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

Nitya Alahari
Kerry Sublette
Eleanor Jennings
Center for Applied Biogeosciences
University of Tulsa
Greg Thoma
Duane Wolf
University of Arkansas
Kathleen Duncan
University of Oklahoma
Tim Todd
Kansas State University
Mac A. Callaham, Jr.
USDA-Forest Service

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

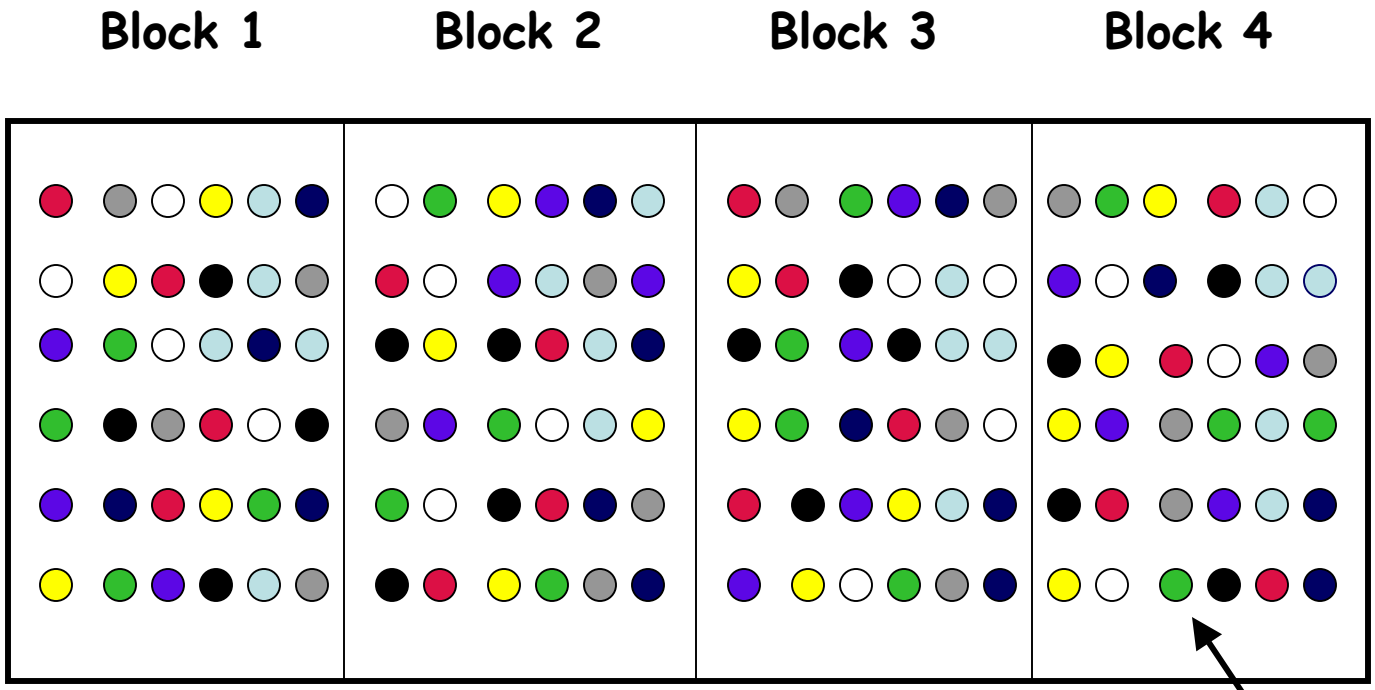
Initial Test Site Conditions

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

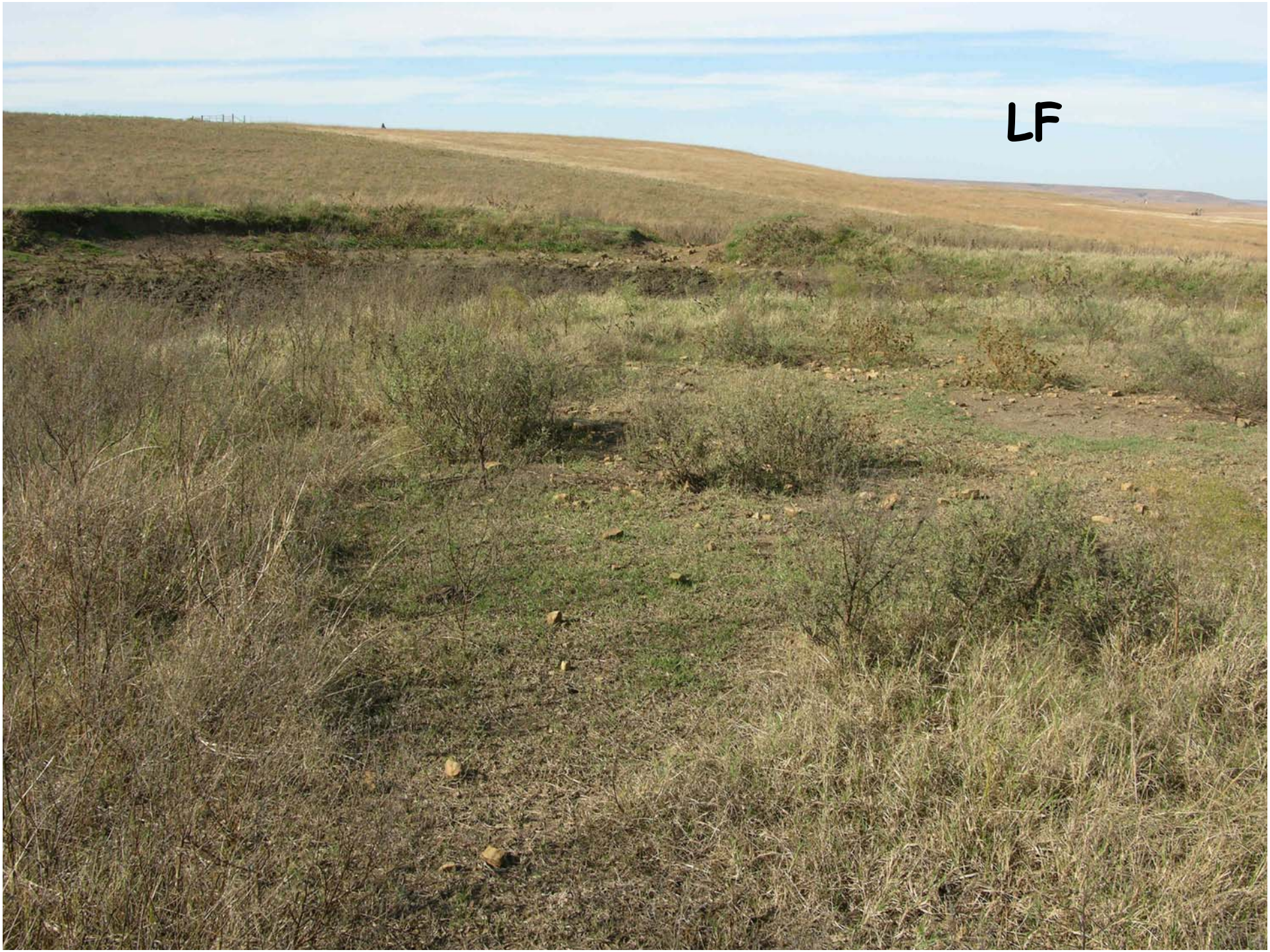
*CH_2Cl_2 extractables (gravimetric)

