Earthworms as Ecoengineers in the Restoration of Oil and Brine-Impacted Soils Following Remediation

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Remediation of Oil and Brine Spills

- Oil
  - Fertilizer
    - Increase rates
    - Prevents depletion of soil nutrient pool
  - Organic matter
    - Increases O_2 infiltration
    - Decay products help rebuild soil structure
    - Substrate for soil fauna
  - Tilling
    - Aeration
    - Mixing
    - Distribute oil in the soil to create more oil-water interface

Remediation of Oil and Brine Spills

- Brine
  - Organic matter
    - Increases permeability to water
    - Decay products help rebuild soil structure
    - Substrate for soil fauna
  - Tilling
    - Mixing
    - Improving permeability
  - Fertilizer
    - Promote biodegradation of organic matter
    - Prevents impact on soil nutrient pool
  - Gypsum
    - Combat sodicity

Restoration of Oil- and Brine-impacted Sites

- Both the original spill and the remediation process disrupt soil ecology
  - Disruptions in N and P cycling
  - Reduced diversity of soil microbes and invertebrates
  - Loss of vegetation
- All levels of ecosystem affected
  - Producers
  - Consumers
  - Decomposers
- Is restoration of the soil ecosystem the real definition of "clean" for a high value site?
  - Left to nature restoration is a lengthy process

Increasing the Rate of Restoration of Soil Ecosystems

- Are earthworms the answer?
  - Earthworm castings
    - contain higher concentrations of SOM and bioavailable nutrients than the surrounding bulk soil
    - exhibit greater microbial activity and higher rates of respiration than bulk soil
    - lead to the formation of stable soil aggregates which increase the permeability of the soil to air and water
  - Earthworm burrows create pathways for root growth, water movement, and nutrient transport
  - Earthworm-related effects stimulate the uptake of nutrients by plants which results in increased growth rates of plants and greater levels of biomass
  - All of these effects are in proportion to the density of earthworms in the soil and can persist for long periods of time

Project Objectives

- Determine the appropriate amendments to optimize the re-introduction of earthworms to oil- and brine-impacted sites which have been remediated but not fully restored.
- These data will
  - Lead to a cost-effective protocol for re-introduction and cultivation of earthworms in these sites
  - Demonstrate the benefits of earthworm re-introduction on re-vegetation of these sites in terms of increased plant biomass and greater species diversity.

Previous Work (Callaham et al., 2002*)

- Greenhouse study of the survival and effects of earthworms (***Eisenia fetida)*** in landfarm soil containing TPH concentrations averaging 33,000 mg/kg.
- Results:
  - earthworms will survive in bioremediated soil with high residual TPH concentrations;
  - organic matter is necessary for their long-term survival;
  - earthworm activity resulted in greater accumulation of above- and below-ground plant biomass.

*Env. Toxicology and Chem., **21**, 1658-1663 (2002)

Results of 17-d Test to Determine Sensitivity of the Earthworm *Eisenia fetida* to NaCl in soil*

Added NaCl (g/kg of soil)	Fraction of replicate microcosms showing evidence of reproduction*	Mean survival (%)
0	4/4	90.0
1	4/4	95.0
3	2/4	90.0
5	0/4	97.5
7.5	0/4	95.0
10	0/4	95.0
15	0/4	90.0

*Art Stewart (Oak Ridge National Lab)

Test Sites

- G7
  - 2000 spill of produced fluids (W/O ratio of 10-15)
  - Four treatments: combinations of hay, fertilizer (13:13:13), and no treatment
  - Treatment terminated in 2004
- LF
  - Site of crude oil landfarm closed in 1997
  - Final TPH (EPA 418.1) < 9000 mg/kg

Treatments / Experimental Design

- Worms only
- Fertilizer only
- Hay only
- Worms + Hay
- Worms + Fertilizer
- Fertilizer + Hay
- Worms + Hay +Fertilizer
- No treatment

- Four blocks each site
- Four replicates of each treatment in each block
- Sacrificial sampling of one replicate of each treatment per block per site

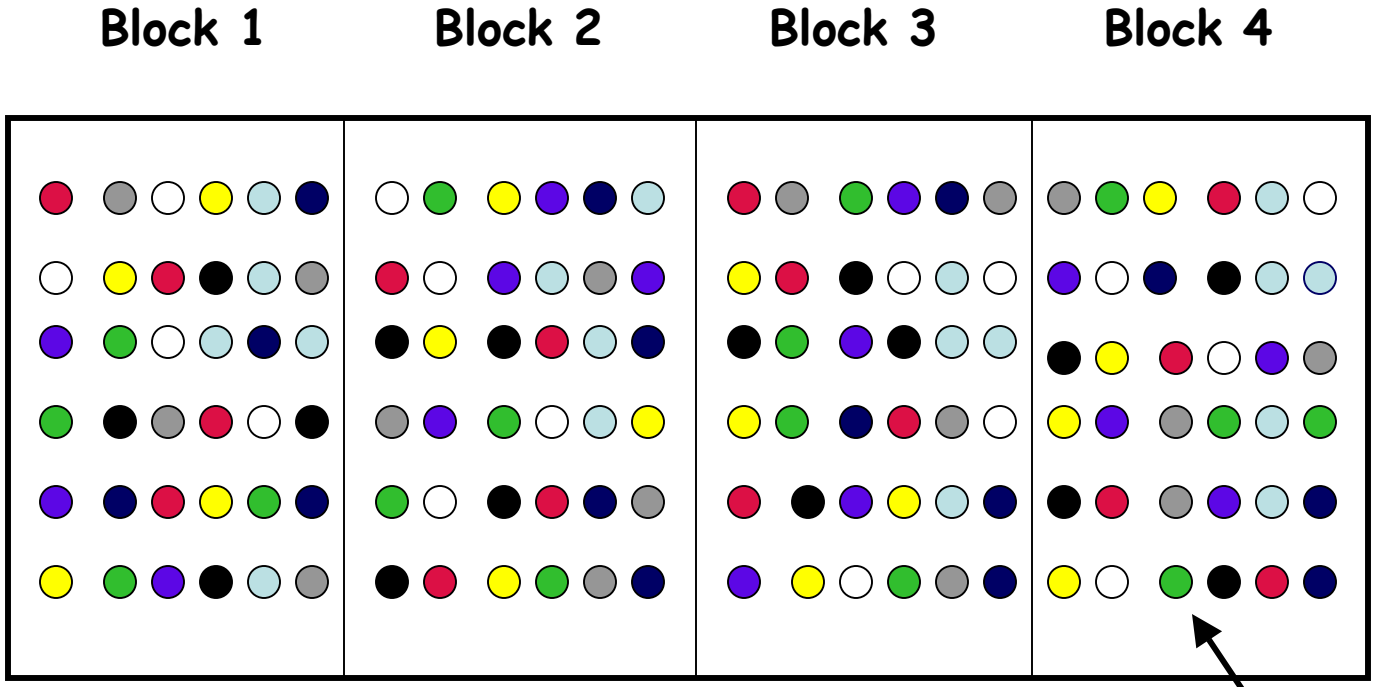
Initial Test Site Conditions

Block G7	Na^+ (mg/kg) N=3	Cl^- (mg/kg) N=3	Block LF	TPH* (mg/kg) N=4
1	711 ± 198	900 ± 298	5	11546 ± 2404
2	652 ± 39	788 ± 94	6	16634 ± 2184
3	633 ± 201	576 ± 171	7	9535 ± 1903
4	567 ± 79	301 ± 84	8	16511 ± 5350

