中國科學院生態環境研究中心
Research Center for Eco-Environmental Sciences, The Chinese Academy of Sciences

**Arsenic contamination in paddy soils and potential amelioration through rhizosphere approaches**

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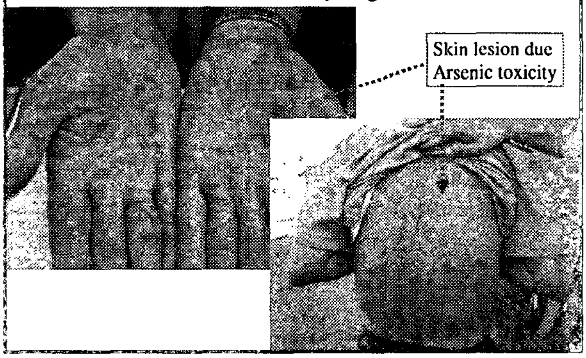
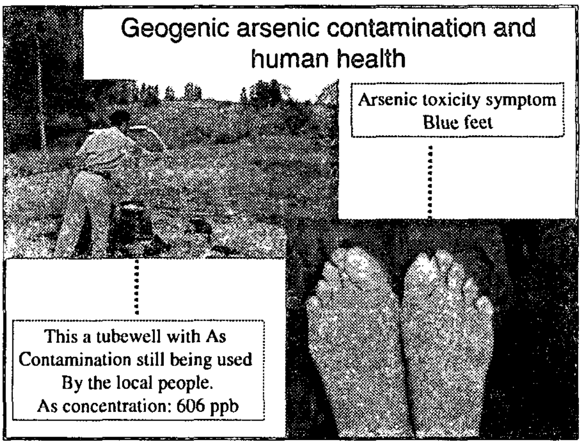
## Sources of arsenic contamination

- Geological sources: mainly through groundwater,such as in Xinjiang and Inner Mongolia;
- Anthropogenic: mining activities, coal burning and agrochemicals; main areas are Guizhou, Yunnan, Hunan and Guangxi provinces (southwest of China)

## Geogenic arsenic contamination and human health-Xinjiang, China




## Geogenic arsenic contamination and human health

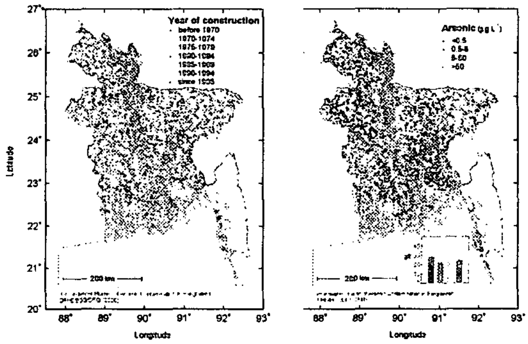



## In Bangladesh

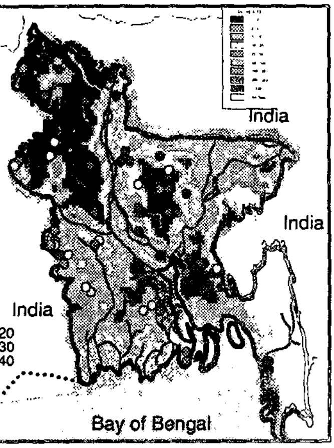
- paddy ice is the main crop and covers about 75% of the total area cropped
- rice is the staple food and rice straw is used as cattle feed
- irrigation of rice is mostly dependent on groundwater, especially during the dry season
- background levels of As in soils are 4-8 mg As/ kg, in areas irrigated with As containing tube-well water soil levels can reach up to 100 mg/kg