TPH (EPA 418.1) < 9000 mg/kg

G7



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


LF

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

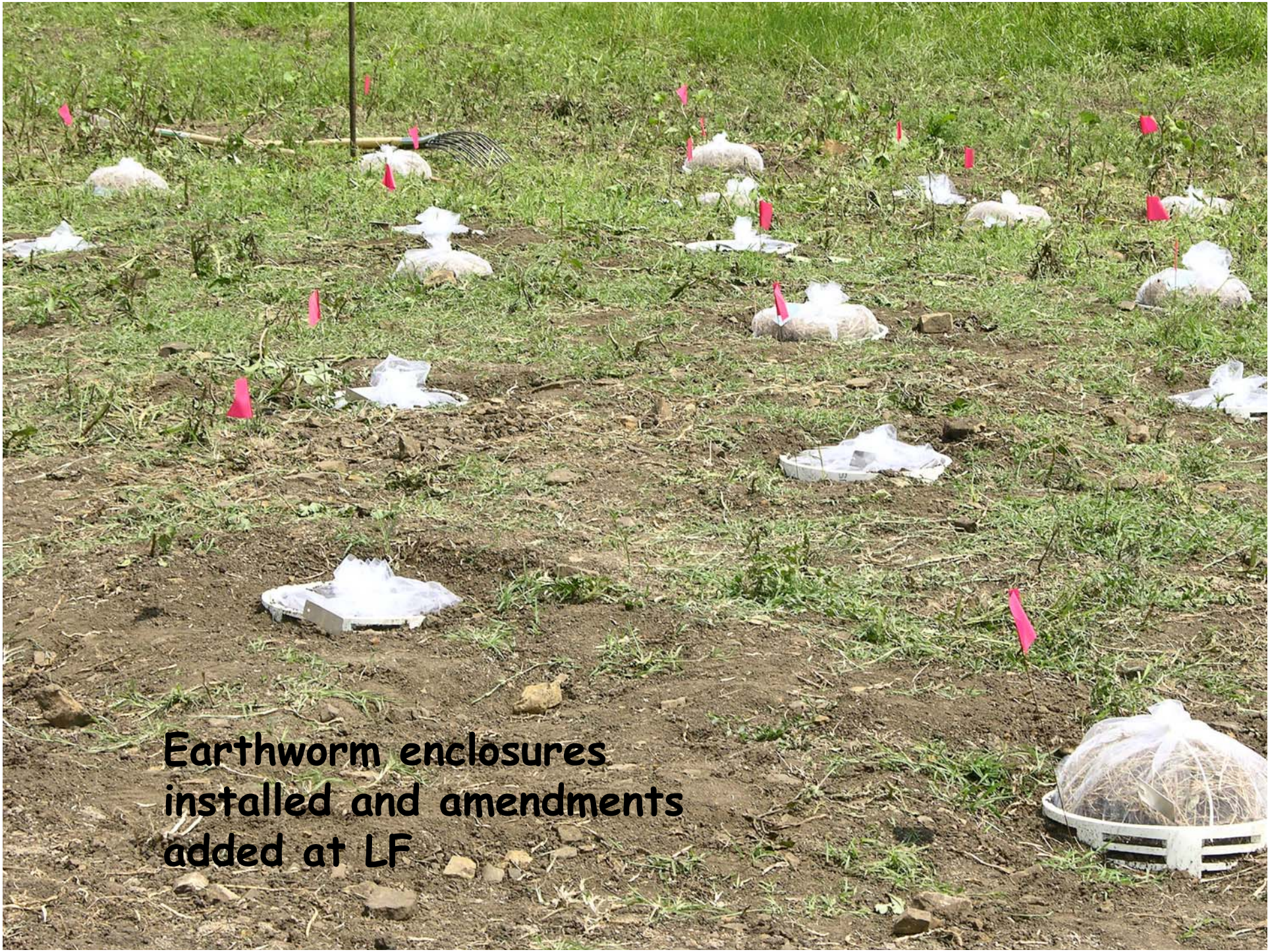
Why *Eisenia fetida?*

- 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


LF

Homogenizing soil from Block 5 for earthworm enclosures at LF


Filling enclosure with homogenized soil at LF


Earthworm enclosures
installed and amendments
added at LF

Entire site covered with hay for moisture and temperature control