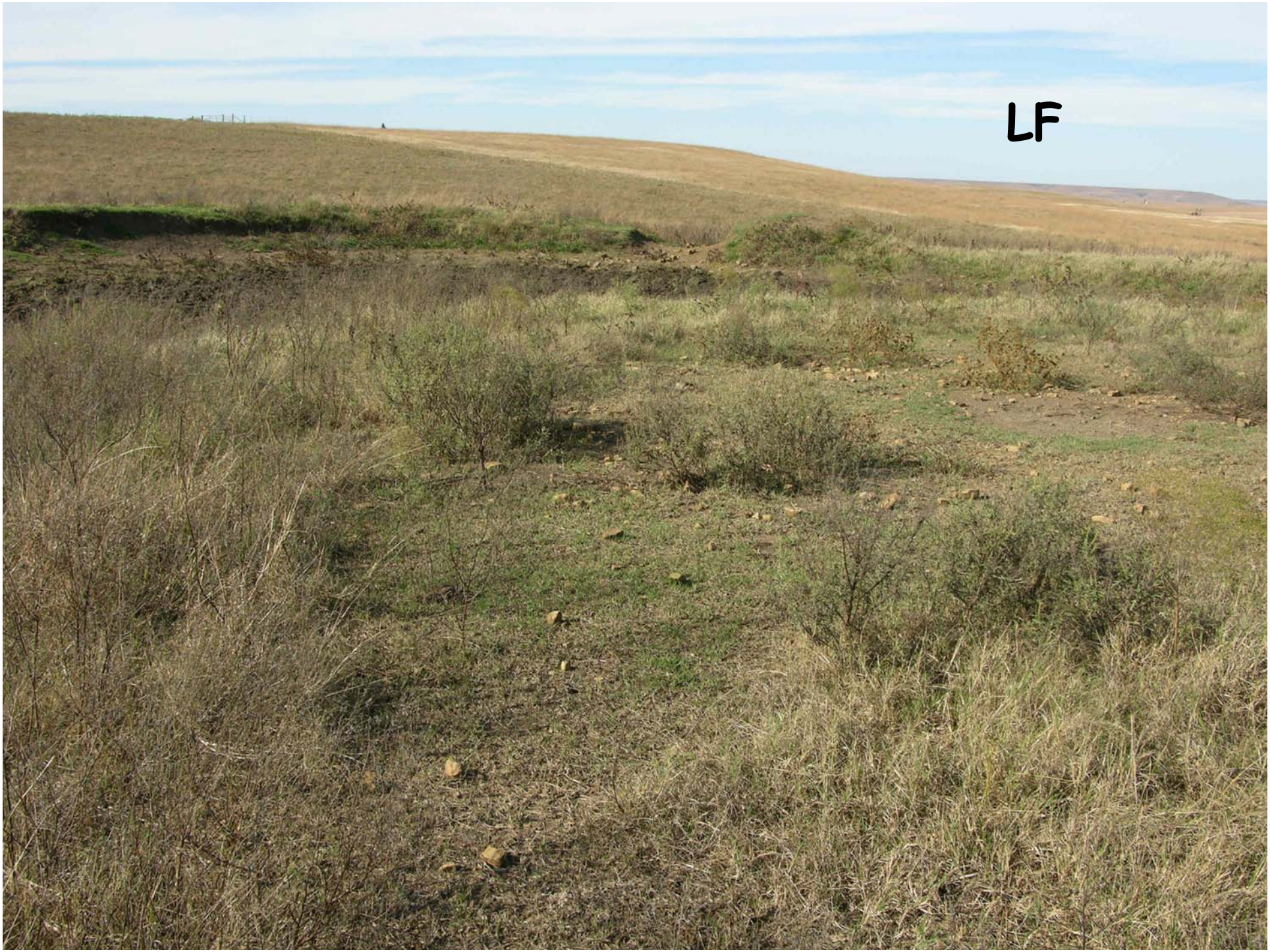
*CH_2Cl_2 extractables (gravimetric)

TPH (EPA 418.1) < 9000 mg/kg

G7



- Worms + Hay + Fertilizer
- Worms + Hay
- Worms + Fertilizer
- Hay + Fertilizer
- Worms
- Hay
- Fertilizer
- No Treatment



Project Timeline

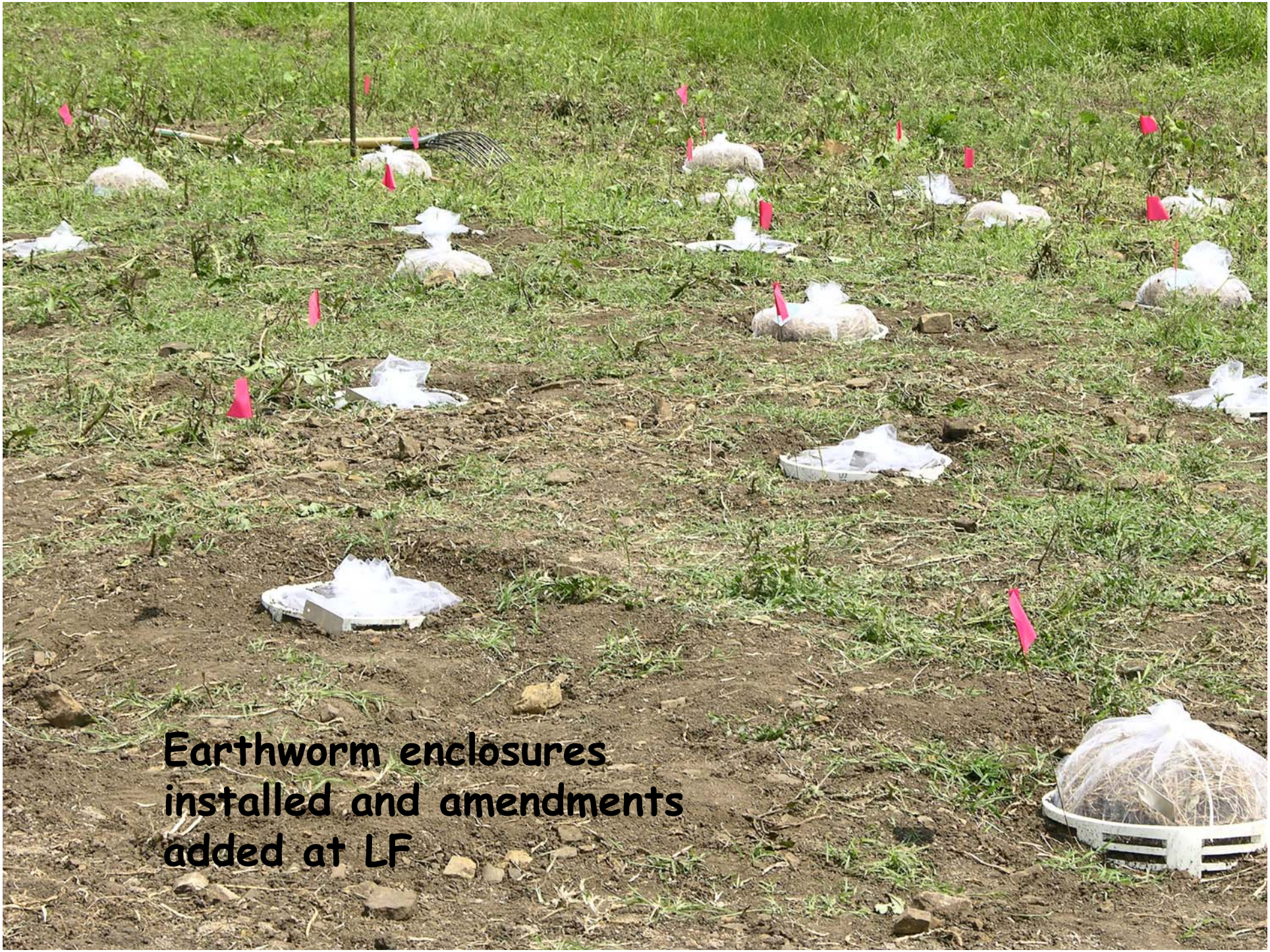
- Rip and till sites; homogenize to extent possible
- Install earthworm enclosures and add amendments (fertilizer and/or hay)
  - G7: May 2, 2005
  - LF: May 31, 2005
- Inoculate with *Eisenia fetida* (5 worms per enclosure per worm treatment); cover with panty hose
  - G7: June 23, 2005
  - Lf: July 7, 2005
- First sampling
  - G7: July 21, 2005
  - LF: August 2, 2005
- Second sampling
  - G7: Oct. 15, 2005
  - LF: Oct. 14, 2005

Why *Eisenia fetida?*

- Readily available commercially all over the U.S. for a reasonable cost ($15-$20/1000 worms).
- Easily cultivated by inexperienced personnel
- Requires high concentrations of soil organic matter and is likely to be replaced by indigenous species when they begin to migrate into the restored sites

