The Many Pasts of Phosphorus

JIM ELSER

Director

SUSTAINABLE PHOSPHORUS ALLIANCE

#PWEEK22

The Many Pasts of Phosphorus

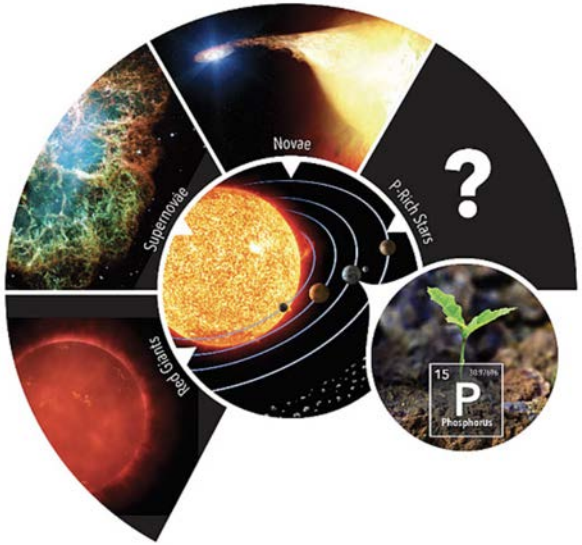
Sustainable Phosphorus Alliance

Jim Elser

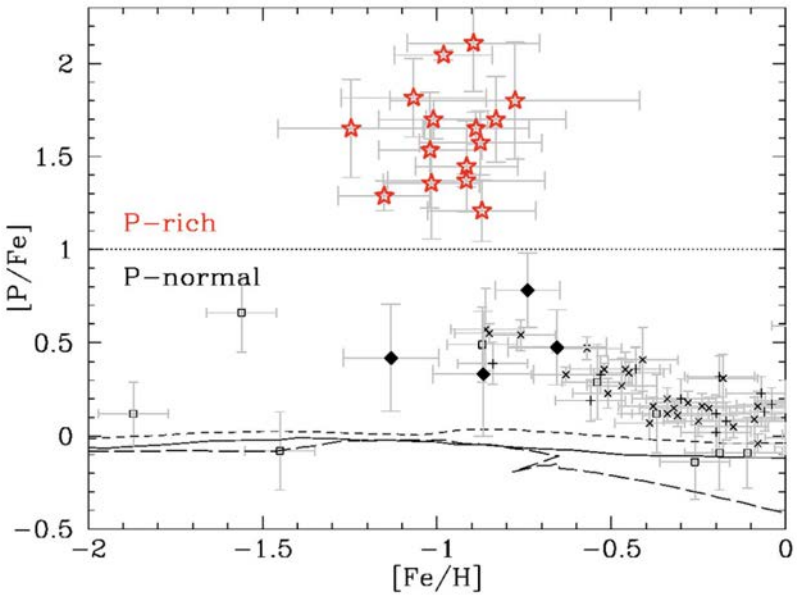
Director, Sustainable Phosphorus Alliance

School of Sustainability, Arizona State University

PHOSPHORUS ATOMS: THEIR DEEP & MYSTERIOUS PAST?



T. Masseron et al.: “Galactic chemical evolution under-predicts the phosphorus we observe in the Milky Way …, suggesting that a source of phosphorus is neglected in the models or even **possibly unknown**.”



Phosphorus abundances as a function of metallicity (iron over hydrogen) for Galactic stars. Red stars show the discovered phosphorus-rich stars, while the black symbols represent phosphorus-normal Galactic stars. Credit: Masseron et al. (2020).

Phosphorus Past

Terra preta: ancient, fertile, anthropogenic soil found amidst infertile soil in the Amazon.

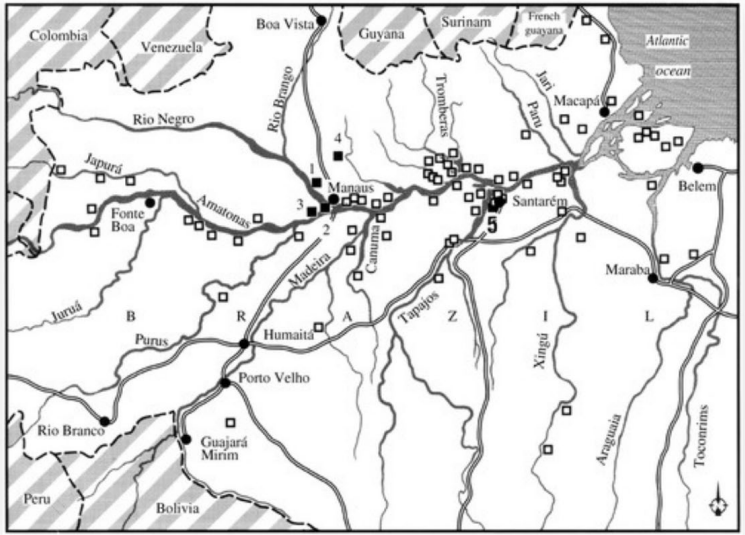


Figure 1 Known occurrence of Terra Preta (do Indio) in central Amazonia.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

Phil. Trans. R. Soc. B (2007) **362**, 187–196
doi:10.1098/rstb.2006.1978
Published online 20 December 2006

Prehistorically modified soils of central Amazonia: a model for sustainable agriculture in the twenty-first century

Bruno Glaser*

Institute of Soil Science and Soil Geography, University of Bayreuth, 95440 Bayreuth, Germany

Terra Preta soils of central Amazonia exhibit approximately three times more soil organic matter, nitrogen and phosphorus and 70 times more charcoal compared to adjacent infertile soils. The Terra Preta soils were generated by pre-Columbian native populations by chance or intentionally adding large amounts of charred residues (charcoal), organic wastes, excrements and bones. In this paper, it is argued that generating new Terra Preta sites ("Terra Preta nova") could be the basis for sustainable agriculture in the twenty-first century to produce food for billions of people, and could lead to attaining three Millennium Development Goals: (i) to combat desertification, (ii) to sequester atmospheric CO_2 in the long term, and (iii) to maintain biodiversity hotspots such as tropical rainforests. Therefore, large-scale generation and utilization of Terra Preta soils would decrease the pressure on primary forests that are being extensively cleared for agricultural use with only limited fertility and sustainability and, hence, only providing a limited time for cropping. This would maintain biodiversity while mitigating both land degradation and climate change. However, it should not be overlooked that the infertility of most tropical soils (and associated low population density) is what could have prevented tropical forests undergoing large-scale clearance for agriculture. Increased fertility may increase the populations supported by shifting cultivation, thereby maintaining and increasing pressure on forests.

Keywords: Terra Preta; Amazonian Dark Earths; C sequestration; humid tropics; charcoal; slash and char

1. INTRODUCTION

Within the landscape of infertile soils (Ferralsols, Acrisols, Lixisols and Arenosols) in central Amazonia, small islands of highly sustainable fertile soils known as Terra Preta (*do Indio*) occur in patches averaging approximately 20 ha (figure 1). Terra Preta soils have on average three times higher soil organic matter (SOM) content, higher nutrient levels and a better nutrient retention capacity than surrounding infertile soils (Sombroek 1966; Zech *et al.* 1990; Glaser *et al.* 2001). Radiocarbon dating indicates that these soils were formed between 7000 and 500 cal yr BP and are of pre-Columbian origin (Neves *et al.* 2001). It still remains a matter of speculation whether these soils were made intentionally or resulted as a by-product of human occupation; what is known, however, is that Terra Preta soils have been under continuous agricultural use for centuries (Woods & McCann 1999; German 2001) and presently Terra Preta is being excavated and sold as fertile soil.

Despite their importance as fertile soil on an otherwise infertile landscape, the traditional knowledge of how Terra Preta soils were produced has been lost. This paper examines the evidence for the processes responsible for Terra Preta genesis and also the reasons why they are so superior in terms of SOM content and nutrient retention capacity in comparison to the surrounding central Amazonian soils. Using this knowledge, the paper addresses the potential of Terra Preta soils in providing future sustainable agriculture in the humid tropics. It concludes that the generation of Terra Preta soils nowadays could enable communities to build up highly productive and sustainable land use systems. They would be, in particular, useful for smallholder farmers for the growth of high-value crops and other horticultural activities.

