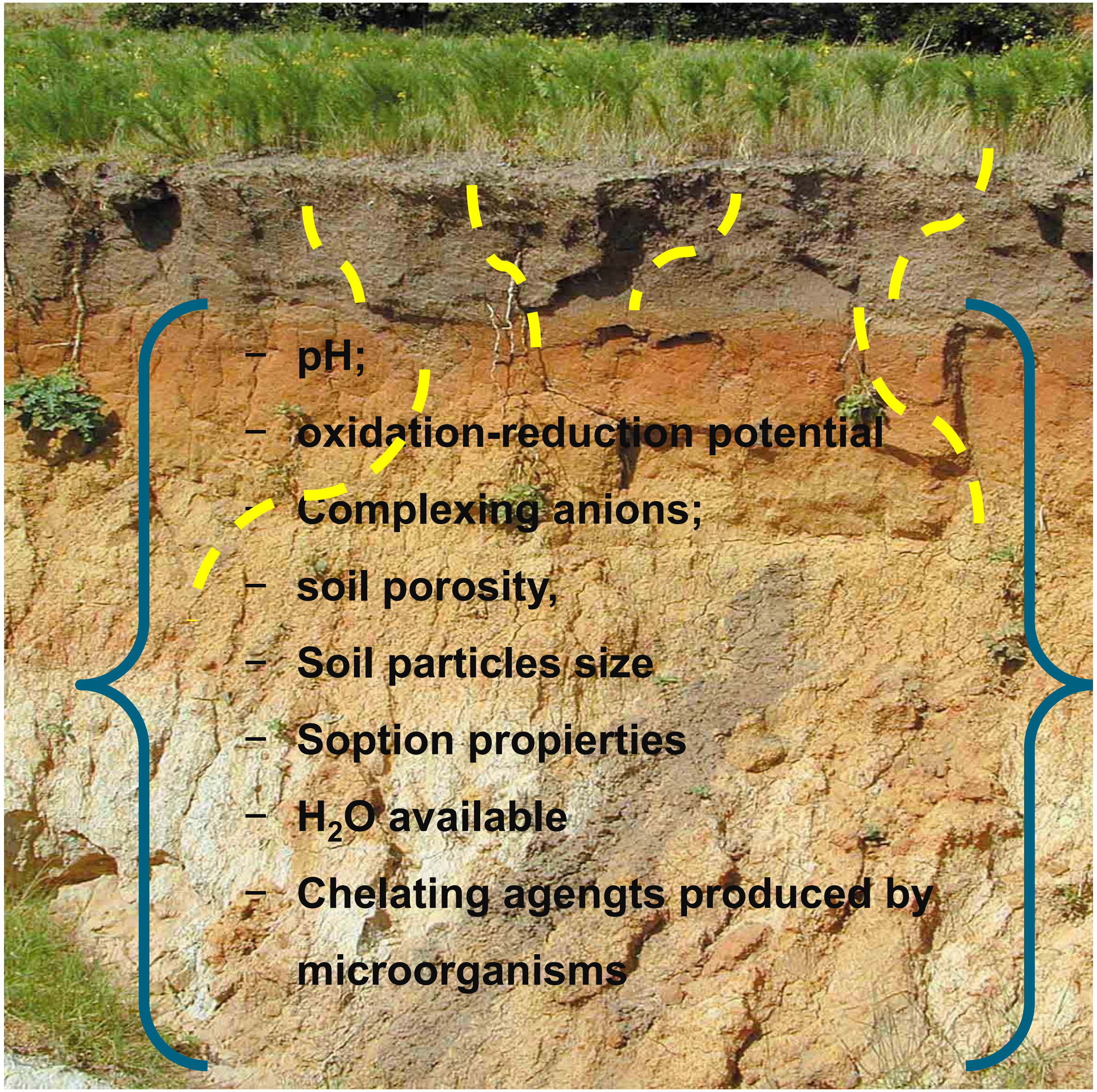


- pH;
- oxidation-reduction potential
- Complexing anions;
- soil porosity,
- Soil particles size
- Soption propierties
- H_2O available

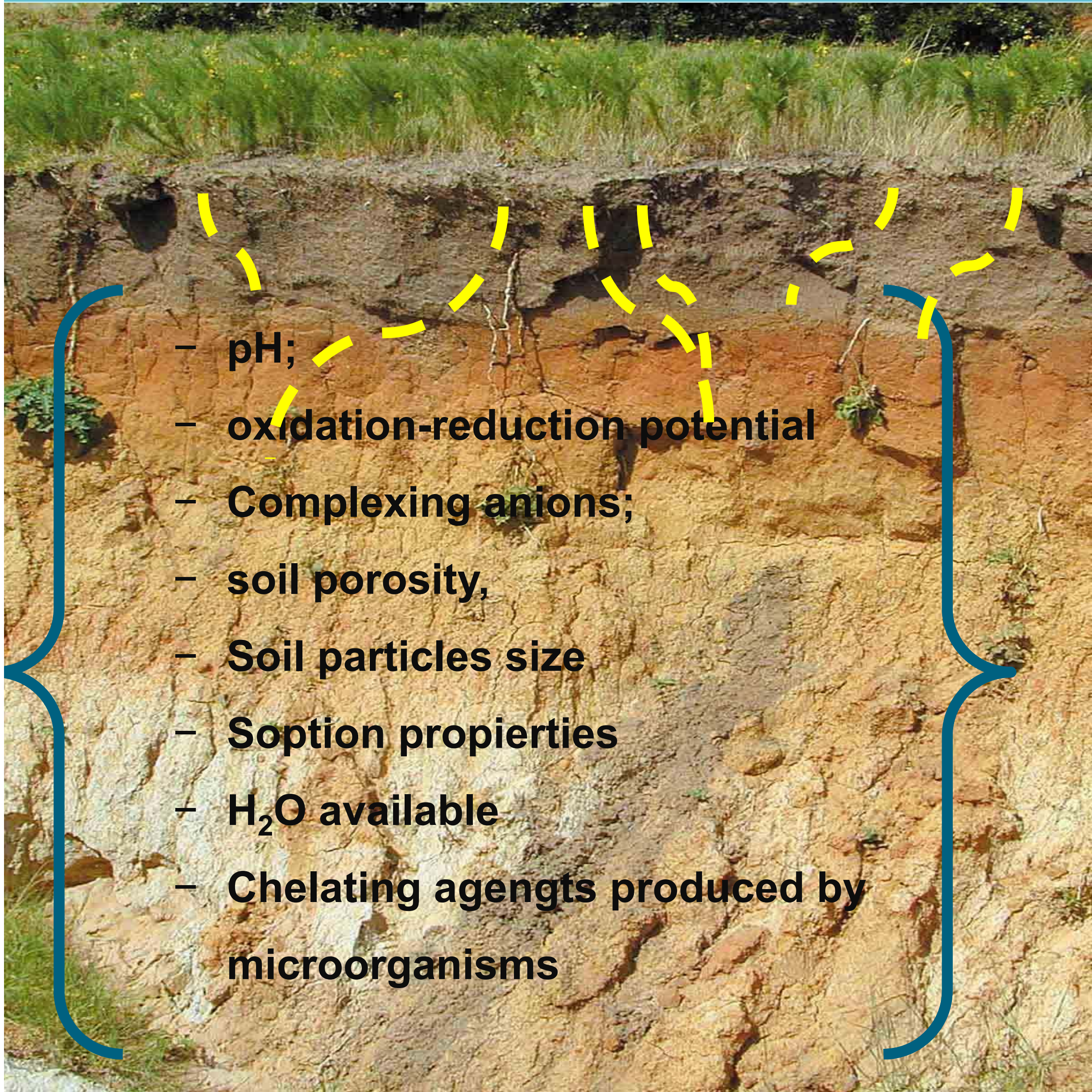
Uranium mobility in soil and its vertical transport (leaching)



Uranium mobility in soil and its vertical transport (leaching)



Uranium mobility in soil and its vertical transport (leaching)



- pH;
- oxidation-reduction potential
- Complexing anions;
- soil porosity,
- Soil particles size
- Soption propierties
- H_2O available
- Chelating agengts produced by microorganisms

What about N, S and P fertilization?

Suelos

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Argentina

Objectives

1. Quantification of the influence of nitrogen, sulfur, and phosphorus fertilization on uranium content in plant material.

2. Characterization of differences in plant growth and uranium uptake between dicotyledonous and monocotyledonous crop species in dependence on the uranium contamination levels of the soil substrate.

Material and methods

Sample site	FAO classification	Soil depth	Carbon content [% C_{org}]
Grassland	Dystric Cambisol/ Orthic Luvisol	Top soil (0-25 cm)	1.9
		Sub soil (25-50 cm)	0.3
Forest	Leptic Podzol	Top soil (0-25 cm)	4.4
		Sub soil (25-50 cm)	3.2

Treatments:

Table 3.3: Characterization of the U, P levels and N, S treatments.

U level in soil[1)]				
Without $CaHPO_4$ supply	**With $CaHPO_4$ supply**			
U_1: 0.34 U_2: 166 U_3: 329 U_4: 660	U_1: $0.2 \cdot 10^{-4}$ U_2: 173 U_3: 385 U_4: 644			

[1] U level in soil: added as U_3O_8
[2] N rate: added as NH_4NO_3
[3] P level in soil: added as $CaHPO_4$
[4] S rate: added as K_2SO_4

Treatments:

Table 3.3: Characterization of the U, P levels and N, S treatments.

U level in soil[1)]		N rate[2)]		
Without $CaHPO_4$ supply	**With $CaHPO_4$ supply**			
[mg kg^{-1}]				
U_1: 0.34	U_1: $0.2 \cdot 10^{-4}$	N_1: 250		
U_2: 166	U_2: 173	N_2: 500		
U_3: 329	U_3: 385	-		
U_4: 660	U_4: 644	-		

[1] U level in soil: added as U_3O_8
[2] N rate: added as NH_4NO_3
[3] P level in soil: added as $CaHPO_4$
[4] S rate: added as K_2SO_4

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Treatments:

Table 3.3: Characterization of the U, P levels and N, S treatments.

U level in soil[1)]		N rate[2)]	P level in soil[3)]	
Without $CaHPO_4$ supply	**With $CaHPO_4$ supply**			
[mg kg^{-1}]				
U_1: 0.34	U_1: $0.2 \cdot 10^{-4}$	N_1: 250	P_1: 334	
U_2: 166	U_2: 173	N_2: 500	P_2: 1,558	
U_3: 329	U_3: 385	-	-	
U_4: 660	U_4: 644	-	-	-

[1] U level in soil: added as U_3O_8
[2] N rate: added as NH_4NO_3
[3] P level in soil: added as $CaHPO_4$
[4] S rate: added as K_2SO_4

Treatments:

Table 3.3: Characterization of the U, P levels and N, S treatments.

U level in soil[1)]		N rate[2)]	P level in soil[3)]	S rate[4)]
Without $CaHPO_4$ supply	**With $CaHPO_4$ supply**			
[mg kg^{-1}]				
U_1: 0.34	U_1: $0.2 \cdot 10^{-4}$	N_1: 250	P_1: 334	S_1: 0
U_2: 166	U_2: 173	N_2: 500	P_2: 1,558	S_2: 50
U_3: 329	U_3: 385	-	-	-
U_4: 660	U_4: 644	-	-	-

[1] U level in soil: added as U_3O_8
[2] N rate: added as NH_4NO_3
[3] P level in soil: added as $CaHPO_4$
[4] S rate: added as K_2SO_4

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Experimental design

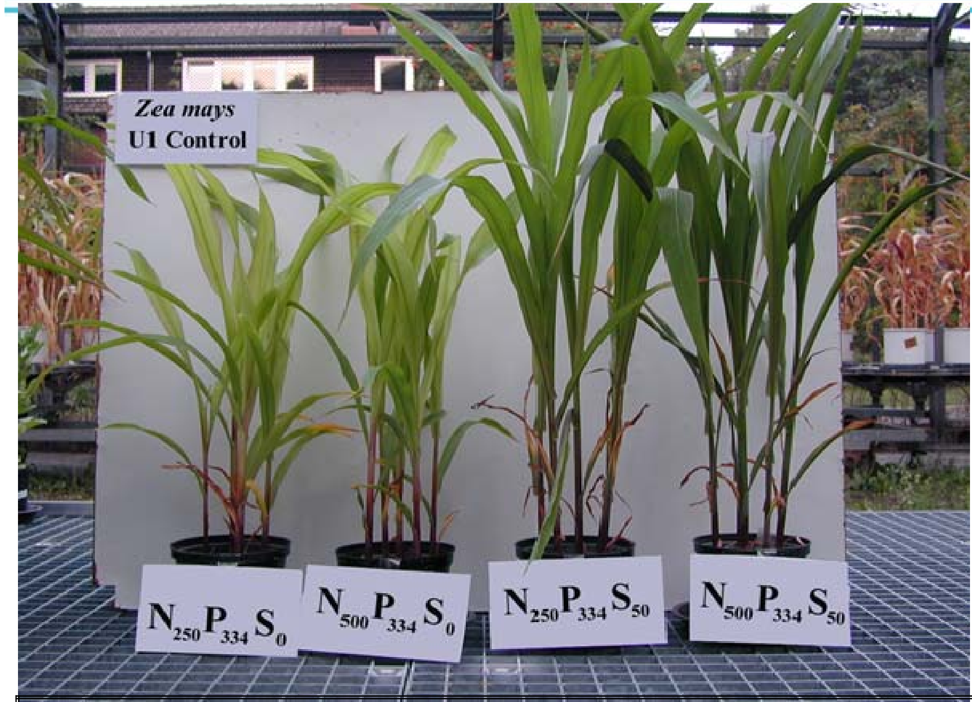
Three agricultural crops with different growth properties were tested:

- Corn, in the following will be referred as maize, (*Zea mays L.*)
- Sunflower (*Helianthus annuus L*.)
- Faba bean (*Vicia faba L*.).

Experiment design.

Each treatment combination was carried out with 3 replications, resulting in a total of 96 pots of maize, 96 pots of sunflowers and 48 pots of faba bean which sums up to a total of 240 pots in the experiment

4.1 Influence of N, P and S rates on biomass production of maize (Zea mays L.)



Biomass [g pot^{-1}]	6.8	6.2	10.6	11.8

N rate [mg kg^{-1}] 1 = 250, 2 = 500
P rate 1 = 334
S rate 1 = 0, 2 = 50

Biomass [g pot^{-1}]	4.9	4.6	13.2	15.3

N rate [mg kg^{-1}] 1 = 250, 2 = 500
P rate 2 = 1,558,
S rate 1 = 0, 2 = 50

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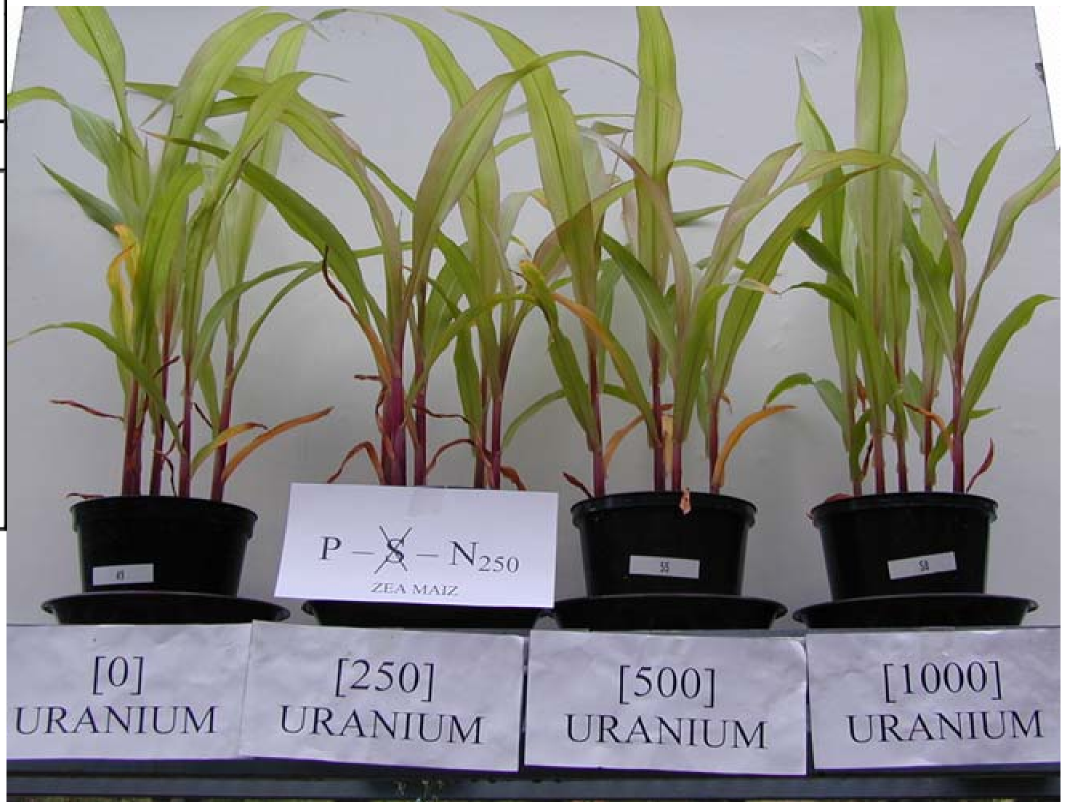
4.1.2 Influence of U contamination levels on biomass of maize

Variable / Factor	Biomass	U concentration	U uptake[1)]
U rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]
1	9.17		
2	7.53		
3	8.33		
4	7.76		
LSD $_{5\%}$	0.90		

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]U rate [mg kg^{-1}]:
1 = 0.34,
2 = 170,
3 = 357,
4 = 652

