Table I. Thermodynamic sequence of soil reduction.

System	$E_o 7^a$ (V)	$pE_o 7^b$
$O_2 + 4\ H^+ + 4\ e = 2\ H_2O$	0.814	13.80
$2\ NO_3^- + 12\ H^+ + 2\ e = N_2 + 6\ H_2O$	0.741	12.66
$MnO_2 + 4\ H^+ + 2\ e = Mn^{2+} + 2\ H_2O$	0.401	6.80
$CH_3COCOOH + 2\ H^+ + 2\ e = CH_3CHOHCOOH$	-0.158	-2.67
$Fe(OH)_3 + 3\ H^+ + e = Fe^{2+} + 3\ H_2O$	-0.185	-3.13
$SO_4^{2-} + 10\ H^+ + 8\ e = H_2S + 4\ H_2O$	-0.214	-3.63
$CO_2 + 8\ H^+ + 8\ e = CH_4 + 2\ H_2O$	-0.244	-4.14
$N_2 + 8\ H^+ + 6\ e = 2\ NH_4^+$	-0.278	-4.69
$NADP^+ + 2\ H^+ + 2\ e = NADPH$	-0.317	-5.29
$NAD^+ + 2\ H^+ + 2\ e = NADH$	-0.329	-5.58
$2\ H^+ + 2\ e = H_2$	-0.413	-7.00
Ferredoxin (ox) + e = Ferredoxin (red)	-0.431	-7.31

[a] E_o corrected to pH 7.0

[b] pE_o corrected to pH 7.0

Source: Ponnamperuma, 1977a.

Table II. Phytotoxicity of some products of the anaerobic decomposition of organic matter found in soils.

Product	Toxic conc.	Seedling	Reference
		Gases	
Ammonia	17.5 mM	Rice	Bonner, 1946
Carbon dioxide	0.2-0.3 bar	Barley	Vlamis & Davis, 1944
	0.05-0.1 bar	Rice	Saito & Takahashi, 1954
Ethylene	1-10 µL/L	Barley, maize rice, wheat	Cannell & Lynch, 1983
Hydrogen sulfide	2 µM	Rice	Mitsui, 1960
		Alcohols	
Ethanol	40 mM	Rice	Takijima, 1963
n-Butanol	10 mM	Rice	Takijima, 1963
		Carbonyls	
Acetaldehyde	4 mM	Rice	Takijima, 1963
Acetone	40 mM	Rice	Takijima, 1963
		Volatile fatty acids	
Acetic acid	1-5 mM	Rice	Rao & Mikkelsen, 1977
n-Butyric acid	1-5 mM	Rice	Rao & Mikkelsen, 1977
Formic acid	6 mM	Rice	Takijima, 1963
Propionic acid	1-5 mM	Rice	Rao & Mikkelsen, 1977
		Phenolic acids	
p-Coumaric acid	15 mM	Wheat	Cannell & Lynch, 1983
p-Hydroxy benzoic acid	7-70 mM	Wheat, maize, sorghum	Cannell & Lynch, 1983
		Thiol	
Ethyl mercaptan	2 mM	Rice	Takijima, 1963

Table III. Kinetics of water-soluble boron, copper, molybdenum, and zinc in three submerged soils.

Element	Concentration (mg/L)			
	1 wk	2 wk	4 wk	6 wk
	Luisiana clay (pH: 4.8; O.M.: 2.8%)			
B	0.55	0.49	0.46	0.30
Cu	0.11	0.11	0.04	0.02
Mo	0.18	0.06	0.15	0.24
Zn	0.30	0.09	0.08	0.03
	Maahas clay (pH: 6.6; O.M.: 2.8%)			
B	1.80	1.01	1.15	1.18
Cu	0.06	0.05	0.03	0.02
Mo	0.04	0.09	0.17	0.12
Zn	0.18	0.08	0.06	0.03
	Keelung silt loam (pH: 7.7; O.M.: 6.9%)			
B	0.48	0.55	0.68	0.52
Cu	0.05	0.05	0.04	0.03
Mo	0.09	0.10	0.17	0.27
Zn	0.14	0.08	0.04	0.03

Source: Ponnamperuma (1977b).

Figure legends

Fig. 1. The temperature profile in a flooded rice field.

Source: Kondo (1952).

Fig. 2. Changes of Eh with time in a well-drained soil and a submerged soil.

Source: Ponnamperuma (1955).

Fig. 3. Changes of Eh in four submerged soils.

Soil No.	pH	Organic Matter (%)	Active Fe (%)	Active Mn (%)
9	6.0	3.9	0.65	0.005
26	7.5	1.1	1.13	0.063
27	6.6	2.0	1.25	0.223
28	4.6	2.9	4.10	0.050

Source: IRRI (1963).

Fig. 4. Kinetics of the pH values of some submerged soils.

Soil No.	Texture	pH	Organic Matter (%)	Active Fe (%)	Active Mn (%)
28	Clay	4.9	2.9	4.70	0.08
35	Clay	3.4	6.6	2.60	0.01
40	Clay	3.8	7.2	0.08	0.00
57	Clay loam	8.7	2.2	0.63	0.07
94	Clay	6.7	2.6	0.96	0.09
99	Clay loam	7.7	4.8	1.55	0.08

Source: Ponnamperuma (1972).

Fig. 5. Kinetics of the specific conductance of four submerged soils.

▽——▽ Silty clay loam (pH 8.7; O.M. 2.2%)

▼——▼ Clay loam (pH 6.7; O.M. 2.6%)

o——o Clay (pH 7.3; O.M. 1.2%)

—— Clay (pH 4.6; O.M. 2.9%)

Source: Ponnamperuma (1977a).

Fig. 6. Kinetics of specific conductance and cation concentrations in a submerged ferrallitic soil.

o Total alkalinity (meq/L)

● $Ca^{2+} + Mg^{2+} + NH_4^+ + Na^+ + K^+$ (meq/L)

▽ $Fe^{2+} + Mn^{2+}$ (meq/L)

▼ Specific conductance (dS/m)

Source: Ponnamperuma (1972).

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Fig. 7. Kinetics of P_{CO_2} in four submerged soils.

Soil	Texture	pH	Organic Matter (%)	Active Fe (%)	Active Mn (%)
■	Clay	5.7	1.3	0.79	0.36
⊙	Clay	5.9	3.3	1.67	0.33
△	Clay	5.4	1.5	1.67	0.20
●	Clay	6.3	2.4	1.27	0.20

Source: IRRI (1965).