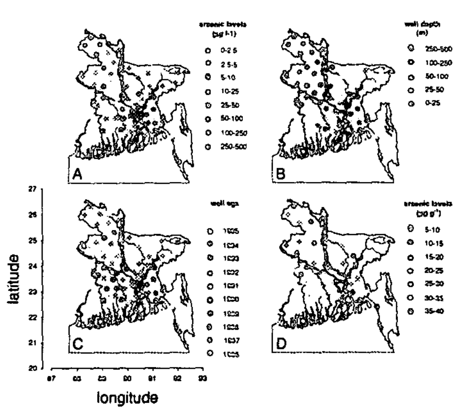
## BGS maps

age of well / arsenic contamination

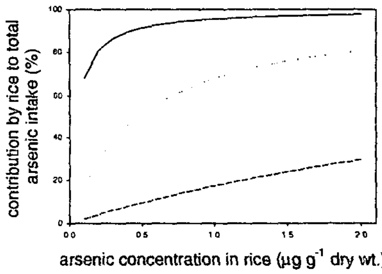


## paddy rice soil survey overlaid with BGS groundwater contamination map



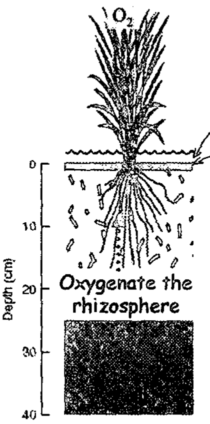

## Arsenic in rice may contribute significantly to human exposure




**Percentage contribution of rice to daily arsenic intake. The percentage daily As intake was calculated using a rice consumption rate of 0.42 kg d$^{-1}$, and that 2 l of groundwater were consumed per day. The solid line is for 0.01 mg l$^{-1}$, dotted line for 0.1 mg l$^{-1}$ and dashed line for 1 mg l$^{-1}$ arsenic in drinking water.**

A study in Bangladesh: Andy Meharg, UK

## Typical profile of paddy soils



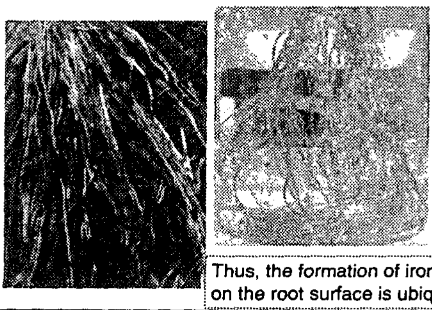

Ofw Layer of standing water occupied by micro and macro-fauna and -flora

Apox Oxic floodwater–soil interface, a few mm to a few cm thick depending on floodwater aeration, soil reducing conditions, mixing by soil animals and percolation

Apg Anoxic soil layer in which pe+pH is below the range at which Fe(III) is reduced, except in the rhizosphere

B Subsoil properties vary with the type of water saturation. In aquic moisture regimes the whole horizon is largely reduced throughout; in epiaquic regimes, where the water table is perched, the horizon generally remains oxic and is mottled along wide pores

## In the rhizosphere, there is a strong oxygenation process



Thus, the formation of iron plaque on the root surface is ubiquitous.

## What are the potential role of iron plaque on root surface??

Iron plaque, mainly iron oxide, may alter the environmental behavior of many nutrient and contaminant ions in the rhizosphere;

- This talk will focus on arsenic: arsenic contamination in paddy soil is a chemical disaster in South-east Asia

## Arsenic in paddy soil

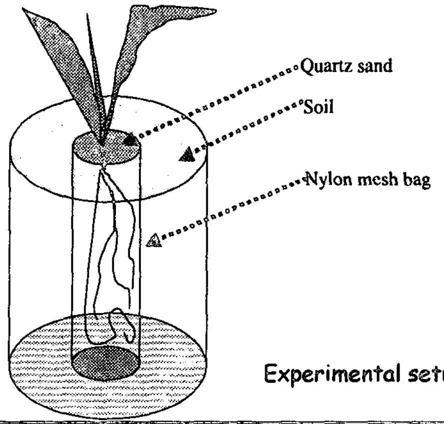
- Arsenate, mainly in aerobic conditions;
- Arsenite, mainly in anaerobic conditions;
- In the rhizosphere of rice plants, arsenite may be converted to arsenate;
- Arsenate has very high affinity for iron oxide, may form iron-arsenate precipitation, and reduce its bioavailability