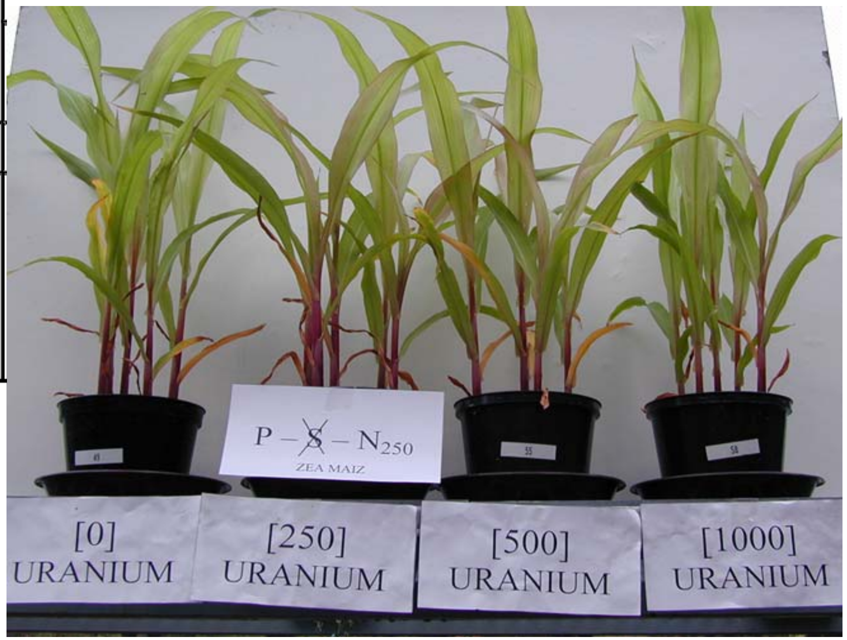


Variable / Factor	Biomass	U concentration	U uptake[1)]
U rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]
1		0.01	
2		1.21	
3		1.66	
4		3.98	
LSD 5%		0.87	

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]U rate [mg kg^{-1}]:
1 = 0.34,
2 = 170,
3 = 357,
4 = 652



4.1.2 Influence of U contamination levels on U uptake of maize

Variable / Factor	Biomass	U concentration	U uptake[1)]
U rate[2)]	[g pot⁻¹]	[mg kg⁻¹]	[µg pot⁻¹]
1			10
2			7.39
3			10.88
4			23.24
LSD $_{5\%}$			4.50

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]U rate [mg kg⁻¹]:
1 = 0.34,
2 = 170,
3 = 357,
4 = 652

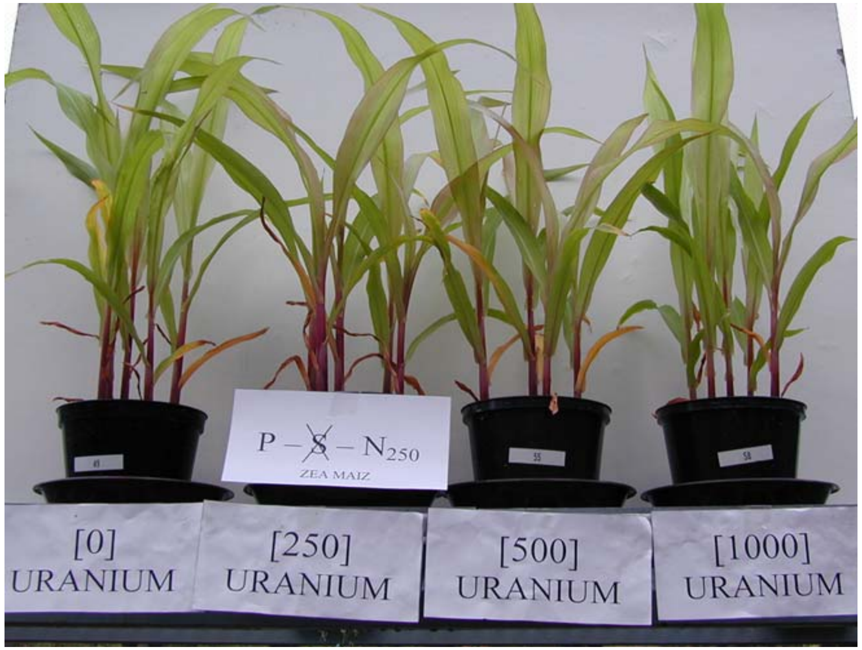
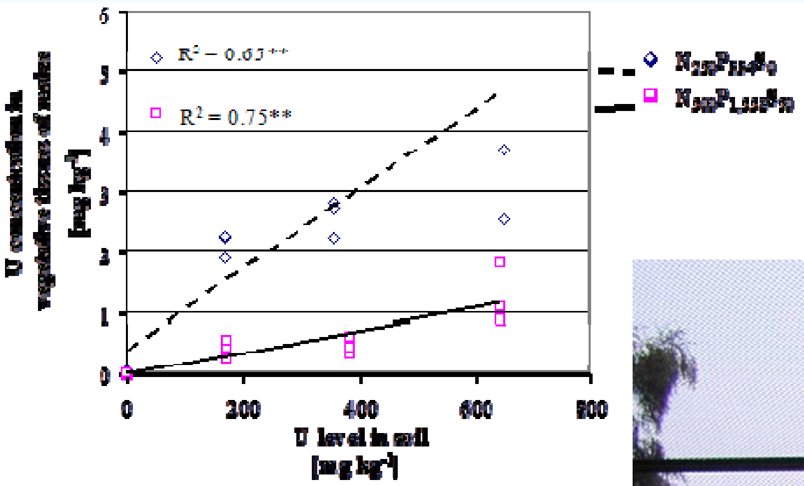


Figure 4.5: Influence of the U rate on the U concentration in vegetative tissue of maize in relation to the P, N and S rates.



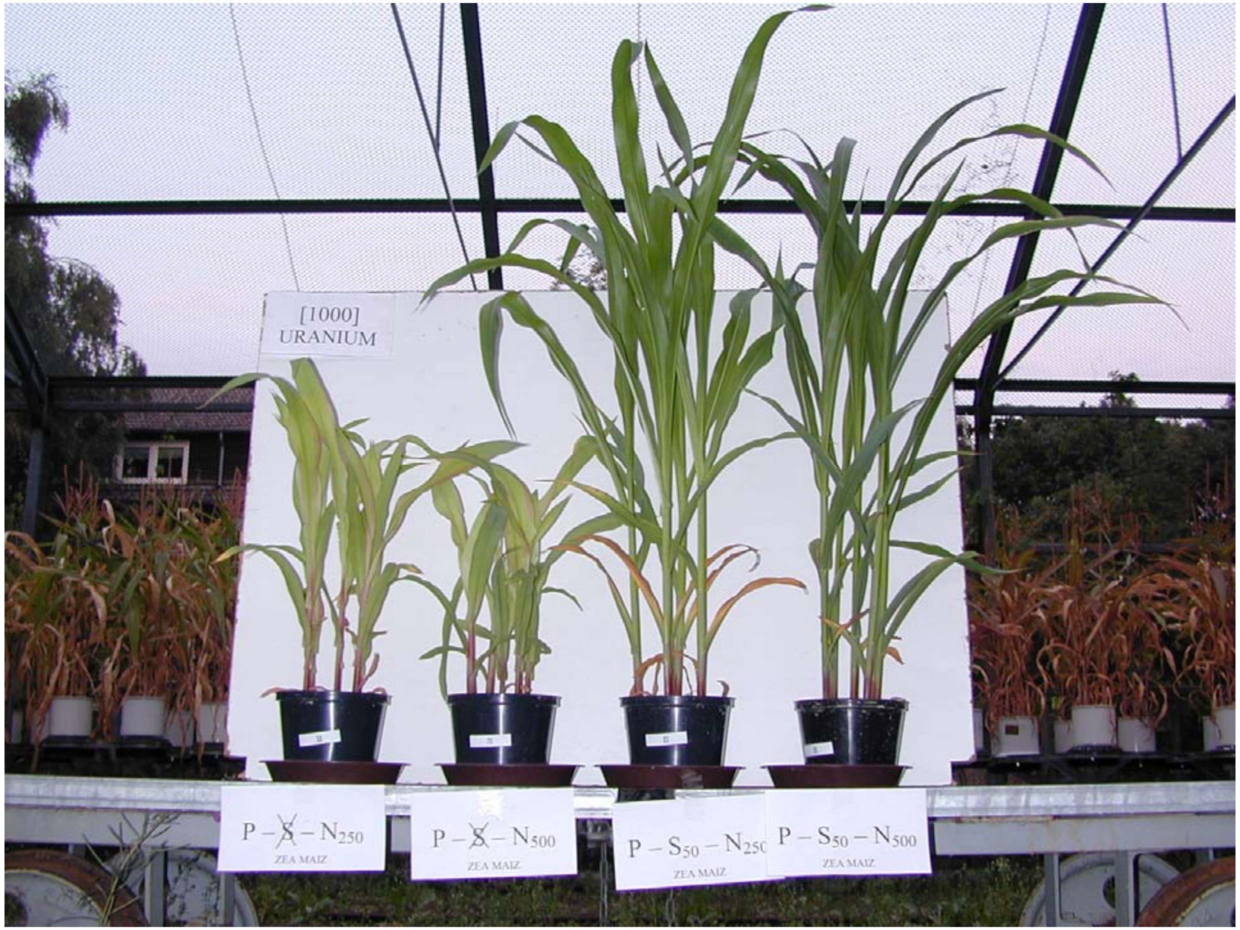


Table 4.4: Influence of the N rate on biomass production, U concentration, U uptake and the concentrations of macro and micronutrients in maize (4 way ANOVA).

Variable / Factor	Biomass	U-concentration	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
N rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]					[mg kg^{-1}]					
1		1.29	8.88		0.25	0.080	0.44		101.3		19.5			
2		2.14	11.92		0.28	0.100	0.58		130.3		23.1			
LSD $_{5\%}$		0.62	3.18		0.01	0.003	0.08		15.9		2.0			

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]N rate [mg kg^{-1}]: 1 = 250, 2 = 500

The higher N rate significantly increased ($p < 0.05$) the concentrations of:

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Table 4.5. Influence of P rate on biomass production, U concentration, U uptake and the concentration of macro and micronutrients in maize (4 way ANOVA).

Variable / Variable / Factor	Biomass	U concentration	U Uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
P rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]					[mg kg^{-1}]					
1				2.68			0.44		108.6					1.5
2				2.93			0.57		123.0					1.8
LSD $_{5\%}$				0.10			0.08		15.9					0.2

[1]U uptake was calculated as follows: $$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

The rate of P significantly increased ($p < 0.05$) the concentrations of N, Ca, Fe and Mo, while..

Table 4.5. Influence of P rate on biomass production, U concentration, U uptake and the concentration of macro and micronutrients in maize (4 way ANOVA).

Variable / Factor	Biomass	U concentration	U Uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
P rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]					[mg kg^{-1}]					
1			13.97							55.9	23.0		8.4	
2			6.84							36.5	19.6		6.7	
LSD $_{5\%}$			3.18							6.2	2.0		1.7	

[1]U uptake was calculated as follows: $U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$

it led to a significant decrease of the Mn, Zn, B-concentrations and the U uptake (Table 4.5).

Table 4.6. Influence of S rate on biomass production, U concentration, U uptake and the concentrations of macro and micronutrients in maize (4 way ANOVA).

Variable / Factor	Biomass	U-concentrations	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
S rate[2)]	[g pot-1]	[mg kg-1]	[µg pot-1]	[%]					[mg kg-1]					
1	62		10.16											1.5
2	11.770		10.65											1.8
LSD 5%	0.64		3.18											0.2

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]S rate [mg kg-1]: 1 = 0, 2 = 50

The rates of S significantly increased ($p < 0.05$) the biomass production and the concentration of Mo, whereas…

Table 4.6. Influence of S rate on biomass production, U concentration, U uptake and the concentrations of macro and micronutrients in maize (4 way ANOVA).

Variable / Factor	Biomass	U-concentrations	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
S rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]					[mg kg^{-1}]					
1	62	2.50		3.59	0.31				130.8	47..4	22.7		8.4	
2	11.770	0.94		2.02	0.23				100.7	45.1	20.0		6.7	
LSD $_{5\%}$	0.64	0.62		0.10	0.01				15.9	6.2	2.0		1.7	

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]S rate [mg kg^{-1}]: 1 = 0, 2 = 50

the concentrations of U, N, P, Fe, Zn and B significantly decreased.

Decreasing values can be explained by a dilution effect caused by the growth promoting influence of N, P and S

Interactions…

Table 4.7: Statistical significance (F test) for the comparison of the influence of U, P, N and S rates on biomass production, U concentration, U uptake and the concentrations of macro and micronutrients in maize.

	Biomass	U concentration	U uptake	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
U rate	**	***	***	**	***				***		*	***		
N rate		**		***	***	***	**		***		***			
P rate			***	***	***	*	**			***	**		*	***
S rate	***	***		***	***	***			***		*			***
U rate*N rate		*							*					
U rate*P rate			*						*					
U rate*S rate		**							*	*				
N rate*P rate					***						*			
N rate*S rate				***	**	***					*			**
S rate*P rate	***			***	**	**					*			***
U rate*N rate*P rate					*				**					
U rate*N rate*S rate														
U rate*S rate*P rate									*					
N rate*S rate*P rate		*		*					**					
U rate*N rate*S rate*P rate														

*, **, *** p <0.05, p <0.01, p <0.001 and, respectively

It can be seen that biomass production was also affected by S rate*P rate interaction, U concentration in plant tissues by U rate*N rate, U rate*S rate, and N rate*S rate*P rate interactions as well as U plant uptake by U rate*P rate interaction (Table 4.7).

Regression analysis

For better understanding of the results, the main effects of increasing U rate, low ($N_1P_1S_1$) and high ($N_2P_2S_2$) nutrition levels were separated for regression analysis.

X = U rate Y = Parameter	Treatment	Regression equation	Coefficient of determination (R^2)	Significance
Biomass	$N_1P_1S_1$	Y = 0021 X + 6.66	0.26	ns
	$N_2P_2S_2$	Y = -0.0026 X + 14.67	0.15	ns
U concentration	$N_1P_1S_1$	Y = 0.0065 X + 0.46		
	$N_2P_2S_2$	Y = 0.0018 X - 0.0023	0.75	**
U uptake	$N_1P_1S_1$	Y = 0.0325 X + 3.75		**
	$N_2P_2S_2$	Y = 0.0259 X - 0.97	0.72	**
N concentration	$N_1P_1S_1$	Y = 0.0002 X + 2.34	0.17	ns
	$N_2P_2S_2$	Y = 0.0003 X + 2.30	0.07	ns
P concentration	$N_1P_1S_1$	Y = $5 \cdot 10^{-05}$ X + 0.18	0.48	*
	$N_2P_2S_2$	Y = $3 \cdot 10^{-05}$ X + 0.35	0.03	ns
S concentration	$N_1P_1S_1$	Y = $-1 \cdot 10^{-05}$ X + 0.05	0.73	**
	$N_2P_2S_2$	Y = $-3 \cdot 10^{-06}$ X + 0.14	0.00	ns
Fe-concentration	$N_1P_1S_1$	Y = -0.0270 X + 123.6	0.02	ns
	$N_2P_2S_2$	Y = -0.0835 X + 129.91	0.60	*

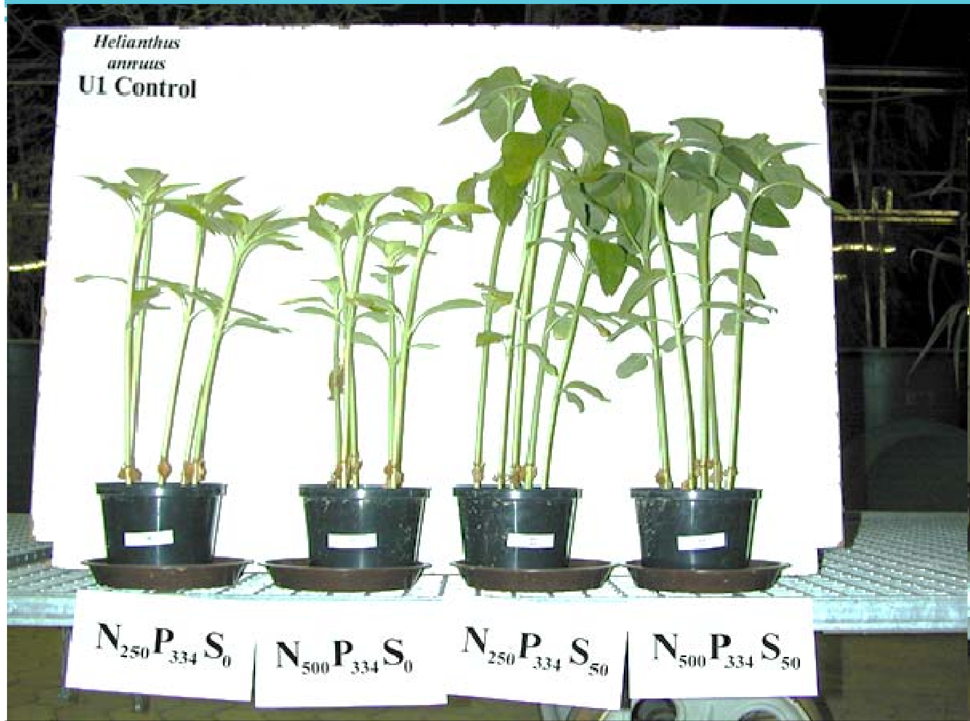
$N_1P_1S_1$-treatment [mg kg^{-1}]: N_1 = 250, P_1 = 334, S_1 = 0
$N_2P_2S_2$-treatment [mg kg^{-1}]. N_2 = 500, P_2 = 1,558, S_2 = 50
*, **, *** and ns: significant at $p < 0.05$, $p < 0.01$, $p < 0.001$ and not significant, respectively

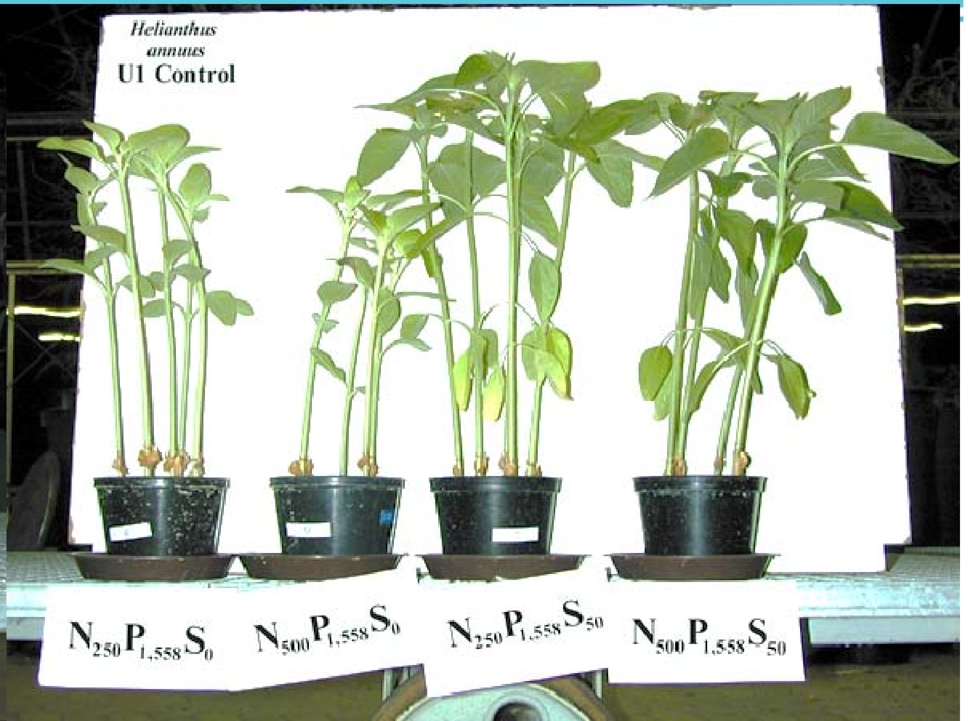
Despite the result from the Table 4.3, which shows that biomass decrease significantly by the U rate (comparison of the mean values), the regression coefficients show (Table 4.8) that the percentage of variance of biomass could not be explained by the U rate for the extreme situation of nutritional level.