Fig. 8. Kinetics of ammonium release in 7 submerged soils.

Source: IRRI (1965).

Fig. 9. Influence of temperature on the kinetics of denitrification in a submerged soil.

Source: Ponnamperuma (1977a).

Fig. 10. Influence of soil properties on loss of ammonia from three flooded soils.

Source: IRRI (1976).

Fig. 11. Kinetics of water-soluble manganese in five submerged soils.

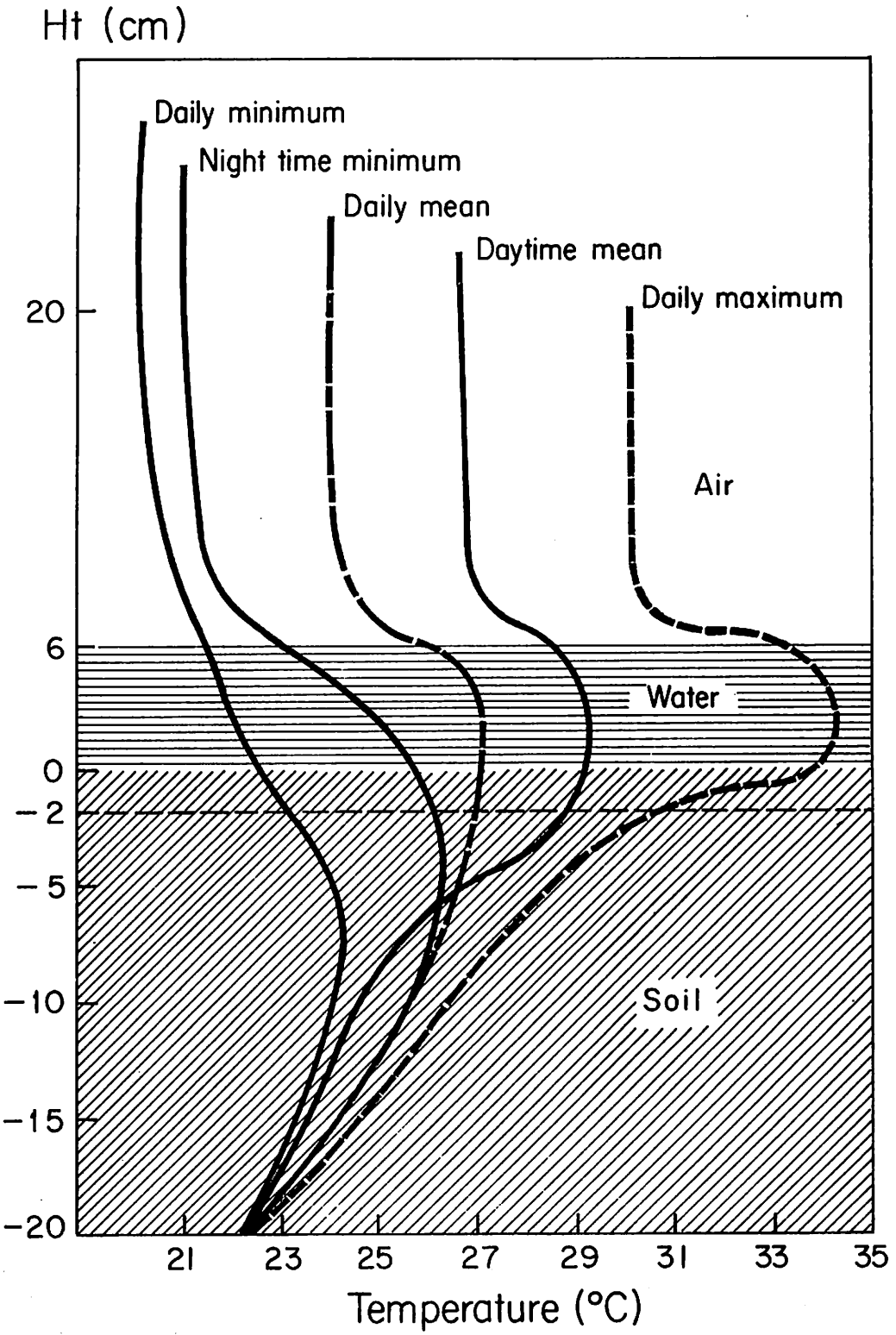
Soil No.	pH	Organic Matter (%)	Active Mn (%)
7	5.9	3.3	0.33
19	5.5	4.2	0.13
10	5.4	1.5	0.20
27	6.6	2.0	0.31
26	7.6	1.5	0.06

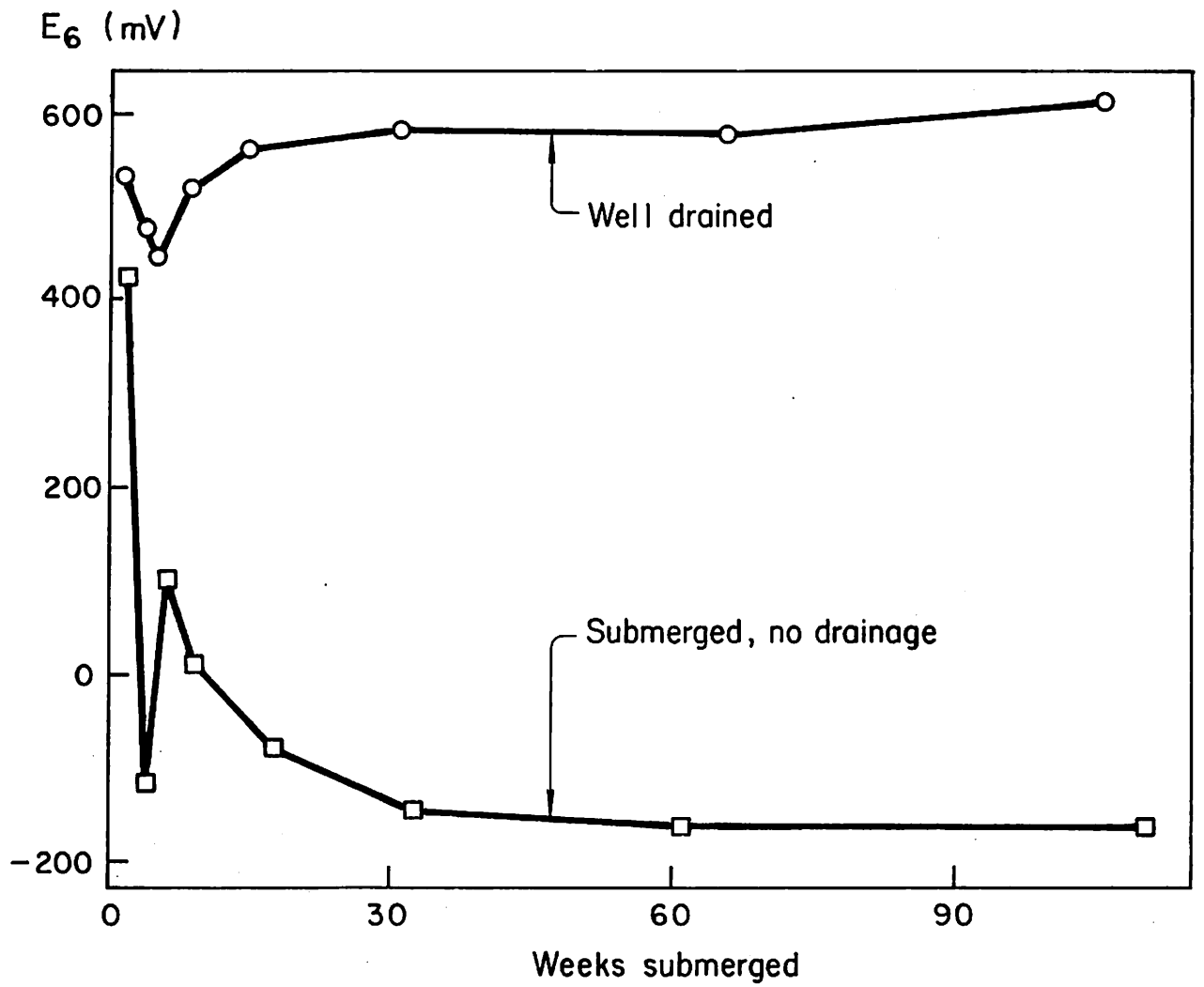
Source: Ponnamperuma (1977b).