2. PROCESSES RESPONSIBLE FOR THE FORMATION OF TERRA PRETA SOILS

(a) *Charcoal formation*

When comparing the SOM composition of Terra Preta soils with adjacent Ferralsols, e.g. by ^{13}C NMR spectroscopy, higher amounts of condensed aromatic (figure 2*b*) and carboxylic moieties are obvious (Zech *et al.* 1990; Glaser *et al.* 2003*b*). Using molecular markers such as benzenepolycarboxylic acids, it has been shown that charring processes are responsible for the formation of condensed aromatic structures (Glaser *et al.* 1998, 2003*a*; Brodowski *et al.* 2005) and that Terra Preta soils contain on average 70 times more charcoal compared to the surrounding Ferralsols (Glaser *et al.* 2001).

Biomass charring leaves behind a continuum of carbon combustion products known as black or pyrogenic carbon ranging from slightly charred organic matter (figure 2*a*) retaining the shape of the original material to highly graphitized soot spheroids derived

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One contribution of 14 to a Theme Issue 'Biodiversity hotspots through time: using the past to manage the future'.

Use of Tropical Rainforests by Native Amazonians

These sophisticated and complex agricultural systems can serve as models of sustainable agroecosystems

Darna L. Dufour

Indigenous peoples have lived in the rainforests of Amazonia for a long time, probably thousands of years. They were once more numerous and occupied more of Amazonia than they do today. Those groups known ethnographically live in interfluvial regions and share a broadly similar subsistence pattern based on horticulture, hunting, fishing, and collecting. They provide the best example of sustainable use of tropical rainforests under low population densities.

Of the ways in which Amerindians use the rainforest, the best documented are their diverse, multistoried agricultural plots, or swiddens. More recently studied is their management of swidden fallows, in which annual crops are combined with perennial tree crops and the natural process of reforestation. Some groups also modify what appears to be primary forest by planting along trailsides and campsites. The result of their agricultural practices is a mosaic of vegetational patches in different stages of succession and under differing degrees of management. This vegetational mosaic is then used for food, materials, and medicinals, as well as for hunting game animals.

The objectives of this article are briefly to summarize the history of indigenous peoples, describe some of the contributions anthropology and allied disciplines have made to understanding how these peoples use tropical rainforests, and, finally, to compare this knowledge briefly with patterns of use characteristic of other populations. Many examples are drawn from the Tukanoan Indians in the Colombian Vaupes region in Northwest Amazonia, the area with which I am most familiar.

Much that has been considered natural forest is probably the result of centuries of human use

History of native Amazonians

When the Europeans arrived, the indigenous population of Amazonia was much greater than it is today. One estimate is that the Amerindians numbered approximately 6.8 million in an area of almost 10 million km^2 (Denevan 1976)[1]. Population density was highest in the floodplains of the major rivers, or what is referred to as *várzea*, and along the Atlantic coast. Early explorers such as G. Carvajal and F. Orellana reported dense settlements along the banks of the Amazon in the 1540s and a level of social organization referred to as a chiefdom (Roosevelt 1989). The remains of large middens (refuse heaps), as well as the extent and depth of *terra preta do indio*[2] (Indian black earth) provide additional evidence that the riparian zones of major rivers were heavily populated (Roosevelt 1989, Smith 1980). The interior forests and savannas, or *terra firme*, appear to have been much more sparsely populated (Denevan 1976).

The indigenous population in the floodplain declined rapidly, and, by only 150 years after Orellana's expedition, the chiefdoms were extinct (Roosevelt 1989). The severe depopulation that followed this contact is assumed to have been the result of a combination of disease, slavery, and warfare. The rate of population decline in the more isolated interior forest areas was probably lower than in the floodplain, because many of these groups had only sporadic contact with outsiders until well into this century (Denevan 1976).

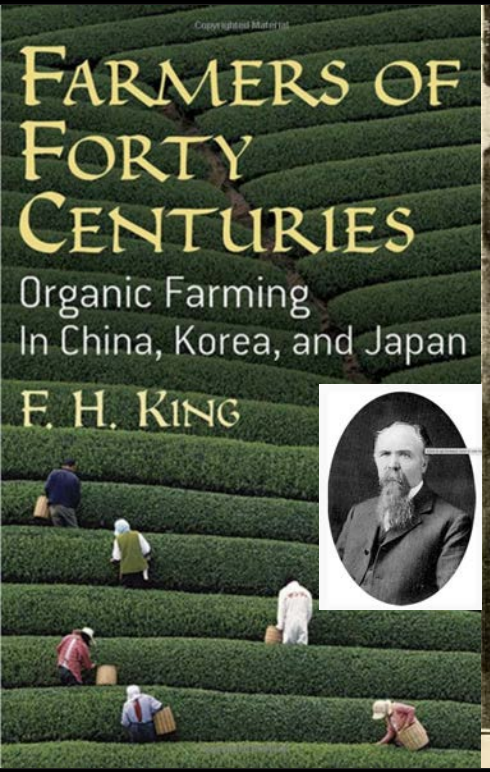
In the early 1970s, the indigenous population of Amazonia was estimated at less than 500,000 (Denevan 1976). In Brazil alone, the population dropped between 1900 and 1957 from approximately 1 million to less than 200,000 (Ribeiro 1967). Amerindians are now confined to interior forests and savannas, and the once

Darna L. Dufour is an associate professor of anthropology at the University of Colorado, Boulder, CO 80309.

[1]The use of Amazonia in this article follows that of Denevan (1976). It refers to greater Amazonia, which includes the tropical lowlands and plateaus east of the Andes and north of the Tropic of Capricorn, except for the Gran Chaco region. It is an area considerably larger than the drainage of the Amazon and its tributaries.

[2]*Terra preta do indio* is a soil darkened by the residue of repeated fires. It characterizes ceramics and other remains of human activity (Smith 1980).