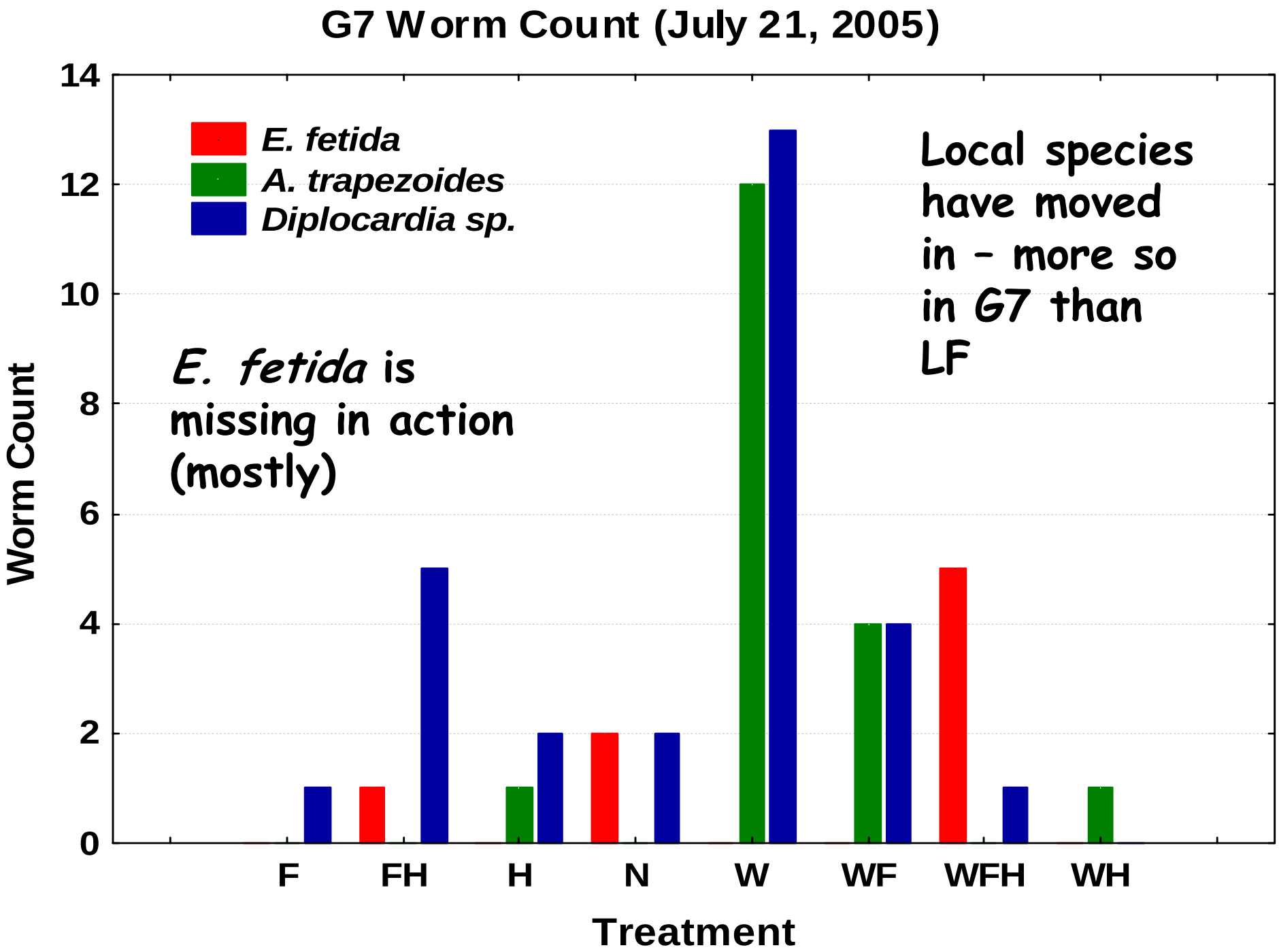
Site Maintenance

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

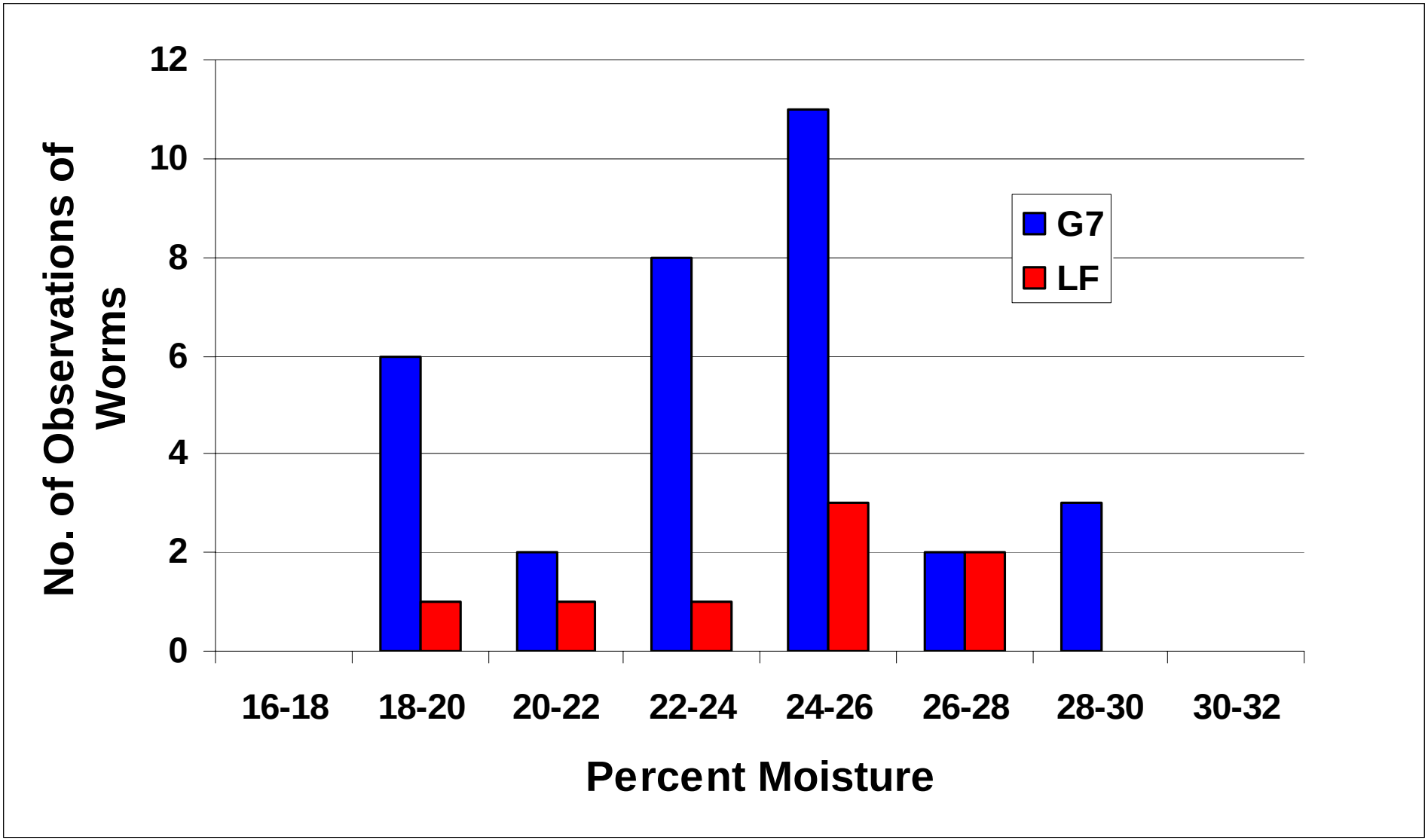
- Each site watered every other day unless there was sufficient rain

Sampling and Analysis

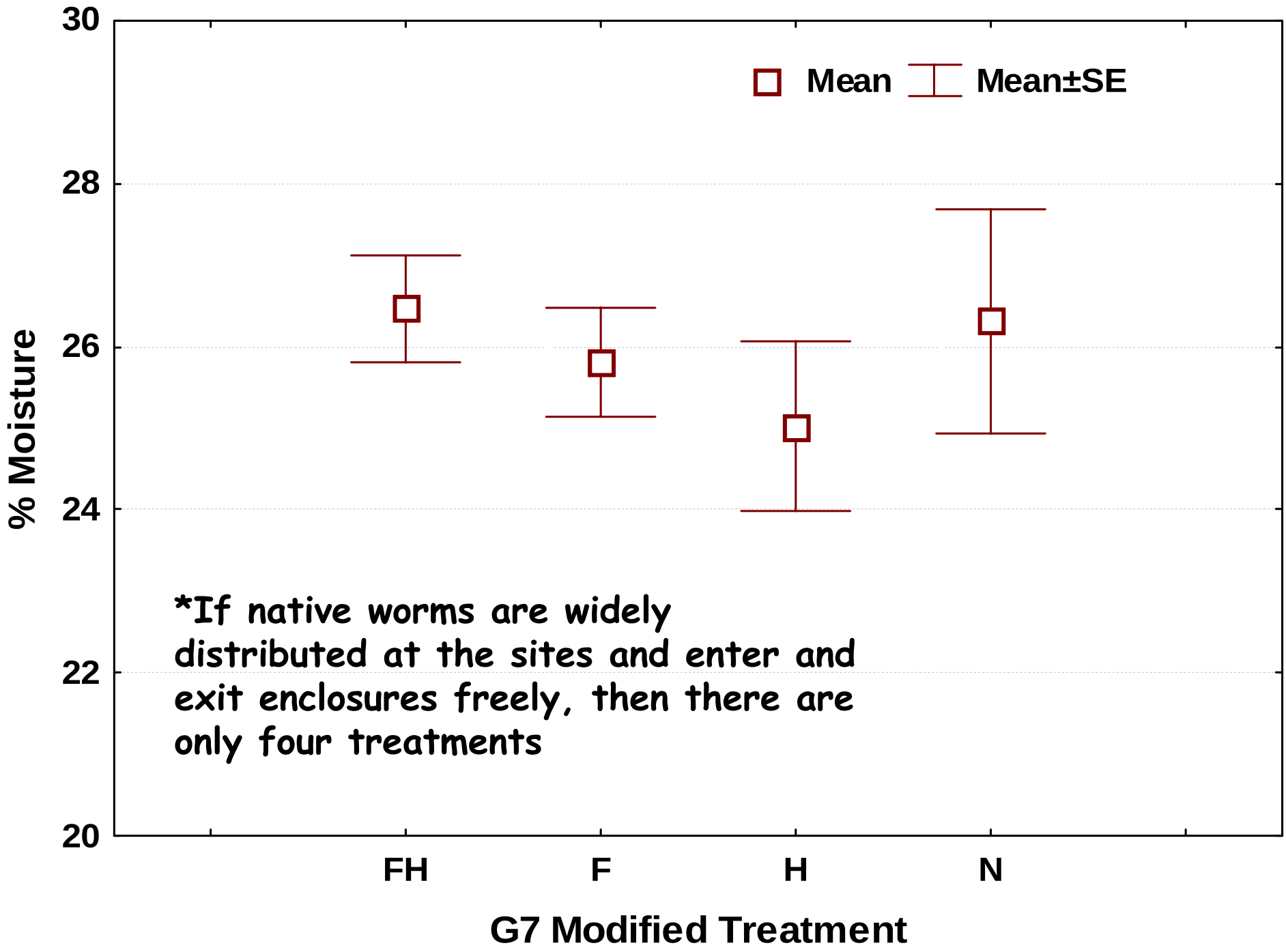
	Spring		Fall	Spring		Fall
Nutrients	X		X	X		X
Brine	X		X	X		X
TPH	X		X	X		X
PLFA	X		X	X		X
DNA						X
N cycling bacteria	X		X	X		X
Nematodes	X		X	X		X
Plants			X	X		X
Earthworms	X		X	X		X