The Figure 4.6 shows that not visible relationship exists among the U rate and the biomass.

Figure 4.6: Influence of the U rate on biomass of maize in relation to low P, N and S rates (photos D. Gardiman).

4.1.3 Biomass production of sunflower (*Helianthus annuus L.*)





Biomass [g pot^{-1}]	4.2	4.0	7.6	7.0

N rate [mg kg^{-1}] 1 = 250, 2 = 500
P rate 1 = 334, 2 = 1,558,
S rate 1 = 0, 2 = 50

Biomass [g pot^{-1}]	3.3	3.3	8.5	7.5

N rate [mg kg^{-1}] 1 = 250, 2 = 500
P rate 2 = 1,558,
S rate 1 = 0, 2 = 50

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Leaf weight and leaf area index

LEAF WEIGHT								
	U rate[1)]	LW[2)]	N rate[3)]	LW	P rate[4)]	LW	S rate[5)]	LW
	1	0.64 a	1	0.61 a	1	0.62 a	1	0.34 a
	2	0.58 b	2	0.63 a	2	0.62 a	2	0.90 b
	3	0.62 a						
	4	0.64 a						
LSD[6)]$_{5\%}$		0.04		0.03		0.03		0.03

[1]U rate [mg kg^{-1}]: 1 = 0.34, 2 = 170, 3 = 357, 4 = 652
[2]LW [g pot^{-1}]: leaf weight
[3]N rate: 1 = 250, 2 = 500
[4]P rate : 1 = 334, 2 = 1,558
[5]S rate: 1 = 0, 2 = 50
[6]LSD: least significant difference. Mean values followed by different letters in column indicate statistically different mean at $p<0.005$

The Table 4.11 shows that U rate significantly decrease the leaf weight in the 170 mg kg^{-1} U rate compared to the control, whereas that S rate has the distinctly strongest influence on the LW with a mean increase by 264%.

Influence of U, P, N and S rate on leaf area index (LAI) of sunflower (4-way-ANOVA).

LEAF AREA INDEX								
	U rate[1)]	LAI[2)]	N rate[3)]	LAI	P rate[4)]	LAI	S rate[5)]	LAI
	1	202.80 a	1	201.86 a	1	193.18 a	1	120.92 a
	2	199.56 a	2	210.12 a	2	218.80 b	2	291.06 b
	3	203.62 a						
	4	217.99 b						
LSD[6)] $_{5\%}$		11.89		8.41		8.41		8.41

[1]U rate [mg kg^{-1}]: 1 = 0.34, 2 = 170, 3 = 357, 4 = 652
[2]LAI [cm^2 pot^{-1}]: leaf area index
[3]N rate: 1 = 250, 2 = 500
[4]P rate : 1 = 334, 2 = 1,558
[5]S rate: 1 = 0, 2 = 50
[6]LSD: least significant difference. Mean values followed by different letters in column indicate statistically different mean at p<0.005

The leaf area index was significantly higher in the 652 mg kg^{-1} U rate compared that of control and the lower U rates. Besides S rate, which had also the strongest influence of 240% on LAI; the P rate had an important significantly increment of 113% on the mentioned parameter.

Interactions…

Table 4.13: Statistical significance (F test) for the comparison of the influence of U, P, N and S rates on leaf weight and leaf area index of sunflower.

	Leaf weight	**Leaf area index**
U rate	**	**
P rate	ns	***
S rate	***	***
N rate	ns	ns
U rate * N rate	ns	ns
U rate * P rate	*	ns
U rate * S rate	ns	ns
P rate * S rate	***	***
P rate * N rate	*	***
S rate * N rate	***	***
U rate * P rate * N rate	ns	ns
U rate * P rate * S rate	**	*
U rate * S rate * N rate	ns	ns
P rate * S rate * N rate	ns	*
U rate * P rate * S rate * N rate	ns	ns
*, **, *** and ns: significant at p <0.05, p <0.01, p <0.001 and not significant, respectively		

The Table 4.13 shows that despite <u>P-and N rate, individually, had not influenced on LW,</u> interactions in a 2 ways levels have been observed. It can be seen that LAI parameter was affected by several interactions as well

At the extreme nutritional levels

Table 4.14: Regression coefficients for the relationships between U rate and leaf weight and leaf area index in relation to the nutrient content of sunflower.

X = U-rate Y = Parameter	Treatment	Regression equation	Coefficient of determination (R^2)	Significance
Leaf weight	$N_1P_1S_1$[1)]	Y = 0.0001 X + 0.38	0.30	ns[3)]
	$N_2P_2S_2$[2)]	Y = 0.0002 X + 1.07	0.13	ns
Leaf area index	$N_1P_1S_1$	Y = 0.0271 X + 134.07	0.15	ns
	$N_2P_2S_2$	Y = 0.0158 X + 353.52	0.01	ns

[1]$N_1P_1S_1$-treatment [mg kg^{-1}]: N_1 = 250, P_1 = 334, S_1 = 0

[2]$N_2P_2S_2$-treatment [mg kg^{-1}]: N_2 = 500, P_2 = 1,558, S_2 = 50

[3]ns: not significant difference

However, at the extremes of deficient ($N_1P_1S_1$) and sufficient ($N_2P_2S_2$) nutritional level no relationships between U rate and LW, and U rate and LAI were found.

Influence of the U rate on biomass production in sunflower

Table 4.15: Influence of the U rate, U concentration in sunflower (4 way ANOVA).

Variable / Factor	Biomass	U concentration	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
U rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]					[mg kg^{-1}]					
1	5.7													
2	4.5													
3	4.7													
4	4.5													
LSD[4)] $_{5\%}$	0.4													

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]U rate [mg kg^{-1}]: 1 = 0.34, 2 = 170, 3 = 357, 4 = 652

[3]<LLD: lower limit of detection (15 ng L^{-1})

[4]LSD: least significant difference

The U contamination levels significantly decreased the biomass production in U_2 (170 mg kg^{-1}), U_3 (357 mg kg^{-1}), and U_4 (652 mg kg^{-1}) treatments compared to the control.

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Influence of the U rate

Table 4.15: Influence of the U rate on biomass production, U concentration, U uptake and the concentration of macro and micronutrients in sunflower (4 way ANOVA).

Variable / Factor	Biomass	U concentration	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
U rate[2)]	**[g pot^{-1}]**	**[mg kg^{-1}]**	**[µg pot^{-1}]**	**[%]**					**[mg kg^{-1}]**					
1					0.26									
2					0.27									
3					0.29									
4					0.31									
LSD[4)] $_{5\%}$					0.02									

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]U rate [mg kg^{-1}]: 1 = 0.34, 2 = 170, 3 = 357, 4 = 652

[3]<LLD: lower limit of detection (15 ng L^{-1})

[4]LSD: least significant difference

The P concentration was significantly higher in the U_3 (357 mg kg^{-1}) and U_4 (652 mg kg^{-1}) treatments compared to the control.

Influence of the U rate

Table 4.15: Influence of the U rate on biomass production, U concentration, U uptake and the concentration of macro and micronutrients in sunflower (4 way ANOVA).

Variable / Factor	Biomass	U concentration	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
U rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]					[mg kg^{-1}]					
1				3.1										
2				3.3										
3				3.2										
4				3.5										
LSD[4)] 5%				0.2										

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]U rate [mg kg^{-1}]: 1 = 0.34, 2 = 170, 3 = 357, 4 = 652

[3]<LLD: lower limit of detection (15 ng L^{-1})

[4]LSD: least significant difference

The N concentration was significantly higher in the U_4 (652 mg kg^{-1}) treatment compared with the rest of U rates.

Influence of the U rate

Table 4.15: Influence of the U rate on biomass production, U concentration, U uptake and the concentration of macro and micronutrients in sunflower (4 way ANOVA).

Variable / Factor	Biomass	U concentration	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
U rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]					[mg kg^{-1}]					
1									96.9			7.1		0.7
2									62.5			6.6		0.8
3									84.8			13.9		1.2
4									89.4			8.8		0.9
LSD[4)] $_{5\%}$									12.4			1.5		0.2

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]U rate [mg kg^{-1}]: 1 = 0.34, 2 = 170, 3 = 357, 4 = 652

[3]<LLD: lower limit of detection (15 ng L^{-1})

[4]LSD: least significant difference

Additionally at U_3 (357 mg kg^{-1}) rate the Cu and Mo concentrations increased, while that of Fe decreased in the U_2 (170 mg kg^{-1}) rate

Summarizyng the influence of the U rate

Table 4.15: Influence of the U rate on biomass production, U concentration, U uptake and the concentration of macro and micronutrients in sunflower (4 way ANOVA).

Variable / Factor	Biomass	U concentration	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
U rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]					[mg kg^{-1}]					
1	5.7	<LLD[3)]	<LLD	3.1	0.26	0.16	1.77	0.19	96.9	123.	32. 1	7. 5	24.	0.7
2	4.5	0.9	3.6	3.3	0.27	0.16	1.81	0.20	62.5	109.9	31.6	6.6	26.5	0.8
3	4.7	2.3	9.8	3.2	0.29	0.16	1.79	0.20	84.8	116.2	34.7	13.9	25.1	1.2
4	4.5	4.3	17.3	3.5	0.31	0.17	1.87	0.22	89.4	108.5	28.2	8.8	26.4	0.9
LSD[4)] $_{5\%}$	0.4	0.8	3.9	0.2	0.02	0.02	0.15	0.02	12.4	21.9	4.6	1.5	2.8	0.2

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]U rate [mg kg^{-1}]: 1 = 0.34, 2 = 170, 3 = 357, 4 = 652

[3]<LLD: lower limit of detection (15 ng L^{-1})

[4]LSD: least significant difference

Influence of the N rate

Table 4.16: Influence of the N rate on biomass production, U concentration, U uptake and the concentration of macro and micronutrients in sunflower (4 way ANOVA).

Variable / Factor	Biomass	U concentration	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
N rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]						[mg kg^{-1}]				
1	5.02	1.50	6.01	2.55	0.27	0.15	1.75	0.21	79.5	120.8	31.7	9.5	25.8	0.9
2	4.63	2.29	9.32	4.01	0.29	0.18	1.86	0.20	87.4	108.3	31.7	8.9	25.4	1.0
LSD[3)] 5%	0.30	0.56	2.76	0.11	0.01	0.01	0.11	0.01	8.7	15.5	3.3	1.0	2.0	0.2

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake\ i}}{n}$$

[2]N rate [mg kg^{-1}]: 1 = 250, 2 = 500
[3]LSD: least significant difference

The higher N rate significantly increased the concentrations of U, P, S and U uptake ($p<0.05$). The biomass production significantly decreased, due to the very strong effect of S-deficiency.

Influence of the P rate

Table 4.17: Influence of the P rate on biomass production, U concentration, U uptake and the concentrations of macro and micronutrients in sunflower (4 way ANOVA).

Variable / Factor	Biomass	U concentration	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
P rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]					[mg kg^{-1}]					
1	5.04	2.26	10.13	3.15	0.15	0.16	1.60	0.21	81.2	136.7	34.1	9.0	26.1	0.8
2	4.61	1.53	5.20	3.41	0.42	0.17	2.02	0.20	85.6	92.4	29.2	9.3	25.1	1.0
LSD[3)] 5%	0.30	0.56	2.76	0.11	0.01	0.01	0.11	0.01	8.7	15.5	3.3	1.0	2.0	0.2

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

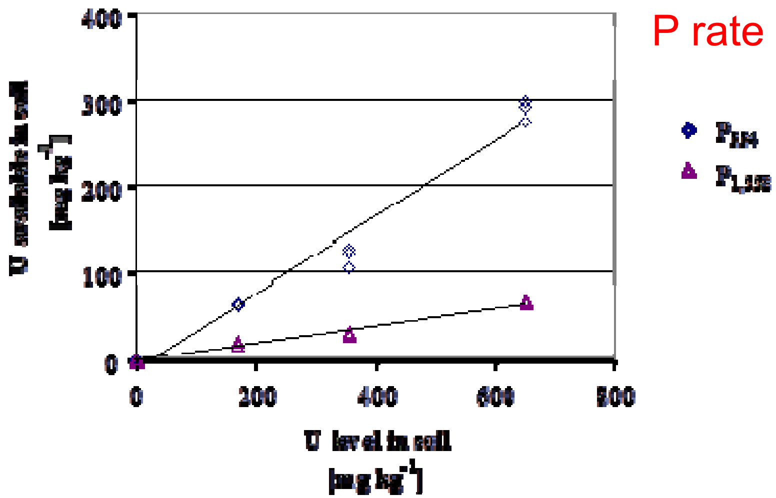
[2]P rate: [mg kg^{-1}]: 1 = 334, 2 = 1,558

[3]LSD: least significant difference

The P rate significantly increased the concentrations of N, S and Ca ($p<0.05$), while it led to a significant decrease of the biomass production, U, Mg, Mn and ZN concentrations and U uptake

P fertilization and the heavy metals availability in soils

In both maize and sunflower crops, it was observed that:



P rate significantly decrease the biomass,

the U concentration, and

the U uptake by the treatment.

P fertilization have been well demonstrated to be effective reducing heavy metals availability in soils.

It is important to recognize that depending on the nature of P compounds and the heavy metal species some of these materials contain high levels of metals and can act as an agent of metal introduction to soils.

Influence of the S rate

Table 4.18: Influence of the S rate on biomass production, U concentration, U uptake and the concentration of macro and micronutrients in sunflower (4 way ANOVA).

Variable / Factore	Biomass	U concentration	U uptake[1)]	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
S rate[2)]	[g pot^{-1}]	[mg kg^{-1}]	[µg pot^{-1}]	[%]					[mg kg^{-1}]					
1	2.93	2.26	5.88	3.86	0.31	0.07	1.95	0.22	81.2	78.4	33.6	9.5	32.1	1.0
2	6.72	1.52	9.45	2.70	0.25	0.25	1.66	0.18	85.7	150.7	29.7	8.9	19.1	0.8
LSD[3)] $_{5\%}$	0.30	0.56	2.76	0.11	0.01	0.01	0.11	0.01	8.7	15.5	3.3	1.0	2.0	0.2

[1]U uptake was calculated as follows:

$$U_{uptake} = \frac{\sum_{i=1}^{n} U_{uptake_i}}{n}$$

[2]S rate [mg kg^{-1}]: 1 = 0, 2 = 50

[3]LSD: least significant difference

The S rate significantly ($p<0.05$) increased the biomass production and U uptake whereas the concentrations of N, P, Ca, Mg, Zn and B significantly decreased.

Decreasing values can be explained by a dilution effect caused by the growth promoting influence of N, P and S.

Interactions…

Table 4.19: Statistical significance (F test) for the comparison of the influence of U, P, N and S rates on biomass production, U concentration, U uptake and the concentration of macro and micronutrients in sunflower.

	Biomass	U concentration	U uptake	N	P	S	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
				Concentrations										
U rate	***	***	***	***	***	ns	ns	*	***	ns	ns	***	ns	***
N rate	**	*	*	***	*	***	*	ns	ns	ns	ns	ns	ns	ns
P rate	**	*	***	***	***	***	***	ns	ns	***	**	ns	ns	*
S rate	***	*	*	***	***	***	***	***	ns	***	*	ns	***	*
U rate *N rate	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
U rate *P rate	ns	ns	*	ns	*	ns	ns	ns	**	ns	ns	ns	ns	ns
U rate *S rate	ns	ns	*	**	ns	ns	ns	ns	**	*	ns	ns	ns	ns
N rate*P rate	*	ns	ns	ns	***	*	ns	ns	**	***	ns	ns	*	ns
N rate*S rate	ns	ns	ns	ns	***	***	***	***	**	ns	***	ns	**	*
S rate*P rate	***	ns	ns	***	ns	***	*	***	ns	**	ns	ns	**	ns
U rate *N rate*P rate	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
U rate *N rate*S rate	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
U rate *S rate*P rate	ns	ns	ns	*	ns	ns	ns	ns	**	ns	ns	ns	ns	ns
N rate*S rate*P rate	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
U rate *N rate*S rate*P rate	ns	ns	ns	ns	ns	Ns	ns	ns	ns	ns	ns	ns	ns	ns

*, **, *** and ns: significant at p <0.05, p <0.01, p <0.001 and not significant, respectively

In the case of sunflower, no so many interactions like in maize were found. For instance, no interactions on U concentrations in plant tissues were observed. Nevertheless, N rate*P rate and S rate*P rate interactions affected the biomass production. In addition, the U plant uptake was influenced by U rate *P rate and U rate *S rate interactions as well (Table 4.19).

Comparison of growth and uranium uptake of dicotyledonous, monocotyledonous and leguminous species

Table 4.28: Comparison of the regression significance for the relationships between U rates and biomass, U concentration in plant tissue and U plant uptake of maize, sunflower and faba bean in relation to the P, N, and S rates.

X = U rate in soil Y = Parameter	Treatment	Maize		Sunflower		Faba bean		
		R^2	Sig.[1)]	R^2	Sig.	Treatment	R^2	Sig.
Biomass [g pot^{-1}]	$N_1P_1S_1$	0.26	ns	0.39	ns	P_1S_1	0.09	ns
	$N_2P_2S_2$	0.15	ns	0.27	ns	P_2S_2	0.03	ns
U concentration [mg kg^{-1}]	$N_1P_1S_1$	0.65	**	0.91	***	P_1S_1	0.84	**
	$N_2P_2S_2$	0.75	**	0.71	**	P_2S_2	0.62	*
U uptake [µg kg^{-1}]	$N_1P_1S_1$	0.65	**	0.84	***	P_1S_1	0.87	**
	$N_2P_2S_2$	0.72	**	0.77	**	P_2S_2	0.56	ns

[1]Sig. Significance
R^2 Coeficient of determination
*, **, *** and ns: [1]significant at p <0.05, p <=0.01, p <0.001 and not significant, respectively

Biomass production

The U rate effects were modified by the effects of N, P, and S rates, which was very well demonstrated by ANOVA methods.