Phosphorus Past



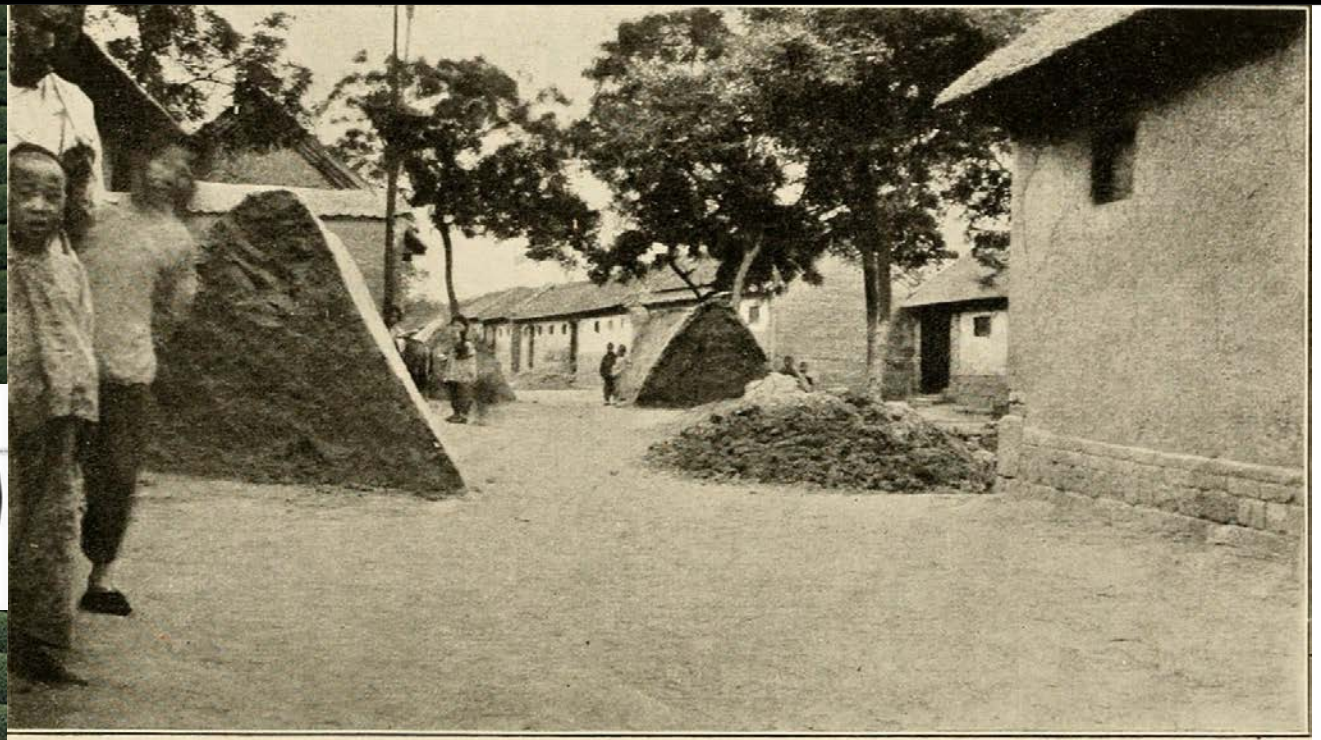
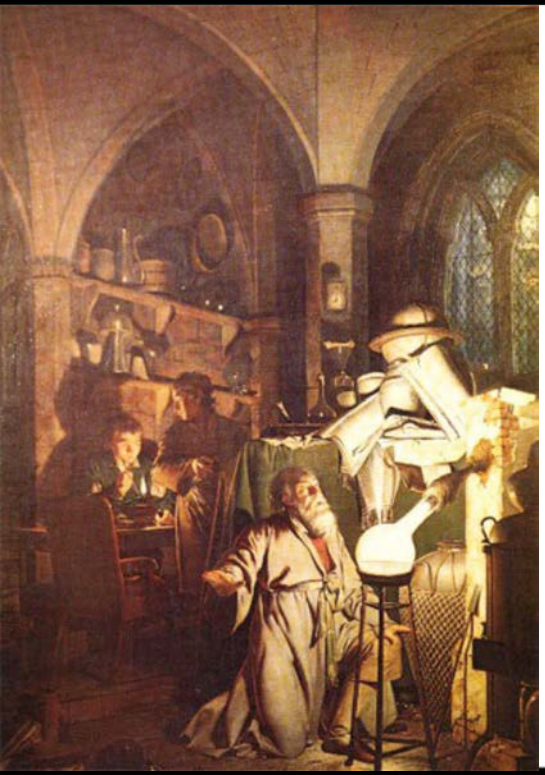
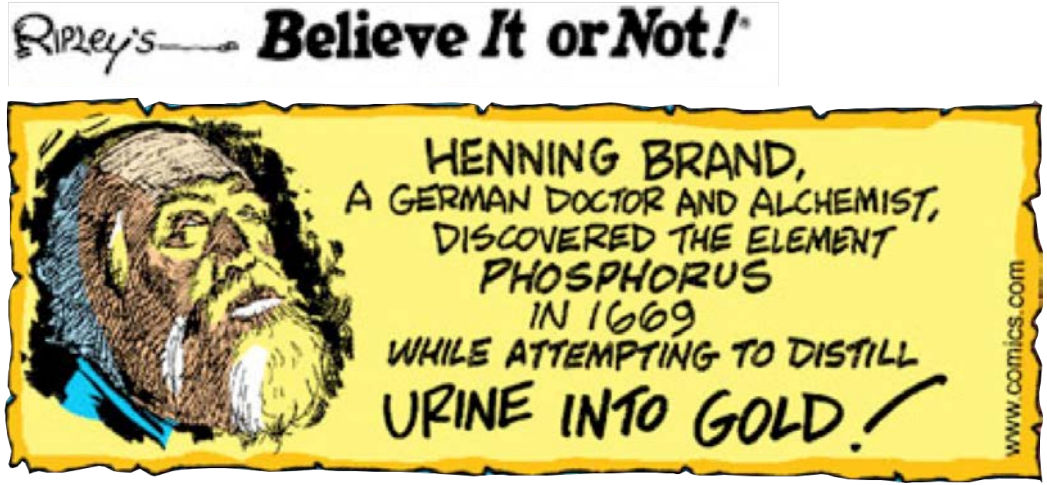


FIG. 118. – Farm village street with stacks of earth and piles of compost for use as fertilizer, Shantung.

Phosphorus Past



Henning Brand (1630 -1710)
German alchemist & the discoverer of phosphorus while searching for the “philosopher’s stone”.



Phosphorus Fertilizers: Past

Rothampsted Research

- the oldest continuously operating agricultural research station in the world
- founded in 1843 when John Bennet Lawes began collaboration with Joseph Henry Gilbert, a chemist
- initiated the classical Rothamsted long term experiments on Broadbalk field

ROTHAMSTED RESEARCH

Yields of Winter Wheat Under Continuous Culture
Broadbalk Field—Rothamsted

Bushels of Grain Per Acre

Plot No.	Treatment	Mean Yield 1852-1925
2A	Farmyard manure	30.0[a]
2B	Farmyard manure	36.2
3-4	Unmanured	12.5
5	Complete minerals, no nitrogen	12.9
6	Minerals plus 43 lbs. of nitrogen in sulphate of ammonia	23.3
7	Minerals plus 86 lbs. of nitrogen in sulphate of ammonia	32.9
8	Minerals plus 129 lbs. of nitrogen in sulphate of ammonia	37.5
9	Minerals and 43 lbs. of nitrogen in nitrate of soda	25.9[b]
10	Sulphate of ammonia containing 86 lbs. of nitrogen, and no minerals	20.3
11	Sulphate containing 86 lbs. of nitrogen and superphosphate	23.0
12	Sulphate of ammonia containing 86 lbs. of nitrogen, superphosphate and sulphate of soda	29.3
13	Sulphate of ammonia containing 86 lbs. of nitrogen, superphosphate and sulphate of potash	31.7
14	Sulphate of ammonia containing 86 lbs. of nitrogen, superphosphate, and sulphate of magnesia	25.6

15	Minerals and two applications of sulphate of ammonia, totalling 86 lbs. of nitrogen, all applied in the autumn	30.1
16	Minerals, and nitrate of soda amounting to 86 lbs. of nitrogen	33.2
17-18	Minerals and sulphate of ammonia containing 86 lbs. of nitrogen, applied in alternate years	30.1
17-18	Minerals only, (Sulphate of ammonia applied in alternate years as above—this average from 17 and 18 with minerals only)	15.1
19	Rape cake containing 86 lbs. of nitrogen	23.5[c]
20	Sulphate of ammonia containing 86 lbs. of nitrogen and sulphates of potash, soda, and magnesia	17.6[d]

[a]Mean of 26 years, 1900-1925.
[b]Mean of 41 years, 1885-1925.
[c]Mean of 33 years, 1893-1925. Rape "cake" is rape seed from which oil has been expelled.
[d]Mean of 18 years, 1906-1925 excluding 1912 and 1914.

