"Towards a mechanistic understanding of the impact of volcanic ash on plants and soils"

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Towards a mechanistic understanding of the impact of volcanic ash on plants and soils

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Terrestrial ecosystems
Tephra impact on vegetation
Objective:

to investigate experimentally the main factor dictating the impacts of tephra on plant leaf physiology
Plant species chosen for the experiment

**Rice**
- Hairless leaves
- Stomata on the upper and lower surfaces

**Tomato**
- Pubescent leaves
- Stomata on the lower surface
CO$_2$ enters leaf through stomata
Experimental procedure: growth conditions

1. Seed germination
2. Transfer to hydroponic solution
3. 1st tephra application
4. 2nd tephra application
5. 1st measurement
Experimental procedure: tephra application

250 μm

29.5 cm

135 cm

25 grams of tephra/box

2 plants/box
Physical damage of the plant: decreased growth
Lower biomass of tephra-treated plants

Control plants

Tephra-treated plants

50-70% decrease

40-80% decrease

Number of days after the first tephra application
Lower sugar content in tephra-treated plants

Total solubility sugar content (mg/gMF)

Control plant

- Shoots: Green diamonds
- Roots: Red circles

Tephra-treated plant

- Shoots: Green diamonds
- Roots: Red circles

Number of days after the first tephra application
CARBON DIOXIDE
WATER
ENERGY

GLUCOSE
Energy source
Lower chlorophyll content in tephra-treated leaves

<table>
<thead>
<tr>
<th>Number of days after the first tephra application</th>
<th>Total Chlorophyll (mg/gMF)</th>
<th>Control</th>
<th>Tephra covered plants</th>
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Total Chl decrease by 27-45 %
Light green color of tephra-treated leaves

Control plant  Tephra-treated plant
Good photosynthetic efficiency

Number of days after the first tephra application

Control

Tephra covered leaves
Short-time tephra effect

Gas exchange disfunction

Downregulation of photosynthetic activity

Photosynthesis (μmol.m⁻².s⁻¹)

Stomatal conductance (mmol.m⁻².s⁻¹)

Number of days after the first tephra application

Control

Tephra covered leaves
Adaptation development

Stomatal conductance (mmol.m\(^{-2}\).s\(^{-1}\))

Photosynthesis (μmol.m\(^{-2}\).s\(^{-1}\))

Number of days after the first tephra application

- Control
- Tephra covered leaves

Stabilization of photosynthetic activity

Gas exchange regulation
Light stage

Water + light = chemical energy

Light → H₂O → chemical energy → O₂
Light stage

Water + light = chemical energy

Dark stage

Chemical energy + CO₂ = sugar

Light \rightarrow H₂O \rightarrow \text{chemical energy} \rightarrow O₂ \rightarrow CO₂ \rightarrow \text{sugar}
Light stage

Water + light = chemical energy

Chemical energy + CO₂ = sugar

Dark stage

Control  Tephra covered leaves

CO₂

sugar

\[ \text{CO}_2(i) \text{(μmol.mol}^{-1}) \]

Number of days after the first tephra application

250  270  290  310  330  350  370  390  410

0  5  10  15

21
Conclusions: plant response to tephra stress

Direct effect
5-7 days

Plant resistance: avoidance
- Stomatal closure
- Heat shock
- Pigment degradation
  - Decreased photoprotection function!
  - Down-regulation of photosynthetic activity!

Acquired resistance
7-14 days

Plant resistance: tolerance
- Thermal regulation
- Activation of antioxidant system
- Stabilization of photosynthetic efficiency
- Pigment degradation
- Higher CO₂ concentration

Decreased sugar synthesis
Impact of tephra deposition on water infiltration in soil
Rain-induced crusts effect on soils

- Infiltration
- Run-off
- Water erosion
- Gas exchange
  Seed emergence

*time*
Tephra types for the experiment

- **San-Cristobal, 2000**: 6.8% < 2 μm
- **EYJA, 2010**: 3.4% < 2 μm
- **Merapi, 2010**: 8% < 2 μm
Experimental set-up

- Rainfall simulator (needles)
- Pump
- Tephra columns
- Rotating plate
- Electrical motor
Objective:
to assess the mechanisms of formation of tephra crusts by looking at their morphological properties
Rainfall initiation: distinct pellet formation (MER, SC)