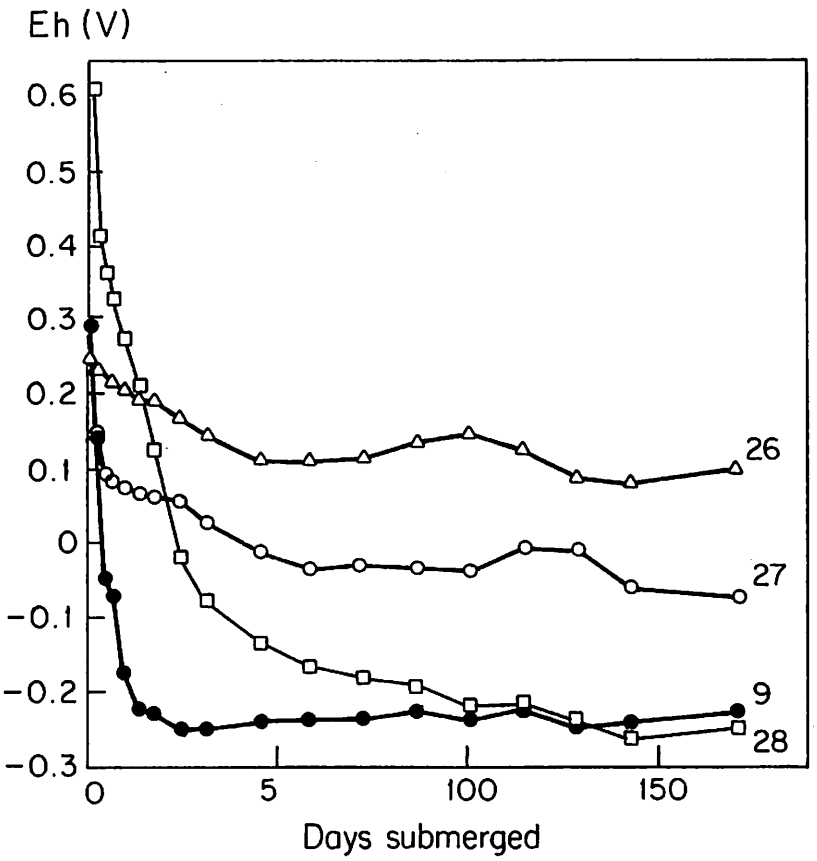
Fig. 12. Kinetics of water-soluble iron in five submerged soils.

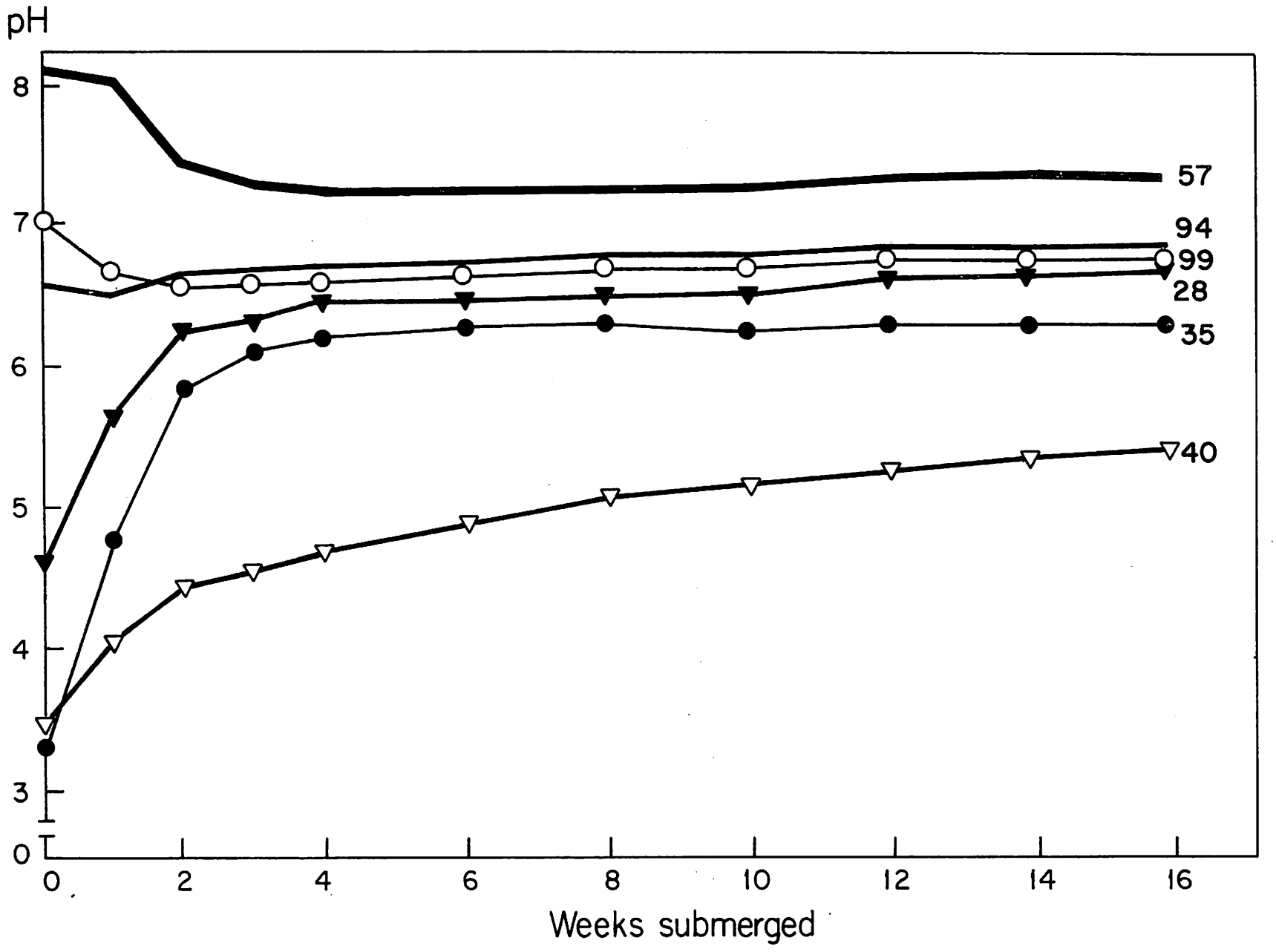
Soil No.	Texture	pH	Organic Matter (%)	Active Fe (%)	Active Mn (%)
21	Clay loam	4.6	4.1	2.78	0.02
15	Clay loam	5.3	2.5	0.91	0.05
19	Clay loam	5.5	4.2	2.30	0.13
27	Clay	6.6	2.0	1.60	0.31
26	Clay loam	7.6	1.5	0.30	0.06