Phosphorus Fertilizers: Past

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ROTHAMSTED RESEARCH

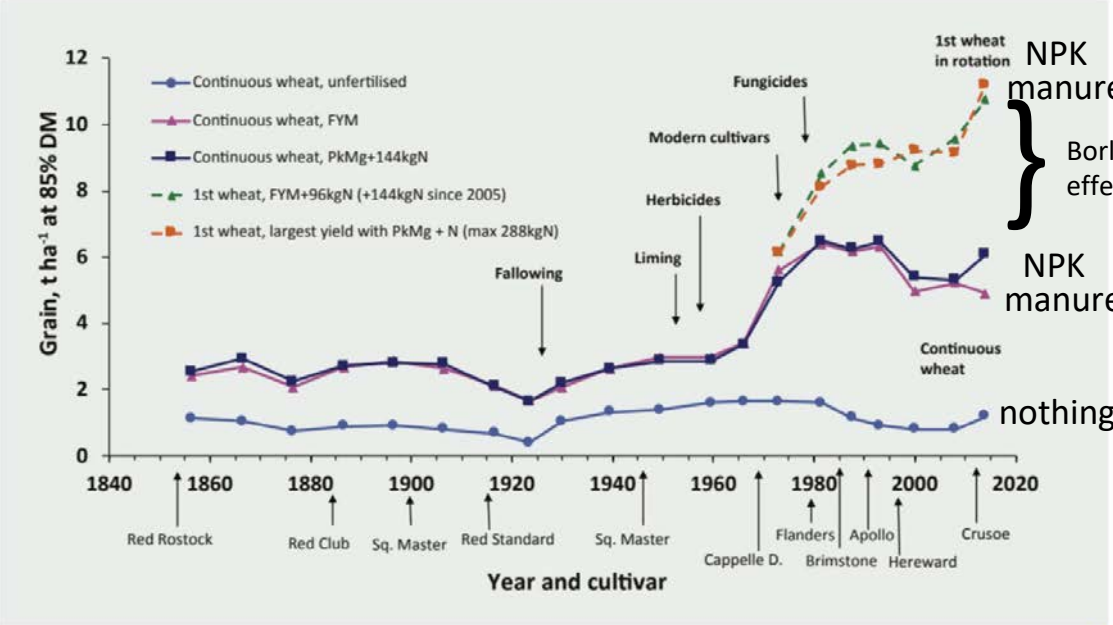
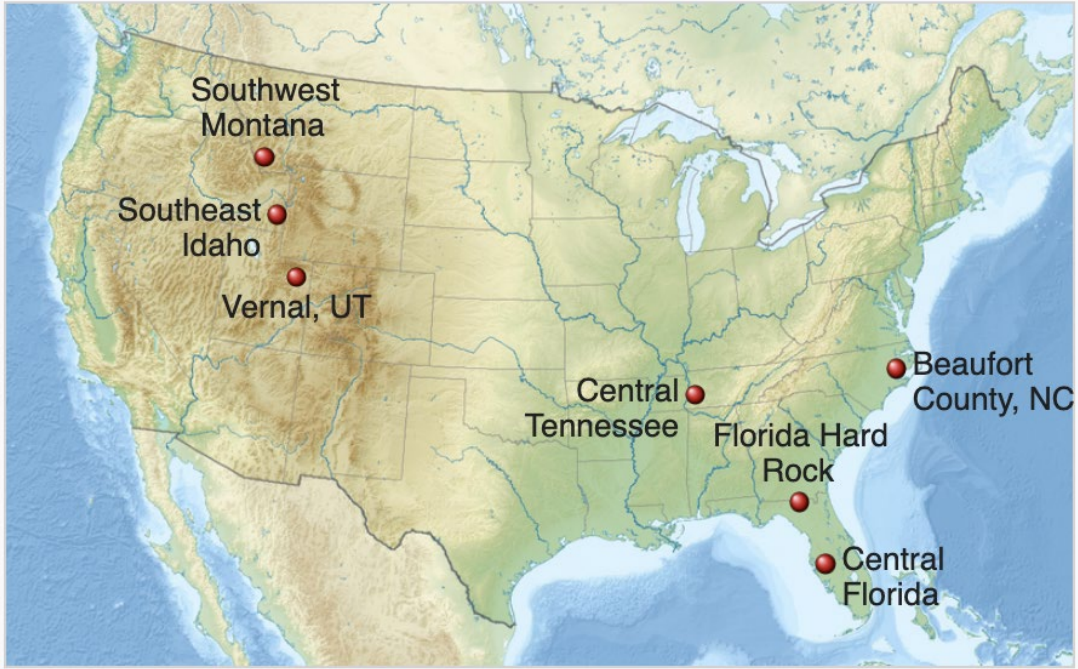


Fig. 1 Broadbalk: Mean yields of wheat grain and changes in husbandry (1852-2016)

ROTHAMSTED RESEARCH

Phosphorus Fertilizers: Past



Phosphate Mining Districts

1868: first mines in coastal S Carolina
1885: SC produced 50% of global P rock
1890's: SC declined; Florida increased

THE FERTILIZER TRADE IN NORTH CAROLINA IN 1886.

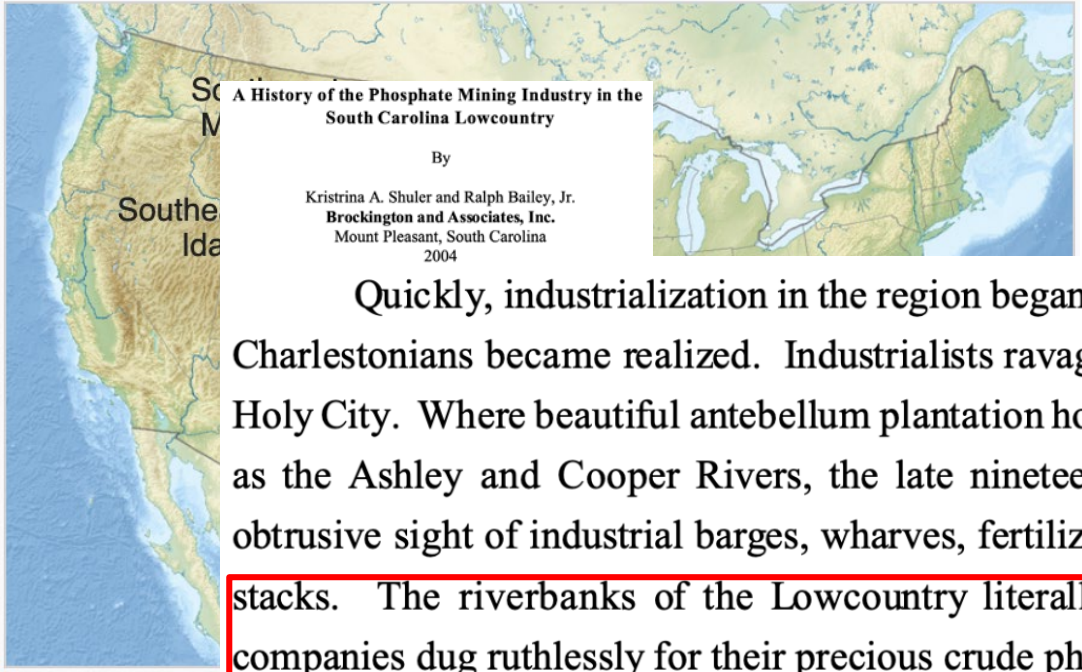
W. B. PHILLIPS.

About 100,000 tons of Commercial Fertilizers are used in North Carolina annually, sold by 58 companies under 90 brands. Each brand pays an annual license tax of $500.00. Since the establishment of the Agric. Dept. in 1877, and the inauguration of the fertilizer control by the Agric. Expt. and Fert. Control Station, the number of brands and consumption of Commercial Fertilizers has shown a marked increase.