No relationships between U contamination levels and biomass production were shown in all three crops (Table 4.28).

U concentration in the vegetative tissue

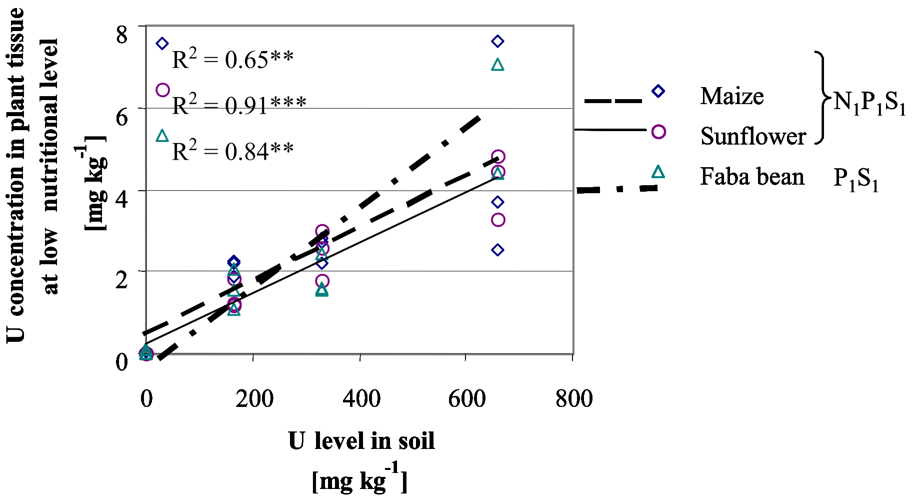


Figure 4.18: Influence of U rate on the U concentration in plant tissue of maize, sunflower and faba bean at low ($N_1P_1S_1$) nutritional level.

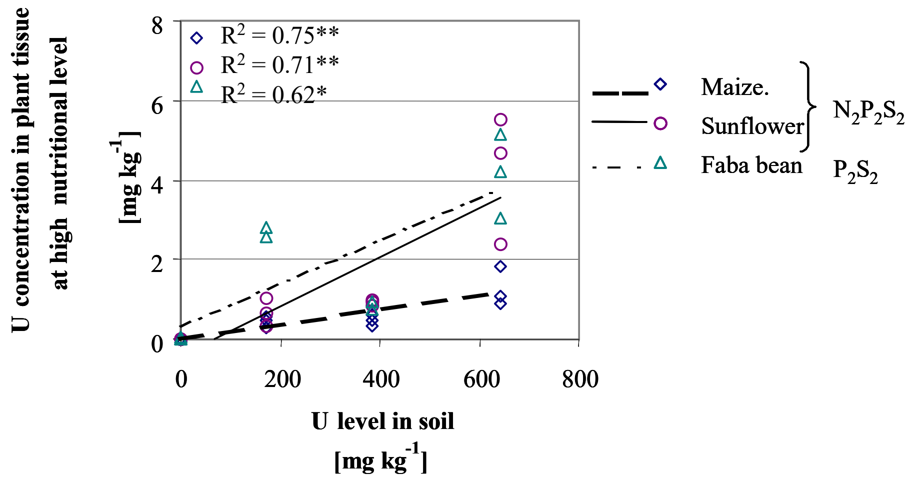


Figure 4.19: Influence of U rate on the U concentration in plant tissue of maize, sunflower, and faba bean at high ($N_2P_2S_2$) nutritional level.

U concentration

The highest values of U concentration in the vegetative tissue at both low ($N_1P_1S_1$) (Figure 4.18) and at higher nutritional level ($N_2P_2S_2$) were showed for faba bean, the (Figure 4.19). The stronger influence of the nutrient supply on the U concentration in vegetative plant tissues was found for maize, which had shown values of U concentration about more than 3 time lower than for faba bean and sunflower.

Influence of U rate on the U plant uptake

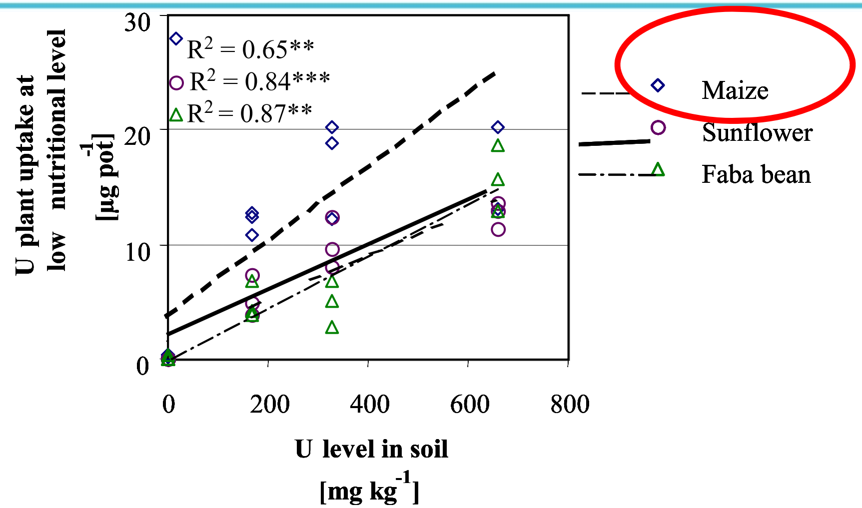


Figure 4.20: Influence of U rate on the U plant uptake by maize, sunflower and faba bean at low nutritional level

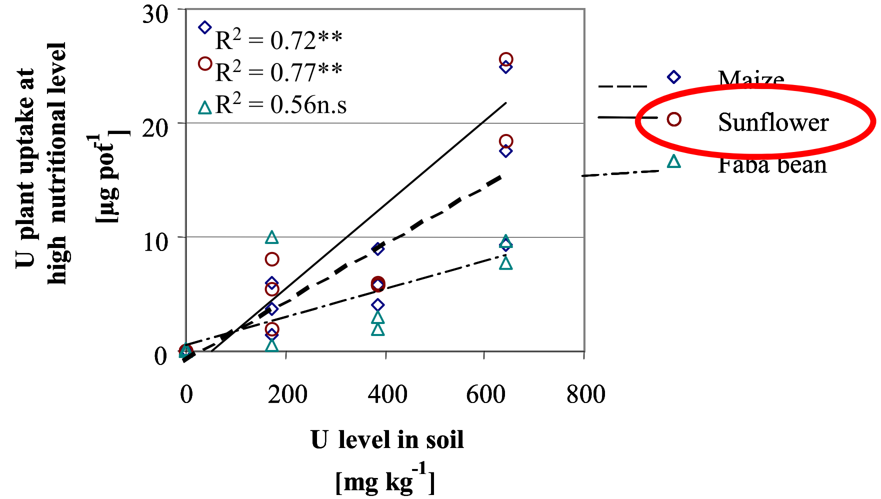


Figure 4.21: Influence of U rate on the U pant uptake by maize, sunflower and faba bean at high ($N_2P_2S_2$) nutritional level.

The U uptake was calculated as a product between U concentration in plant tissues and biomass. A sufficient nutrient supply (N, P and S) is expecting a higher biomass production since more nutrients available lead to a high uptake. For the parameter U uptake, the maize crop showed a near 2 times higher increase in U uptake than faba bean and sunflower at the lower nutrient level (Figure 4.20). In contrast at the high nutrient level the U plant uptake was most strongly increased in case of sunflower and about 3 times higher than for faba bean (Figure 4.21).

Concentration factor:

The concentration factor (CF) describes the amount of one element expected to enter a plant from its substrate, under equilibrium conditions (Sheppard and Sheppard, 1985).

Assessment models normally make use of a plant/substrate concentration factor, referred as a concentration factor (CF) to estimate the transport of radionuclides and other elements of interest through the food chain as well as in biochemical explorations for uranium (Mortverdt, 1994).

$$CFi \frac{Cpr}{Csr}$$

Where:

CFi: is the concentration factor for the transport of the stable isotopes from the soil (s) in vegetal products (p) [μg g-1 DM / μg g-1 DM]

Cpr: concentration ratio of the stable isotope in the plant [μg g-1 DM]

Csr: concentration of the plant available stable isotope in the soil [μg g-1]

Table 4.30: Concentration factors of maize, sunflower and faba bean in relationship with the mineral nutrients P, N and S

Treatments				U plant available in soil ↑			U concentration in plant tissues			Concentration factor: $CFi\frac{Cpr}{Csr}$ ↓		
				Maize	Sunflower	Faba bean	Maize	Sunflower	Faba bean	Maize	Sunflower	Faba bean
P_1	N_1	S_1	U_2	64.32	57.37	54.1	2.12	1.4	1.55	0.0330	0.0244	0.0287
			U_3	118.16	122.88	114.19	2.57	2.5	1.9	0.0218	0.0200	0.0164
			U_4	288.39*	288.39*	288.39*	4.62	4.2	6.6	0.0160	0.0145	0.0229
		S_2	U_2	55.99	59.90	52.46	0.58	0.7	1.05	0.0103	0.0112	0.0199
			U_3	124.49	117.67	124.75	1.01	1.7	1.9	0.0081	0.0148	0.0154
			U_4	288.39*	288.39*	288.39*	2.65	3.1	4.5	0.0092	0.0107	0.0157
	N_2	S_1	U_2	63.68	60.13		2.33	1.2		0.0366	0.0199	
			U_3	110.69	108.57		2.65	4.25		0.0239	0.0391	
			U_4	288.39*	288.39*		5.78	6.4		0.0201	0.0223	
		S_2	U_2	60.00	60.10		0.95	0.8		0.0159	0.0134	
			U_3	127.11	113.66		1.48	4.65		0.0117	0.0409	
			U_4	288.39*	288.39*		4.03	5.3		0.0140	0.0183	
P_2	N_1	S_1	U_2	15.89	14.77	14.14	0.97	1.3	1.98	0.0610	0.0861	0.1396
			U_3	48.38	56.23	25.99	1.23	1.9	1.9	0.0254	0.0336	0.0768
			U_4	84.87	63.66	60.16	2.70	4.9	5.9	0.0319	0.0769	0.0992
		S_2	U_2	17.47	13.44	13.14	0.66	0.33	2.7	0.0379	0.0242	0.2049
			U_3	32.46	31.34	33.25	0.42	0.4	0.7	0.0129	0.0121	0.0258
			U_4	70.67	62.63	75.16	1.04	1.7	4.13	0.0147	0.0265	0.0549
	N_2	S_1	U_2	16.79	20.18		1.67	1.14		0.0995	0.0563	
			U_3	33.14	33.53		3.42	2.15		0.1032	0.0642	
			U_4	62.83	64.69		9.77	4.9		0.1556	0.0760	
		S_2	U_2	18.81	14.48		0.43	0.7		0.0228	0.0462	
			U_3	30.41	29.31		0.47	0.9		0.0155	0.0317	
			U_4	67.76	65.87		1.26	4.2		0.0186	0.0636	

(*) U available of a composite sample. Calculated in vegetative tissues. Not include roots.

It can be seen that sulfur fertilization increase the uranium plant uptake but sulfur rate is correlated with more vigorous growth, which dilute the uranium concentration in plant tissue, thereby small CF were observed.

P rate in soil influenced on U plant availability in soil this could be explain because of the precipitation of insoluble uranyl phosphate minerals. On the other hand, N ratios had not influenced significantly on the CF.

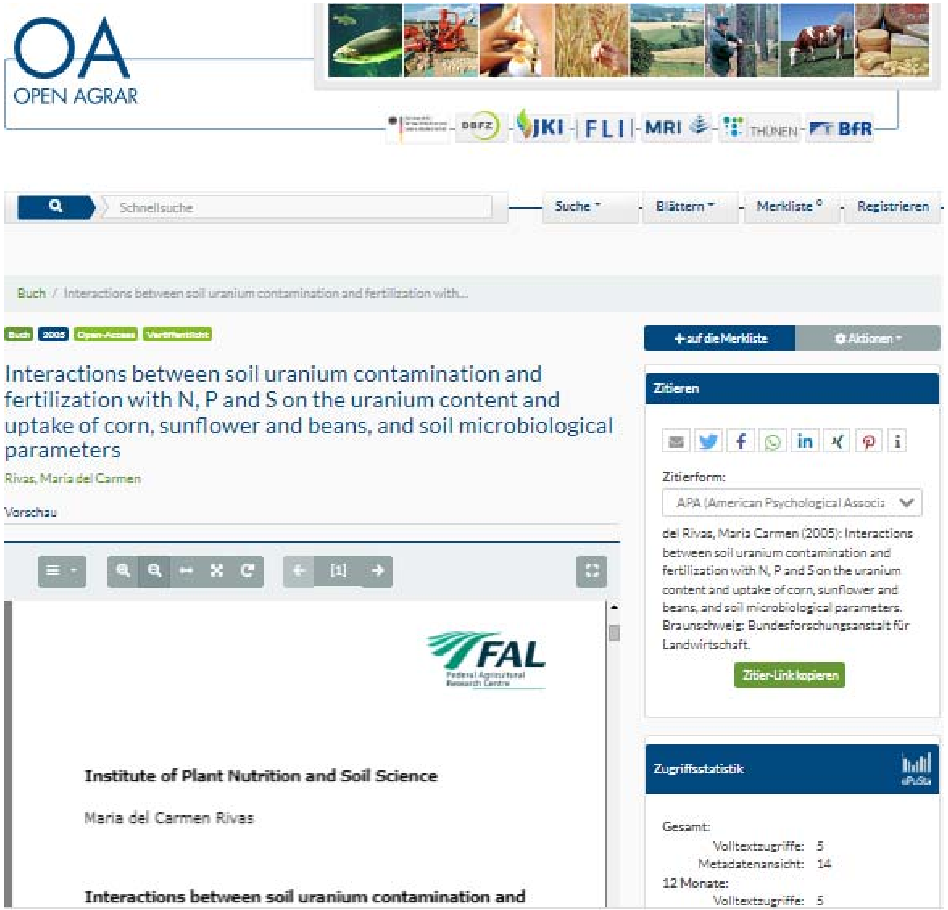
The CF values decreased as the corresponding soil concentration increased

Objectives

1. Quantification of the influence of nitrogen, sulfur, and phosphorus fertilization on uranium content in plant material.

2. Characterization of differences in plant growth and uranium uptake between dicotyledonous and monocotyledonous crop species in dependence on the uranium contamination levels of the soil substrate.

https://www.openagrar.de/receive/timport_mods_00005823



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Ministerio de Agricultura, Ganadería y Pesca Argentina

中国科学院沈阳应用生态研究所
Institute of Applied Ecology.Chinese Academy of Sciences

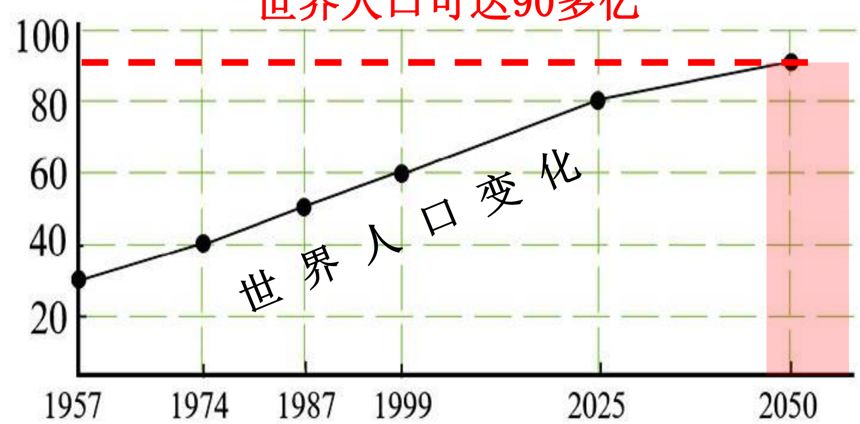
2022 CCFEA Forum

Current Challenges in Fertilizers: from Education to Application

稳定性肥料发展现状与研究进展

石元亮 研究员
中国科学院沈阳应用生态研究所

稳定性肥料发展现状



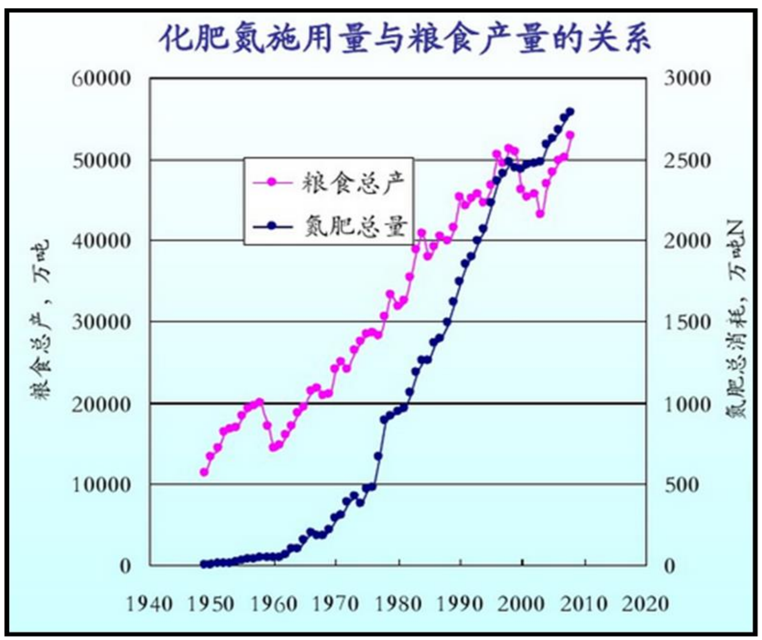
粮食短缺

解决 途径

主要手段

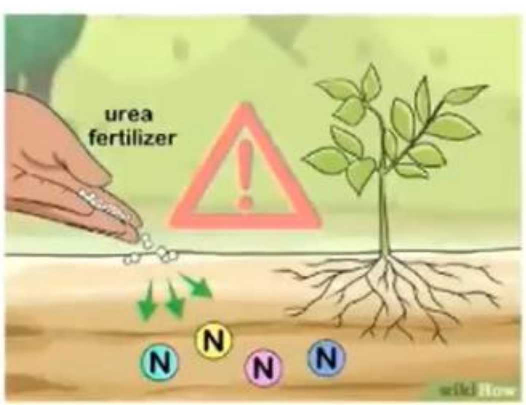
提高作物产量

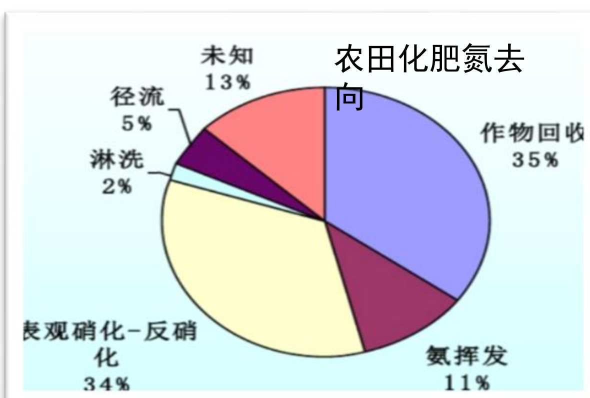
施用化学肥料



氮肥低效利用率引起的氮外溢是造成农业源氮污染的主要途径

- ◆农业源贡献70%氧化亚氮排放；提升氮肥效率、降低用量是最有潜力的氧化亚氮排放控制措施（Tian et al., 2022）。
- ◆德国从2020年2月1日开始禁用常规尿素，规定必须添加氮肥增效剂施用；
- ◆英国政府也在考虑禁止使用固体尿素肥料或限制固体尿素肥料的使用期，来减少NH_3的排放；
- ◆由于肥料品质和使用问题造成了环境污染。我国必须提高氮肥的利用率，进而减少氮对环境的污染（朱兆良院士）