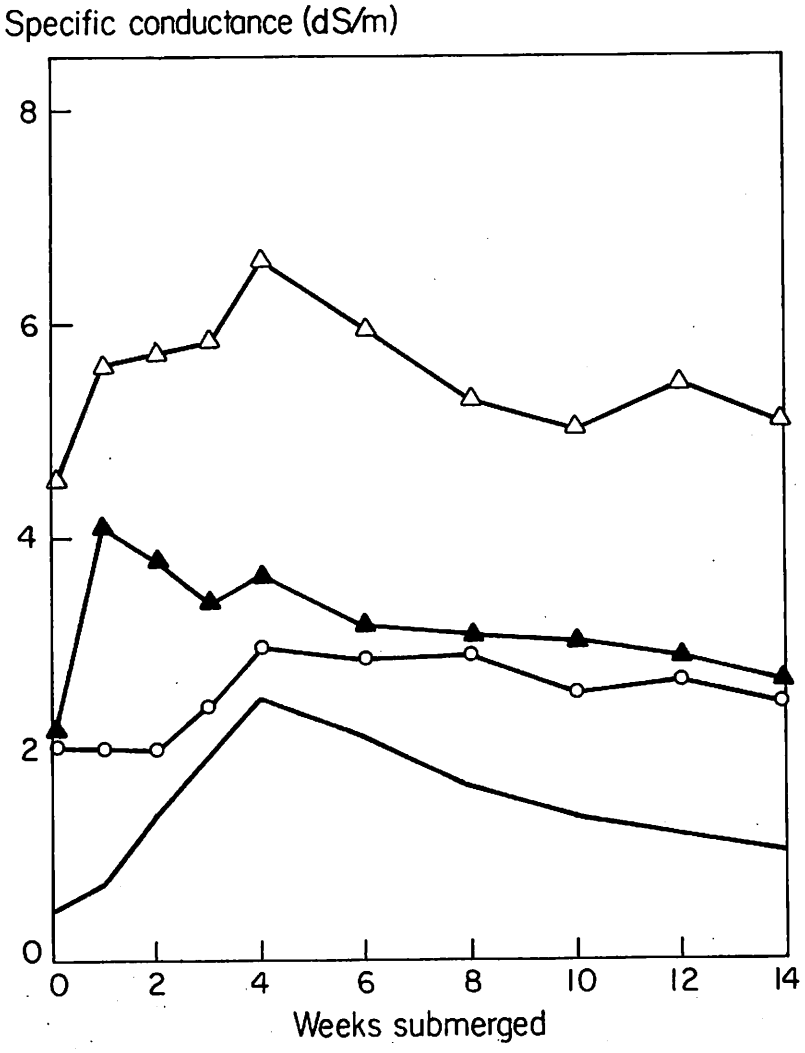
Source: Ponnamperuma (1977a).