Brands of Fertilizers entered and amounts consumed from 1879 to 1886, inclusive:

	Brands.	Consumption. short tons.
1879.	42	60,000
1880.	48	80,000
1881.	58	85,000
1882.	86	92,000
1883.	92	95,000
1884.	80	95,000
1885.	83	95,000—100,000
1886.	90	95,000—100,000

Phosphorus Fertilizers: Past



Phosphate Mining Districts

A History of the Phosphate Mining Industry in the South Carolina Lowcountry

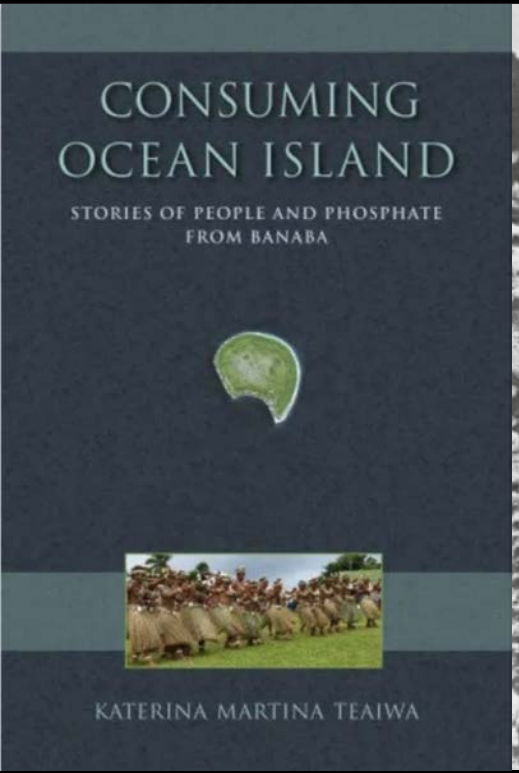
By

Kristrina A. Shuler and Ralph Bailey, Jr.
Brockington and Associates, Inc.
Mount Pleasant, South Carolina
2004

Quickly, industrialization in the region began to take its toll, and many of the fears of local Charlestonians became realized. Industrialists ravaged the once winsome local landscape of the Holy City. Where beautiful antebellum plantation homes had dotted the banks of local rivers such as the Ashley and Cooper Rivers, the late nineteenth century mining industry ushered in the obtrusive sight of industrial barges, wharves, fertilizer mills, phosphate drying sheds, and smoke stacks. The riverbanks of the Lowcountry literally were gutted and carted off piecemeal as companies dug ruthlessly for their precious crude phosphates to sell.

1868: first mines in coastal S Carolina
1885: SC produced 50% of global P rock
1890's: SC declined; Florida increased

Phosphorus Fertilizers: Past

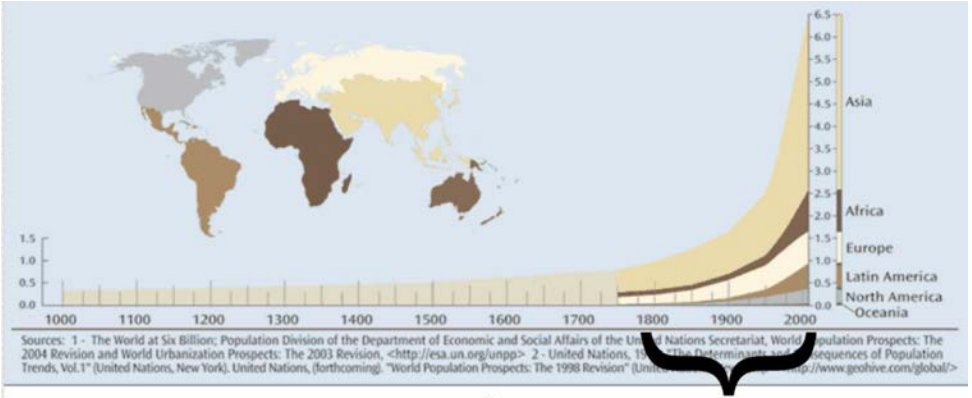


Phosphorus Fertilizers: Past

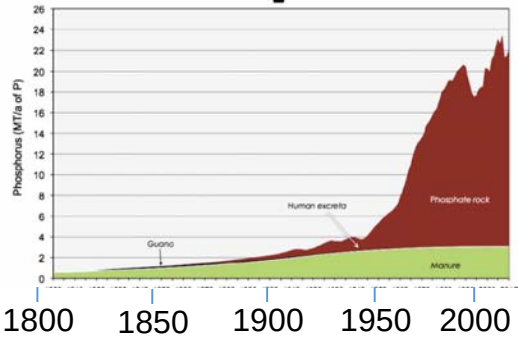
source: wikimedia commons

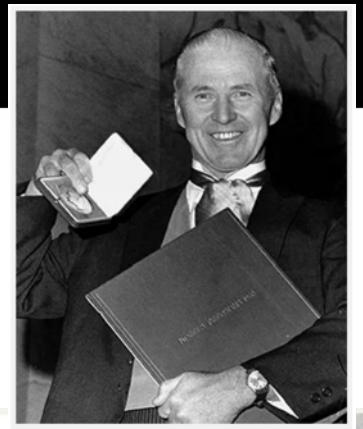
I cannot over-emphasize the importance of Phosphorus not only to agriculture and soil conservation but also to the physical health and economic security of the people of the nation.

Phosphorus Fertilizers: Past



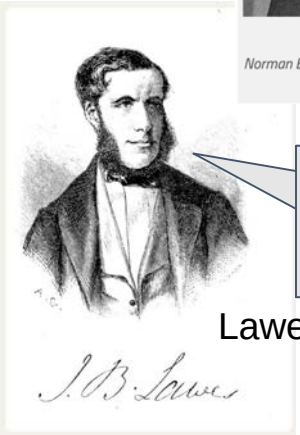
"Green Revolution" = high yield crops + water + fertilizer





Norman Borlaug

Photo: NTB scanpix
Norman Borlaug was awarded the Nobel Peace Prize in 1970 for his work to stop hunger.



Lawes

Hey! What about us?

Gilbert

Henry Gilbert, portrait by his brother Josiah, c.1840

Phosphorus & Water: Past

A Relation of an Inland-Sea, near Danzick, *yeilding at a certain season of the year a green substance, which causeth certain death; together with an Observation about white Amber: Communicated by Mr.* Kirkby, *in a Letter written to the Publisher from* Danzick Decemb. 19. 1671.

PHILOSOPHICAL TRANSACTIONS: GIVING SOME ACCOMPT OF THE PRESENT Undertakings, Studies, and Labours OF THE INGENIOUS IN MANY CONSIDERABLE PARTS OF THE WORLD

Vol I.
For *Anno* 1665, and 1666.

In the *SAVOY*,
Printed by *T. N.* for *John Martyn* at the Bell, a little without *Temple-Bar*, and *James Allestry* in *Duck-Lane*, Printers to the *Royal Society*.

the Cole-pearch. The water ſvveet and vvholeſome; but only in the three Summer months, June, July, and Auguſt, it becoms every year, during the dry weather, green in the midle vvith an hairy effloreſcence; vvhich green ſubſtance, being by ſome violent vvind forced a ſhore, and vvith the vvater drunk by any Cattel, Dog, or Poultry, cauſeth certain and ſudden death;

