Agricultural applications of biosolids treated with fly ash and lime (NVS)

Pinchas Fine, Arie Bosak
Anna Beriozkin
and plenty more
ARO, Volcani Center

An overview of possible benefits and risks from using NVSs

- **Direct agricultural benefits:**
  - Fertilizer substitute, source of essential microelements and viable organic matter additive.
  - Soil disinfection (in light-textured soils);
  - Improve sodic soils (acid soils) and other problematic soils (e.g., sandy, crust forming);
  - Potentially improves quality of agricultural products;
- **Risks:**
  - High pH;
  - Phytoavailability of oxyanionic trace and heavy metals;
  - Allegedly diminishes the phytoavailability of P and essential micro-nutrients (especially Fe).
- **Benefits the Environment:**
  - Circumvents composting thus reducing emissions of GHG, ammonia (≈40 kg N/ton!), odors and dust;
  - Eliminates antibiotic resistant microorganisms.
  - Reuse of byproducts, conserves nonrenewable resources, maintains the recycling principal;
- **Benefits the urban sector**
  - significant reduction of expenditures on WWTF construction and maintenance;

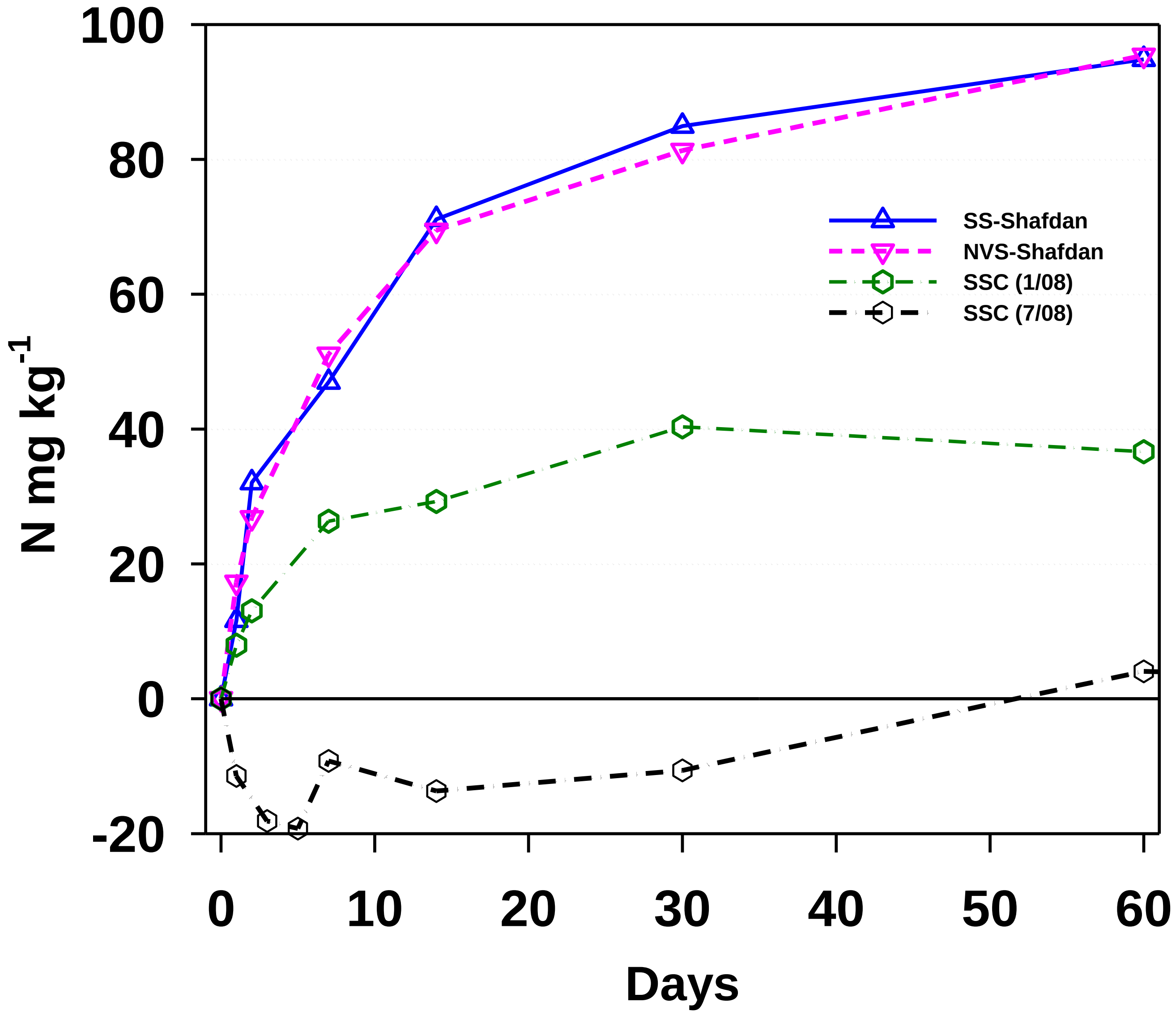
Composition of Israeli sludge types (2011 data)