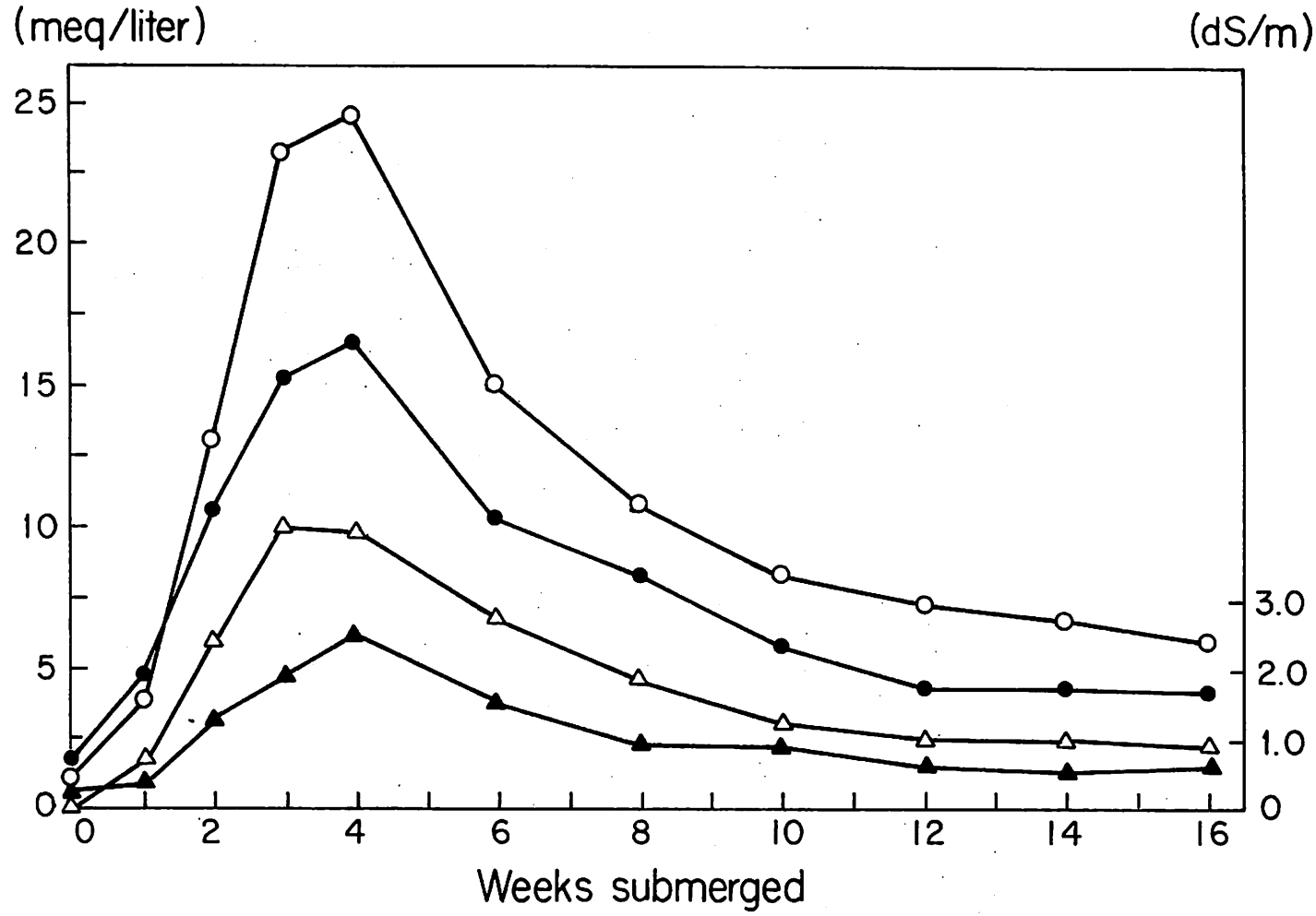

Ht (cm)
Daily minimum
Night time minimum
Daily mean
Daytime mean
Daily maximum
Air
Water
Soil
20
6
0
−2
−5
−10
−15
−20
21
23
25
27
29
31
33
35
Temperature (°C)

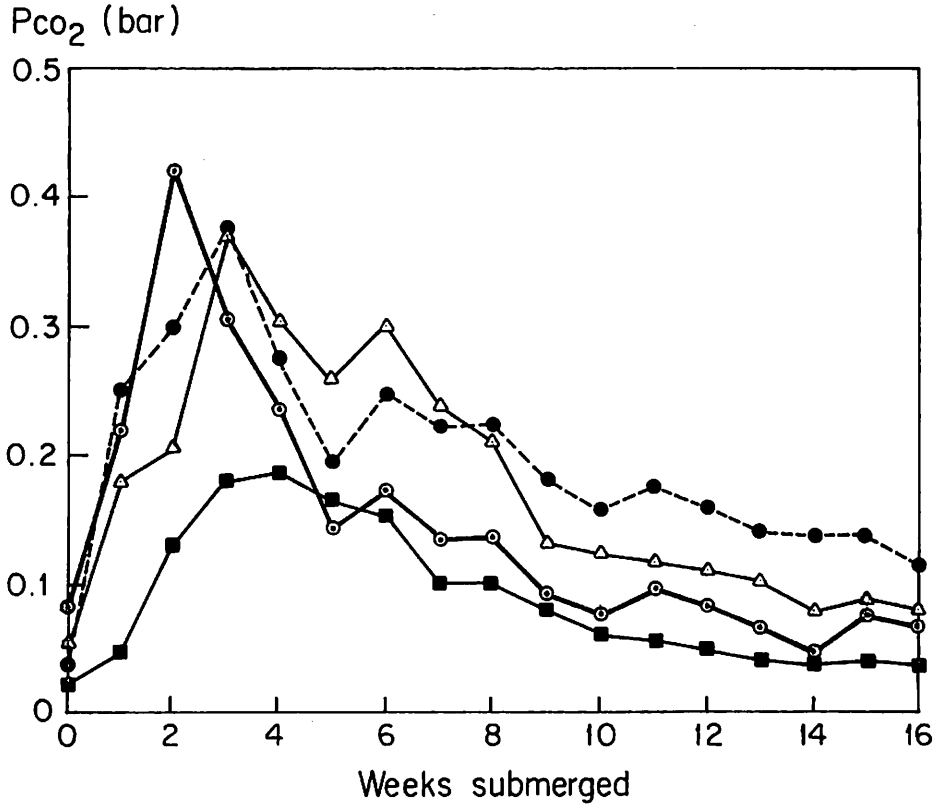

E_6 (mV)
600
400
200
0
−200
Well drained
Submerged, no drainage
0
30
60
90
Weeks submerged