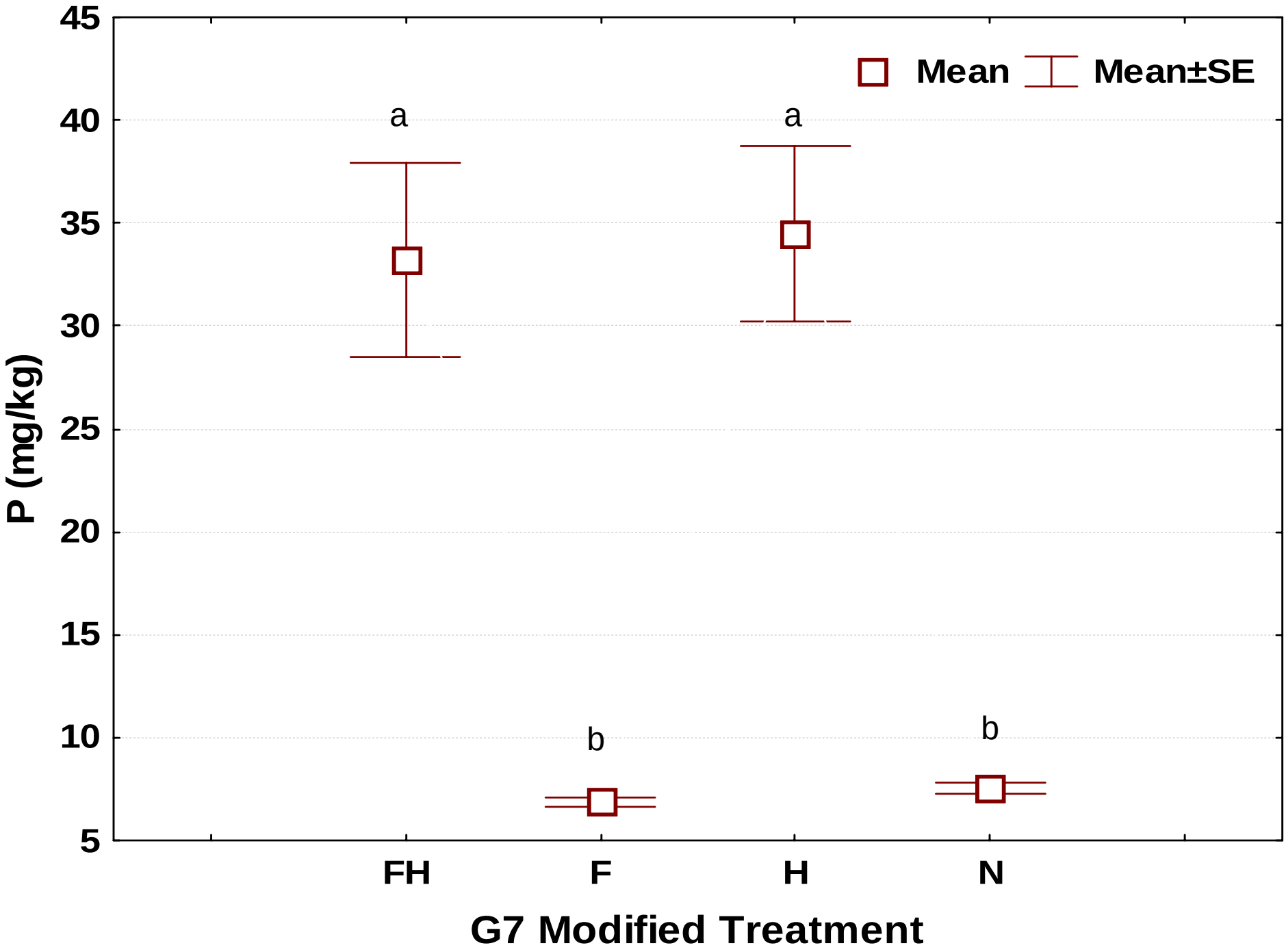

G7 Worm Count (July 21, 2005)
E. fetida
A. trapezoides
Diplocardia sp.
Local species have moved in – more so in G7 than LF
E. fetida is missing in action (mostly)
Worm Count
0
2
4
6
8
10
12
14
F
FH
H
N
W
WF
WFH
WH
Treatment

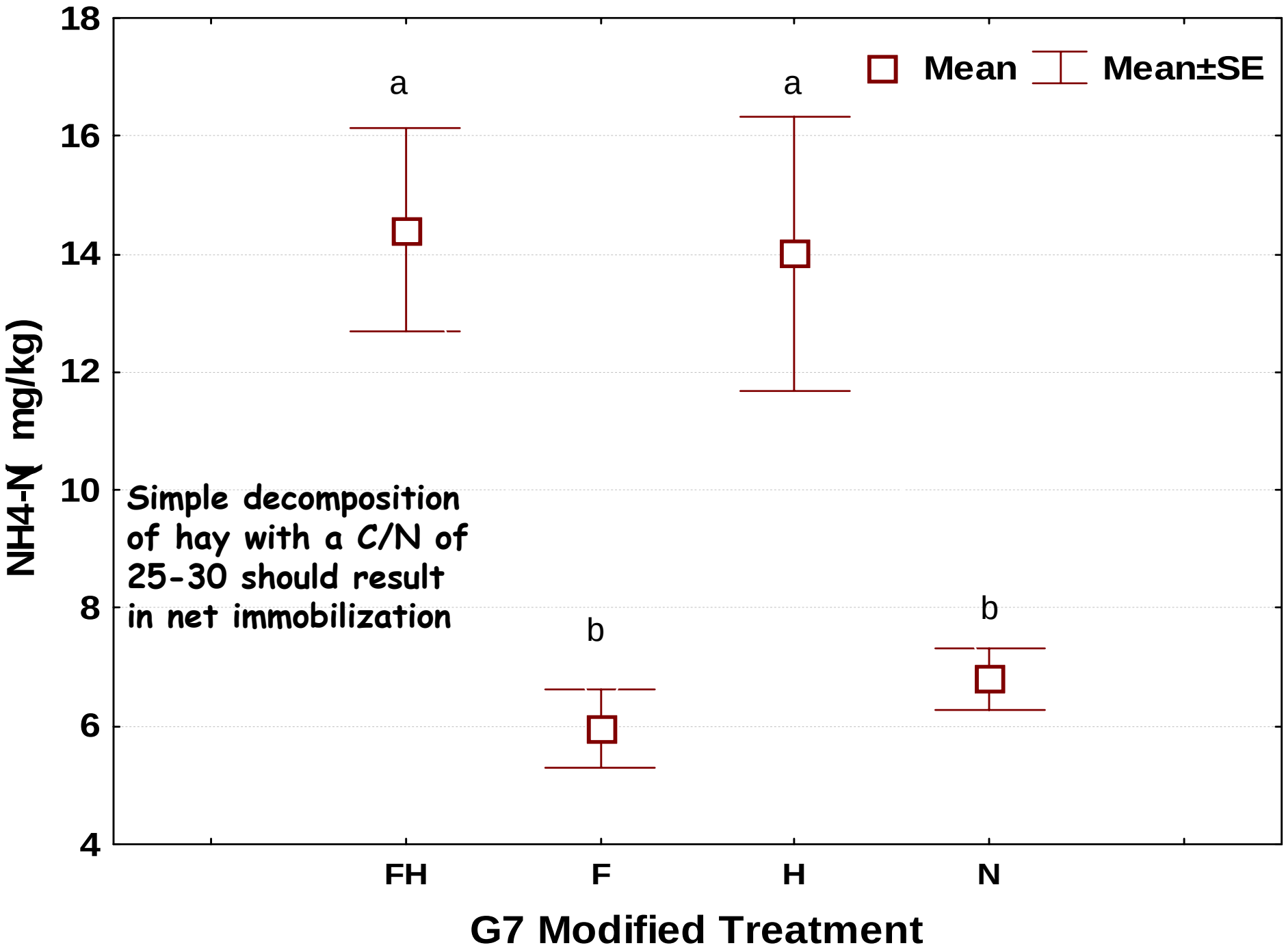
Frequency of worm observations related to soil moisture