Constituent	Units	Shafdan sludge	NVS	Sludge compost	Israel upper bound
$C_{Organic}$	%	37.7	8.6	22.2	
N_{Total}	%	6.39	0.86	2.1	
C_{Org}/N_{Org}	ratio	6.1	10.3	12.2	
P_{Total}	%	1.33	0.40	1.29	
pH (1:5)		5.8	12.2	6.6	
EC (1:5)	dS/m	5.9	6.9	6.6	
Cd	mg/kg	2.9	0.7	1.1	20
Cr	- " -	65	80	110	400
Cu	- " -	150	40	230	600
Hg	- " -	< 0.1	< 0.1		5
Ni	- " -	45	40	60	90
Pb	- " -	30	35	40	300
Zn	- " -	950	150	1,200	2500

Nitrogen bioavailability

Net mineralization of organic N

Incubation study: application rate (8-50 tons/ha) equivalent to application of 500 kg N/ha (incubation at optimal moisture content, 30ºC)



Mineralization parameters of sludge organic N in amended sand at a load equivalent to 500 kg total N_T ha^{-1}

Calculated using a 2 parametric exponential rise equation:
$N_t = N_{0*}(1-e^{-kt})$: N_t = mineral N at time = t; N_0 = potentially mineralizable organic N; k = the equation rate constant

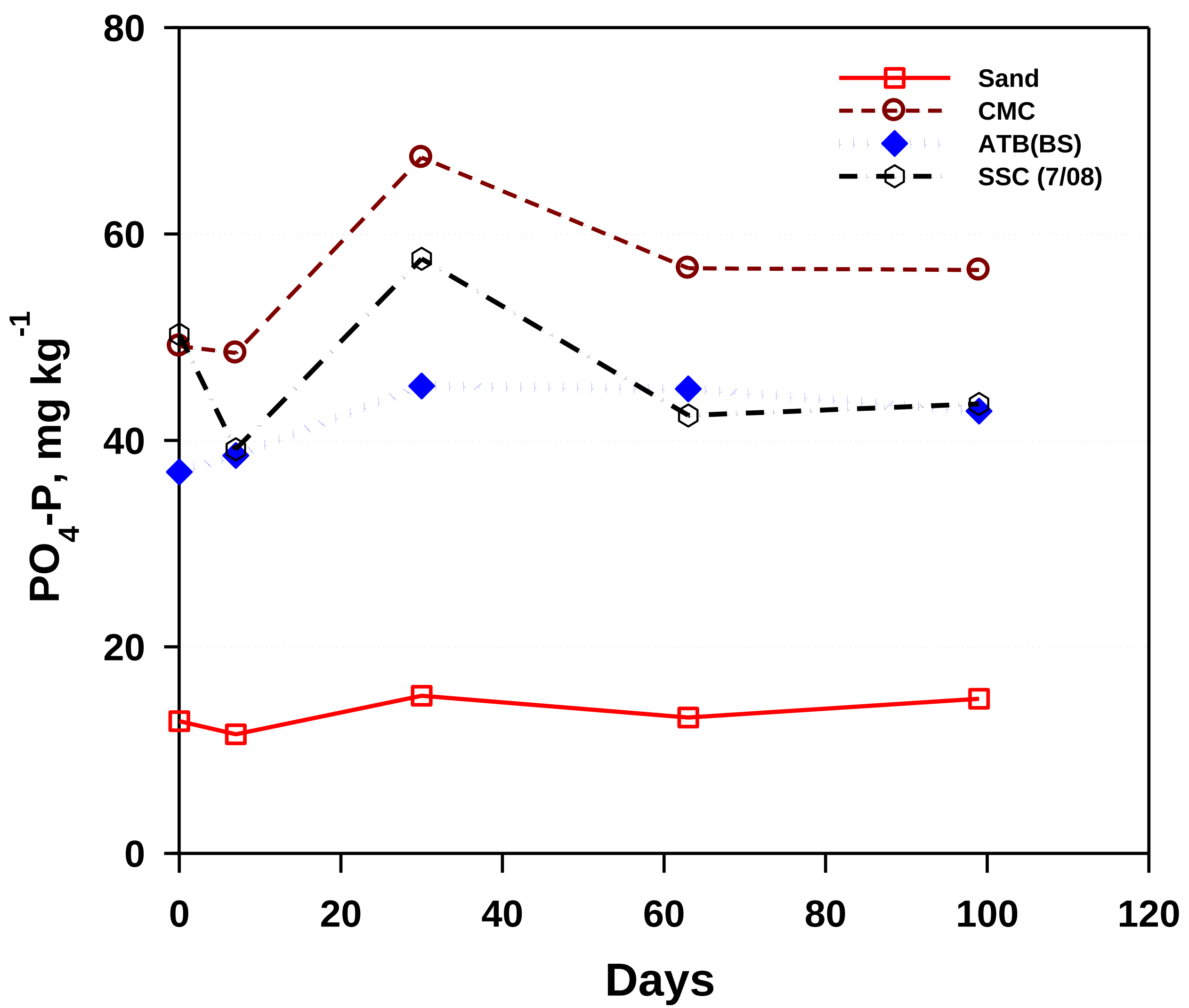
Sludge type	N_0 (mg N kg^{-1})	*p*	N_0/N_T (%)	k (day^{-1})	*p*	r^2
Untreated (Tel-Aviv)	90.5 ± 5.8	<0.0001	45	0.12 ± 0.02	0.008	0.97
NVS (Tel-Aviv)	88.5 ± 4.6	<0.0001	44	0.13 ± 0.02	0.002	0.98
Compost(Jan 08)	37.0 ± 2.0	<0.0001	19	0.18 ± 0.03	0.004	0.97
Compost(July 08)	-20		-10 - 0			