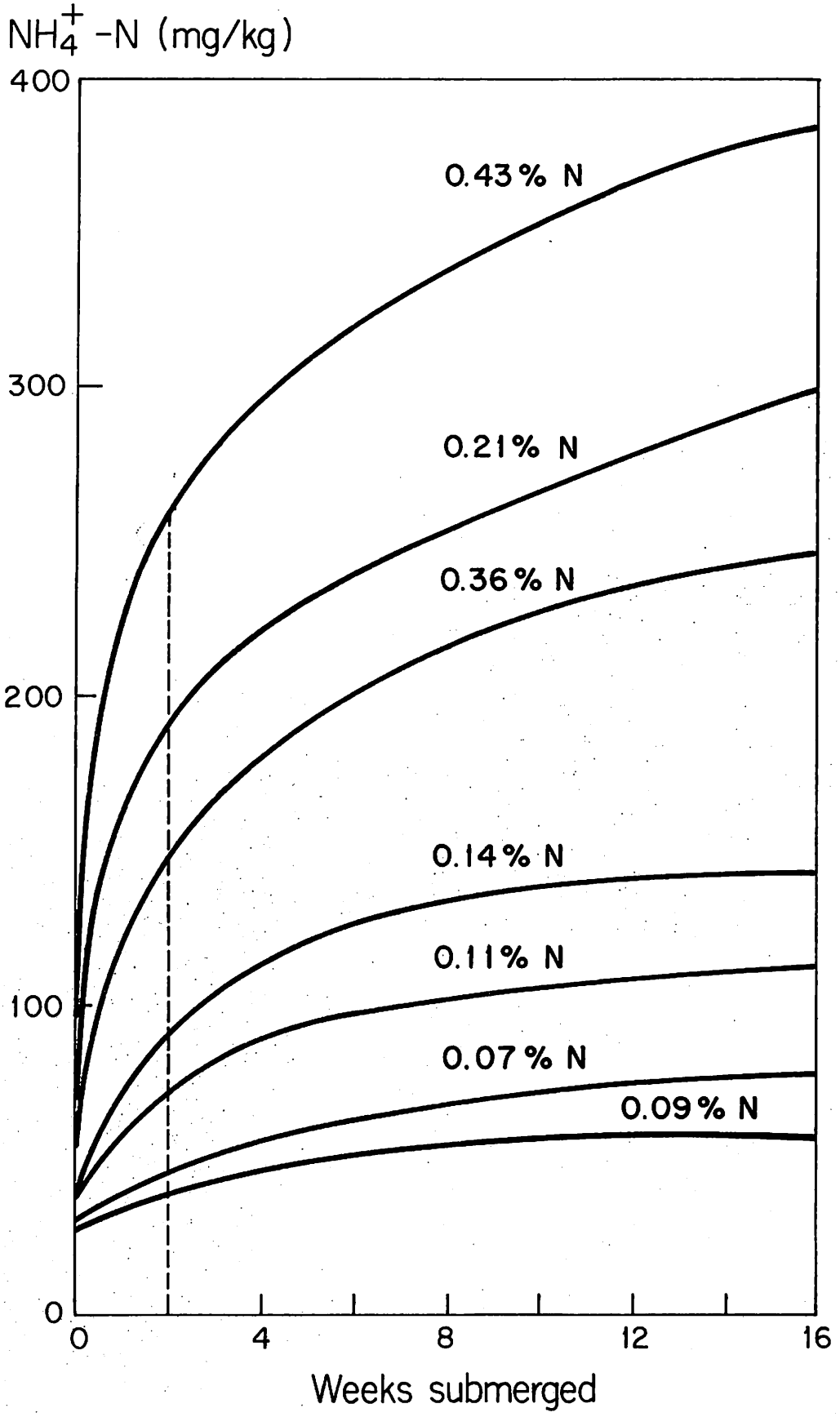

Eh (V)
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
0
5
100
150
Days submerged
26
27
9
28