新型肥料是统筹解决当下粮食、环境、资源、土壤等难题的有效途径

粮食安全需要：降本增效，增加粮食产量，稳产高产；

降低碳排放需要：高利用率，实现投入少、少生产，降低资源损耗；

1吨尿素=1.2吨无烟煤=4.0 吨二氧化碳；

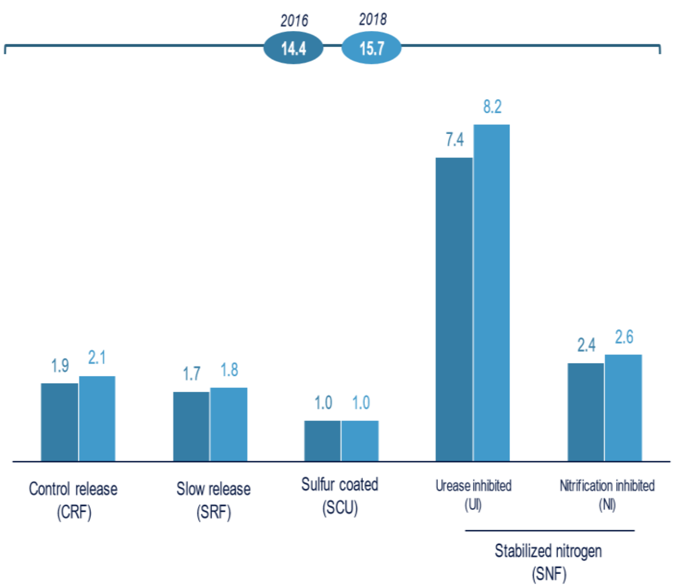
提高肥力需要：提升土壤氮肥力水平，减缓有机质分解；

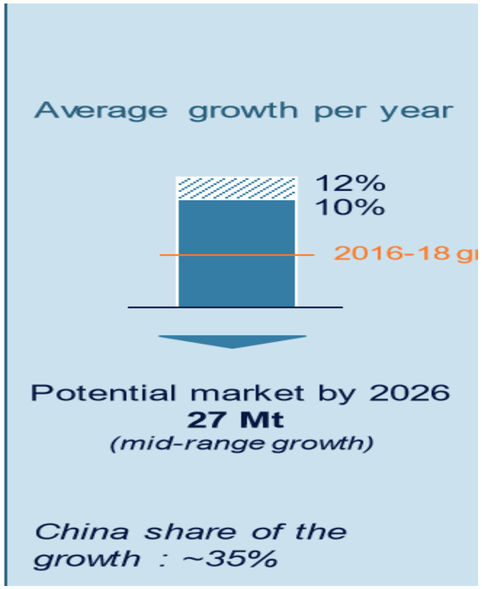
保护环境需要：减少氮向大气、水体外溢（硝酸盐）， 减少温室气体排放，实现生态持续。

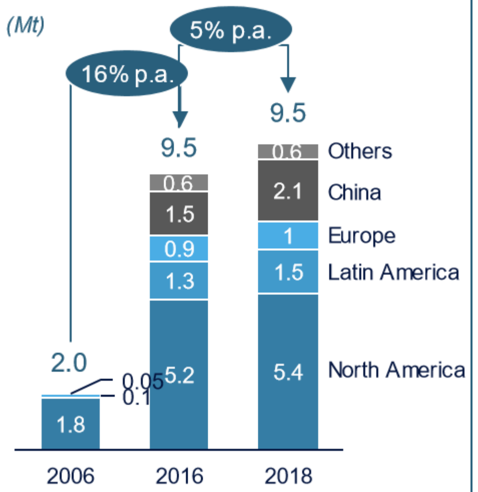
硫包衣尿素　无机包裹肥料　聚合物包膜肥料　稳定性肥料　有机无机复混肥　大颗粒缓释复合肥

稳定性肥料市场空间巨大

IFA预计2026年全球稳定性肥料市场规模将达到2700万吨







Several regulation to push for NUE improvement:

- *RenovaBio* in Brazil
- 2020 regulation in Germany
- Blue Sky clear policy in China
- GHG reduction emissions policies

核心-脲酶抑制剂

硝化抑制剂

稳定性肥料概念及原理

- 稳定性复合肥料
- 稳定性掺混肥料
- 稳定性复合氮肥
- 稳定性尿素
- 稳定性二铵

概念：

指在生产期间被加入了脲酶抑制剂或硝化抑制剂（包括两者同时加入)，调节土壤酶及微生物的活性，减缓尿素的水解和对铵态氮的硝化-反硝化作用，从而达到肥料氮素缓慢释放和减少损失目的的一类肥料。

抑制剂是稳定性肥料的核心物质！

现在已经探索广泛使用的材料

种类	作用对象	技术	原理
脲酶抑制剂	酰胺态氮	醌类、酰胺类、多元酸、多元酚、腐殖酸、甲醛等 NPBT / NPPT / HQ / TU	抑制分解尿素的脲酶活性，减缓尿素分解成为铵态氮的速度。
硝化抑制剂	铵态氮	吡唑、嘧啶、吡啶、噻唑、硫脲和酰胺类化合物等 Nitrapyrin / DCD / DMPP	抑制硝化细菌活性，减缓铵态氮向硝态氮的速度。

每年欧洲消费量为80万吨，北美12万吨，中东和非洲约8万吨，多采用**单一抑制剂技术**

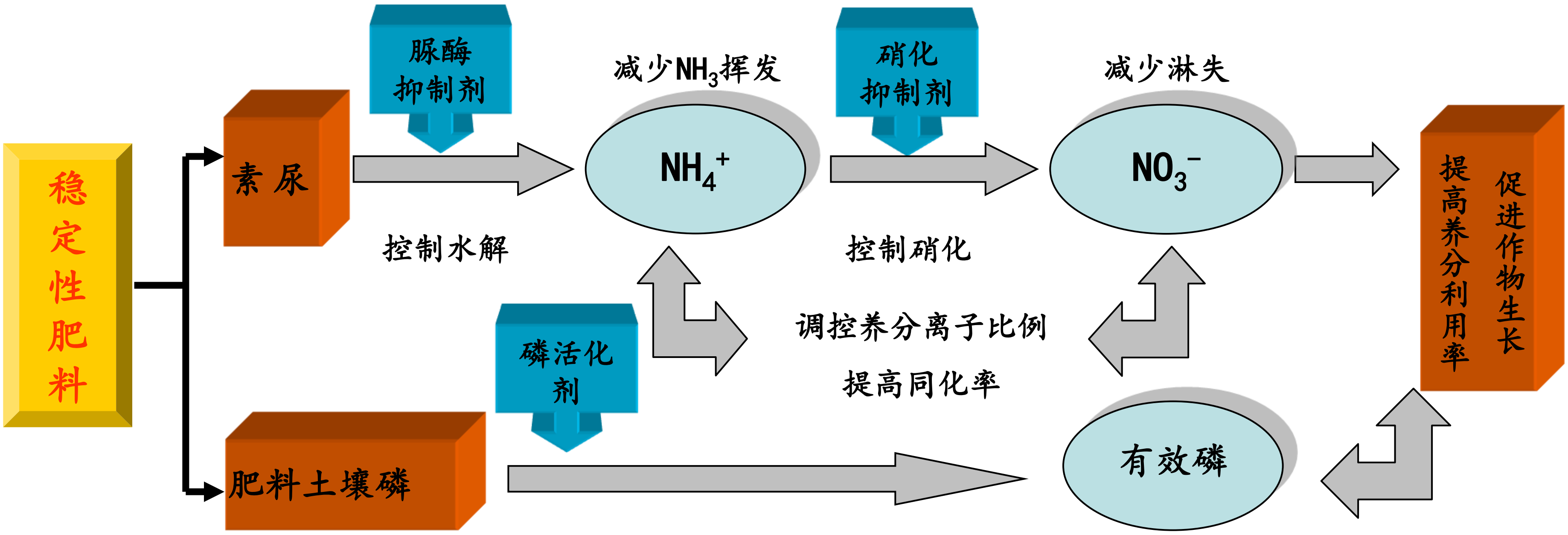
主要生产企业	核心成分
德国康朴	硝化抑制剂Nitrophos（双氰胺DCD） NovaTec（3,4-甲基吡唑磷酸盐 DMPP）
德国巴斯夫	脲酶抑制剂Limus（NBPT 和NPPT ）
比利时的索尔维	硝化抑制剂AgRhoNH4 Protect
美国科迪华	伴能氮肥增效剂 2-氯-6-三氯甲基吡啶
美国Koch Agronomic Services	硝化抑制剂CENTURO 脲酶抑制剂AGROTAIN (N- 丁基硫代磷酰三胺NBPT) 脲酶抑制剂ANVOL（DUROMIDE和NBPT）

国内外技术对比-国际领先

产品 / 性能	本产品	添加N-serve®的缓释肥料	添加Didin®的缓释肥料	添加Agrotain®的缓释肥料	乐喜施
价格（元/吨）	1750-1850	3200-4800	3200-4900	3500-5700	4500-5500
单位面积投入（元/hm^2）	37.5-52.5	158	--	157	120-133
利用率（%）	45-54	40-50	40-55	35-45	42
增产（%）	10.2-19.1	6.7-13.7	9-20	3.8-6.1	5-7.3
肥效期（天）	110-130	80-90	100-110	65-80	120-360
环境效应	N_2O排放减少46-74%，减少流失63%	N_2O排放减少41%，减少氮淋失15-40%	N_2O排放减少45-64%，减少氮淋失13-20%	减少氮淋失5-10%	N_2O排放减少52-56%
结论	国际领先水平	国际先进	国际领先	国际先进	国际先进