Ammonia volatilization loss during composting = 3500 - 4500 tons N per 100,000 dry tons sludge (Israel approx. yearly production)

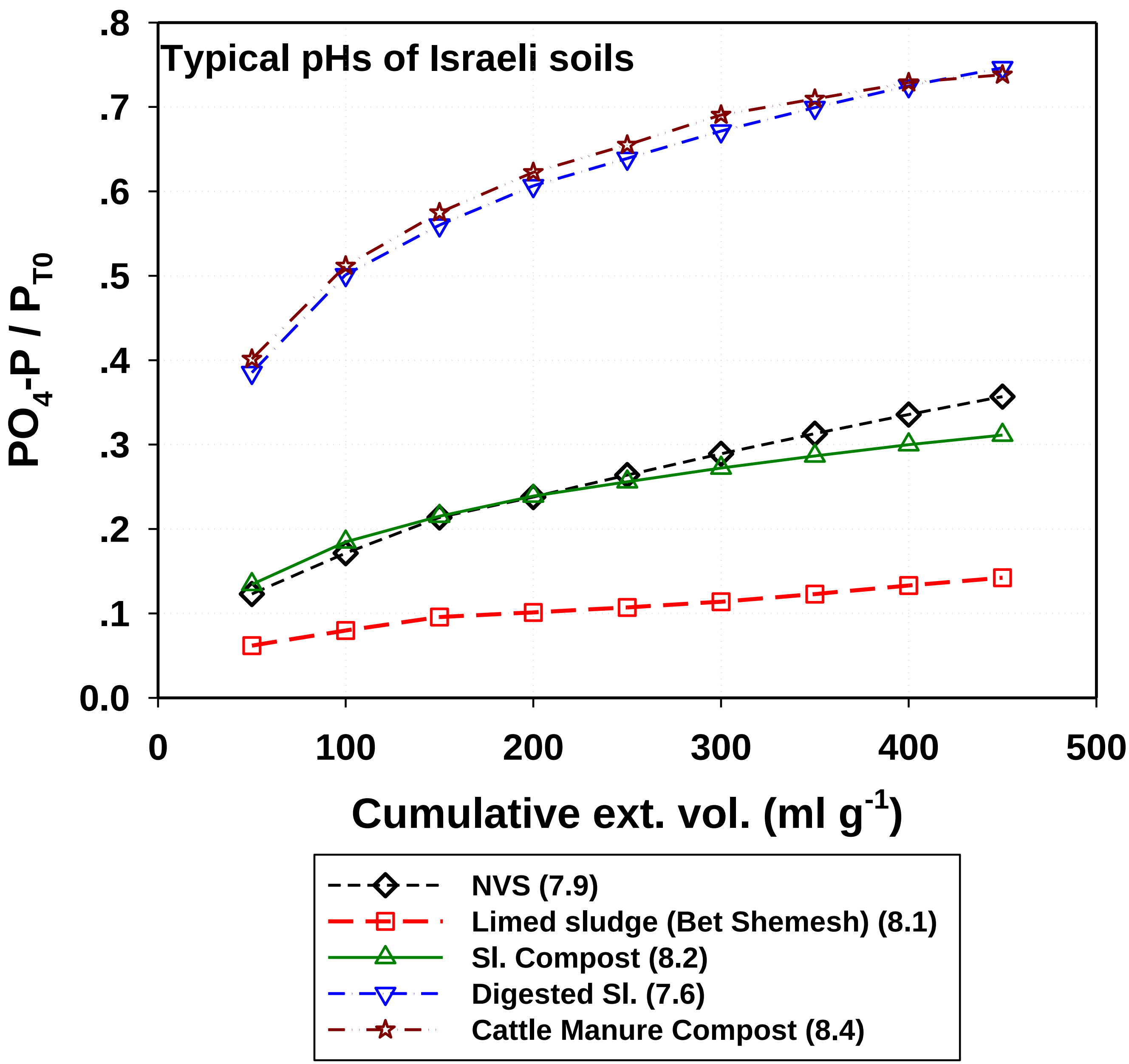
Phosphorus potential phytoavailability

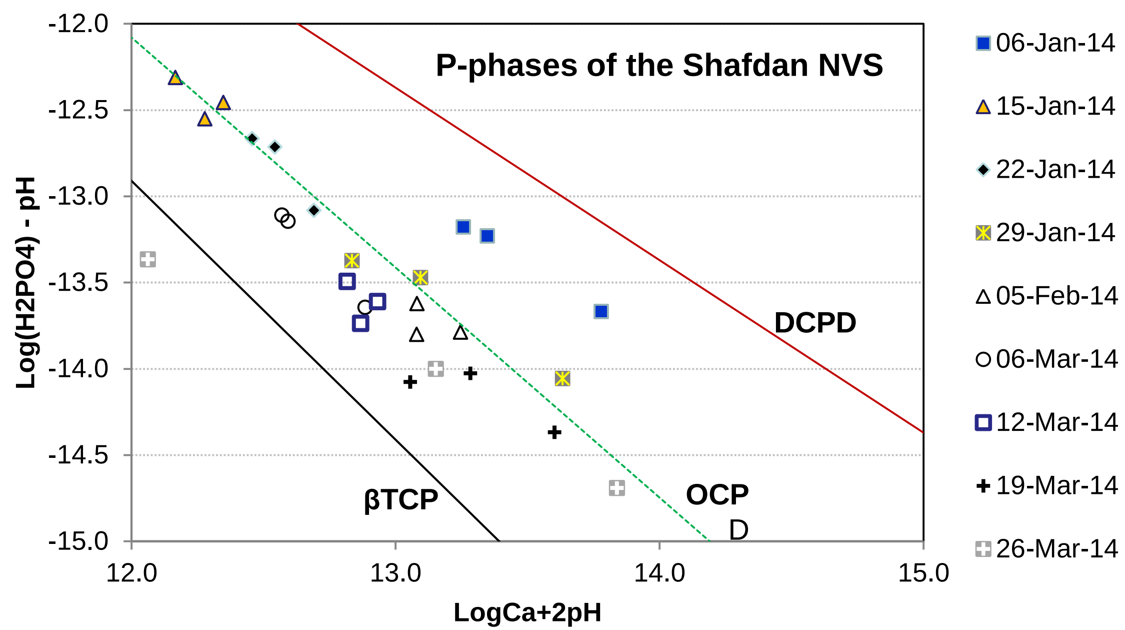