Homogenizing soil from Block 5 for earthworm enclosures at LF

Filling enclosure with homogenized soil at LF



Entire site covered with hay for moisture and temperature control

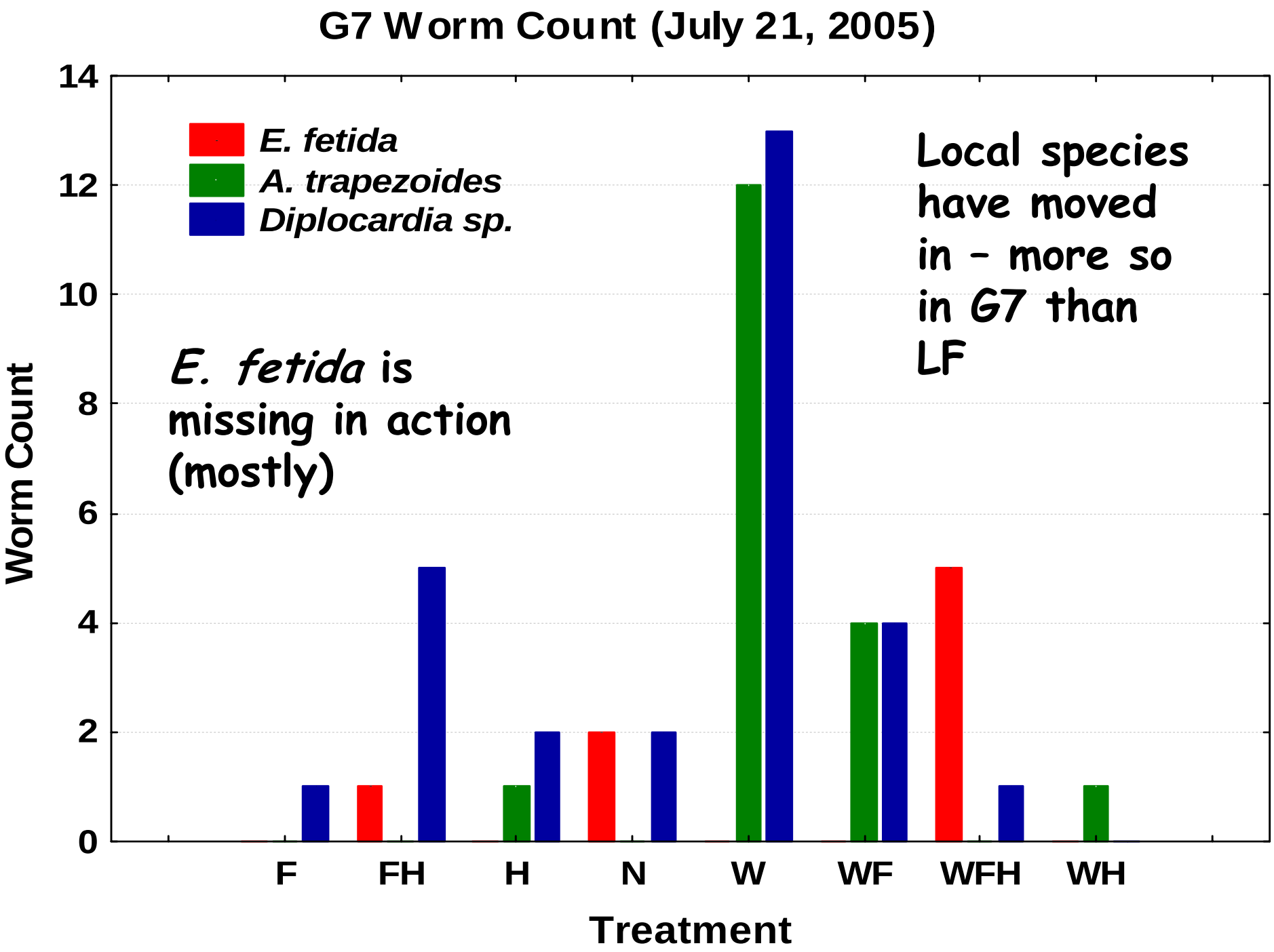
Site Maintenance

- Barb wire fence to keep out buffalo; electric fence to keep out coyotes

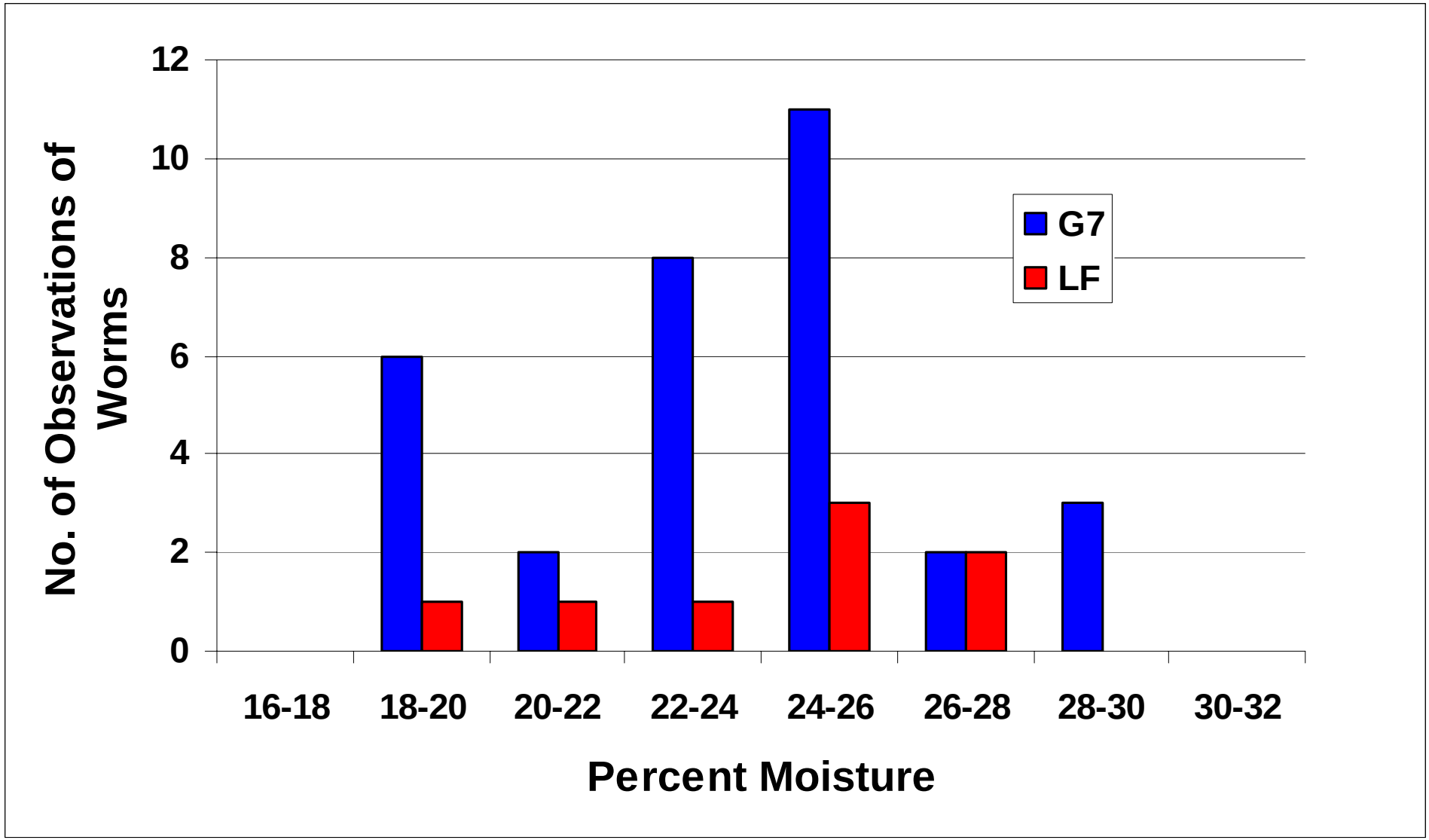
- Each site watered every other day unless there was sufficient rain