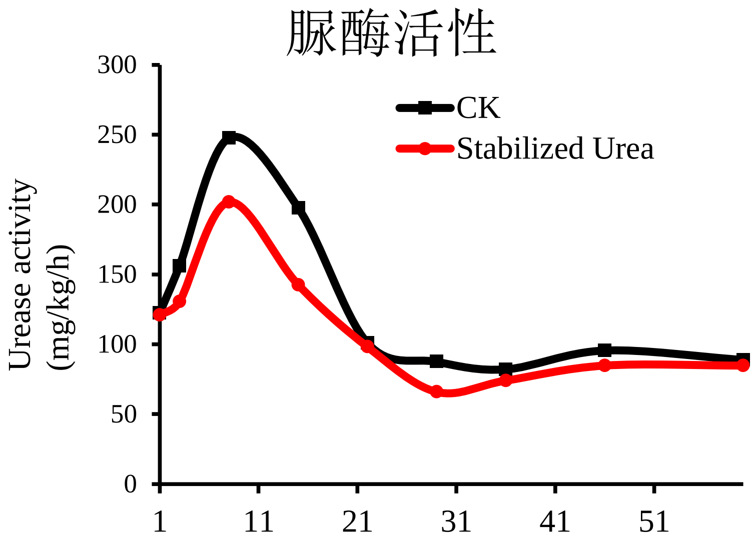
每吨肥料成本增加：本技术 73元/吨， BASF技术 210元/吨

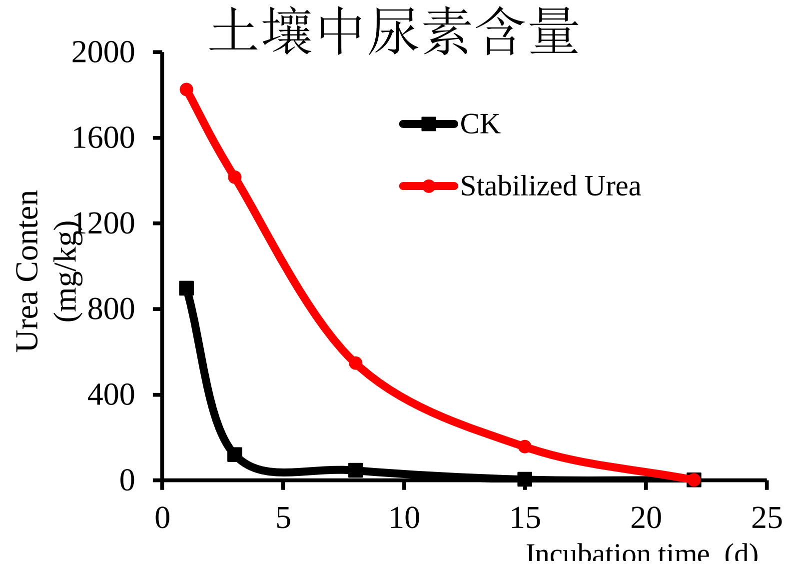
技术原理：核心–脲酶抑制剂+硝化抑制剂 = 双向调控、协同增效



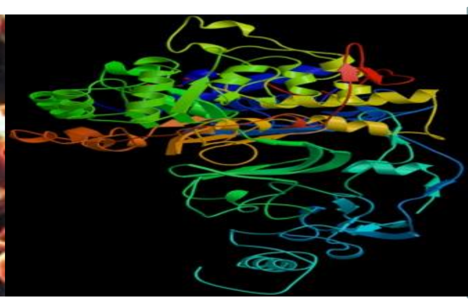
普通氮肥（尿素）利用率仅为30-35%，有效期40-50天左右

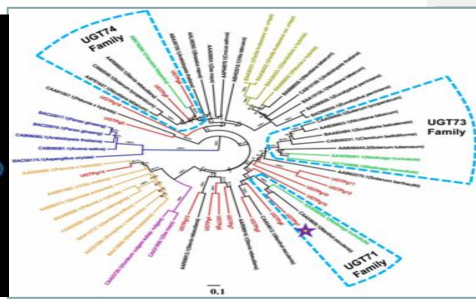
抑制机理-脲酶活性





- **脲酶抑制剂抑制脲酶活性达到 45天**
- **延迟尿素水解7-10天**

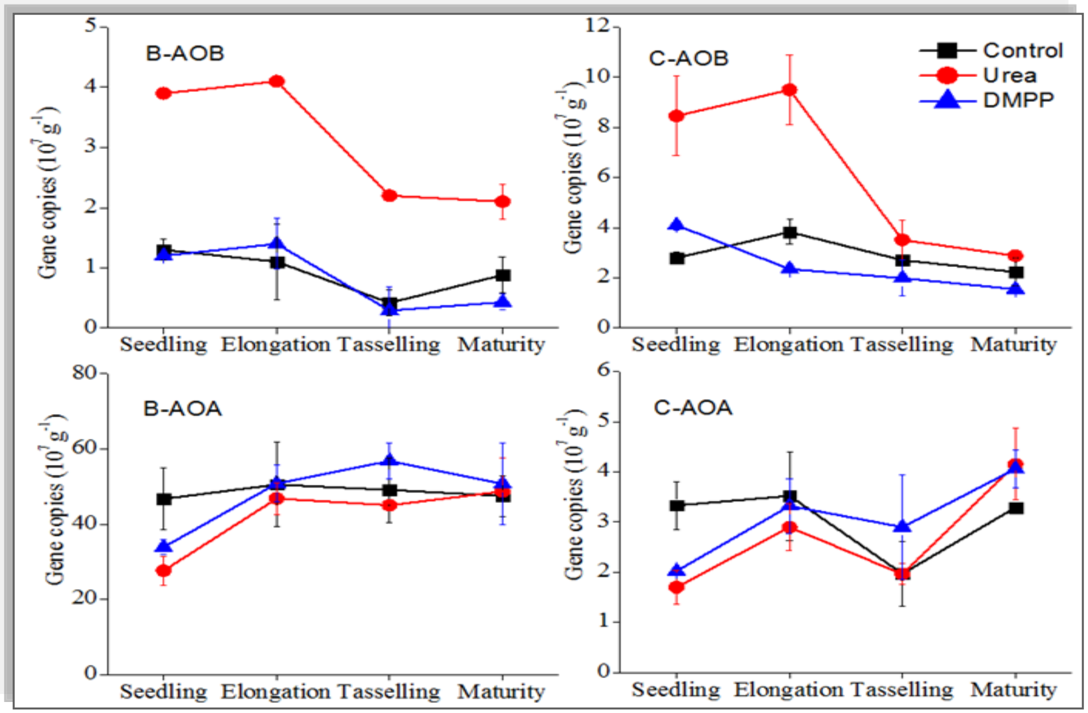




抑制机理-对硝化微生物的抑制

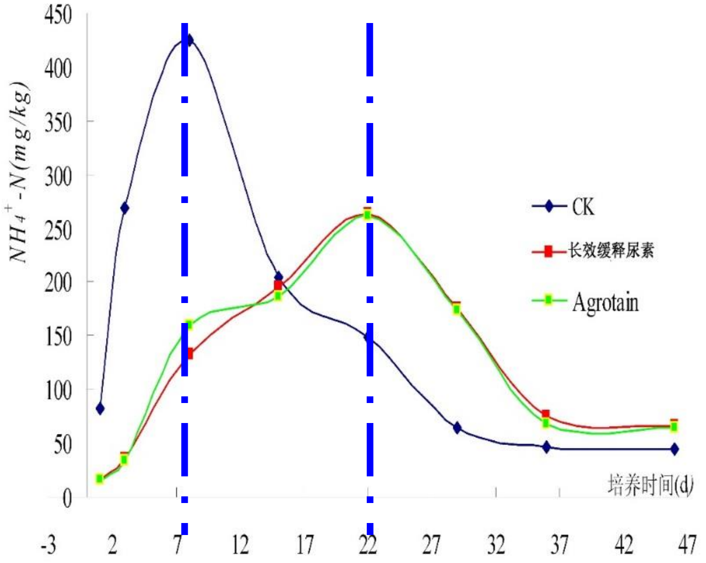
AOB

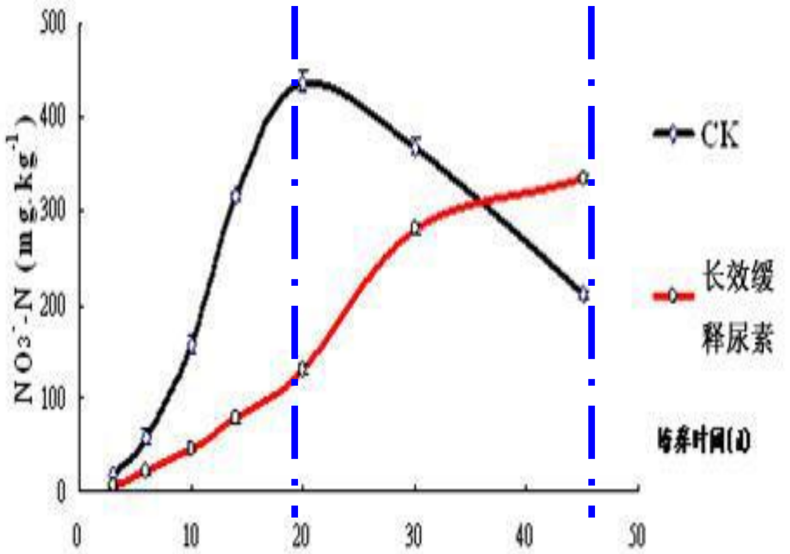
AOA



- DCD and DMPP(3, 4-二甲基吡唑磷酸盐) 抑制 AOB丰度
- AOA 丰度无显著变化

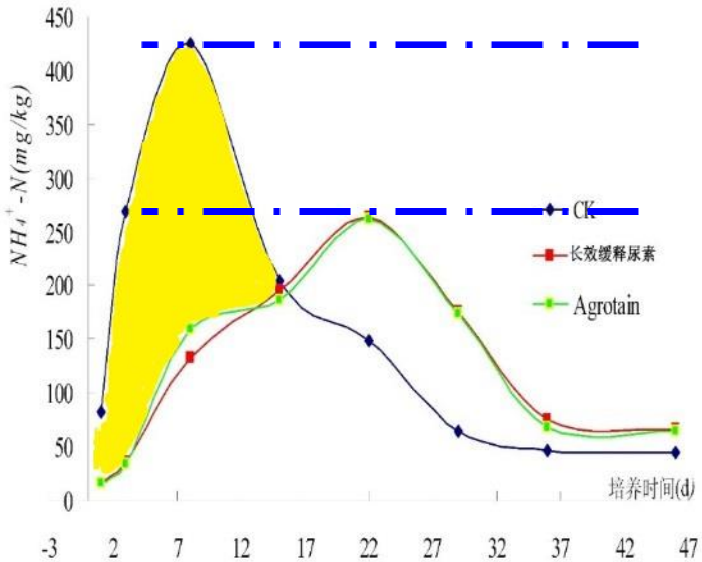
①控氮长效技术

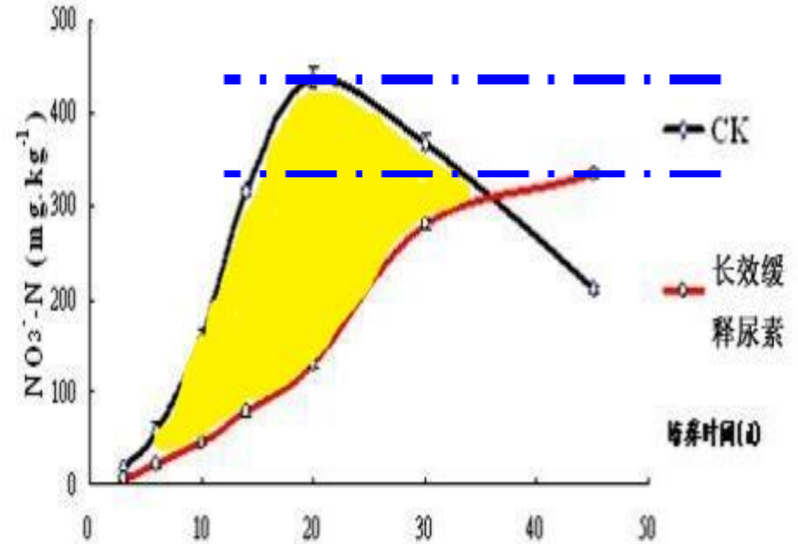




铵态氮释放高峰期向后推迟15天左右，硝态氮释放高峰期共向后推迟25天左右，肥效期延长到90-120天，满足大田作物一季生长的需要，一次施肥免追肥。

②控氮高效技术

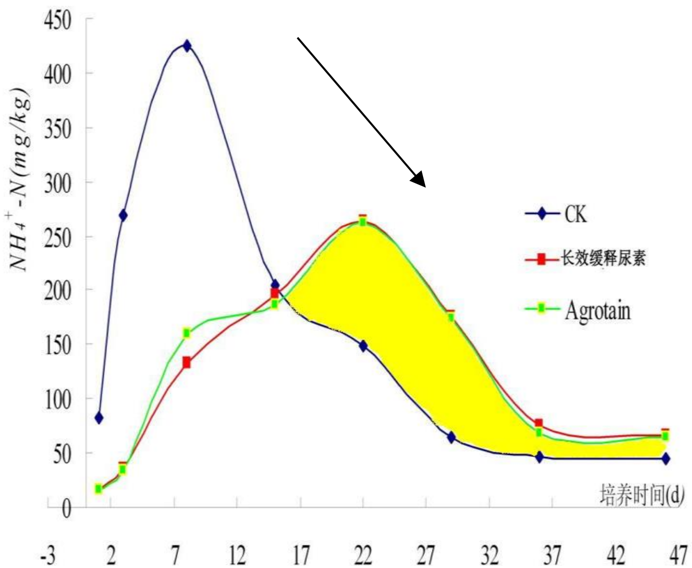


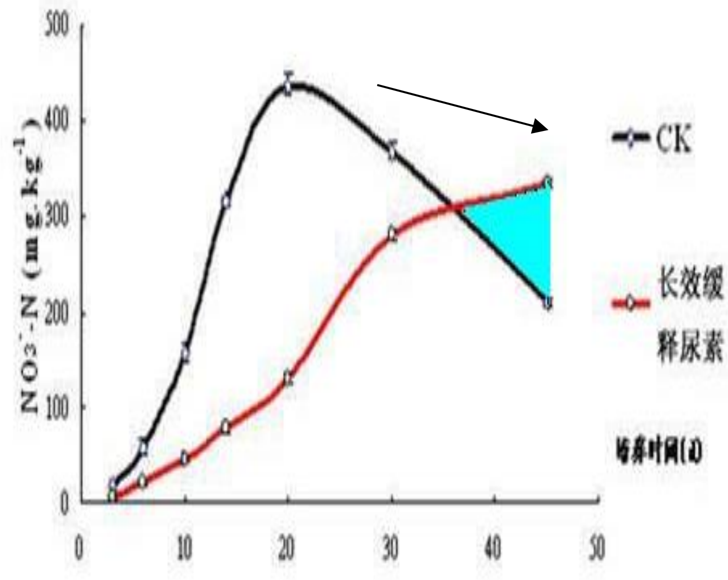


铵态氮释放高峰值下降，降低氨压，减少氨的挥发损失（黄色区域）；

铵态氮向硝态氮的转化受到抑制，可减少硝态氮的淋溶损失（黄色区域）。

③增铵营养技术





延长土壤中铵态氮的释放周期，增加铵态氮在土壤中的的比例（铵态氮：硝态氮>3/7），进而使N利用率提高30%。

技术特点：

（1）氮肥利用率得到提高

氮肥利用率由30%提高到42%，多年多地实验证明，在玉米、水稻等作物上减少氮肥使用量20%不会造成减产。

（2）氮肥肥效期得到延长

尿素肥效期由60天延长到90-120天，为普通尿素的2倍。可实现大田作物一次性施肥无需追肥。

（3）降低面源污染环境友好

减少氮淋失48.2%，降排N_2O 64.7%；本产品对环境安全，无残留（当年在土壤中降解率达到99%以上。）

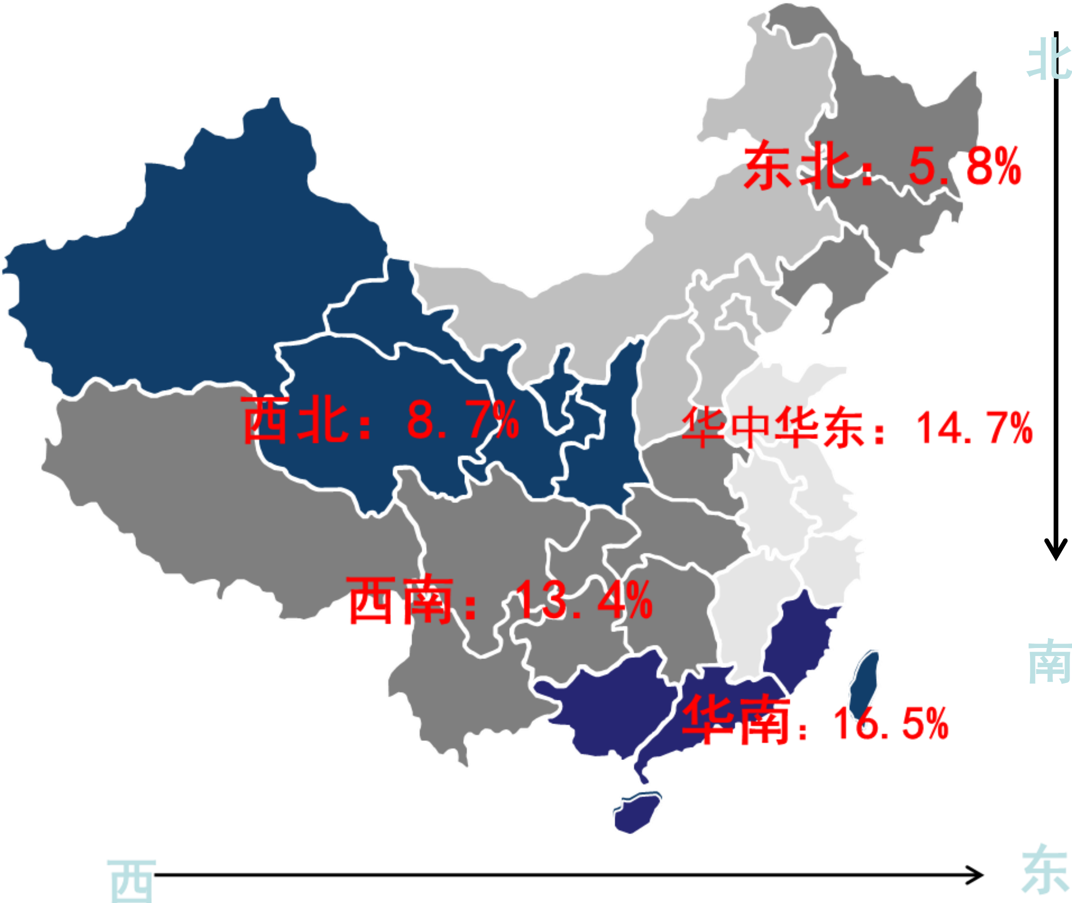
（4）生产工艺简单成本低

设备投资极少，工艺结合好，化肥成本增加只有普通复合肥的2%-3%。

（5）增产效果明显肉眼可见

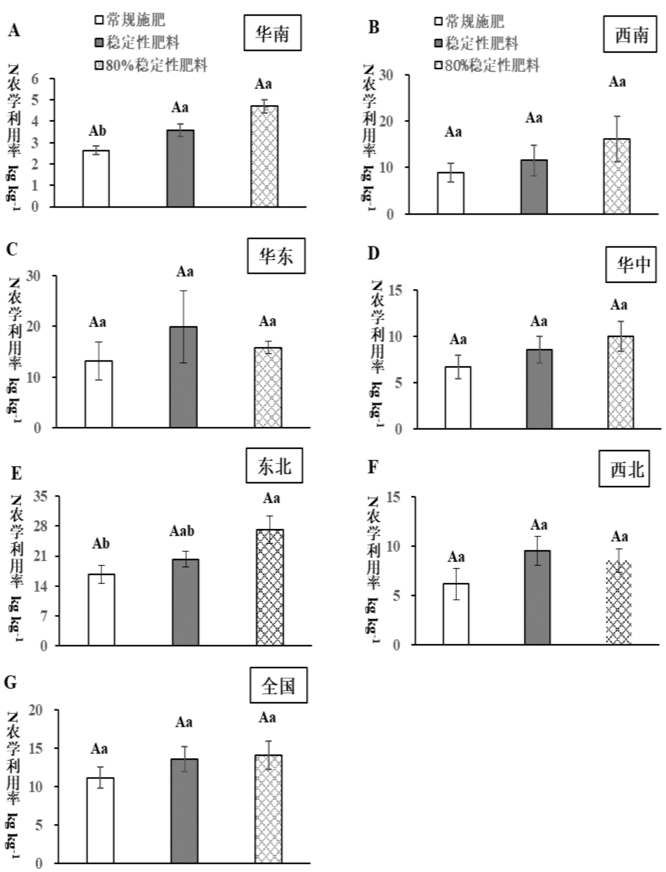
等氮量施肥平均增长8-21%，减少25%用肥量不减产。

稳定性肥料在不同区域的增产效果



- ♣由北向南稳定性肥料增产幅度越来越大
- ♣由西向东越来越增产
- ♣这和土壤及环境条件有关，包括养分含量和PH

等养分及减施肥条件下稳定性肥料对氮肥利用率的影响



不同区域的N肥农学利用率（NAE）增幅

	华南	西南	华中	华东	西北	东北	全国
SF vs CK	36.11%	29.84%	51.02%	27.25%	21.00%	**54.73%**	**21.77%**
80%SF vs CK	78.24%	**81.41%**	49.22%	20.10%	38.96%	62.10%	**26.39%**
80%SF vs SF	30.95%	40.11%	17.27%	-20.48%	33.97%	-10.19%	**3.79%**

1）**东北地区**NAE（kg kg^{-1}，16.74 -27.14）明显高于其它地区，华东次之（13.16-19.87），华南最小（2.63-4.69）。

2）**等养分稳定性肥料（SF）**施用后，东北的NAE增幅最大，达到54.73%，其次是华中（51.02%），平均**提高全国NAE22%左右**。

3）80%稳定性肥料(80%SF)施用后，西南的NAE增幅最大，达到81.41%，其次是华南（78.24%），平均**提高全国NAE26%左右**。

4） 80%SF VS SF:华东和东北的NAE降低20.48%和10.19%，其它区域增加40.11%-17.27%，**全国平均增加NAE 3.8个百分点左右。**

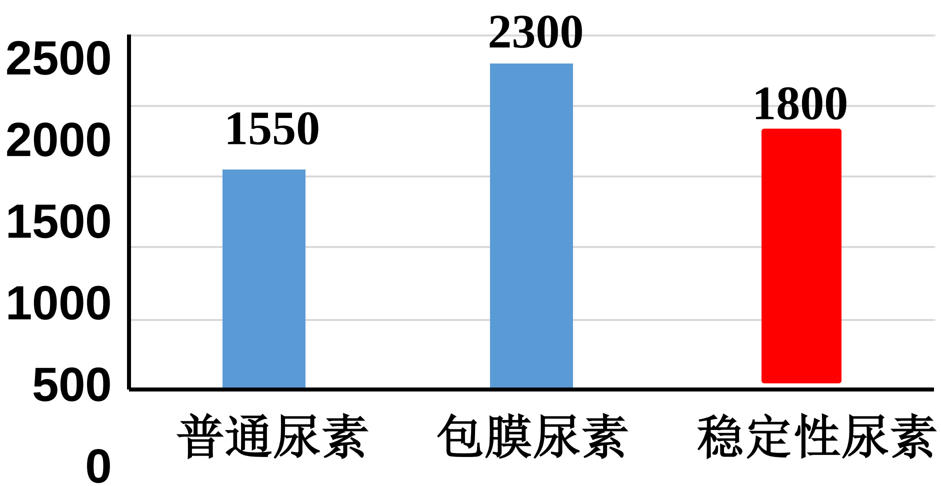
增产增收

作物	施肥处理	增产（kg/亩）	增产率（%）	多投入（元/亩）	增收（元/亩）
玉米	农户施肥	-	-	-	-
	常量稳定性肥料	59.84	12.99	-10.07	142.0
	减量20%稳定性肥料	28.79	6.99	-40.41	102.3
水稻	农户施肥	-	-	-	-
	常量稳定性肥料	32.62	23.9	12.3	131.6
	减量20%稳定性肥料	-16.04	-17.2	-8.5	-126.9
花生	农户施肥	-	-	-	-
	常量稳定性肥料	50	15	10.38	412.0
	减量20%稳定性肥料	32.3	9.7	8.3	365.0
大豆	农户施肥	-	-	-	-
	常量稳定性肥料	18.78	12.23	8.75	75.1
	减量20%稳定性肥料	4.22	2.75	7	21.1

减投20%，平均增产12.32kg/亩，增收90.35元/亩。

成本-收益分析

价格 （元/吨）



以玉米为例 (公顷)：

成本收益	普通氮肥	稳定性氮肥
产量（kg）	10140	10924
氮肥（元）	606.1	703.8
增收（元）	——	**1808.1**
NH_3	——	**11.3**
N_2O	——	7.7
DIN	——	238.9
增收（元）	——	**2065.9**

沈阳2380-2480元/吨，中储粮2680元/吨

玉米收购价格（ 2020.11.16 ）

生 态 补 偿

专一性

高效性

稳定性肥料

环保性

经济性

产品研究重要时间节点

20世纪60-70年代

开始稳定性
肥料研究

周礼恺 (生态所)