Potentially phyto-available P

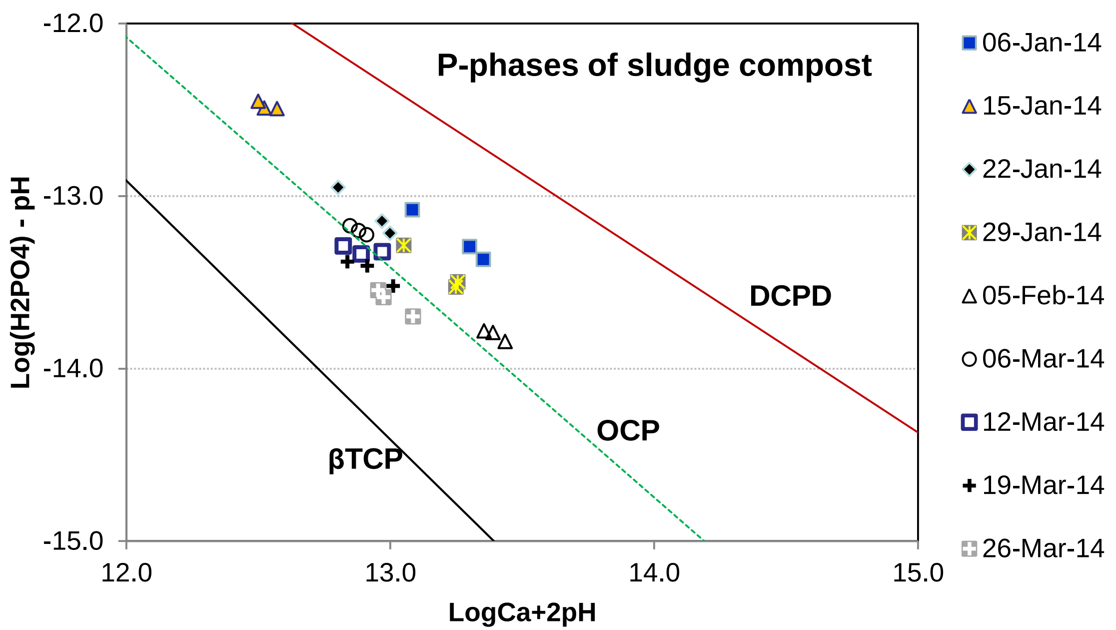
Incubation study - application rate 8-50 tons/ha, equivalent to application of 500 kg N/ha (incubation at optimal moisture content, 30ºC)