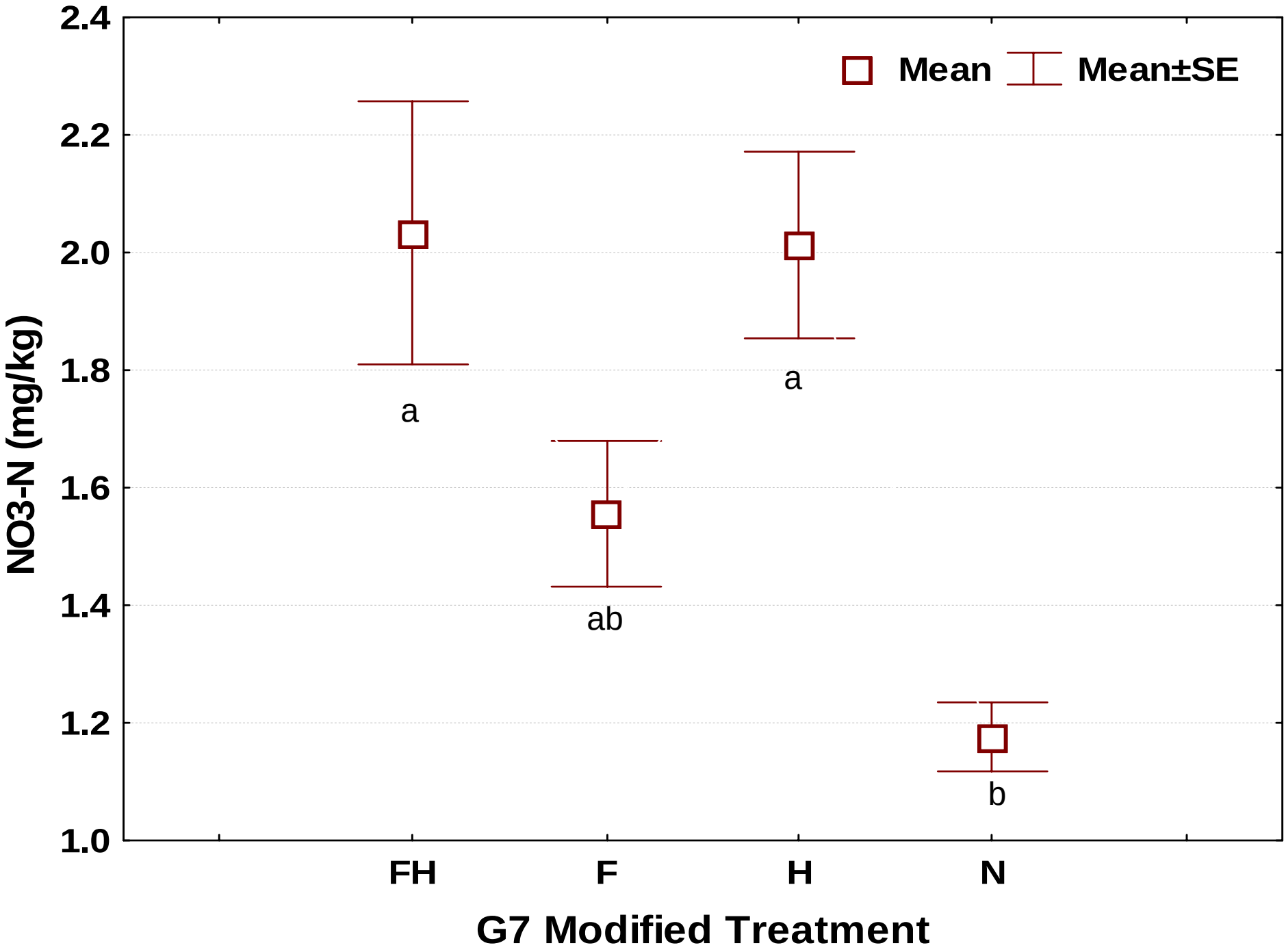


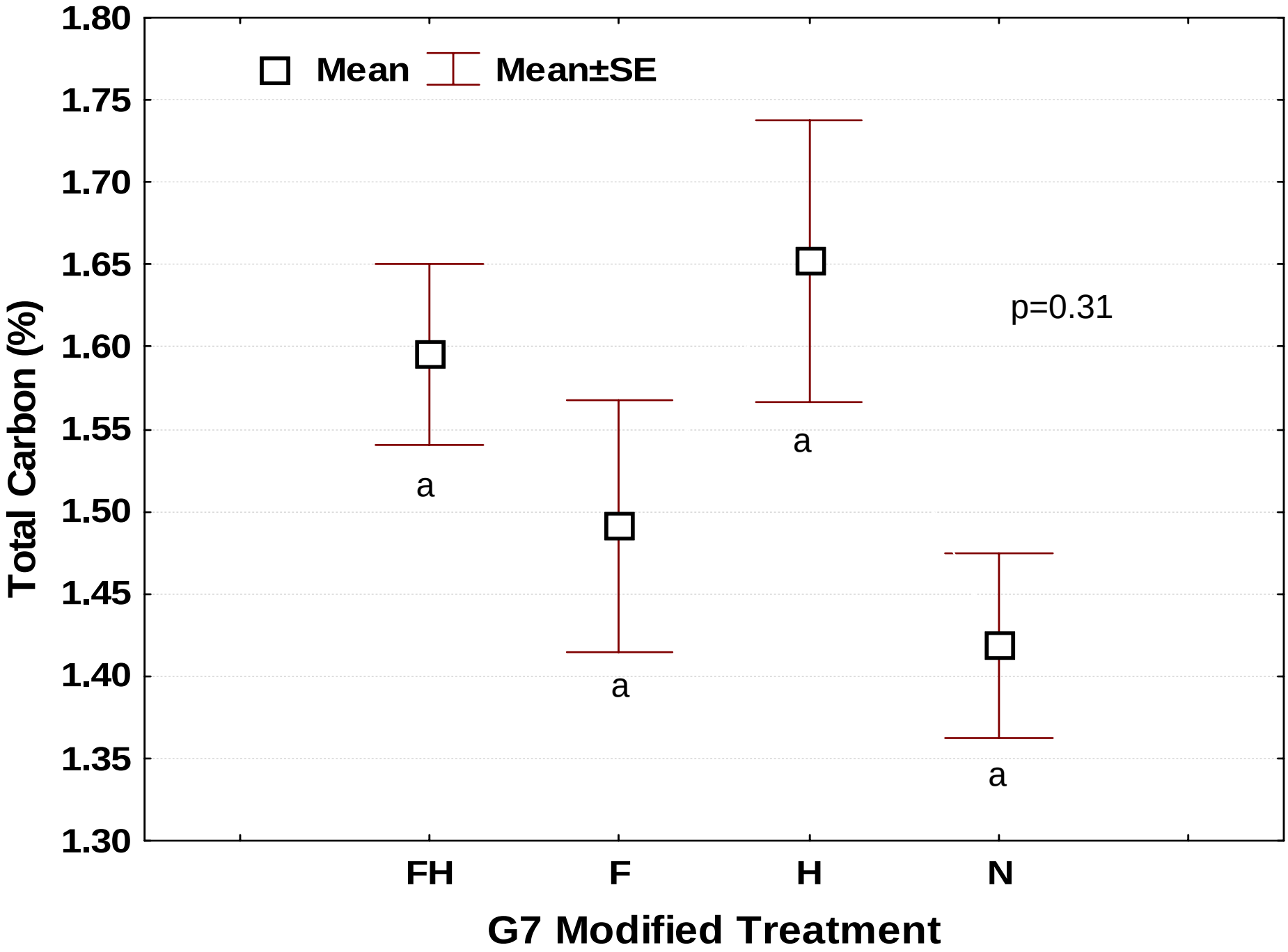
On average soil moistures in LF were 4% lower than in G7 (avg. 26%)