ELSEVIER
Toxicon
Volume 108, 15 December 2015, Pages 285-286

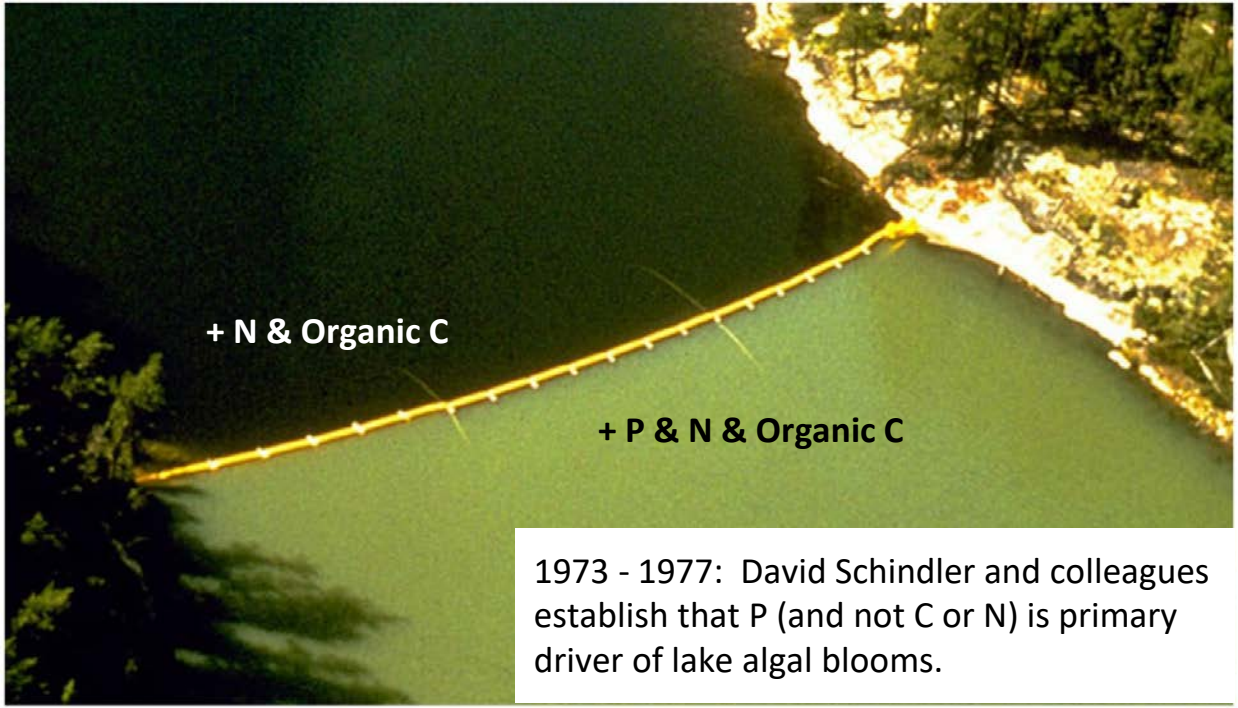
Correspondence

Publication in 1672 of animal deaths at the Tuchomskie Lake, northern Poland and a likely role of cyanobacterial blooms

Geoffrey A. Codd, Marcin Pliński, Waldemar Surosz, John Hutson, Howard J. Fallowfield

The water sweet and wholesome, but only in the three summer months…it becomes every year, during the dry weather, **green** in the middle with a hairy efflorescence; which **green substance**, being by some violent wind being forced ashore, and with the water drunk by any cattle, dog, or poultry, **causeth certain and sudden death**."

Phosphorus & Water: Past



1973 - 1977: David Schindler and colleagues establish that P (and not C or N) is primary driver of lake algal blooms.

An experiment in Lake 226 to test eutrophication. Carbon and nitrogen were poured into a lake with a curtain in the middle. Phosphorus was added to one side which caused it to cloud with algae. IISD EXPERIMENTAL LAKES AREA

IER 2008 VOL 322 SCIENCE www.scie
Published by AAAS

Phosphorus & Water: Past

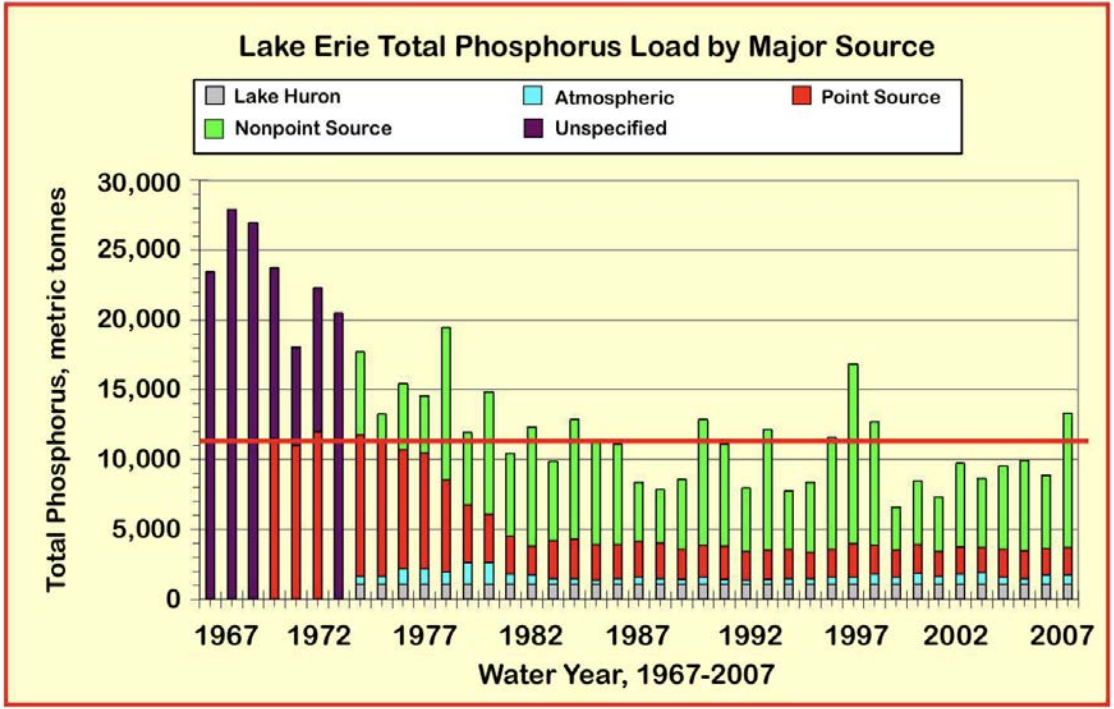


Figure 3— Annual loading of total phosphorus to Lake Erie, 1967 – 2007.
(Historical data from David Rockwell, U.S.EPA and David Dolan, University of Wisconsin Green Bay. Data from 2002-2007 are based on personal communication from David Dolan to David Baker, Heidelberg University. Graph prepared by David Baker)

Phosphorus & Sustainability: The Past is Present & The Future is NOW

So here we are.

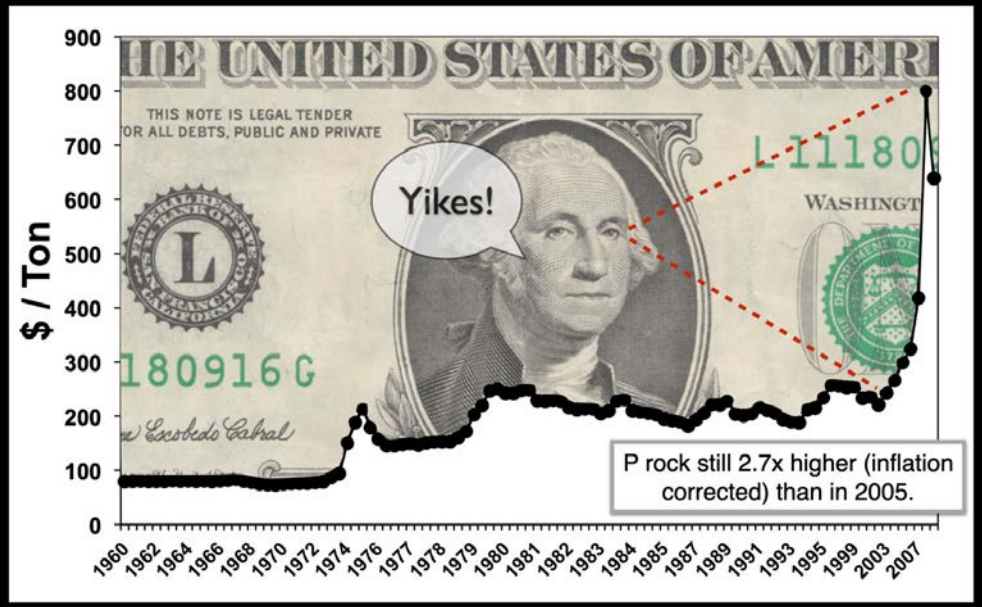
We solved the “easy” phosphorus problems of the **past**.

- Need more yield? Add P to soil.
- Lakes too green? Reduce the point sources of P.

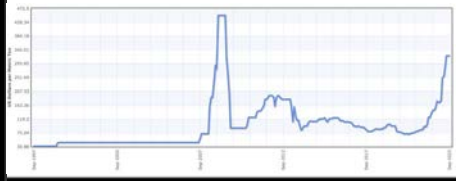
Now we have the wicked problem:

Increase food production while protecting drinking water and aquatic biodiversity.