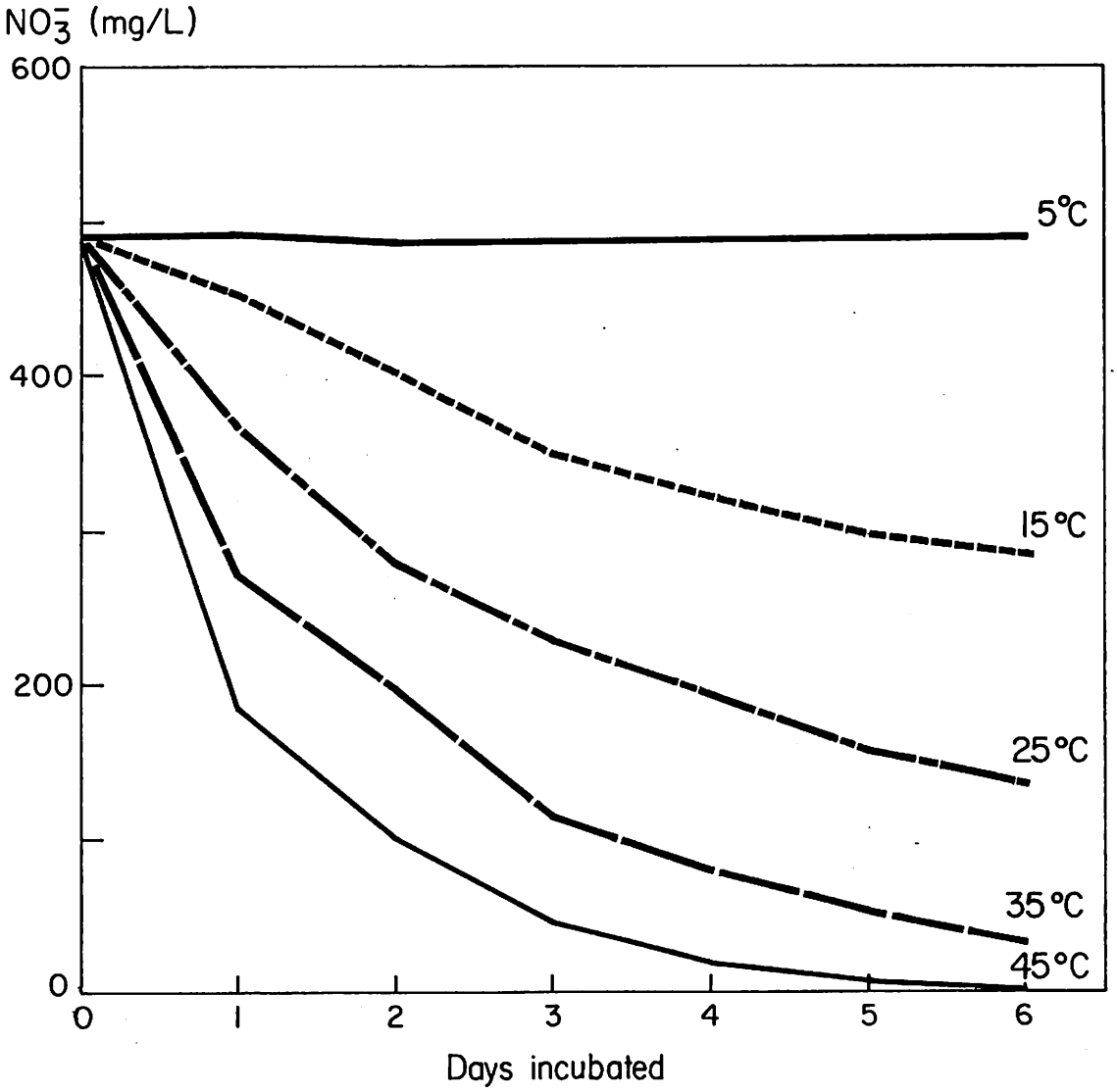

pH
8
7
6
5
4
3
0
0
2
4
6
8
10
12
14
16
Weeks submerged
57
94
99
28
35
40

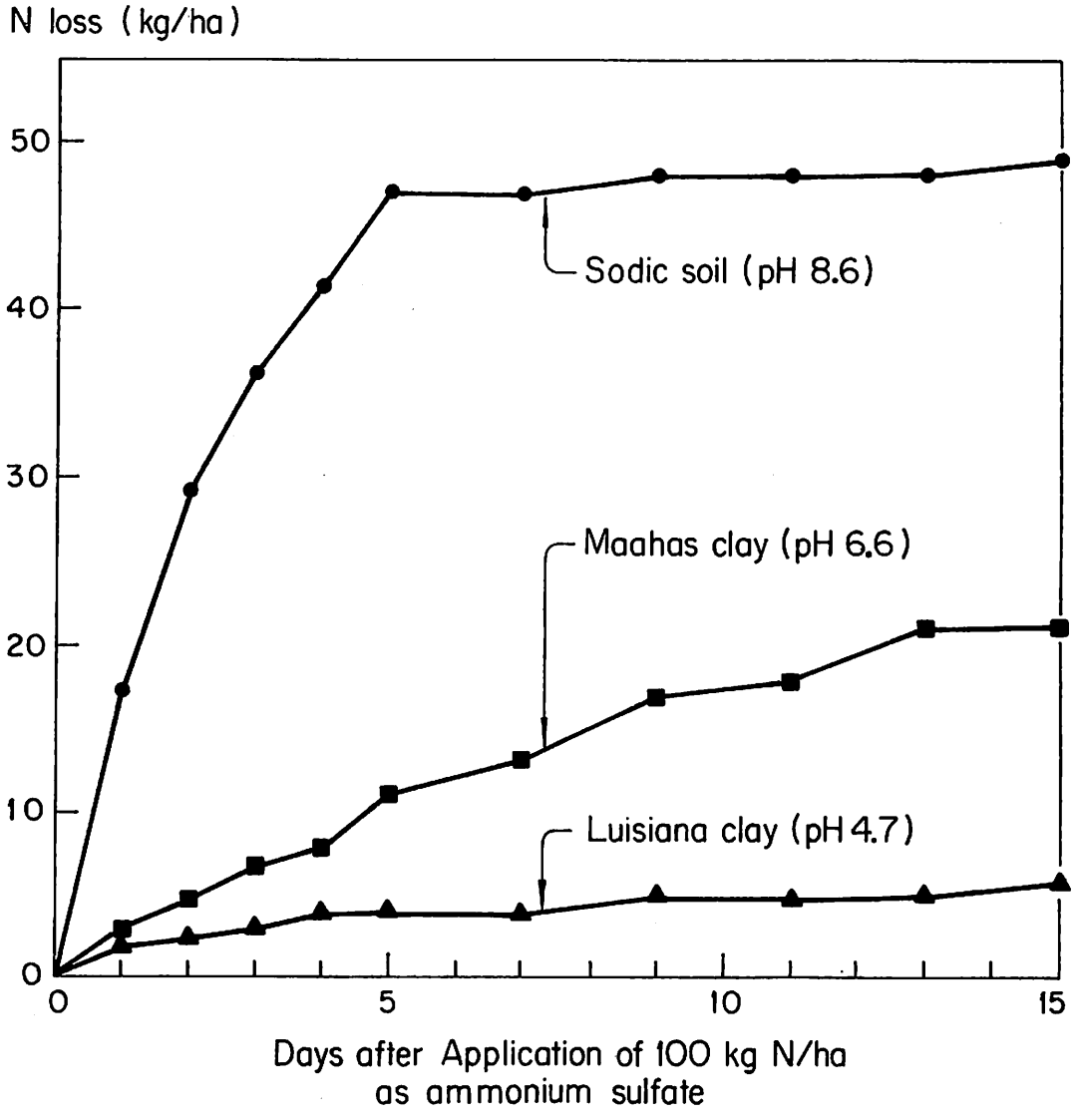

Specific conductance (dS/m)
8
6
4
2
0
0
2
4
6
8
10
12
14
Weeks submerged

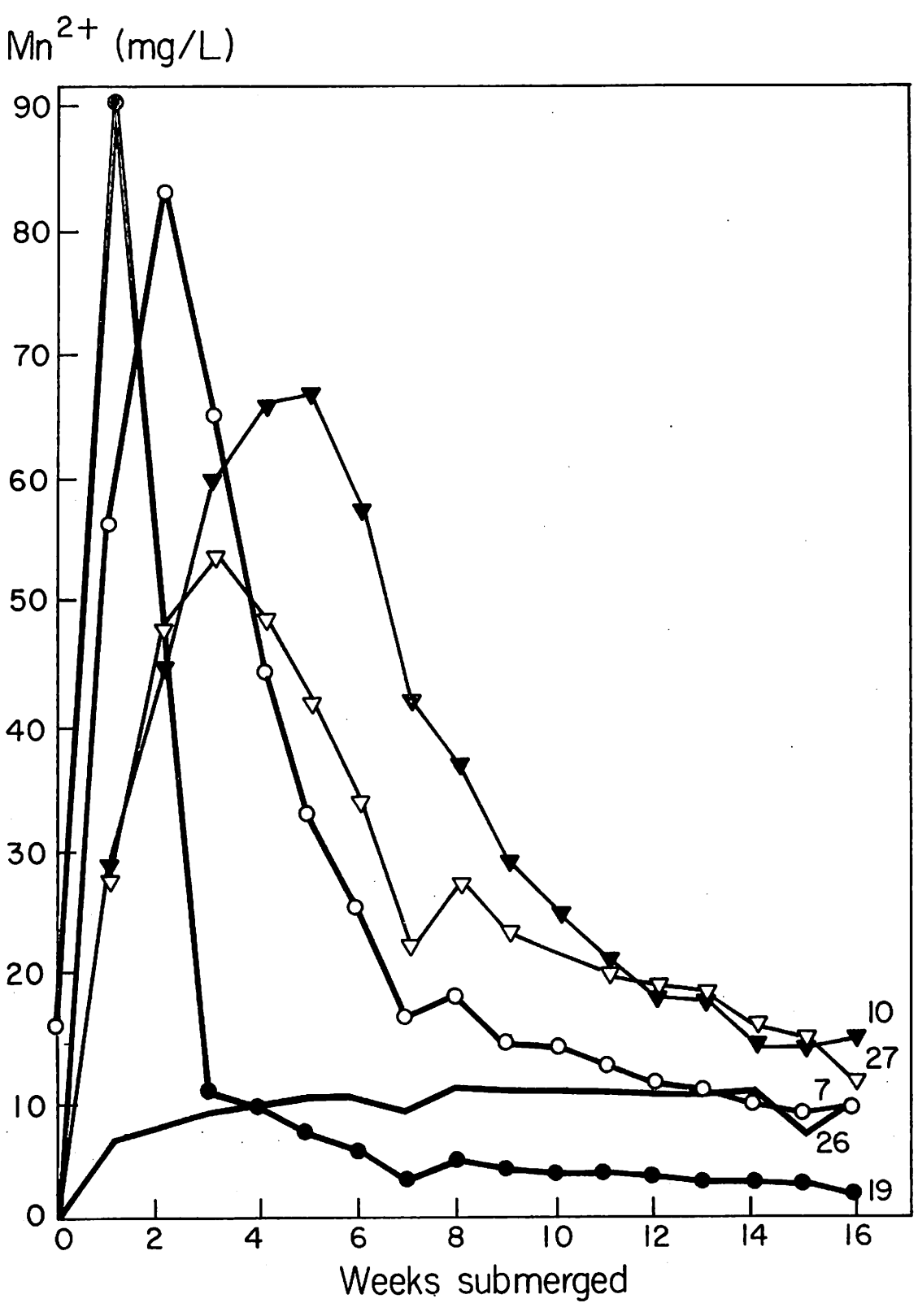

(meq/liter)
(dS/m)
25
20
15
10
5
0
3.0
2.0
1.0
0
0
2
4
6
8
10
12
14
16
Weeks submerged

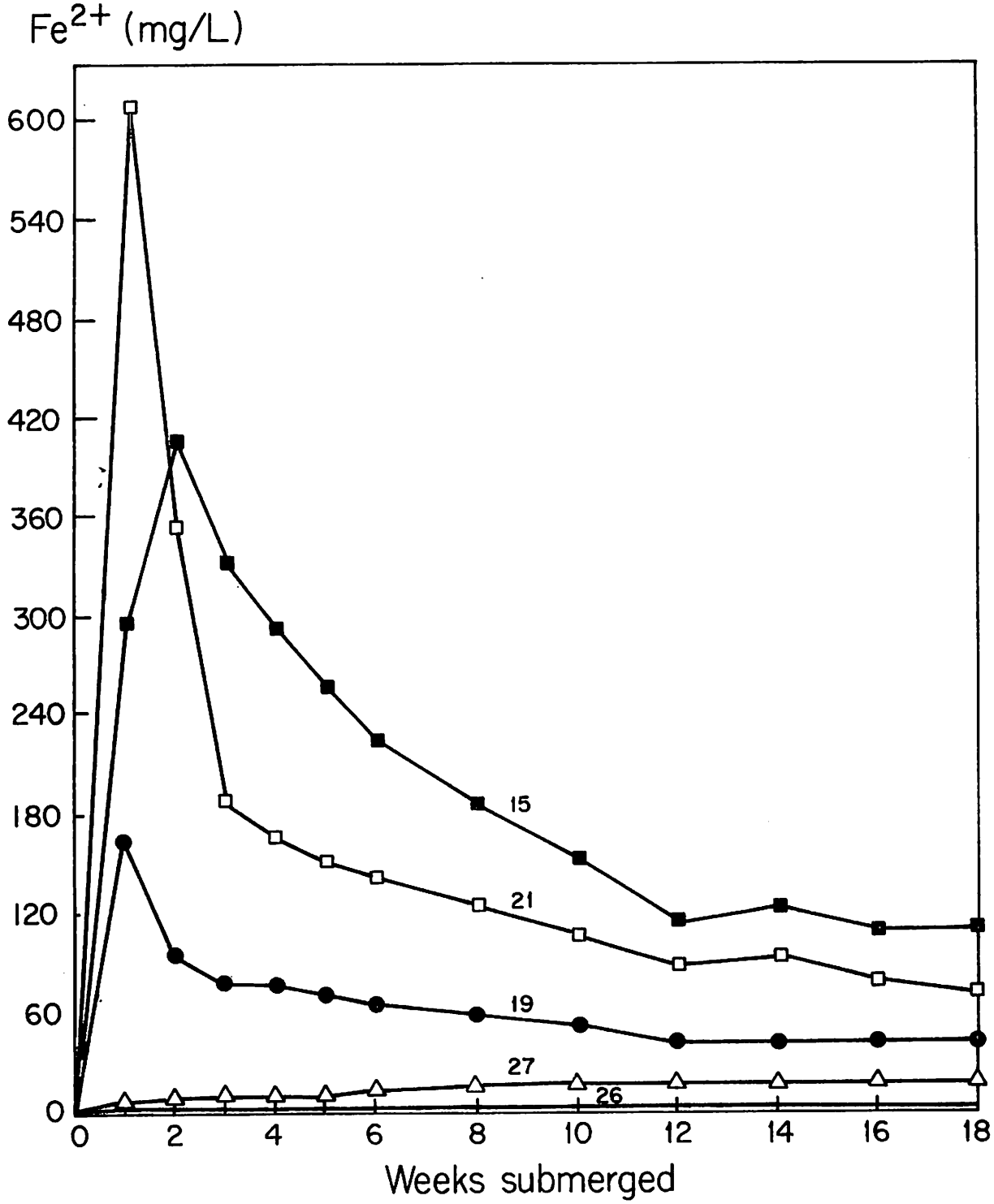

Pco2 (bar)
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
Weeks submerged


NH_4^+ -N (mg/kg)
400
300
200
100
0
0.43% N
0.21% N
0.36% N
0.14% N
0.11% N
0.07% N
0.09% N
0
4
8
12
16
Weeks submerged


NO_3^- (mg/L)
600
400
200
0
0
1
2
3
4
5
6
Days incubated
5°C
15°C
25°C
35°C
45°C


N loss (kg/ha)
50
40
30
20
10
0
0
5
10
15
Sodic soil (pH 8.6)
Maahas clay (pH 6.6)
Luisiana clay (pH 4.7)
Days after Application of 100 kg N/ha
as ammonium sulfate


Mn2+ (mg/L)
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
Weeks submerged
10
27
7
26
19


Fe2+ (mg/L)
600
540
480
420
360
300
240
180
120
60
0
0
2
4
6
8
10
12
14
16
18
Weeks submerged
15
21
19
27
26