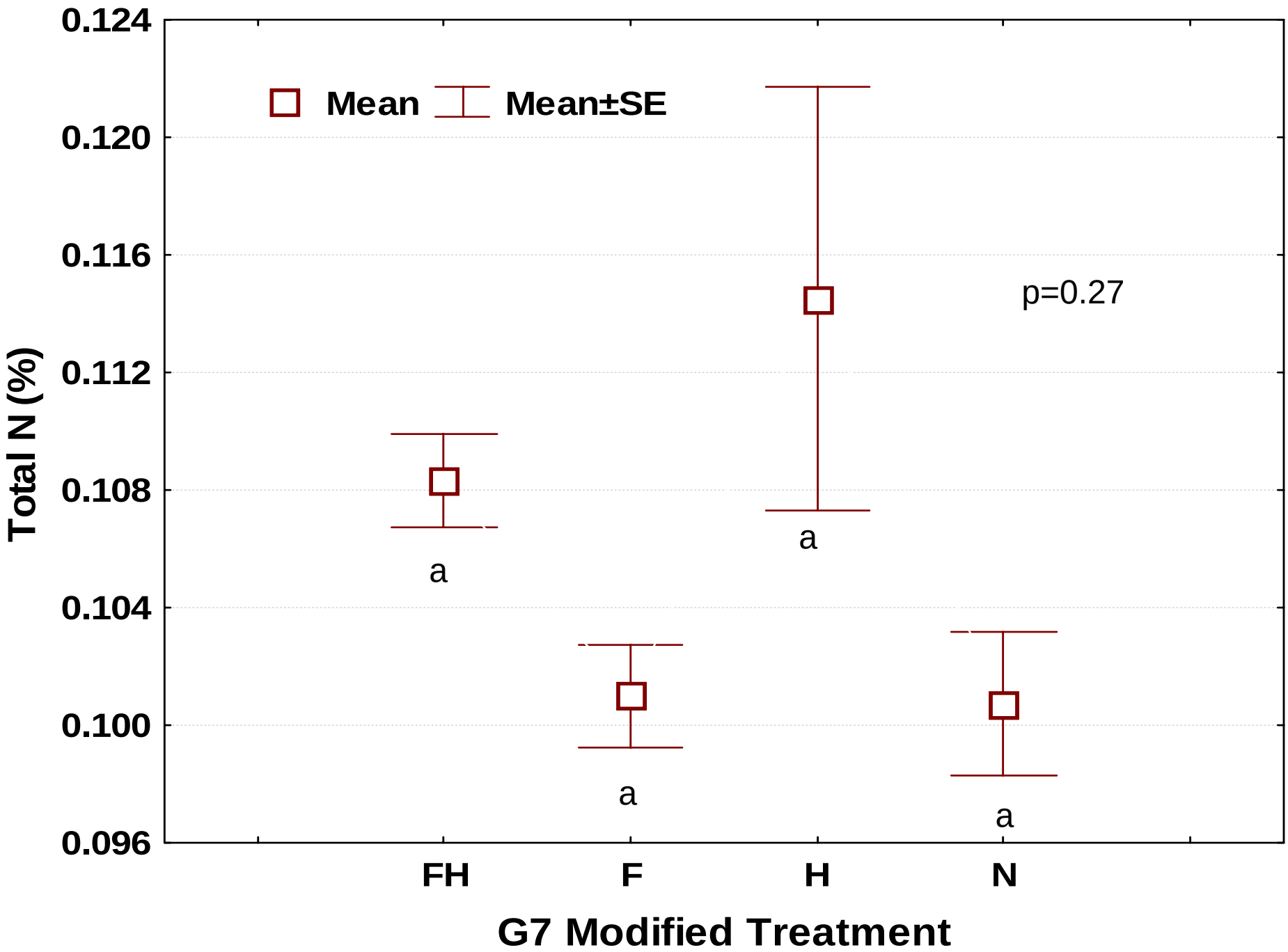

30
28
26
24
22
20
% Moisture
Mean
Mean±SE
*If native worms are widely distributed at the sites and enter and exit enclosures freely, then there are only four treatments
FH
F
H
N
G7 Modified Treatment

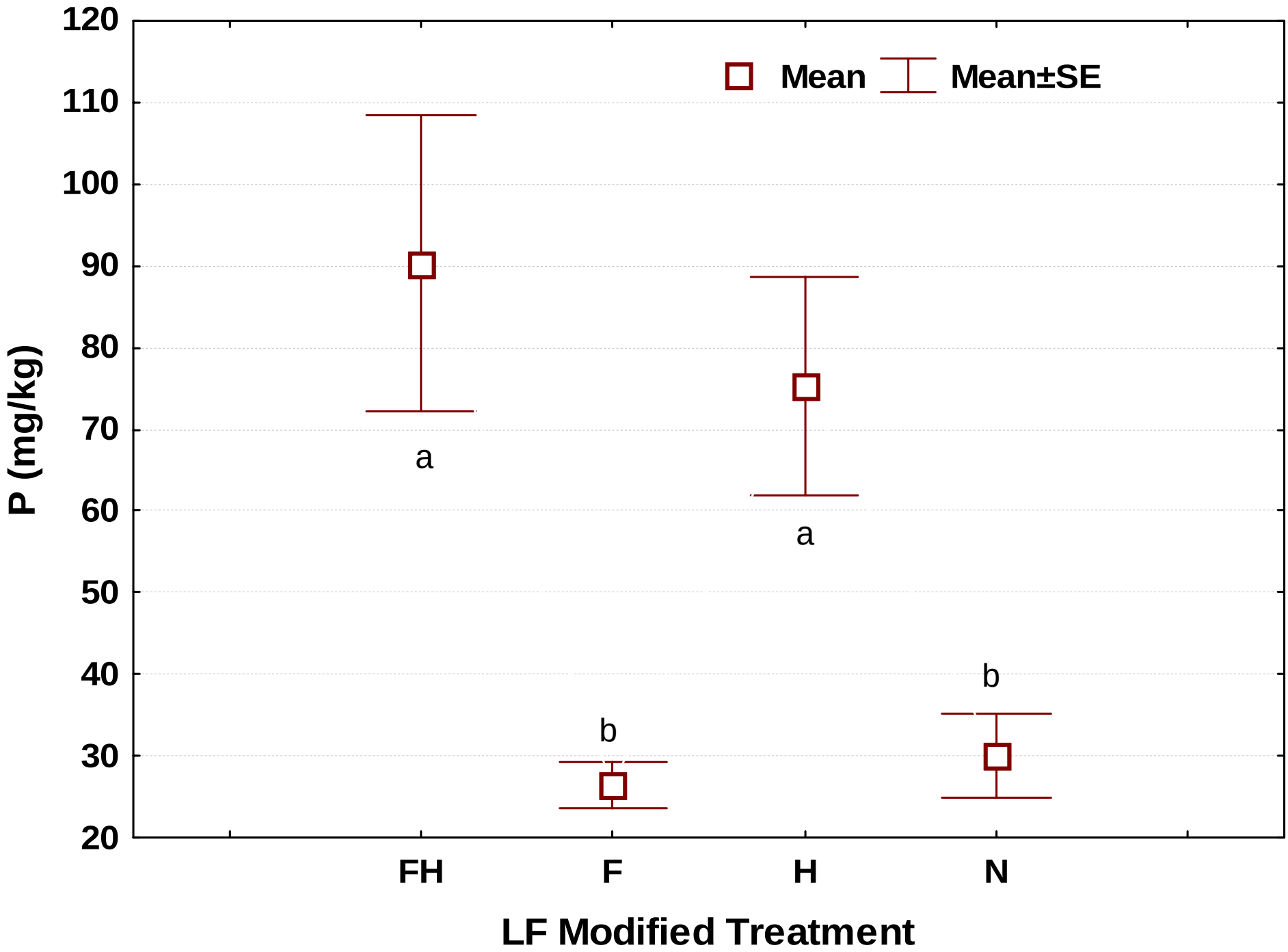

Mean
Mean±SE
45
40
35
30
25
20
15
10
5
P (mg/kg)
a
a
b
b
FH
F
H
N
G7 Modified Treatment