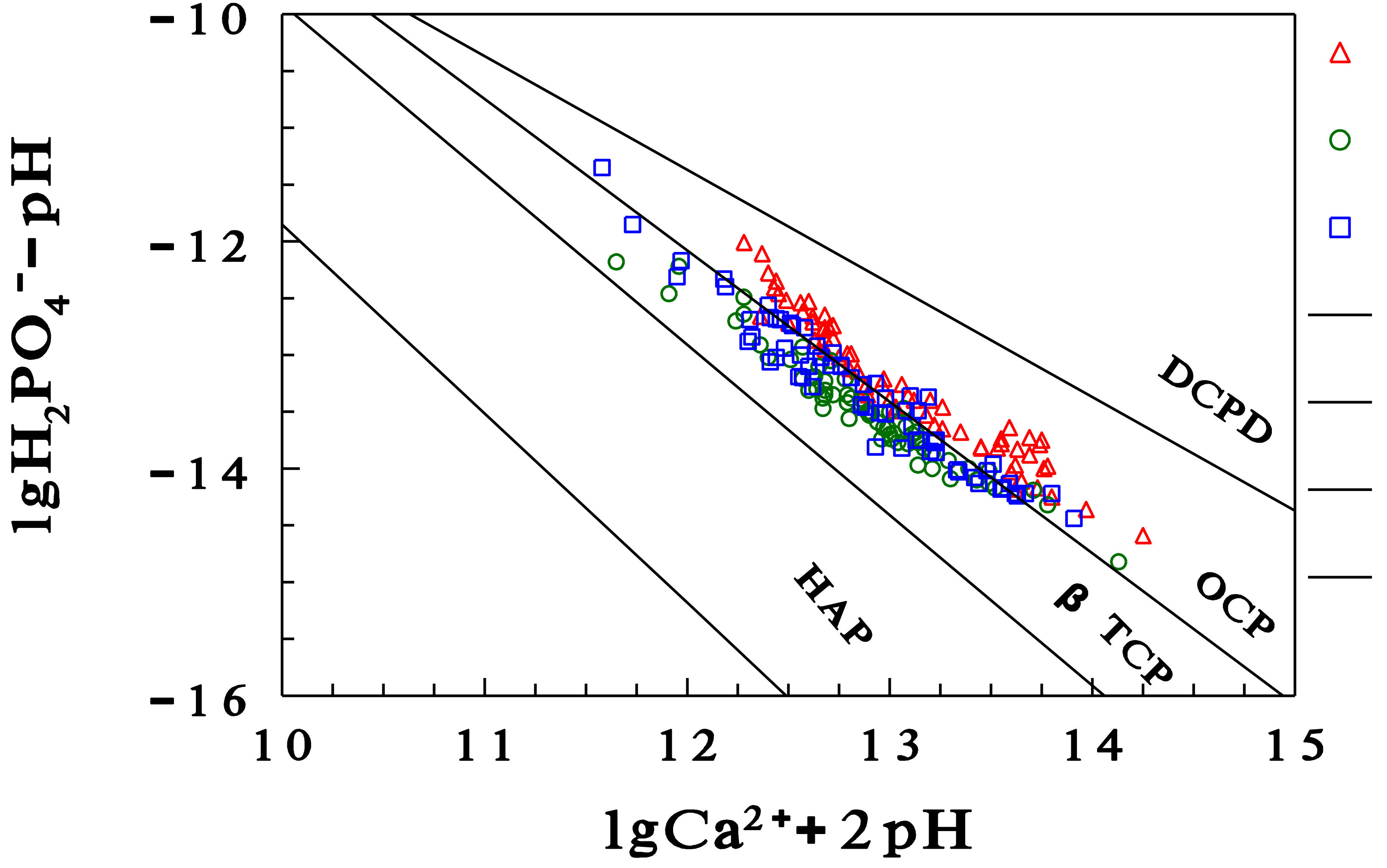
Dissolution of inorganic P in sludge types and manures




P-phases of the Shafdan NVS
DCPD
OCP
βTCP
D
Log(H2PO4) - pH
LogCa+2pH
-12.0
-12.5
-13.0
-13.5
-14.0
-14.5
-15.0
12.0
13.0
14.0
15.0
06-Jan-14
15-Jan-14
22-Jan-14
29-Jan-14
05-Feb-14
06-Mar-14
12-Mar-14
19-Mar-14
26-Mar-14


P-phases of sludge compost
DCPD
OCP
βTCP
Log(H2PO4) - pH
LogCa+2pH
-12.0
-13.0
-14.0
-15.0
12.0
13.0
14.0
15.0
06-Jan-14
15-Jan-14
22-Jan-14
29-Jan-14
05-Feb-14
06-Mar-14
12-Mar-14
19-Mar-14
26-Mar-14

P-Phases in sandy soil under long-term organic regime following application of broilers litter



Heavy and trace elements

Field experiment - silage corn – wheat rotation, started in 2011 (Revadim, Vertisol)

lettuce in 200-L lysimeters

Three soils; 4-8 reps./treatment;

Manures applied twice: in 2011 and in 2012.