Sampling and Analysis

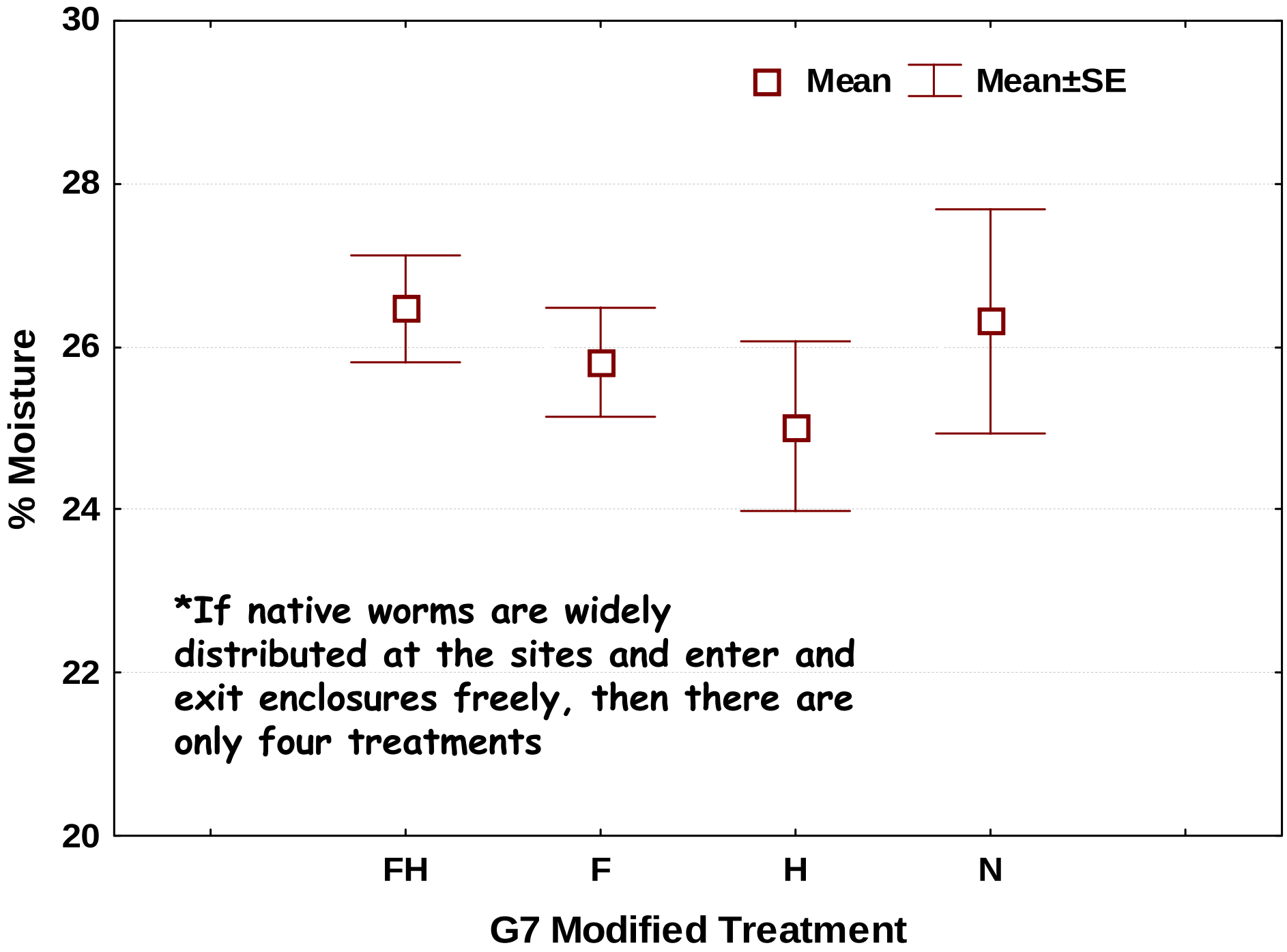
	Spring		Fall	Spring		Fall
Nutrients	X		X	X		X
Brine	X		X	X		X
TPH	X		X	X		X
PLFA	X		X	X		X
DNA						X
N cycling bacteria	X		X	X		X
Nematodes	X		X	X		X
Plants			X	X		X
Earthworms	X		X	X		X