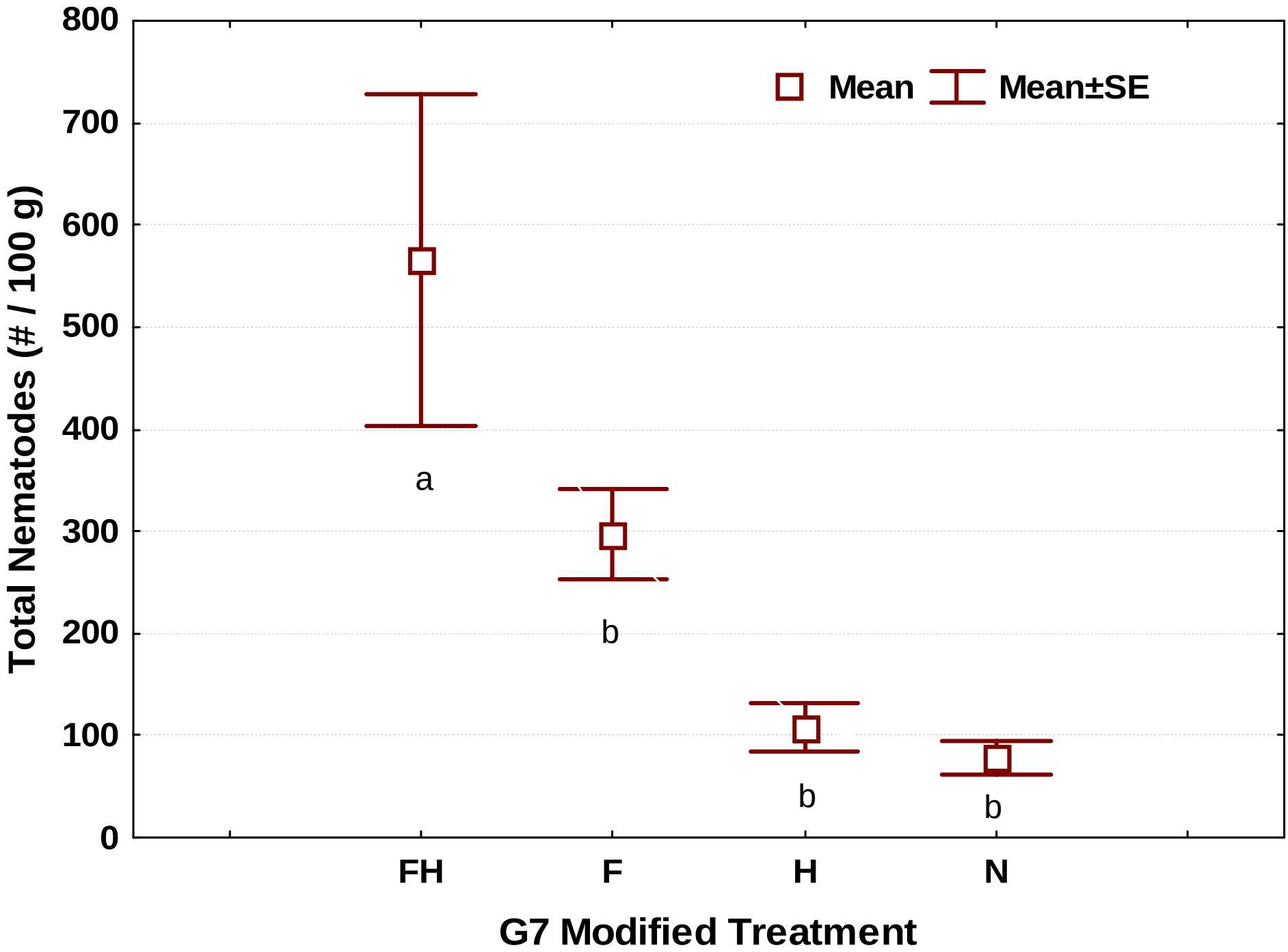

Mean
Mean±SE
18
16
14
12
10
8
6
4
NH4-N (mg/kg)
a
a
b
b
Simple decomposition
of hay with a C/N of
25-30 should result
in net immobilization
FH
F
H
N
G7 Modified Treatment

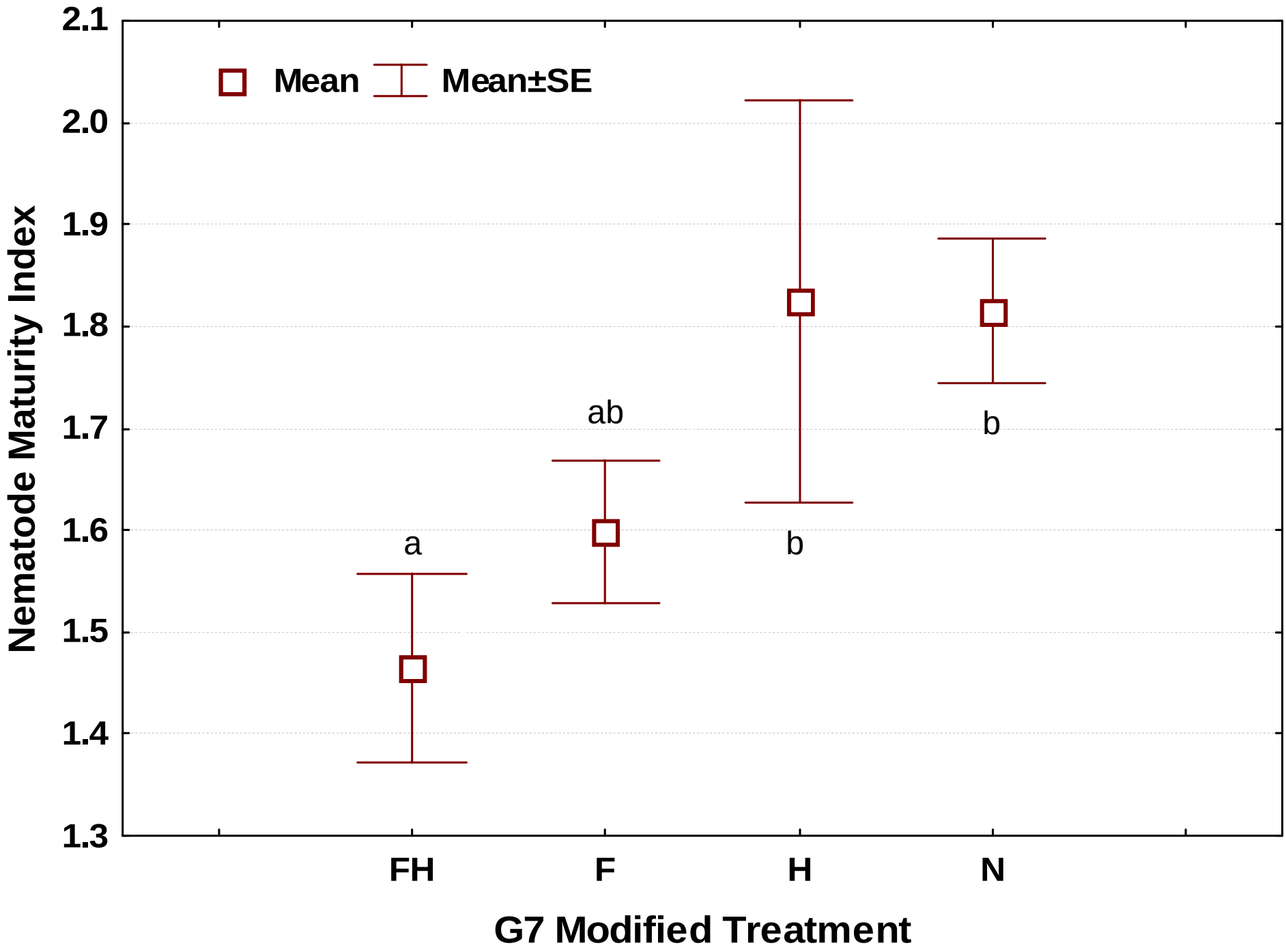

Mean
Mean±SE
NO3-N (mg/kg)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
a
ab
a
b
FH
F
H
N
G7 Modified Treatment


Mean
Mean±SE
Total Carbon (%)
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
p=0.31
a
a
a
a
FH
F
H
N
G7 Modified Treatment


0.124
0.120
0.116
0.112
0.108
0.104
0.100
0.096
Total N (%)
Mean
Mean±SE
p=0.27
a
a
a
a
FH
F
H
N
G7 Modified Treatment