Arsenic in soil-rice systems thus plays an important role in human health

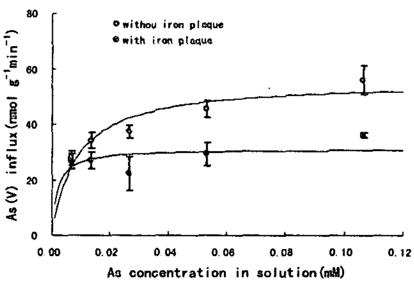
Given the ubiquity of iron plaque on root surface of rice plants, it is critical to understand the role of iron plaque in controlling the dynamics of arsenic in soil-rice systems

## Experiment

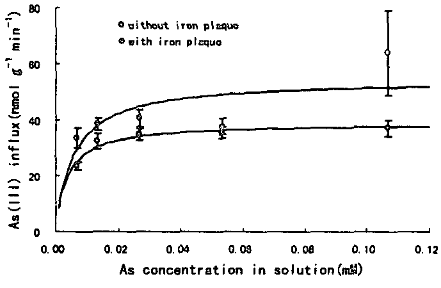
- Rice seedlings grown in mesh bag filled with quartz, surrounded by soil under submerged conditions;
- After a certain period (2 months), seedlings removed from quartz, washed;
- Treatments: roots exercised, some roots washed in DCB to remove iron plaque, others remain iron-coated;
- Uptake experiments, including kinetic study;



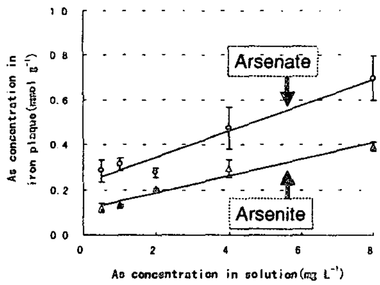

Experimental setup




The presence of iron plaque strongly sequestrate arsenate on the *root surface, thus potential reduce uptake into plant*



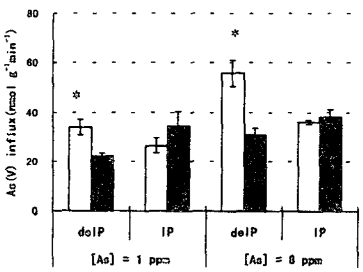

However, the presence of iron plaque slightly increased the uptake of arsenite into rice plant



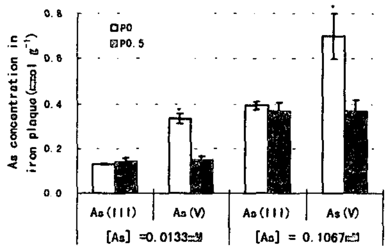

Arsenic sequestration in iron plaque increased with external As concentrations, and arsenate had higher affinity to iron plaque than arsenite

The presence of iron plaque may alter the perceived P-As interactions

Usually P inhibit plant uptake of arsenate due to the chemical similarity between the two ions



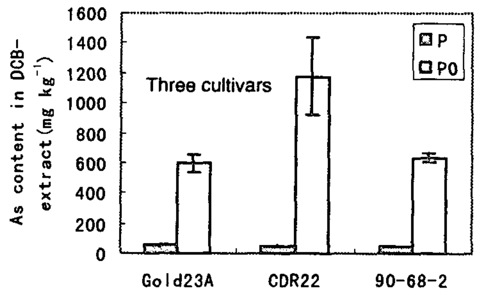

With the presence of iron plaque, phosphate did not affect Arsenate influx, however, without iron plaque the addition of Phosphate reduced arsenate influx significantly