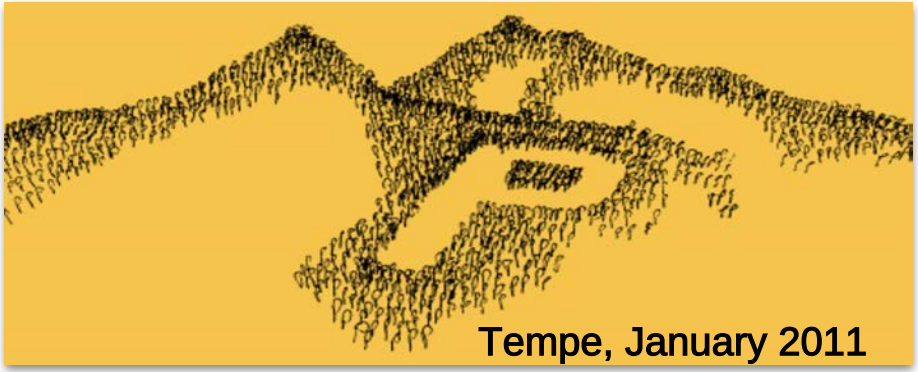
A wicked wake up call.

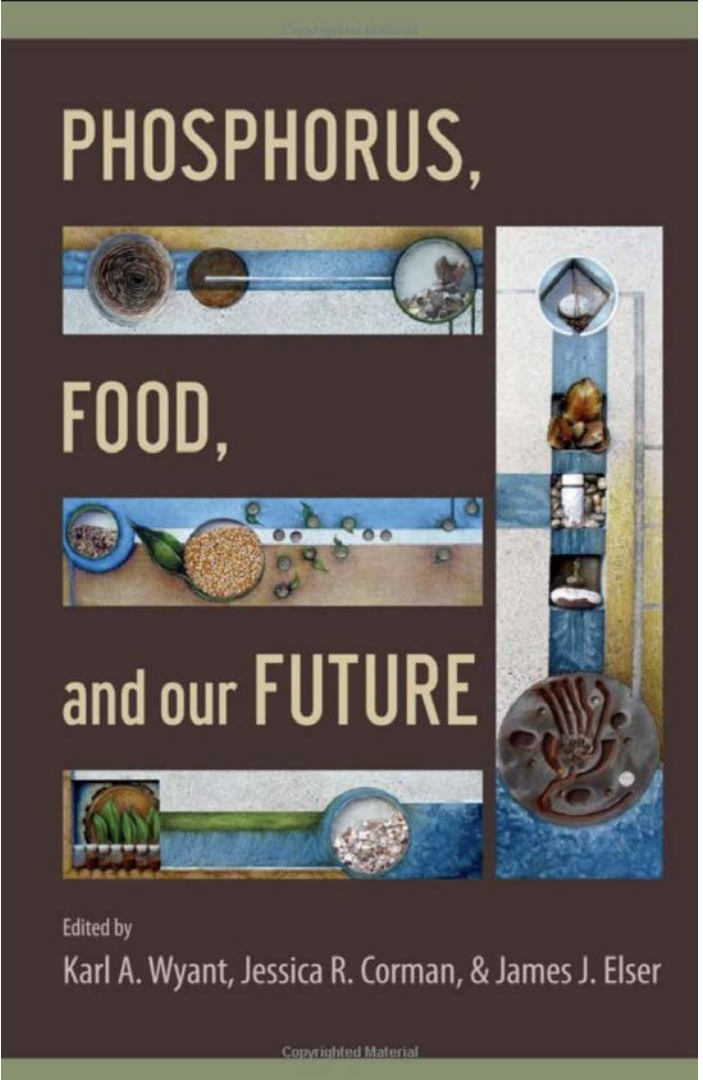


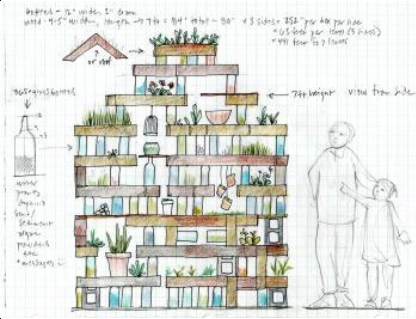
From: Elser and White. Foreign Policy magazine (online, 4/22/10)



Linköping Sweden,
2010



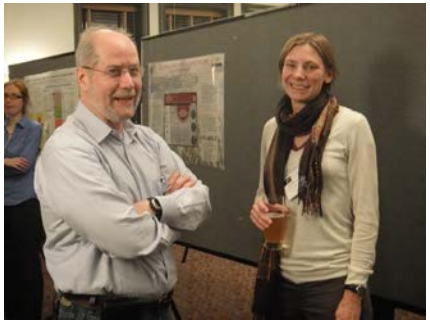




Juried art exhibition
(artist - scientist partners)

Dave Vaccari

Elizabeth Cook



Dan Childers

David Iwaniec

Kimo Van Dijk

Rebecca Hale

Dana Cordell

Arianne Cease

Jess Corman

Elizabeth Cook

Stuart White

Jim Elser

consensus statement

The Phoenix Phosphorus Declaration

We have achieved broad agreement on important issues surrounding phosphorus sustainability challenges and opportunities and seek to raise global awareness about them among all those with a stake in the future of food, water, and the biosphere. All of humanity, and indeed all living species, has this stake.

We find:

- Essential and limited. Phosphorus is essential for all life because it is part of critical molecules like DNA. It is a limited natural resource needed to sustain the vitality and productivity of all ecosystems, including farms.
- Imbalanced cycle. Mining of phosphorus for fertilizer production has massively altered the cycling of phosphorus on Earth. This increased phosphorus use has greatly expanded global capacity for food production but also has led to amplified phosphorus losses from cities, towns, and farms that can lead to degraded water quality, impair freshwater and marine fisheries, and alter natural biodiversity.
- Food security. Phosphorus has a key role in global food security, as reliable access to affordable fertilizer can allow farmers to improve yields and increase quality of life, especially in the developing world.
- Recycle and reuse. Currently, much phosphorus is lost in crop waste, food spoilage, and animal & human waste. Recycling this phosphorus can reduce geopolitical and other uncertainties surrounding phosphorus fertilizer markets and enhance farmer prosperity.
- Reduce demand. Phosphorus natural resources can be extended by improving efficiency of use in agriculture, reducing erosion, limiting losses in mining & industry, and eating lower in the food chain.
- Interconnected. Phosphorus stewardship is coupled to other major global sustainability challenges, including those involving energy, water, and other chemical elements.
- Entrepreneurship. There are great economic opportunities to innovate and create new industries for phosphorus supply diversification and for improved agricultural phosphorus efficiency. However, the suitability of such measures will differ for different environments, cultures, and contexts.
- By closing the human phosphorus cycle and transforming wastes into resources and uncertainty into security, humanity can implement a “new alchemy” in which people become more secure and enjoy greater well-being in a healthy environment.