20世纪80年代中叶

长效尿素问世

20世纪80年代后期

稳定性复合肥料

硝化抑制剂首次
加入碳酸氢铵
成为肥料成品

20世纪90年代

脲酶抑制剂和
硝化抑制剂共
添加

21世纪早期

缓释尿素问世稳定
性复合肥料投产

2011稳定
复合氮肥推出

2016-目前

稳定性肥料
广泛应用

13.5单分子双
及抑制剂保护

产品研究重要时间节点

1992-1998年
长效碳酸氢铵
国家二等
中科院特等

2001年
稳定性复合肥料
研制成功

2008
稳定性复合肥
国家二等奖

2011年
土壤养分管理国
家工程实验室

2011年
稳定性肥料行
业标准

2012年
稳定复合氮肥
研制成功

2013
稳定性肥料+
聚氨酸推出

2016年
稳定性二铵成功
国家发明二等

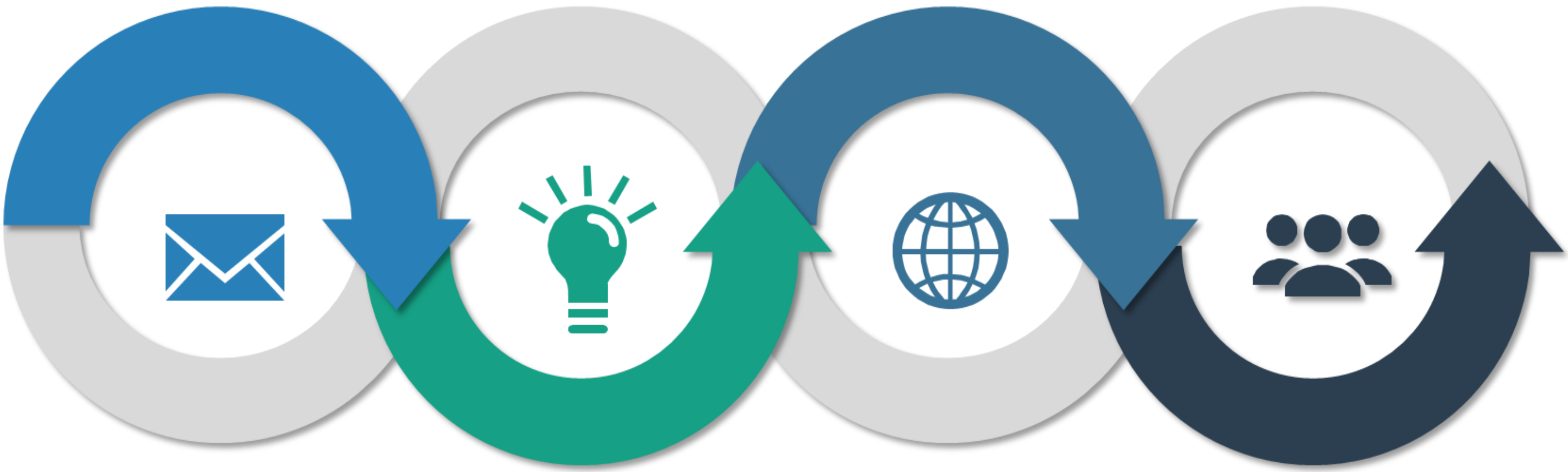
2018年
稳定性肥料国
家标准

2019年
中国科学院绿色
肥料工程实验室

国际肥料科学中
心落户中国

中国科学院沈阳应用生态研究所---稳定性肥料的技术输出基地

基础牢固　　积淀深厚　　国内领先　　资源完整



基础牢固：已初步建立完整的“实验室-中试线-合作企业-推广联盟”产学研模式。

积淀深厚：李庆逵院士、沈善敏研究员、周礼凯研究员等老一辈科学家上世纪70年代开始稳定性肥料、长效氮肥料研究，培养了一大批科研人才。

国内领先：2项国家科技进步奖、1项行业标准、1项国家标准。

资源完整：土壤学、植物营养学、生态学、微生物学、环境科学等学科资源完善。

研究基础

项目支持：863重大课题： 新型高效肥料研制与产业化

973项目： 肥料减施增效与农田可持续利用基础研究

国家948项目： 新型缓释性肥料

科技支撑计划项目： 新型高效肥料创制（十一五）

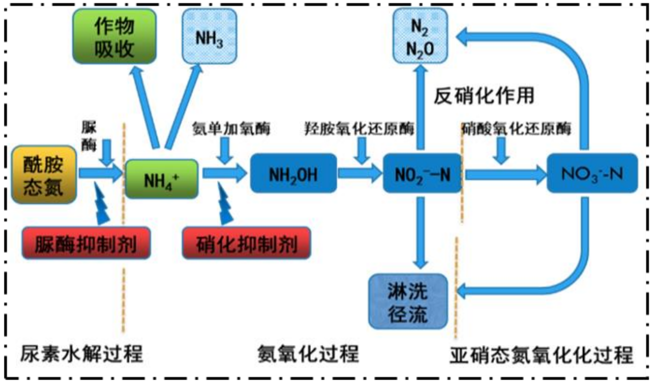
稳定性肥料关键技术研制及产业化（十二五）

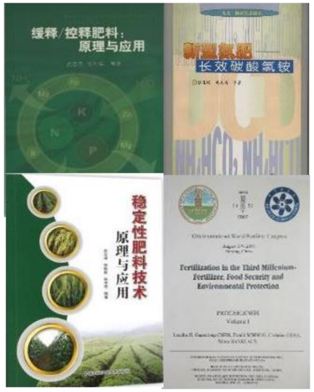
知识创新方向项目： 新型肥料研制

重点研发项目： 新型缓/控释肥料与稳定肥料研制（十三五）

稻田培肥替代品研制及施用关键技术（十三五）

- 获国家奖3项，院特等奖1项，
- 部委级奖23项；
- 出版专著5部；
- 近五年发表SCI 119篇；
- 授权专利47件；



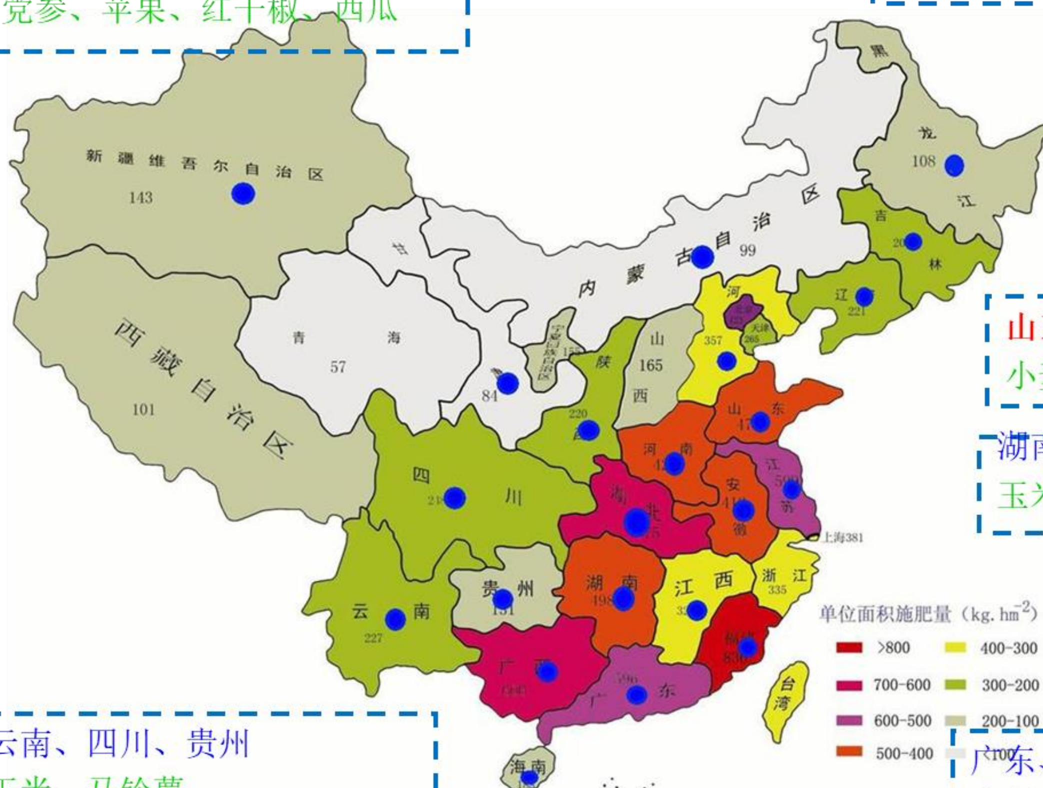


从 2009至今，在中国22个省份的不同作物上建立起不同的试验基地

新疆、甘肃、陕西、内蒙古
棉花、玉米、甜瓜、小麦、马铃薯
当归、党参、苹果、红干椒、西瓜

辽宁、吉林、黑龙江
大豆、玉米、水稻

河南　河北
小麦、水稻、玉米、
胡萝卜、甘薯、西瓜



山东
小麦、水稻、玉米、花生、大葱

湖南、湖北、江西
玉米、水稻、棉花、油菜、脐橙

安徽、江苏
小麦、水稻、玉米、
油桃、黄桃、西瓜

广西、云南、四川、贵州
水稻、玉米、马铃薯
木薯、花椒、辣椒、甘蔗

广东、福建、海南
水稻、菠萝、辣椒、香蕉
茶叶、龙眼、芒果

稳定性肥料产业技术联盟

--致力于肥料产业的健康

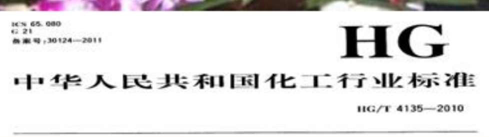
--在肥料企业和研究机构之间建立起桥梁和纽带

--促进不同企业间的合作共赢

稳定性肥料产业技术联盟

成立于2010年10月26日

国家标准和行业标准


ICS 65.080
G 21
备案号：30124—2011

HG

中华人民共和国化工行业标准

HG/T 4135—2010

2011年通过《稳定性肥料》行业标准
标准编号：HG/T 4135-2010


2010-11-22 发布　　2011-03-01 实施

2015年1月20-24日《稳定性肥料》通过国家标准评审

国际平台基础

国际科学肥料中心（CIEC）

CIEC是世界肥料技术原始创新和交流平台

基础研究和共性技术难题研究平台

科技之花 → 工程实验室 → 产业之果

团队建设与国际交流

- 与30多个国家建立了合作关系，主办国际会议14次，邀请国外专家作学术报告 53 次

- 实验楼4000平和中试验条件；
- 拥有完备的肥料及添加剂中试设备，中试车间3500平米
- 造粒工艺设备、流化床、固液添加剂研究设备、有机肥加工设备、生物肥研究设备、原生磷肥设备

稳定性肥料研究进展

依托十三五项目

新材料与技术的突破

新材料-植物源

01

保护技术-固液保护

02

共晶化保护技术

03

解决了 利用率提升、免追肥、高产和环境问题

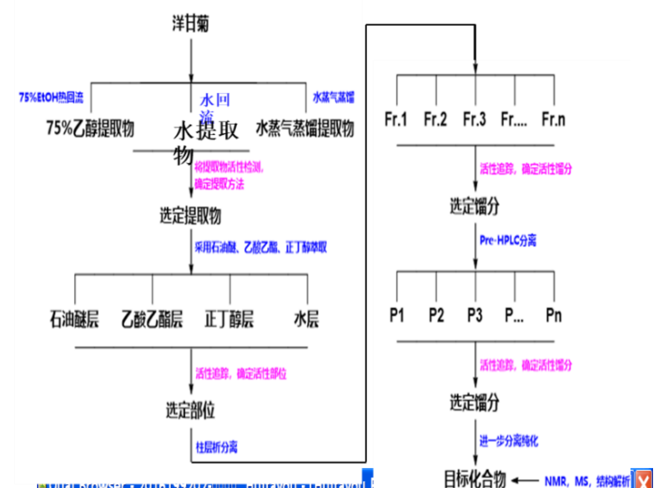
稳定性肥料限制因素---成本高、易分解、多个材料联合应用

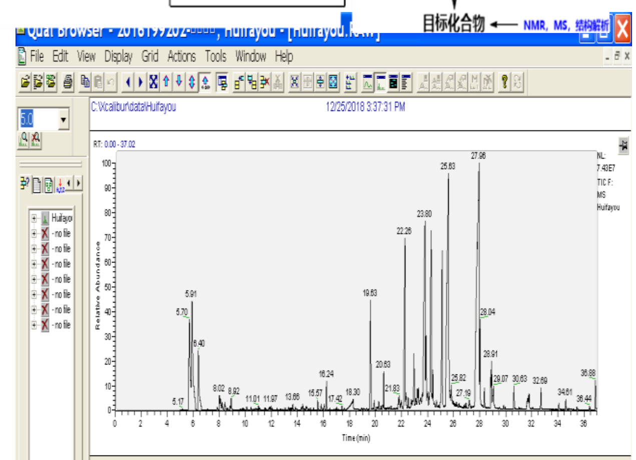
新型抑制剂材料研究

植物源材料 ⇒ 试验 ⇒ 分离 ⇒ 鉴定 ⇓ 合成 ⇐ 田间检验 ⇐ 应用技术

环戊酮　　丙烯酚　　苯酸糖

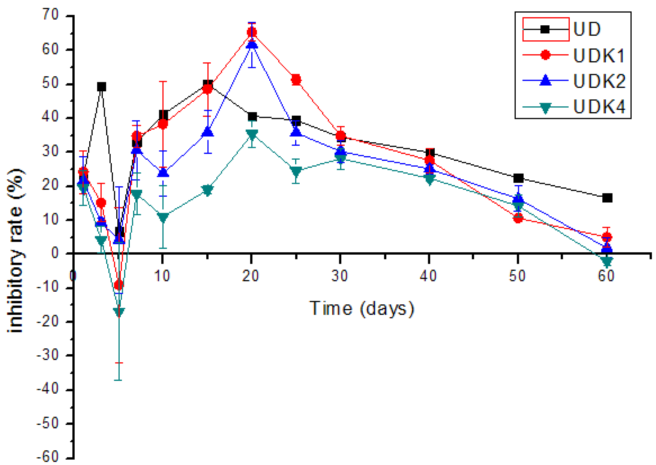
处理	脲酶抑制率 (%)	硝化抑制率 (%)
丙烯酚	50.4	75.2
苯酸糖	22.4	60.3
环戊酮	49.9	86.6
DCD	-	55.1
NBPT	20.8	-