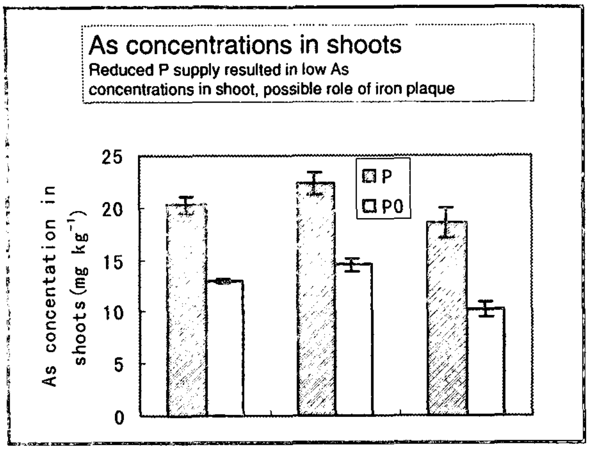

Phosphate desorb arsenate from iron plaque but not arsenite

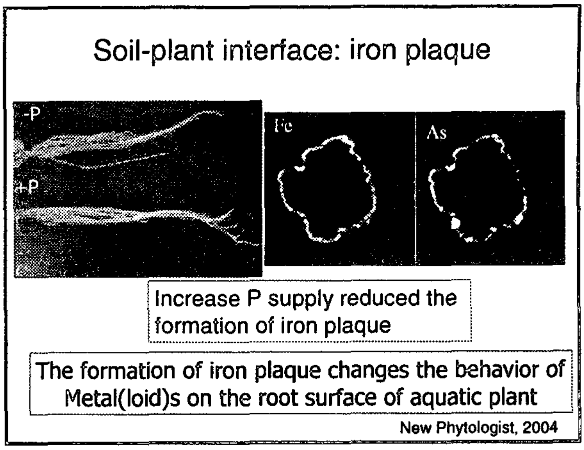
Phosphate nutrition could alter the formation of iron plaque

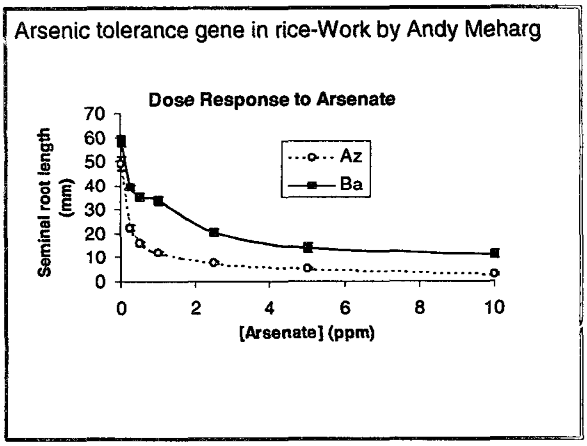
As concentrations in iron plaque (DCB-extracts)