Participants in the 2011
Sustainable Phosphorus Summit
Tempe, Arizona, USA

Linköping Sweden, 2010

Jim Elser

Philippe Hilsinger

Tina Neset

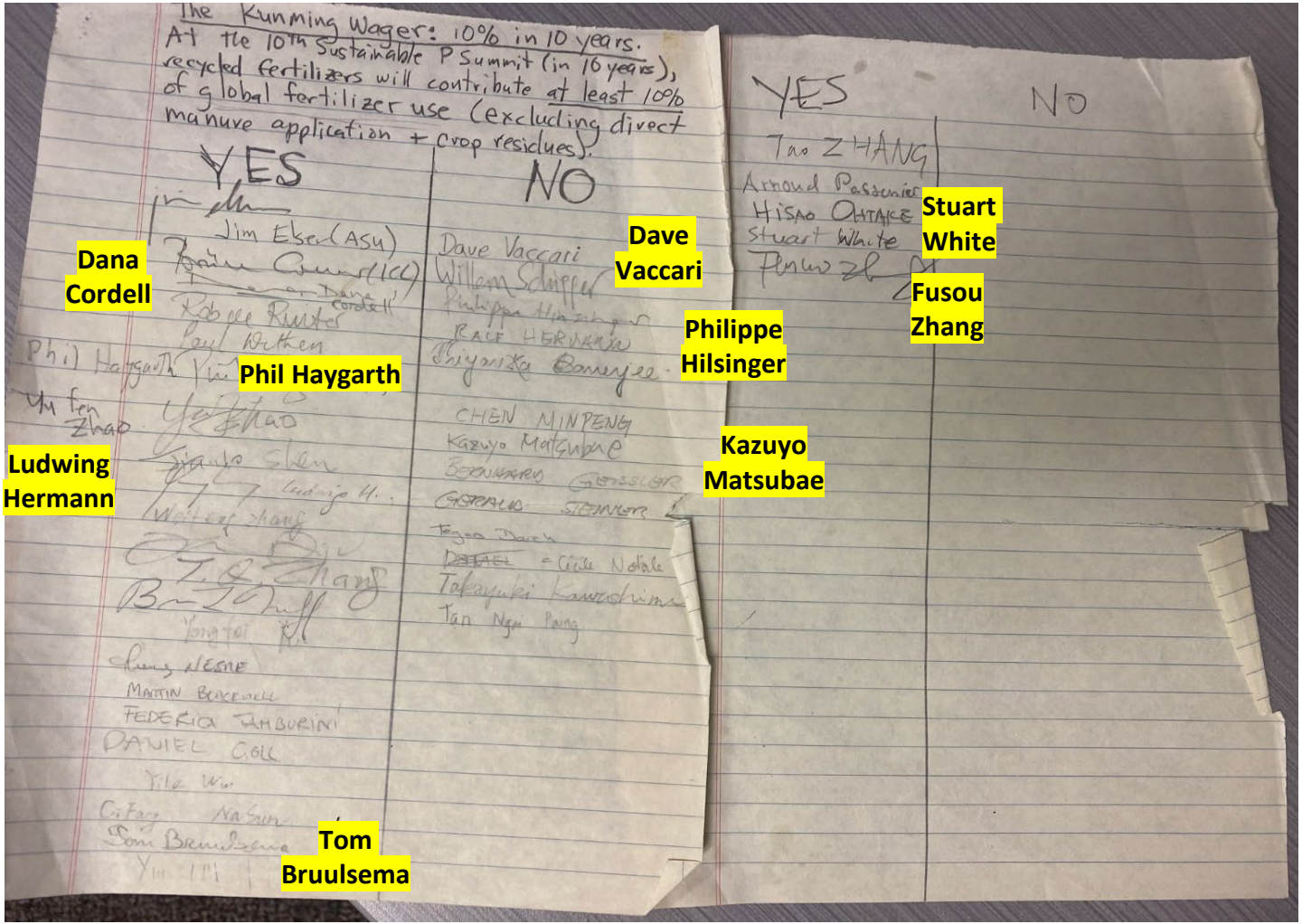
Dana Cordell

Fusuo Zhang

Linköping Sweden, 2009?

"THE KUNMING WAGER
10% in 10 years

At the 10th Sustainable P Summit (in 10 years), recycled fertilizers will contribute <u>at least 10%</u> of global fertilizer use (excluding manure application & crop residues)."



Linköping Sweden, 2010

Organizer:
Vinicius de Melo Benites

6th Sustainable Phosphorus Summit, Brazil, 20-28 August 2018.

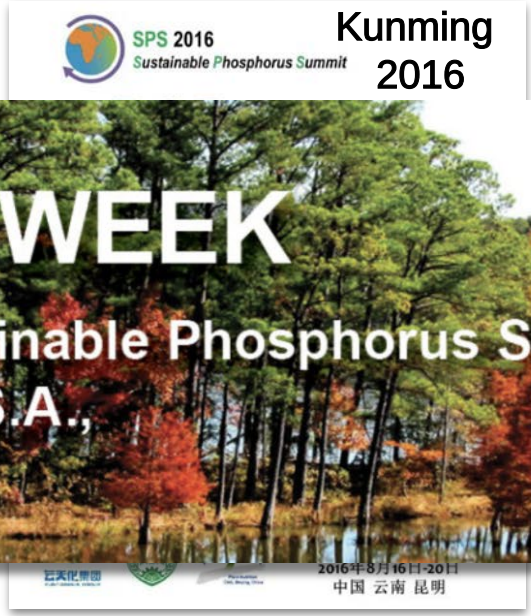
Free full text

Author(s) : Brazil, SUSTAINABLE PHOSPHORUS SUMMIT, 6. , 2018, Brasília, DF
Bulletin; Conference proceedings : Documentos - Embrapa Solos 2019 No.205 pp.unpaginated
Conference Title : 6th Sustainable Phosphorus Summit, Brazil, 20-28 August 2018.

Abstract : This proceedings contains abstracts of papers presented at a conference that brings together diverse science, policy and industry stakeholders from different parts of the food production and consumption chain, to advance knowledge and identify actions regarding the role of phosphorus availability and accessibility in food security and agriculture, protecting the environment, and supporting rural and urban livelihoods. Further, the conference brings together scientists and stakeholders from across the globe, including developing and emerging countries, to foster exchange of views across disciplinary boundaries and societal domains. In order to better improve phosphorus use efficiency along the whole food chain, growing public awareness and re-thinking education and learning on this major issue will also be key.

ISSN : 1517-2627
URL : https://www.infoteca.cnptia.embrapa.b...

Linköping Sweden, 2010



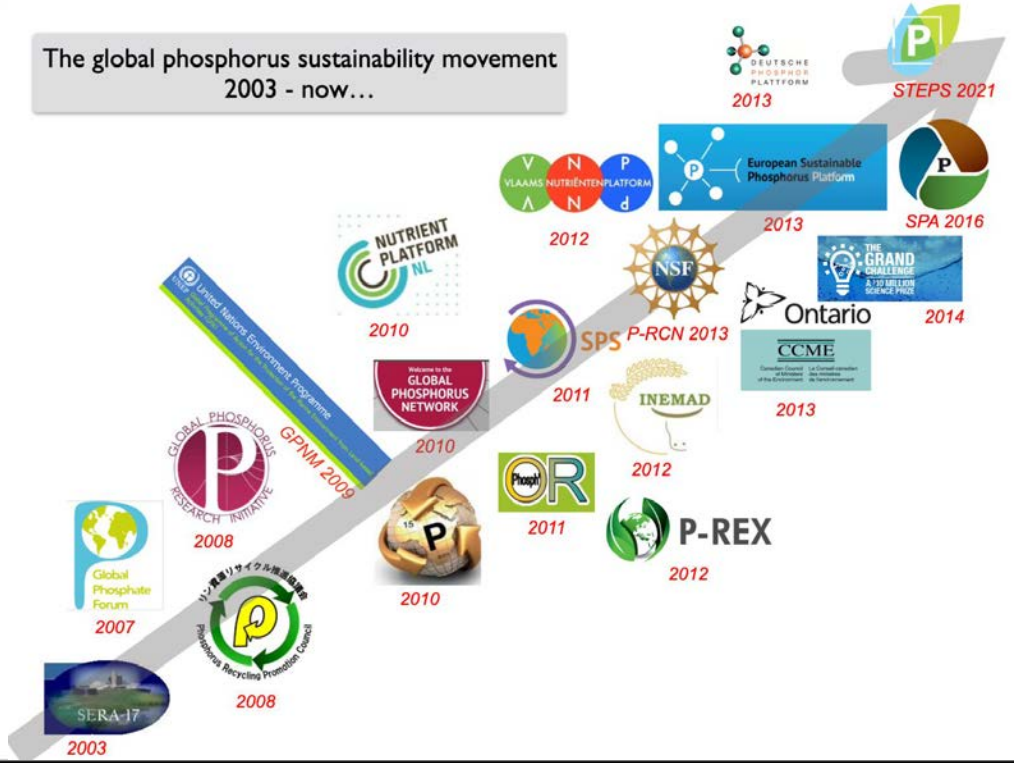
WHERE NEXT?

Africa?

WHO?

If you have ideas, see me or Phil Haygarth before Thurs SPS poster session.

Phosphorus & Sustainability: The Past is Present & The Future is NOW



The future of the world's P system will be shaped in this room.