Impact of soil arsenic on rice yields in Bangladesh

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Arsenic contamination of irrigation water is widespread.

Duxbury 2007, FAO Working Paper
Arsenic in irrigation water builds up in soil.

Fe oxides

Decreasing soil arsenic
Arsenic in irrigation water builds up in soil

Fe oxides

Panaullah 2009, Plant and Soil
Arsenic in soil decreases rice yields

Grain Yield (t/ha) vs. Soil As (mg/kg)

- Far from well
- Near well

Equations:

- Far from well: \( y = -0.11x + 10.6 \), \( R^2 = 0.91 \)
- Near well: \( y = -0.09x + 8.3 \), \( R^2 = 0.91 \)

References:
- Panaullah 2009, Plant and Soil
- Abedin 2002, ES&T
Our goal is to document more widely the effect of arsenic on boro and aman rice yield
Boro rice is the dominant crop in Bangladesh in terms of production and caloric consumption.

Calpe 2006, FAO Working paper
Boro rice
- Jan – May
- Groundwater irrigated
- Transplanted
- Few varieties

Aman rice
- May - Nov
- Rainfed
- Transplanted or broadcast
- Many varieties
Our goal is to document more widely the effect of arsenic on rice yield by:

1. Exchanging soil between high- and low-arsenic plots in farmers’ fields

2. Measuring the difference in yield and soil arsenic between adjacent soil replacement and control plots
How does altering soil arsenic concentration affect rice yields?
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How does altering soil arsenic concentration affect rice yields?
We identified high-arsenic and low-arsenic plots.
Soil replacement increased arsenic in low-As plots.

![Graph showing increased arsenic with soil replacement.](image-url)

- **Low As** and **High As** samples are compared across different depths.
- The y-axis represents depth (cm) and the x-axis represents Kit Extractable As (mg/kg).
- The graph indicates a significant increase in arsenic levels in the replaced layer.
Soil replacement decreased arsenic in high-As plots.
Look at differences between matched pairs of plots.
Look at differences between matched pairs of plots

\[
\text{Soil As}_{\text{Replaced}} - \text{Soil As}_{\text{Control}} = \text{Difference in Soil As}
\]
Look at differences between matched pairs of plots

Soil As\textsubscript{Replaced} - Soil As\textsubscript{Control} = Difference in Soil As

Rice Yield\textsubscript{Replaced} - Rice Yield\textsubscript{Control} = Difference in Rice Yield
Arsenic decreased in high-arsenic plots and increased in low-arsenic plots.

XRF Total Soil Arsenic (mg/kg)
Replaced - Control
Arsenic decreased in high-arsenic plots and increased in low-arsenic plots.
Boro yield difference correlates with soil As difference

\[ y = -0.057x + 0.33 \]

\[ R^2 = 0.46 \]

\[ p = 0.01 \]
BR 29 yield difference correlates with soil As difference

\[ y = -0.057x + 0.38 \]

\[ R^2 = 0.55 \]

\[ p = 0.02 \]
Slope of BR 29 yield-arsenic relationship is somewhat lower than previously observed.

\[ y = -0.057x + 0.38 \]
\[ R^2 = 0.55 \]
Arsenic may decrease boro rice yields by 10-15% nationally.
Plant As correlates with soil As in top 5 cm

\[ y = 0.23x + 0.33 \]
\[ R^2 = 0.46 \]
\[ p = 0.01 \]
Grain As is not easily predicted from soil As

Panaullah 2009, Plant and Soil
Effect of soil replacement can still be seen during aman season.
Yield increased in high-arsenic plots and decreased in low-arsenic plots

XRF Total Soil Arsenic (mg/kg)
Replaced - Control
Yield increased in high-arsenic plots and decreased in low-arsenic plots

XRF Total Soil Arsenic (mg/kg)
Replaced - Control

Rice Yield (t/ha)
Replaced - Control
Aman yield difference correlates with soil As difference

\[ y = -0.025x + 0.01 \]

\[ R^2 = 0.23 \]

\[ p = 0.02 \]
BR 39 yield difference does not correlate with soil As difference

$R^2 = 0.05$
A field kit can be used to identify As-contaminated soils
Kit As correlates with As measured by XRF

\[ R^2 = 0.48 \]
Boro yield difference correlates with kit As difference

\[ y = -0.12x + 0.97 \]

\[ R^2 = 0.77 \]

\[ p < 0.001 \]
Soil removal from rice fields already occurs and could mitigate soil arsenic
In a “soil flip”, we move deep, low-As soil to the surface.
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High Arsenic
0-15 cm