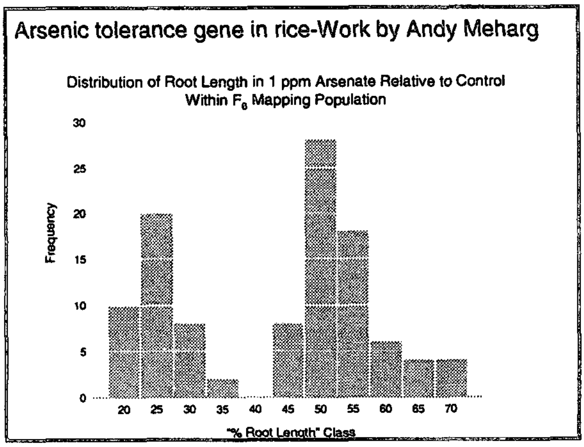


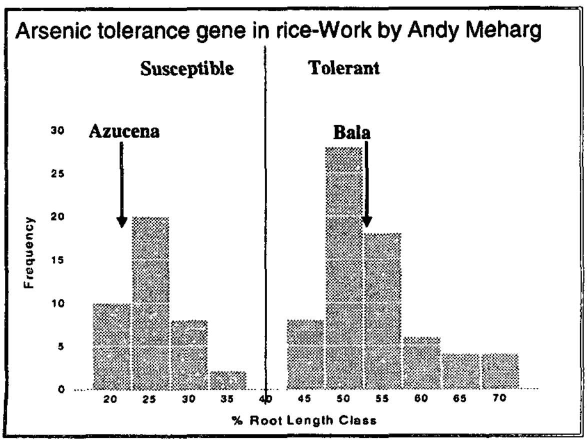

Low P treatment promote the formation of iron plaque

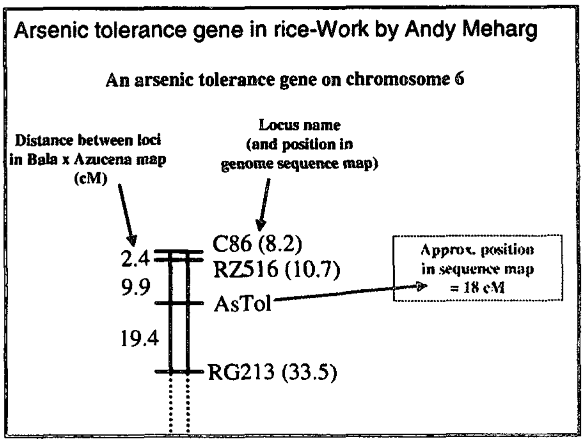

As concentrations in shoots
Reduced P supply resulted in low As concentrations in shoot, possible role of iron plaque
As concentation in shoots (mg kg-1)
25
20
15
10
5
0
P
P0


Soil-plant interface: iron plaque
-P
+P
Fe
As
Increase P supply reduced the formation of iron plaque
The formation of iron plaque changes the behavior of Metal(loid)s on the root surface of aquatic plant
New Phytologist, 2004


Arsenic tolerance gene in rice-Work by Andy Meharg
Dose Response to Arsenate
Seminal root length (mm)
70
60
50
40
30
20
10
0
Az
Ba
0
2
4
6
8
10
[Arsenate] (ppm)

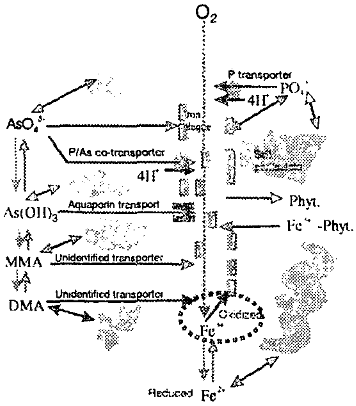

Arsenic tolerance gene in rice-Work by Andy Meharg
Distribution of Root Length in 1 ppm Arsenate Relative to Control
Within F6 Mapping Population
Frequency
30
25
20
15
10
5
0
20 25 30 35 40 45 50 55 60 65 70
"% Root Length" Class


Arsenic tolerance gene in rice-Work by Andy Meharg
Susceptible
Tolerant
Azucena
Bala
Frequency
30
25
20
15
10
5
0
20 25 30 35 40 45 50 55 60 65 70
% Root Length Class


Arsenic tolerance gene in rice-Work by Andy Meharg
An arsenic tolerance gene on chromosome 6
Distance between loci in Bala x Azucena map (cM)
Locus name (and position in genome sequence map)
2.4
9.9
19.4
C86 (8.2)
RZ516 (10.7)
AsTol
RG213 (33.5)
Approx. position in sequence map = 18 cM

To sum-up

- Iron plaque ubiquitous on rice roots;
- Iron plaque can sequestrate As on the root surface, thus affect As uptake into roots;
- Iron plaque acts as a "buffer" for As in soil-rice systems;
- More information is needed;

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- Professors Sally Smith, Andrew Smith (Australia) for stimulating discussions;

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It is generally accepted that arsenic (As) is a toxic and carcinogenic element that occurs widely in soil environments around the world. As enters into soil environments through both natural and anthropogenic pathways. Irrigation of agricultural land with As-contaminated wastewater or groundwater, particularly in Bangladesh, India and South-East Asia, causes the accumulation of As in both soils and plants, and poses long term risks to soil ecosystems and human health. Paddy rice (*Oryza sativa* L.) is the most popular staple food crop in South-East Asia countries such as Bangladesh, West Bengal, China and Thailand, from where large populations are suffering from elevated arsenic in soils, groundwater and food crops, such as rice. In some areas of Bangladesh, the worst affected country, groundwater As concentrations reached 2 mg $L^{-1}$, while the WHO provisional guideline value for drinking water is only 0.01 mg $L^{-1}$. The chronic arsenic poisoning by drinking tube well water and consuming arsenic-contaminated food has become a severe natural disaster in South-East Asia. Understanding how arsenic is taken up by rice plants is of vital importance for the development of efficient strategies (eg. either conventional breeding or genetic engineering) for reducing arsenic accumulation in rice plants. The present paper will discuss the role of rhizosphere processes, particularly rhizosphere oxygenation in controlling the dynamics of As in soil-rice systems.