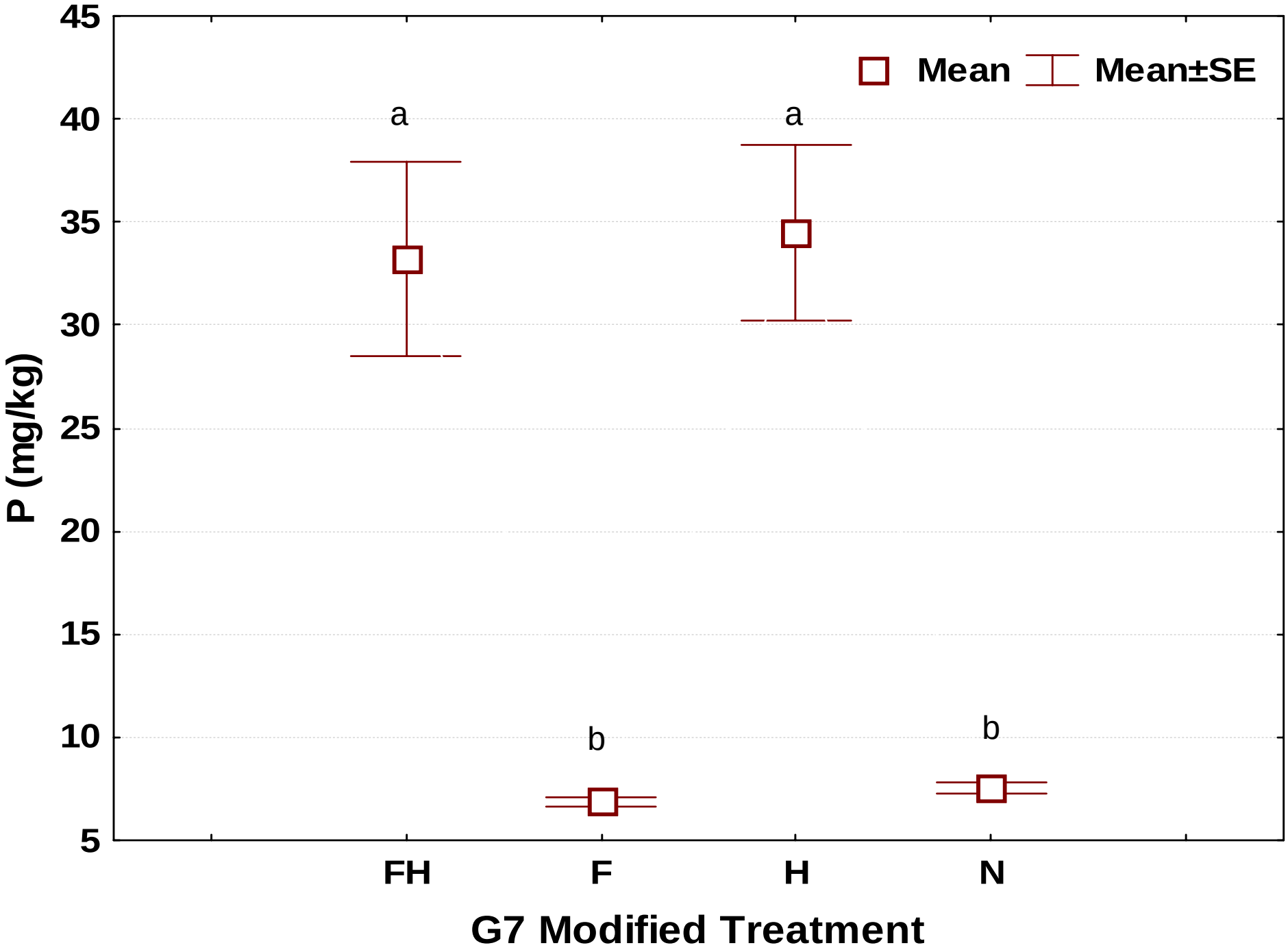


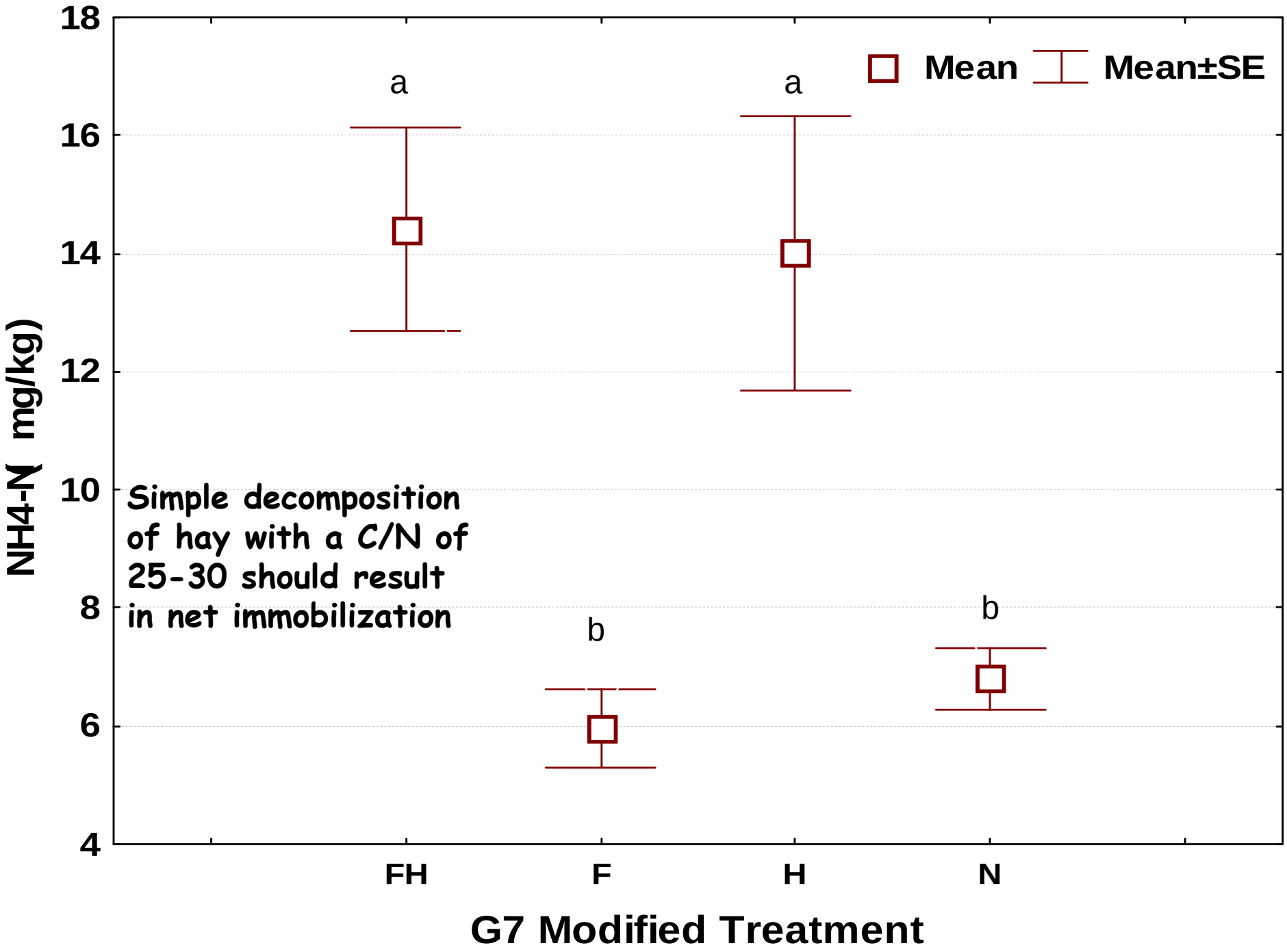
Frequency of worm observations related to soil moisture