Medium Arsenic
15-30 cm

Low Arsenic
30-45 cm
In a “soil flip”, we move deep, low-As soil to the surface
In a “soil flip”, we move deep, low-As soil to the surface
We identified high-arsenic and low-arsenic plots.
Soil flip decreased surface arsenic in high-As plots.
Soil flip decreased surface arsenic in low-As plots

**Kit Extractable As (mg/kg)**

**Depth (cm)**
Soil flip plots have lower concentrations of some nutrients

- **Nitrogen (%):**
  - Control: Lower value
  - Flip: Higher value

- **Organic Carbon (%):**
  - Control: Lower value
  - Flip: Higher value

- **Phosphorus (µg/g):**
  - Control: Lower value
  - Flip: Higher value
Soil arsenic negatively impacts rice yields
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Arsenic may decrease boro rice yields by 10-15% nationally
Soil arsenic negatively impacts rice yields

Arsenic may decrease boro rice yields by 10-15% nationally

Field kit allows on-site measurements of soil As
Soil arsenic negatively impacts rice yields

Arsenic may decrease boro rice yields by 10-15% nationally

Field kit allows on-site measurements of soil As

Farmers may be able to target high-As soil for removal
Aman yield difference weakly correlates with soil As difference

\[
y = -0.012x - 0.077
\]

\[
R^2 = 0.26
\]

\[
p = 0.012
\]
Yield and soil As are uncorrelated
Difference in yield does not correlate with difference in soil As
Difference in yield correlates with difference in soil As

\[ y = -0.12x + 1.09 \]
\[ R^2 = 0.88 \]

\[ y = -0.18x + 0.79 \]
\[ R^2 = 0.81 \]
Design controlled for other factors affecting yield:

- Fertilizer application (TSP, MP, gypsum, zinc, boron)
- Pesticide application
- Farmer care (e.g. weeding)
- Rice variety
- Transplanting date
- Harvesting date
- Local conditions (shade, shelter from wind/rain, etc.)
- Irrigation water arsenic
Yield and potassium are strongly correlated

\[ y = 38.02x + 1.04 \]

\[ R^2 = 0.49 \]
Rice yields declined with increasing soil As

Grain yield (g/pot)

Arsenic soil amendment (mg/kg)

BR29

All rice varieties

Williams 2009, ES&T
Plant As correlates with soil As in top 5 cm

**BR29**

\[ y = 0.31x + 0.74 \]

\[ R^2 = 0.55 \]

**BR28**

\[ y = 0.09x + 0.46 \]

\[ R^2 = 0.78 \]
Two ways of measuring soil As
During the growing season: soil arsenic profiles were measured monthly at each plot.
At harvest: four composited arsenic measurements were made at each plot.
Both measurements of soil As are weakly predictive of soil plant As

Soil As During Growing Season

\[ y = 0.276x - 0.069 \]
\[ R^2 = 0.263 \]

n = 13
slope = 0.276 ± 0.140

Soil As At Harvest

\[ y = 0.170x - 0.847 \]
\[ R^2 = 0.232 \]

n = 13
slope = 0.170 ± 0.093
In contrast, “harvest” soil As is much more predictive of yields.

Soil As During Growing Season

\[ n = 13 \]
\[ \text{slope} = -0.119 \pm 0.021 \]

Soil As At Harvest

\[ n = 16 \]
\[ \text{slope} = -0.090 \pm 0.044 \]
“Harvest” soil As is consistently higher than “growing season” soil As
Can a field kit give farmers an easy way to test their soils?

- 0.5 g soil
- 50 mL water
- 10 minute extraction
Arsenic concentrations decrease away from irrigation inlet
Arsenic concentrations in irrigation water decrease away from the water inlet.
Nutrients don’t differ between replaced and control plots

**Graphs showing nutrient comparison**

- **P Control vs. P Replaced**
- **N Control vs. N Replaced**
- **OC Control vs. OC Replaced**
- **K Control vs. K Replaced**
- **S Control vs. S Replaced**
- **Zn Control vs. Zn Replaced**
Rice is grown in continuously flooded conditions and requires significant water inputs