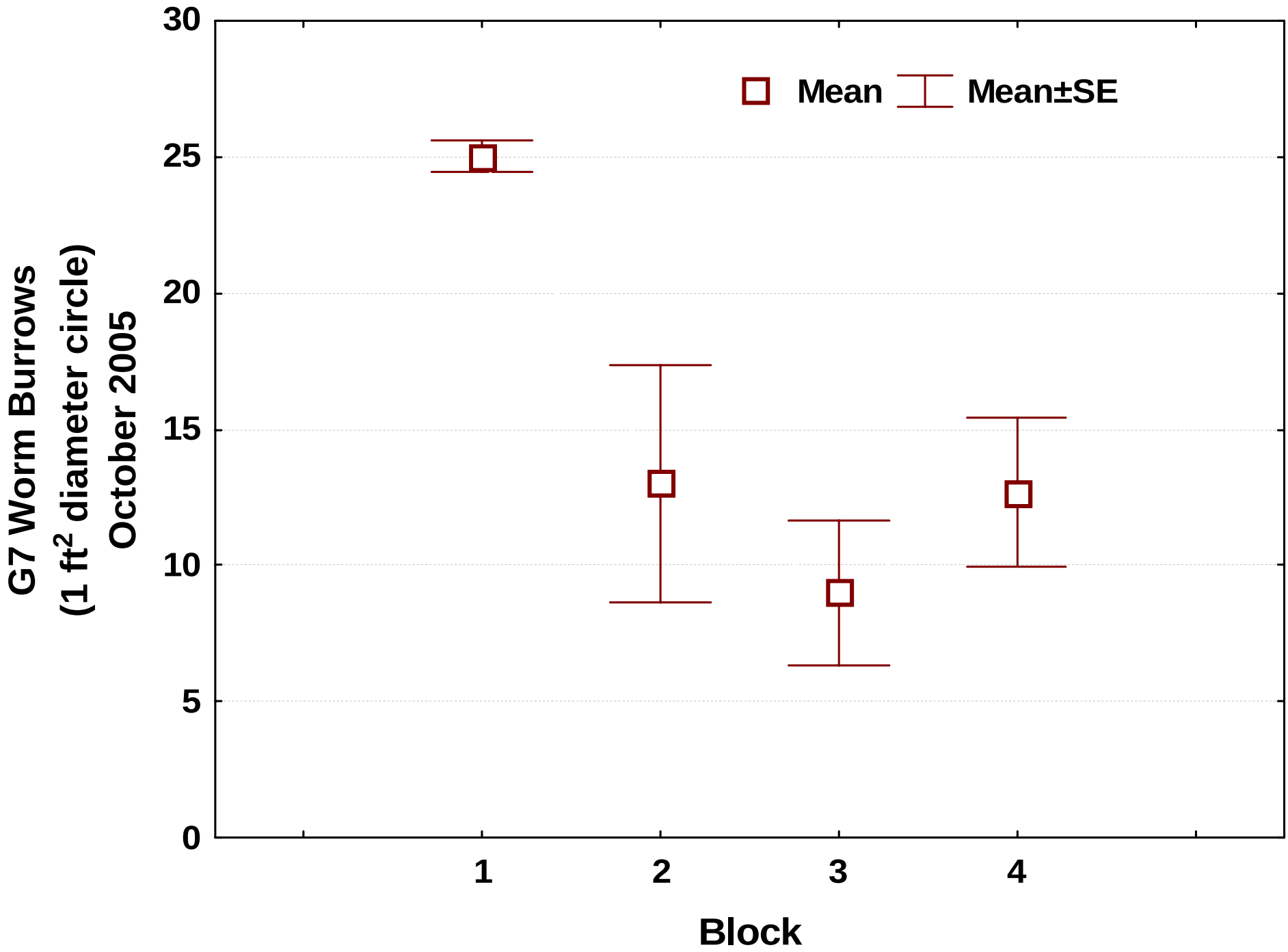

Mean
Mean±SE
120
110
100
90
80
70
60
50
40
30
20
P (mg/kg)
a
a
b
b
FH
F
H
N
LF Modified Treatment

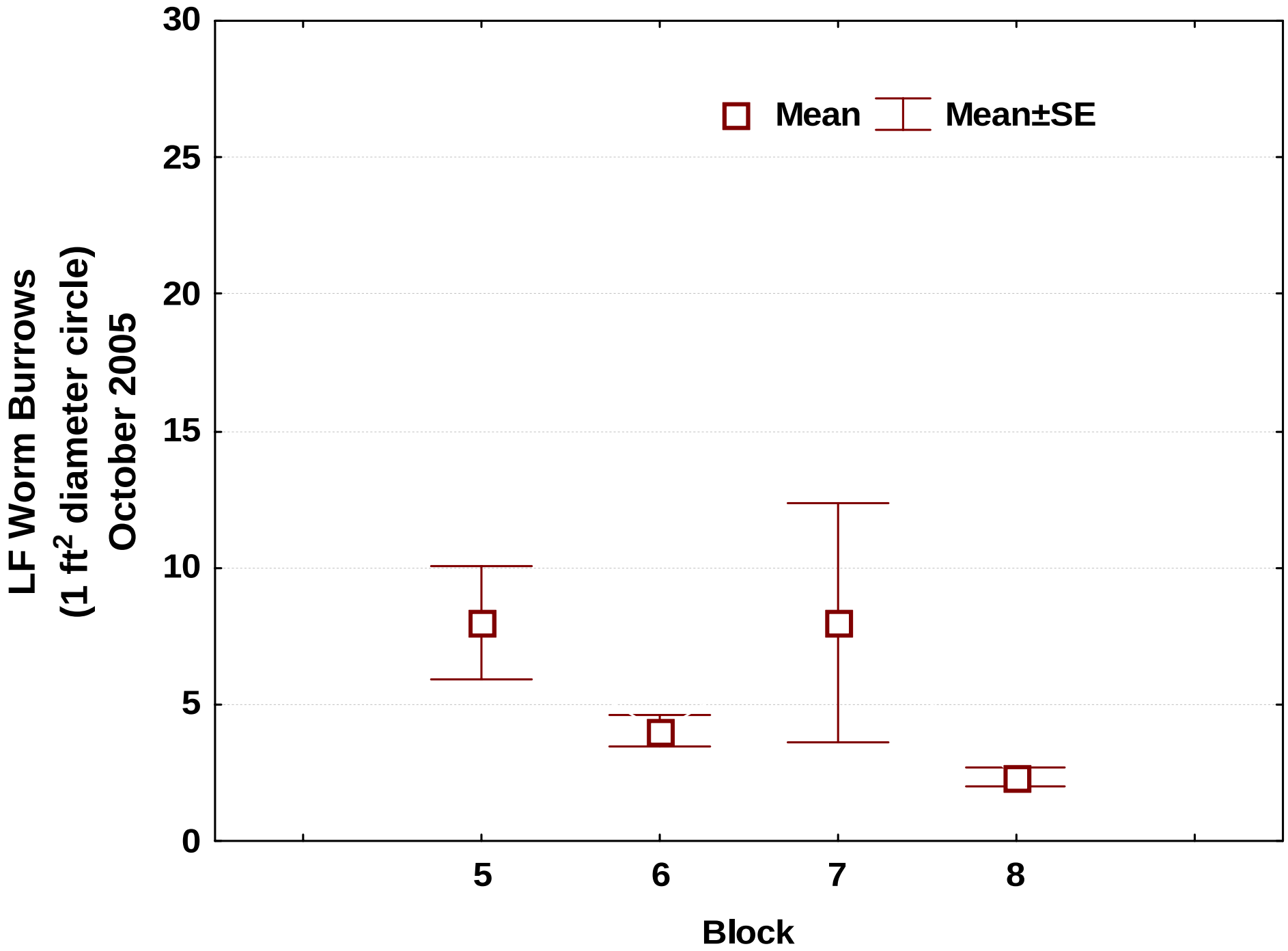

Mean
Mean±SE
800
700
600
500
400
300
200
100
0
Total Nematodes (# / 100 g)
a
b
b
b
FH
F
H
N
G7 Modified Treatment


Mean
Mean±SE
Nematode Maturity Index
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
a
ab
b
b
FH
F
H
N
G7 Modified Treatment

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 (?)


Mean
Mean±SE
G7 Worm Burrows
(1 ft2 diameter circle)
October 2005
30
25
20
15
10
5
0
1
2
3
4
Block


LF Worm Burrows
(1 ft2 diameter circle)
October 2005
30
25
20
15
10
5
0
Mean
Mean±SE
5
6
7
8
Block

Acknowledgement

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