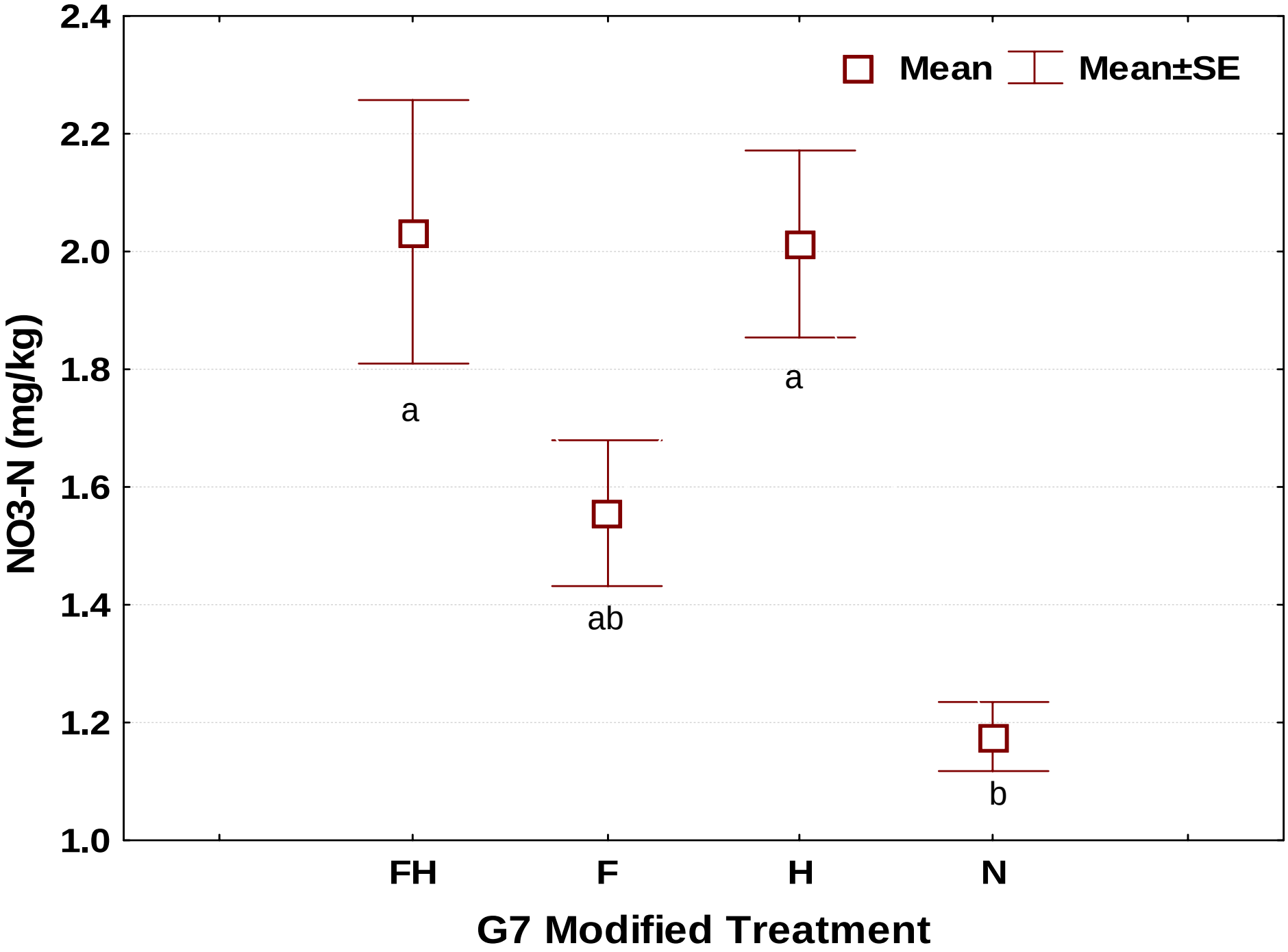


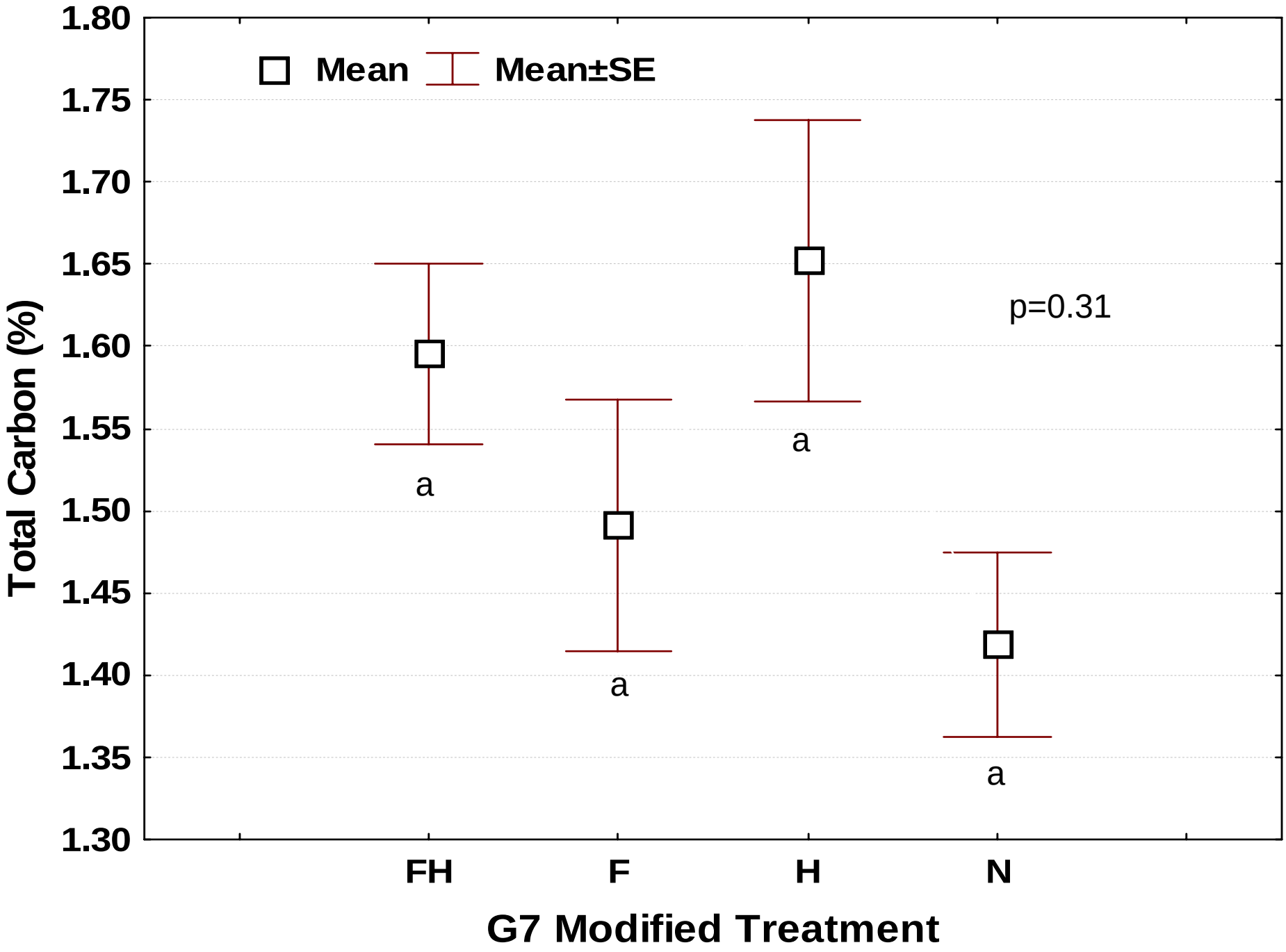
On average soil moistures in LF were 4% lower than in G7 (avg. 26%)