Application rates supplied 500 or 1500 kg N/ha/y,

[in () are loads in dry tons/ha]

Metals in lettuce (mg/kg dw; summer 2002) in lysimeters

Three soils; 4-8 reps./treatment; **two applications**, in 2011 & 2012.

manures added at 500 or 1500 kg N/ha/y (loads are in m^3/ha/y)

Dune sand	As	Cd	Pb	B	Mo	Zn	P	Cu
Control	0.12	0.50 ab	0.09	46 b	0.30 b	37 b	4,867 c	4.2 c
NVS-100*2	0.17	0.29 b	0.11	75 a	1.01 a	48 b	5,166 bc	7.5 a
Sludge-8*2	0.13	0.98 a	0.08	44 b	0.20 b	110 a	6,594 ab	6.5 ab
Sl comp-22*2	0.13	0.50 ab	<0.15	39 b	0.38 b	61 b	6,578 a	5.6 bc
P		*0.014*		*<.0001*	*<.0001*	*0.0001*	*0.0018*	*0.0005*
Nahal-Oz (loessial light-brown loam)								
Control	0.02 b	0.07 b	0.08	37 b	0.54 b	32	4,805	8.0
NVS-100*2	0.15 a	0.11 a	0.13	57 a	0.93 a	42	4,565	8.2
P	*<0.001*	*0.031*		*0.0265*	*0.0147*			
Revadim (vertisol; clayey)								
Control	0.13	0.20	0.29	35	0.30 b	46 bc	6,490	9.3
NVS-100*2	0.22	0.27	0.23	47	0.80 a	40 c	5,140	8.4
NVS-300*2	0.13	0.27	0.32	46	0.76 a	53 ab	6,920	11.7
Sl comp- 22*2	0.09	0.24	0.31	37	0.38 ab	65a	6,614	9.2
P						*0.0006*		
Upper bound*	5	1	1.5					

***Min. of Health (4.A.3): ירקות עליים, סלרי, פטריות, צמחי מאכל וצמחי תבלין מיובשים**

Quantification levels (mg/kg): Cd: 0.035; Pb: 0.30; As: 0.7

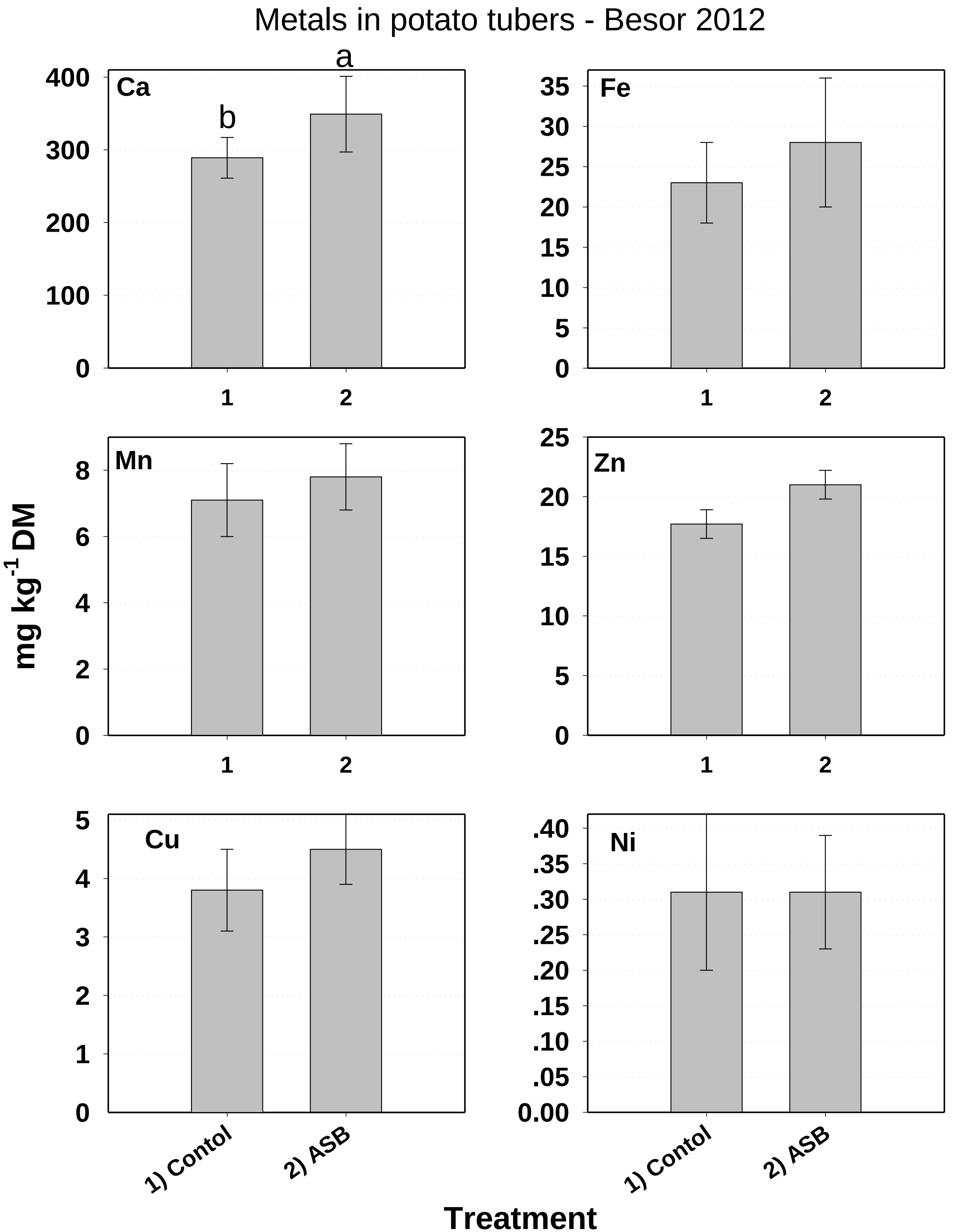
Concentrations (μg kg^{-1} dry) of steroidal hormones in the lettuce plants grown in 220-L containers