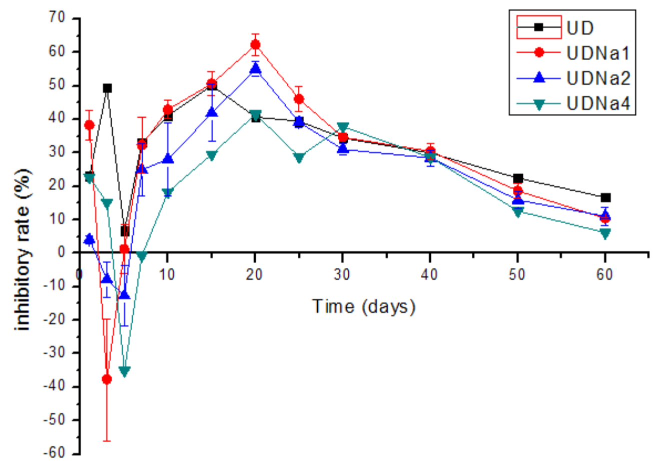


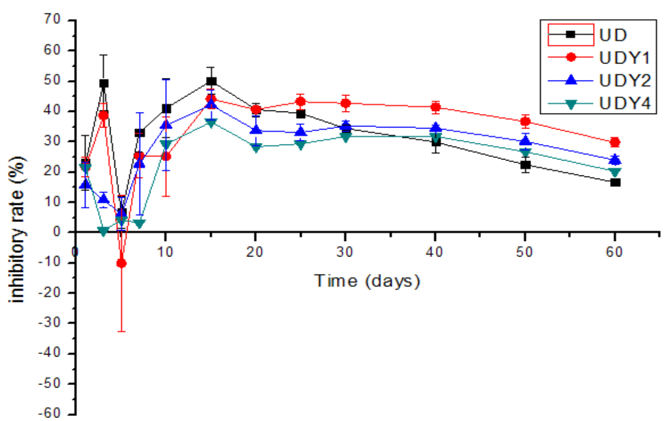


首次获得了3种新型的具有显著硝化抑制与脲酶抑制双重功能的苯酸糖、丙烯酚和环戊酮类物质，脲酶抑制率和硝化抑制剂率可达22.4%- 86.6%。

抑制剂保护技术--硝化抑制剂保护剂







- 保护剂可以累积降低NH_3挥发损失18%-62%，提高土壤中铵态氮的含量
- 可以提高抑制剂的硝化抑制率 23%-78%

抑制剂保护技术--脲酶抑制剂保护剂

加GCL 比单用NBPT，施肥后 5天 10天，

尿素含量分别高 25.4% 37.9%

脲酶活性分别低 42.1% 28.0%

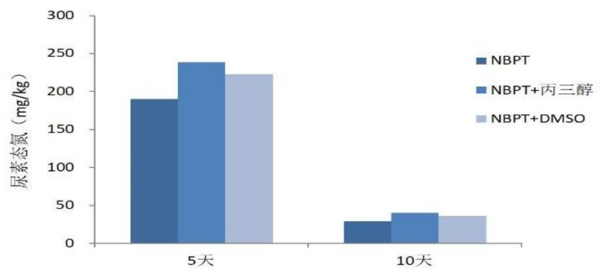
油菜产量增加 15.6%

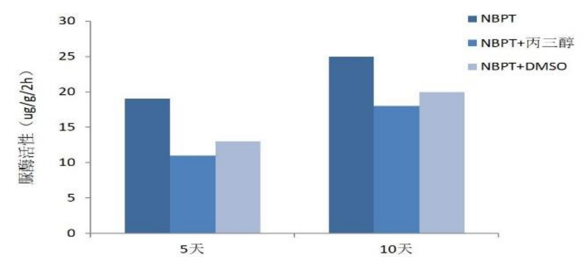
加DMSO 比单用NBPT，施肥后 5天 10天，

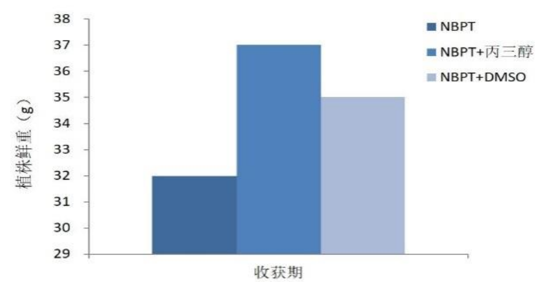
尿素含量分别高 17.2% 24.1%；

脲酶活性分别低 31.6% 20.0%；

油菜产量增加 9.4%。

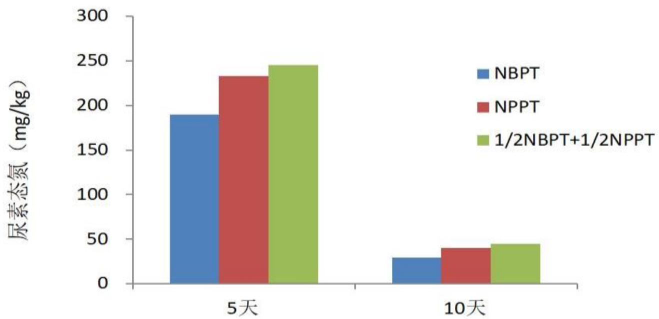


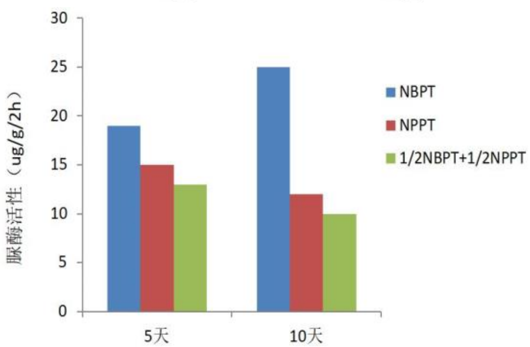


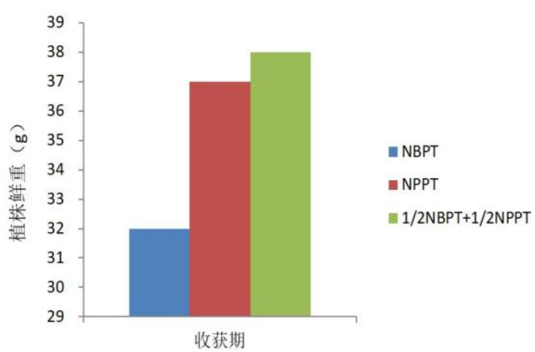


配伍技术

新型脲酶抑制剂的筛选与配伍







NPPT比NBPT，施肥后　5天　10天，

尿素含量分别高　22.6%　37.9%

脲酶活性分别低　21.1%　52.0%

油菜产量增加　15.6%

NBPT+NPPT比NBPT，施后 5天　10天

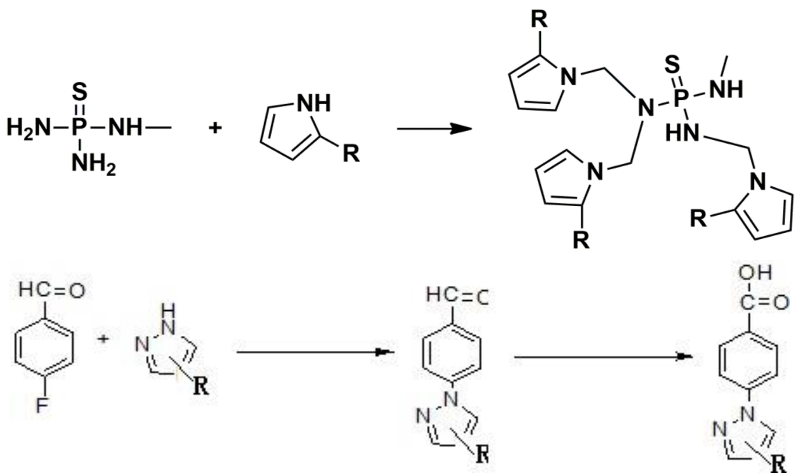
尿素含量分别高　29.0%　55.2%

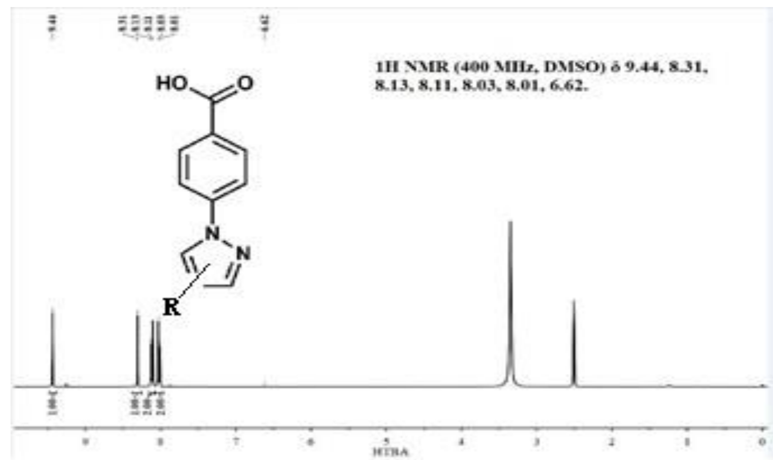
脲酶活性分别低　31.9%　60.0%

油菜产量增加　18.8%

抑制剂保护技术--共晶保护增效技术

新型双先导化合物抑制剂的合成





合成一--具有双重功效的抑制剂，并且通过核磁对其进行表征，获得了苯酸-糖类等新型抑制剂

分子对接技术及“共晶”抑制机理

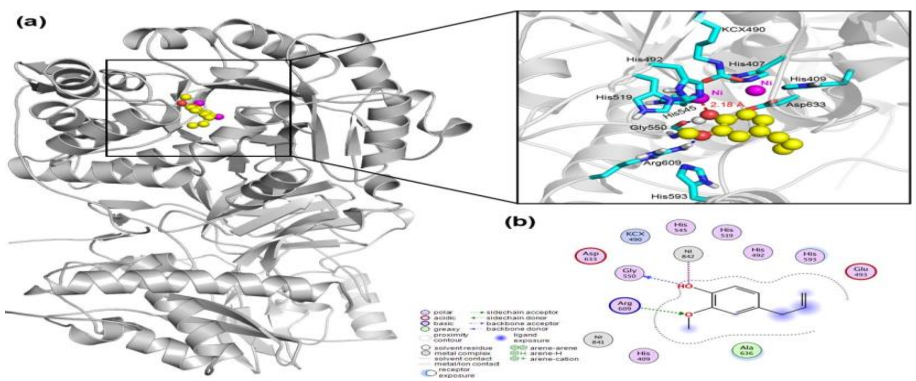


图1. 抑制剂与脲酶 分子对接示意图

通过分子对接技术及动力学，

形成保护型共晶体

DCD/DMPP与NBPT以非共价键作用方式形成 “共晶”抑制剂

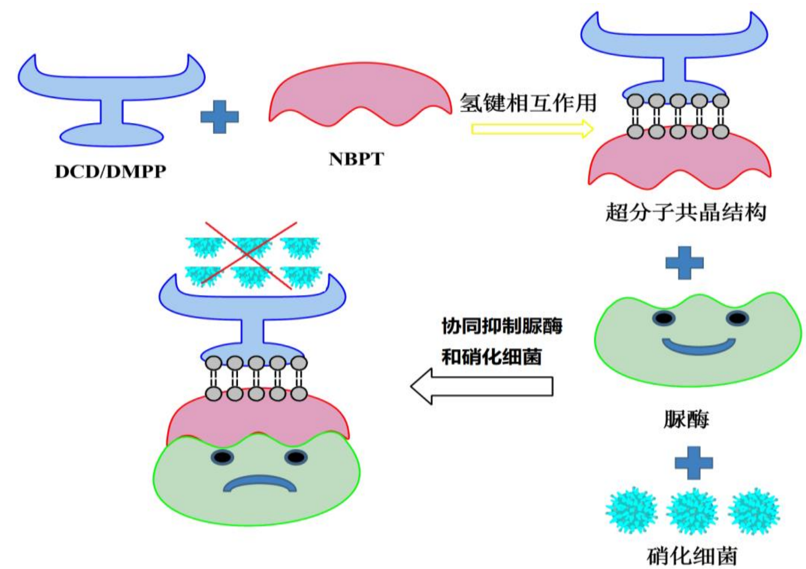


图2. NAM协同抑制机理图

玉米

处理1：常规施肥

(尿素+过磷酸钙+氯化钾，$N:P_2O_5:K_2O=2:1:1$)

处理2：T1(新抑制剂1配施）

处理3：T2(新抑制剂2配施）

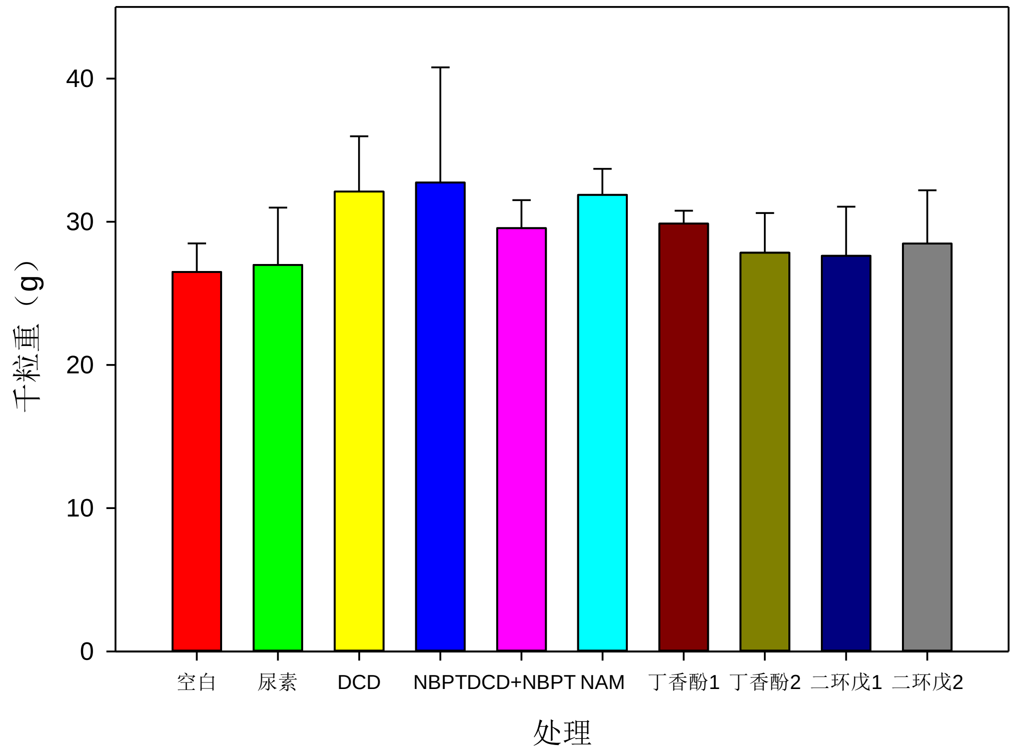
处理4：T3(新抑制剂3配施）

处理5：T4(新抑制剂4配施）

处理	百粒重（g)	产量（kg/ha)	十穗玉米茎粗（cm)	穗长（cm）	秃尖长（cm）	穗行数	行粒数
常规施肥	31.26	11039.48	4.7	19.1	0.6	17	38
T1	31.40	11934.79	4.9	19.8	0.5	17	38
T2	33.34	12619.34	4.9	20.0	0.3	17	40
T3	32.63	11360.66	4.8	20.4	0.4	17	41
T4	34.16	11334.56	4.9	20.2	0.4	18	39

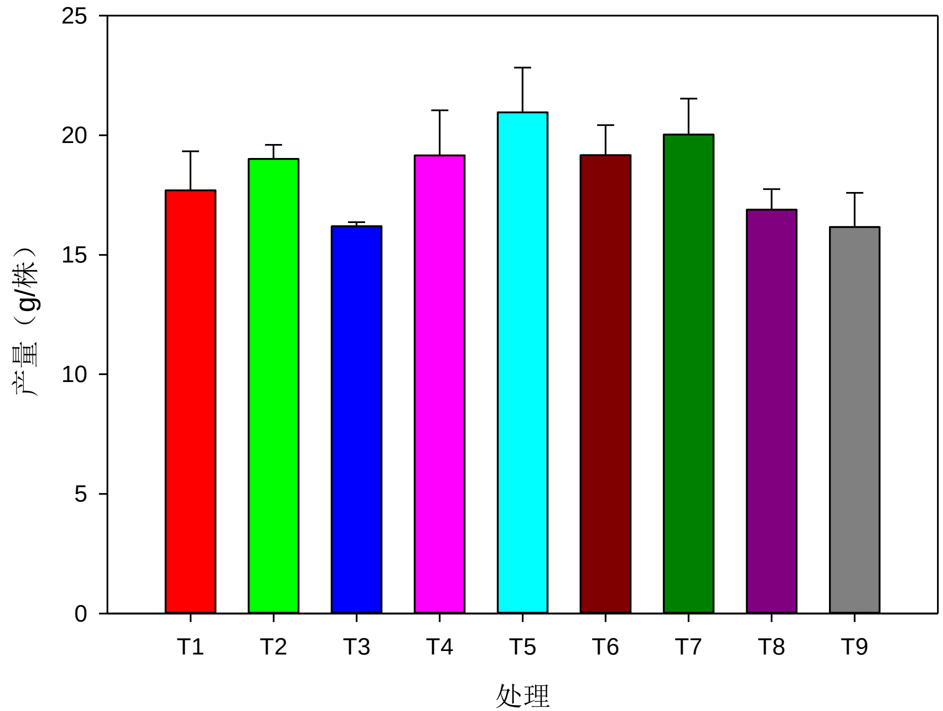
与常规施肥相比，配施新型植物源抑制剂的处理均增加了玉米产量，增产率达10-15.5%。增产效果好于常规抑制剂处理，增加幅度为7-15%。

水稻



与常规施肥相比，配施新型植物源抑制剂的处理均增加了水稻产量，增产率达11-18%。增产效果与常规抑制剂处理相当，能够做到一次性施肥免追肥。

谷子

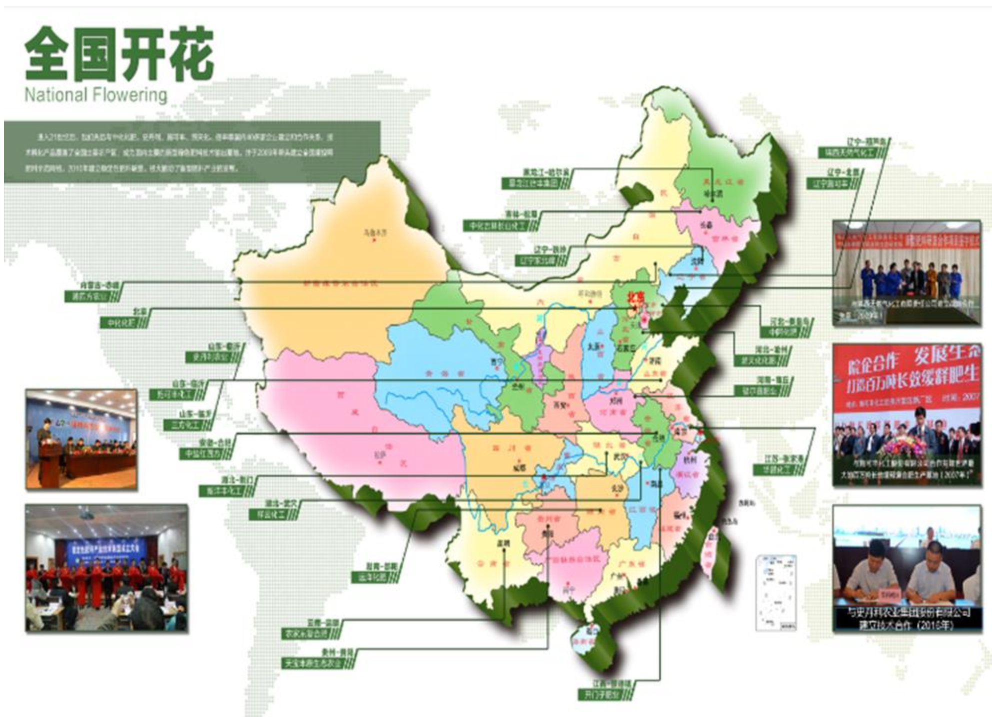


与常规施肥相比，配施新型植物源抑制剂的处理均加谷子产量7.4-15.5%。增产效果好于常规抑制剂处理，增加幅度为11-14%。

新材料与技术的突破-国际领先

性能 \ 产品	新技术产品	NAM 系列产品	巴斯夫（BASF）产品（德国）
成本增加（元/吨）	70-81	74-84	210-220
单位面积投入（元/hm^2）	57-64	63-68	158-165
利用率（%）	58-61	45-50	40-48
增产（%）	10.2-17.5	8.0-16.1	3.1-7.6
肥效期（天）	120-130	110-120	70-76
环境效应	N_2O减少59-79%	N_2O减少46-74%	N_2O 减少 36-41%
结论	国 际 领 先	国 际 领 先	国 际 先 进

新技术对肥料行业的影响



合作企业

稳定性肥料年产150万吨，转化企业48家，占我国高效肥料市场80%以上，引领绿色肥料快速发展

新技术对肥料行业的影响

1. 稳定性肥料将成为减肥的主要应用技术和肥种

国际上——德国、新西兰、法国、澳大利亚、美国

国　内——零增长，减少30%

- 为保证不减产，只能提高利用率
- 稳定性肥料 成本低，增产高，便于生产，农民能接受

2. 长效功能技术---轻简化施肥

- 劳力少，外出打工，无人施肥--农民需要
- 农业不是农民的主要经济来源
- 机械化的发展要求长效，轻简化--耕作方式转变
- 厂家可以根据市场需要生产相应的肥料--影响产品结构

3. 功能化技术---新肥料更专业

- 竞争的需要 差异化，服务于大户与特殊作物
- 不同区域需要 盐碱地，酸性土壤，高温多雨区
- 为企业供应原料肥 长效氮颗粒
- 低温快速吸收的需要，大棚，短生育期作物
- 水稻机械施肥

4、催生复合功能肥料

- 稳定性+聚氨酸技术
- 高分子增效+稳定性 技术
- 抗旱+保水技术
- 双重控制—协同增效
- 抗盐碱+长效技术

稳定性+聚氨酸

作物	增产率%	肥料利用率提高%
玉米	8	13.4
小麦	9.06	28.3

谢谢大家！

IAE

中科院沈阳应用生态研究所