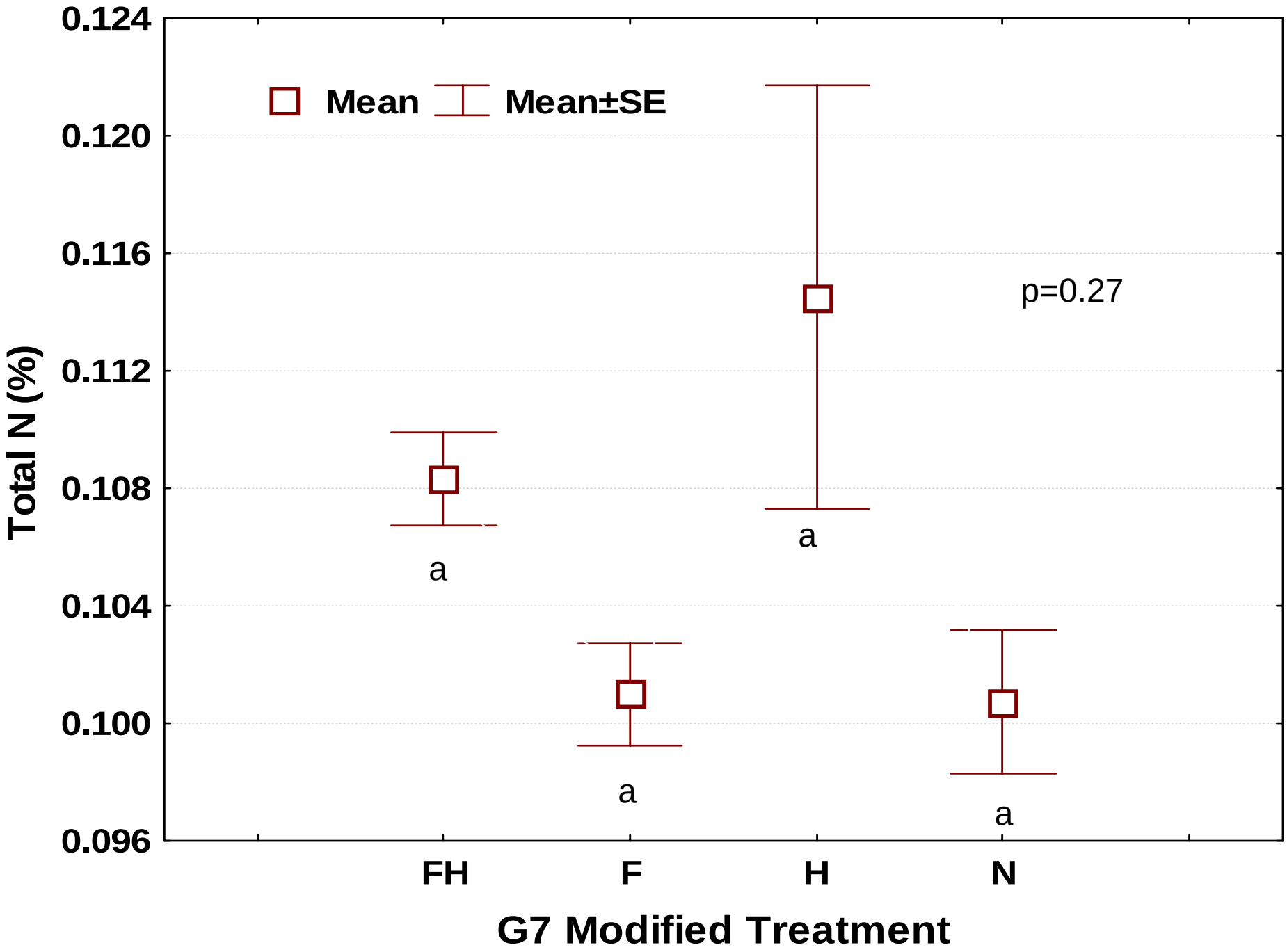


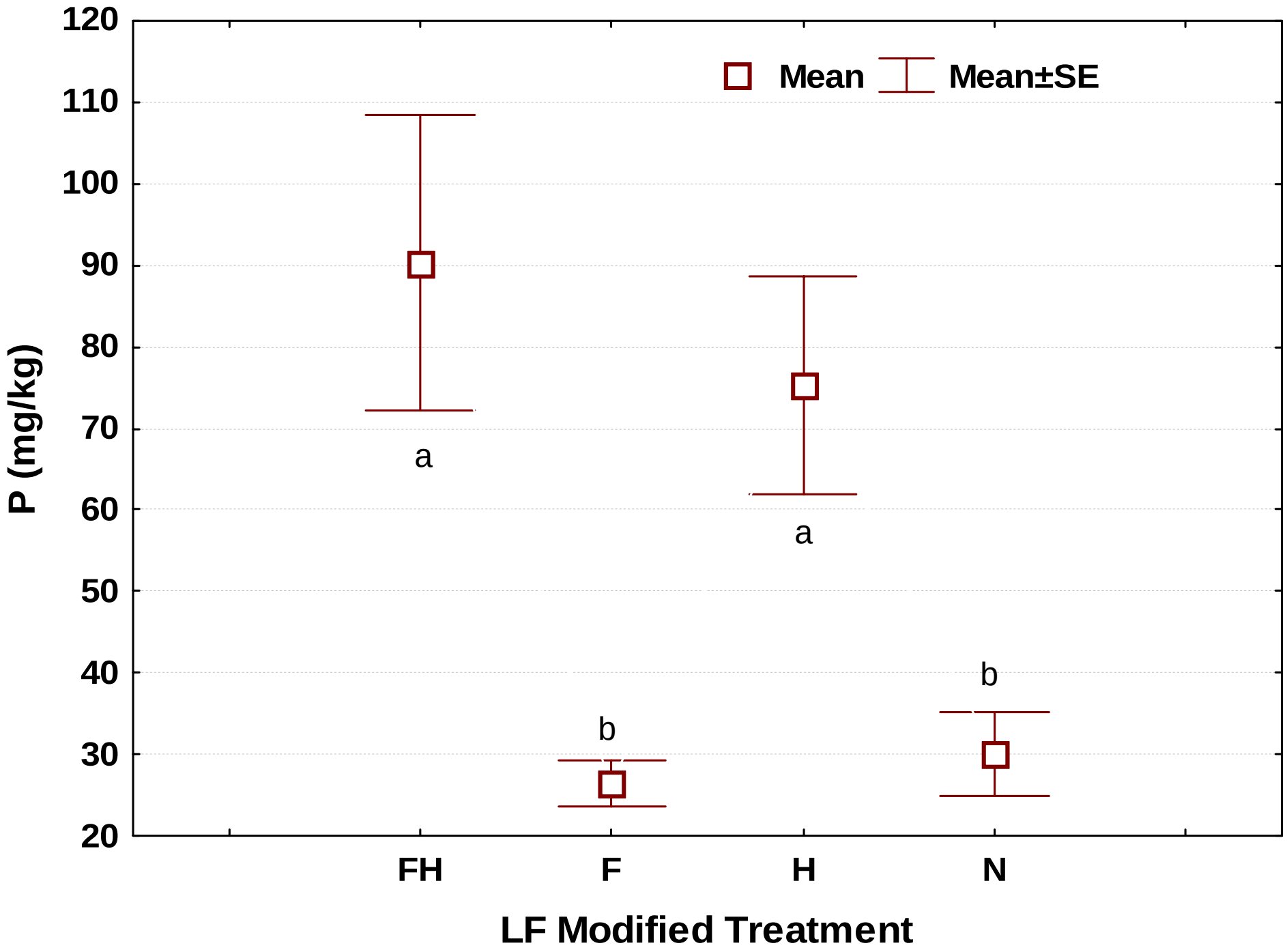


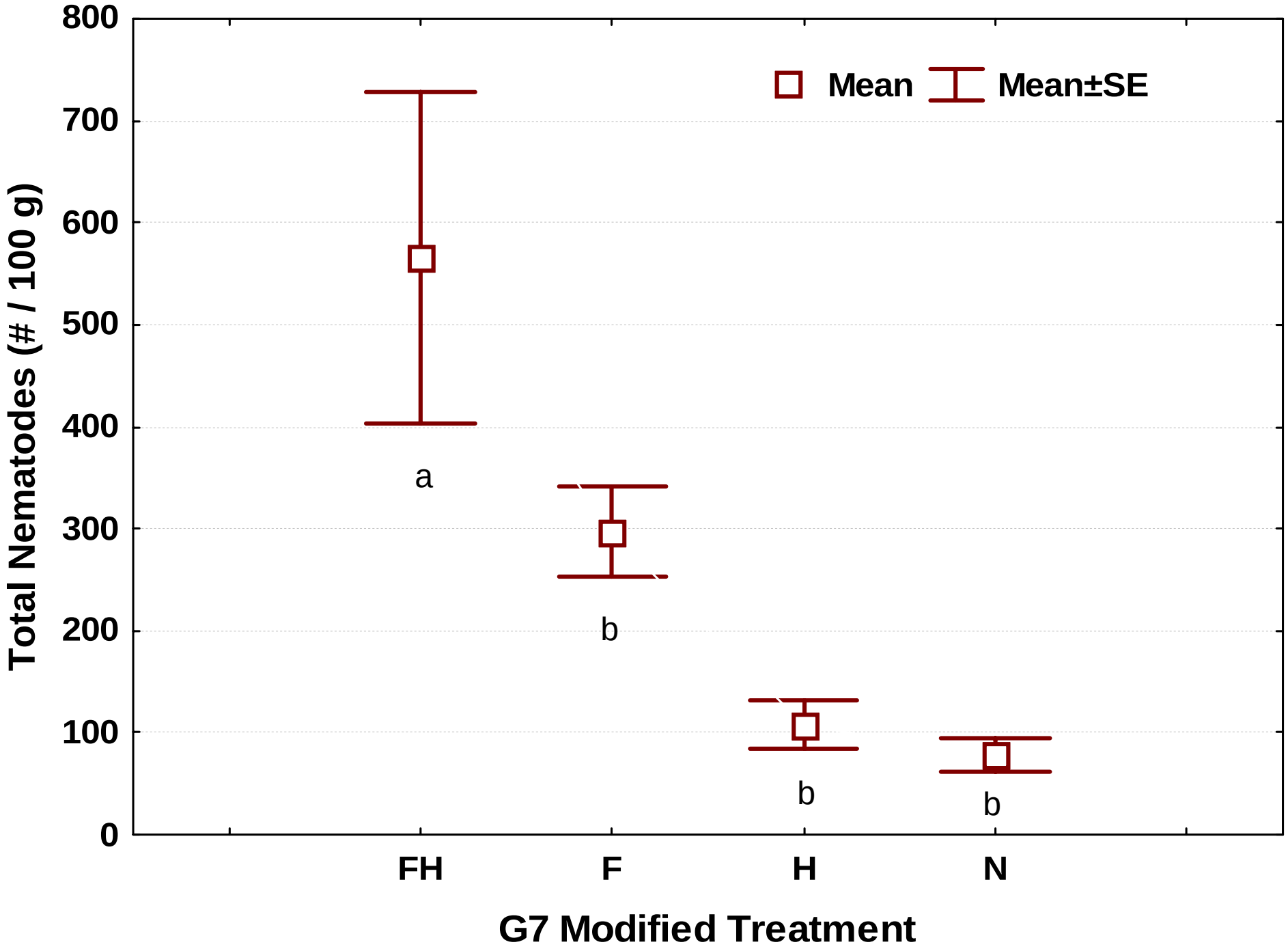


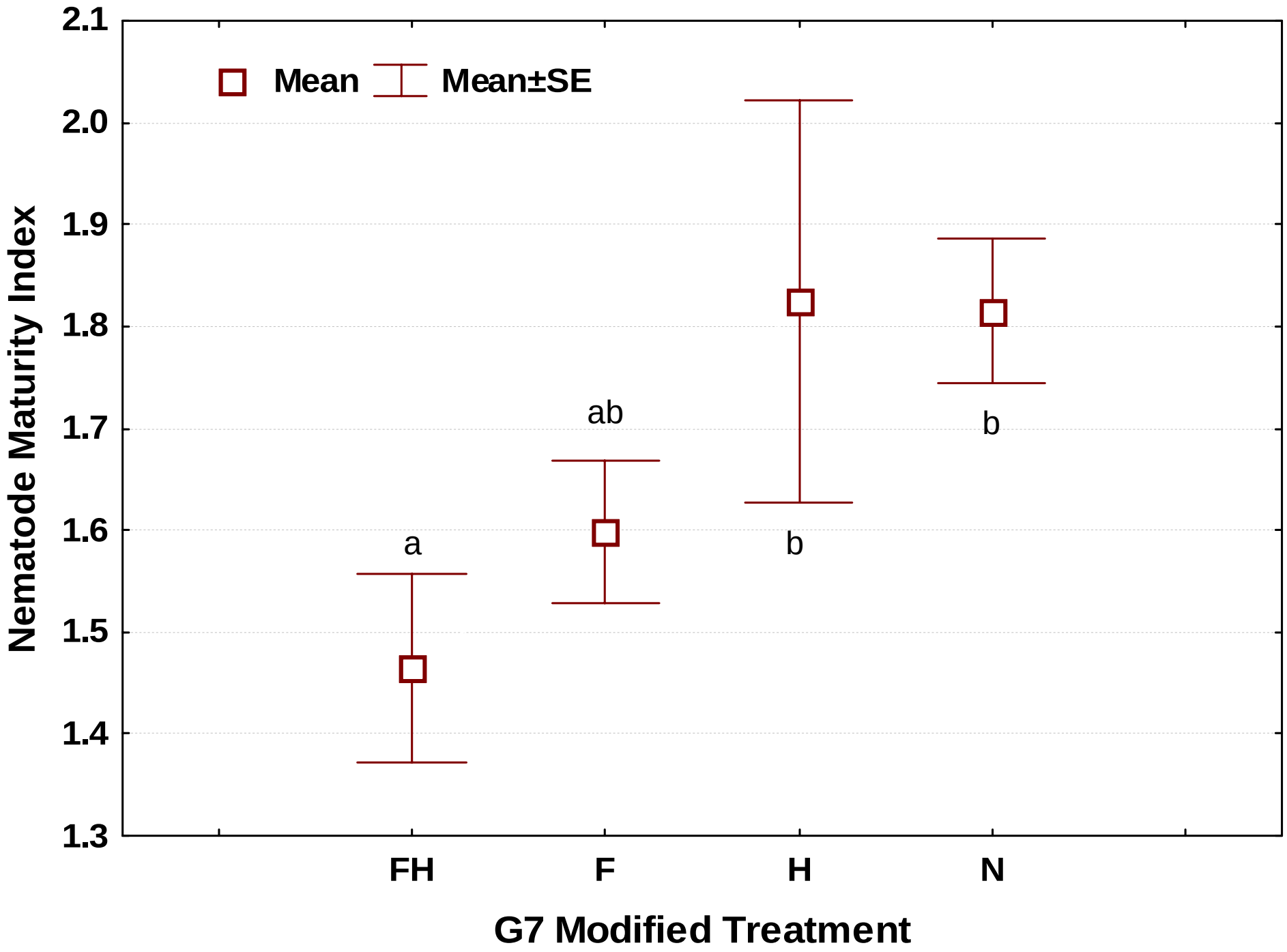






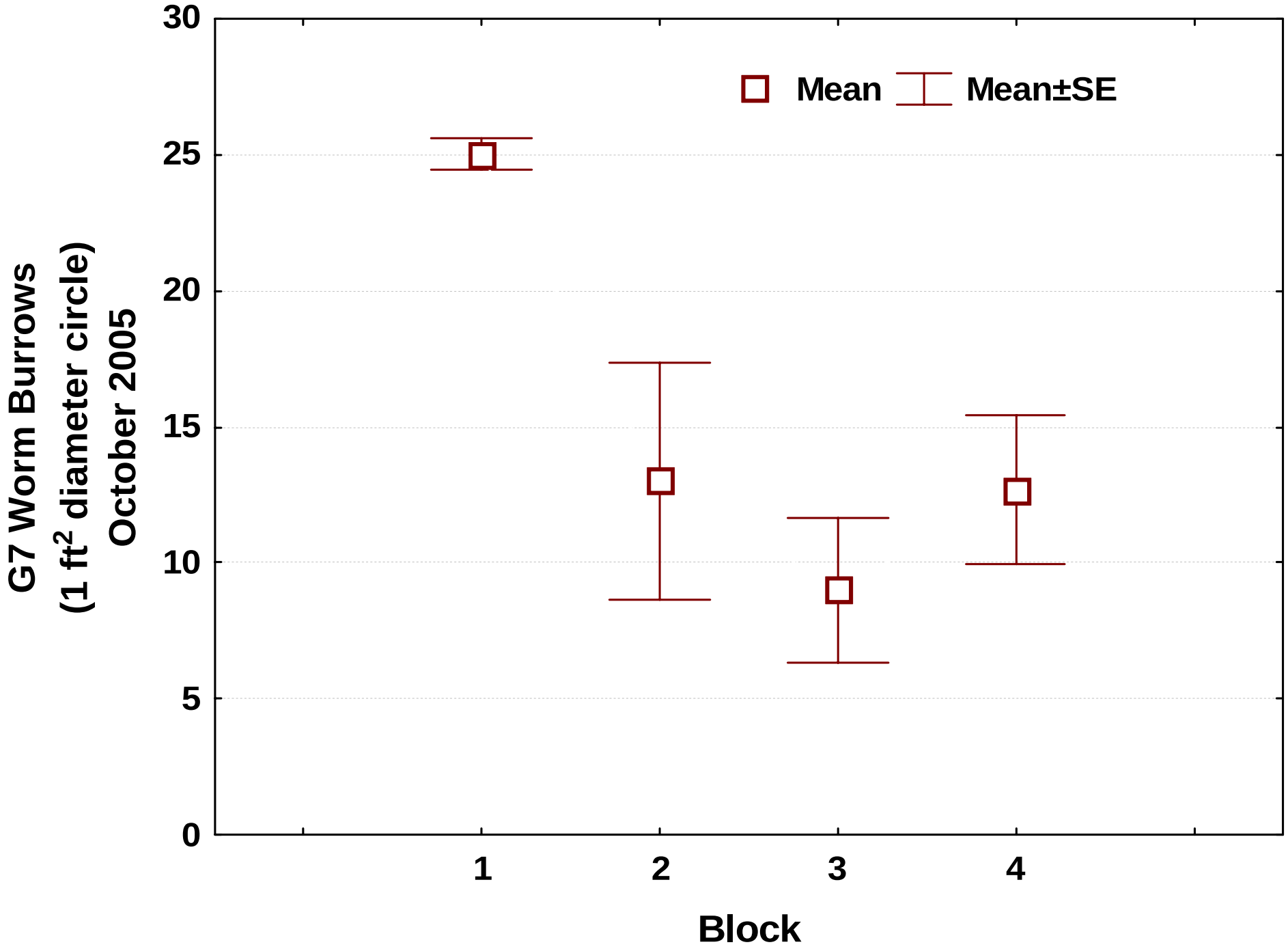


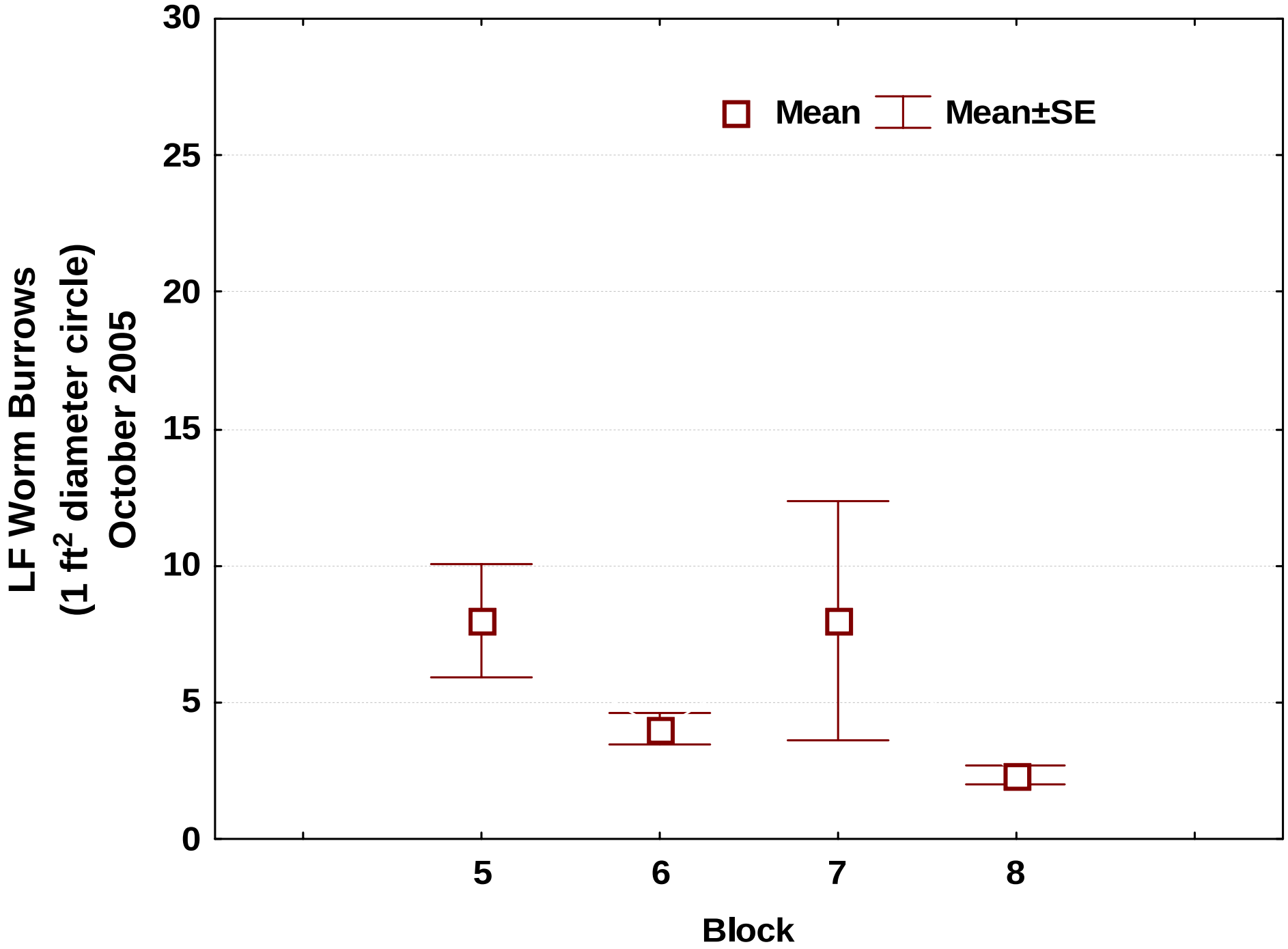




Preliminary Conclusions

- Earthworms will invade and survive in remediated oil- or brine-impacted soil
  - organic matter
  - moisture
- Earthworm activity increases bioavailability of nutrients in these damaged sites (?)





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