Sludge type (in 3 soil types)	**Estrone**		**Testosterone**	
	Winter	Summer	Winter	Summer
Compost (n=32)	0.89±1.17	6.26±4.91	55±93	34 ±51
NVS50 (n=32)	0.76±0.77	8.35±5.9	115±150	28 ±44
Class B (n=8)	1.19±1.44	4.11±2.29	44±51	22 ±21
NVS150 (n=8)	0.65±0.71	6.65±6.59	42±44	14 ±5
Not amended (n=32)	0.41±0.9	6.78±3.78	57±84	38 ±52

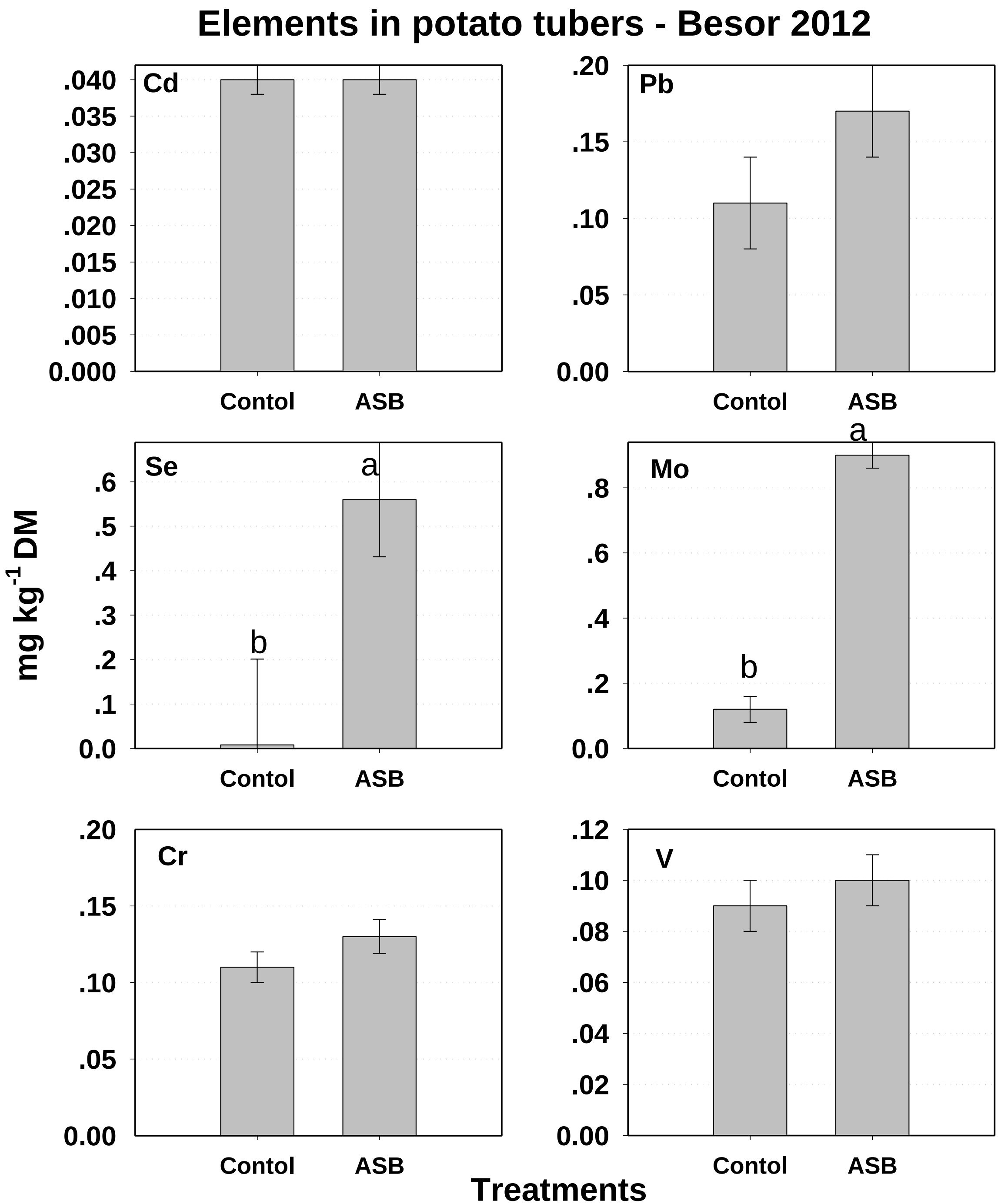
No statistically significant difference between treatment within each of the 4 seasons