Stage 1: 5 mm of rain

Stage 2: 10 mm of rain

Stage 3: 15 mm of rain

Stage 4: 20 mm of rain
Tephra surface characteristics

Rainfall initiation

Stage 1: 5 mm of rain

Stage 2: 10 mm of rain

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Stage 4: 20 mm of rain
Microscopic analysis: tephra crust continuity
Image analysis: crust tephra porosity

Cumulative rainfall (mm) vs. Porosity (%)

- MER
- SC
- EYJA
- undisturbed layer
Image analysis: crust tephra porosity

Porosity (%) vs Cumulative rainfall (mm)

- MER
- SC
- EYJA
- undisturbed layer
Main crust formation processes: MER

Stage 1: 5 mm of rain
Stage 2: 10 mm of rain
Stage 3: 15 mm of rain
Stage 4: 20 mm of rain

Splash erosion
Vertical particle sorting
Vertical particle sorting
Particle sedimentation from suspension
Main crust formation processes: SC

Stage 1: 5 mm of rain
Stage 2: 10 mm of rain
Stage 3: 15 mm of rain
Stage 4: 20 mm of rain

Splash erosion
Compaction
Minor vertical particle sorting
Main crust formation processes: EYJA

Stage 1: 5 mm of rain
Stage 2: 10 mm of rain
Stage 3: 15 mm of rain
Stage 4: 20 mm of rain
Image analysis: tephra crust thickness

![Graph showing the relationship between cumulative rainfall and crust thickness for different sites]

- **MER**
- **SC**
- **EYJA**
- **EYJAAa**

Crust thickness (mm) vs. Cumulative rainfall (mm)
Image analysis: tephra crust thickness

Crust thickness (mm) vs. Cumulative rainfall (mm)

- MER
- SC
- EYJA
- EYJAAa
Image analysis: tephra crust thickness

![Graph showing crust thickness vs. cumulative rainfall for different locations: MER, SC, EYJA, EYJAa. The x-axis represents cumulative rainfall in mm, and the y-axis represents crust thickness in mm. The graph includes error bars for each data point.](image-url)
Conclusions

1) Main mechanisms:
   Rainsplash erosion and vertical particle segregation
2) Formation of critical crust depth

1) Main mechanisms:
   Rainsplash erosion and compaction
2) Initiation of critical crust depth

1) Main mechanism:
   Rainsplash erosion
2) No evidence of critical crust depth development

MER
D50=30 µm

SC
D50=38 µm

EYJA
D50=80 µm
Tephra impact on soil bioweathering
Coniferous forest
Elevation: 1755 m.

Sicily, Etna
Thank you for your attention!
Objectives:

(1) to identify the ways of fungi-tephra interaction;
(2) to assess the effect of fungi on biochemical and biophysical weathering of tephra;
(3) to assess the response of organic matter and weathering to a tephra-mediated increase in soil fungal activity.
Fungal colonization

A. Fluorescence Microscopy

B. Scanning Electron Microscopy
Volcanic soil profile

Fungal activity

- 2014
- 2015
Volcanic soil profile

- Fungal activity
- Fungi origin

Fungi origin:
- *Pseudotomentella* sp. (Basidiomycota)
- *Russula* sp. (Basidiomycota)
- *Ceratobasidium* sp. (Basidiomycota)

Fungal activity profile:
- Biofilm development
- Biomass accumulation

Graph showing:
- Fungal biomass (µg/g) over depth (cm)
- Fungal species distribution

- Tephra
- Fungi colonized tephra
- Soil
- Ash

Species distribution colors:
- Ceratobasidium sp. (Basid.)
- Russula sp. (Basidomycota)
- Pseudotomentella sp. (Basid.)
Volcanic soil profile

Fungal activity
Fungi origin
Tephra weathering

Fungal biomass (μg/g)

Depth (cm)

Fungal species

TRB (cmolc/kg)

- Ceratobasidium sp. (Basid.)
- Russula sp. (Basidomycota)
- Pseudotomentella sp. (Basid.)
Fungi enhanced chemical weathering?

Electron microprobe analysis

![Image showing electron microprobe analysis with measurements and oxides percentage chart.](image-url)
Conclusions

The results of microscopic and molecular analyses demonstrate that tephra colonization by fungi started less than 1 year after the eruption.

There is evidence of physical penetration of fungi into tephra. However, there is no indication of fungi-driven chemical weathering of tephra after two years following deposition.
• Pinatubo ash → sieved with a 250 μm mesh

Physiological measurements, extractions, ...

→ What are the impacts of tephra deposits?