N-Viro – 43 tons/ha
4.1.2012

Control



Metals in potato tubers - Besor 2012
mg kg-1 DM
Ca
a
b
400
300
200
100
0
1
2
Fe
35
30
25
20
15
10
5
0
1
2
Mn
8
6
4
2
0
1
2
Zn
25
20
15
10
5
0
1
2
Cu
5
4
3
2
1
0
1) Contol
2) ASB
Ni
.40
.35
.30
.25
.20
.15
.10
.05
0.00
1) Contol
2) ASB
Treatment


Elements in potato tubers - Besor 2012
mg kg-1 DM
Cd
.040
.035
.030
.025
.020
.015
.010
.005
0.000
Contol
ASB
Pb
.20
.15
.10
.05
0.00
Contol
ASB
Se
a
b
.6
.5
.4
.3
.2
.1
0.0
Contol
ASB
Mo
a
b
.8
.6
.4
.2
0.0
Contol
ASB
Cr
.20
.15
.10
.05
0.00
Contol
ASB
V
.12
.10
.08
.06
.04
.02
0.00
Contol
ASB
Treatments


Selenella®
Un aiuto in più dalla natura
La patata
"Helps more then nature"

Elemental composition of carrots on a sandy Hamra soil applied with 120 Mg ha^{-1} NVS (Aug-Dec 2012)

Element (mg kg^{-1})	Not amended	NVS (120 tons ha^{-1})	*p*
K	37,100	44,100	
N	8,100	10,800	
Na	6,100	7,300	
Ca	4,300	5,000	
P	4,100	4,700	
S	1,400 b	2,100 a	0.04
Mg	1,700	1,900	
Al	260	250	
Fe	150	160	
B	60	80	
Sr	30	40	
Zn	15	20	
Ba	11	12	
Mn	7	11	
Cu	5	6	
Cr	1.8	1.6	
Ni	1.2	1.2	
Mo	0.3 b	0.9 a	0.002
V	0.5	0.6	
Li	0.1	0.2	
Co	0.13	0.16	
As	0.02	0.06	bq
Cd	0.04	0.05	
Pb	-	-	bd

Trifolium-Vicia culture at Mishmar David [very shallow calcareous soil (pale Rendzina)] 5 years after application of Bet-Shemesh ASB at 50 tons ha^{-1}

טוב מַרְאֵה עֵינַיִם מֵהֲלָךְ נָפֶשׁ (קהלת ו', 9)

"Better is what he sees with his eyes than that which goes to sate his appetite" (Ecclesiastyes 9-9)

NVS applied at 50 m^3/ha to Clover/Vicia grown on a shallow calcareous soil

Element (mg/kg)	Amended		Not amended	
Ba	42	b	328	a
Ca	23,000	b	38,000	a
Co	0.21	b	0.62	a
Mg	1,970	b	2,900	a
Mn	66	b	119	a
Na	10,800	b	16,800	a
Pb	0.25	b	1.12	a
Sr	73	b	135	a
K	16,000	a	6,300	b
Mo	2.0	a	0.4	b
P	2,000	a	1,500	b

Reduction of soil-borne plant diseases using alkaline stabilized biosolids

Activation of ammonia toxicity

under transiently elevated soil pH and temperature.

efficiency demonstrated in light-textured soils

Ammonia concentration at different exposure times needed for 100% mortality of *F. oxysporum dianthi* chlamydospore, *Verticillium dahliae* microsclerotia and *Sclerotium rolfsii* sclerotia

Time of exposure (minutes)	**Ammonia concentration (μL L^{-1})**		
	Fusarium oxysporum	***Verticillium dahliae***	***Sclerotium rolfsii***
10	**14.8**	**14.8**	**5.5**
20	**6.9**	**14.8**	**2.3**
30	**6.9**	**14.8**	**2.3**

Resting spores were mounted on agar discs that were pre-dipped in proper growth medium, and placed in gas-tight glass jars at 25°C. Ammonia gas was injected into the jars.

Mortality was determined after 6 days of incubation (n= 10).

Suggested mechanism for soil-borne diseases reduction in calcareous and neutral soils

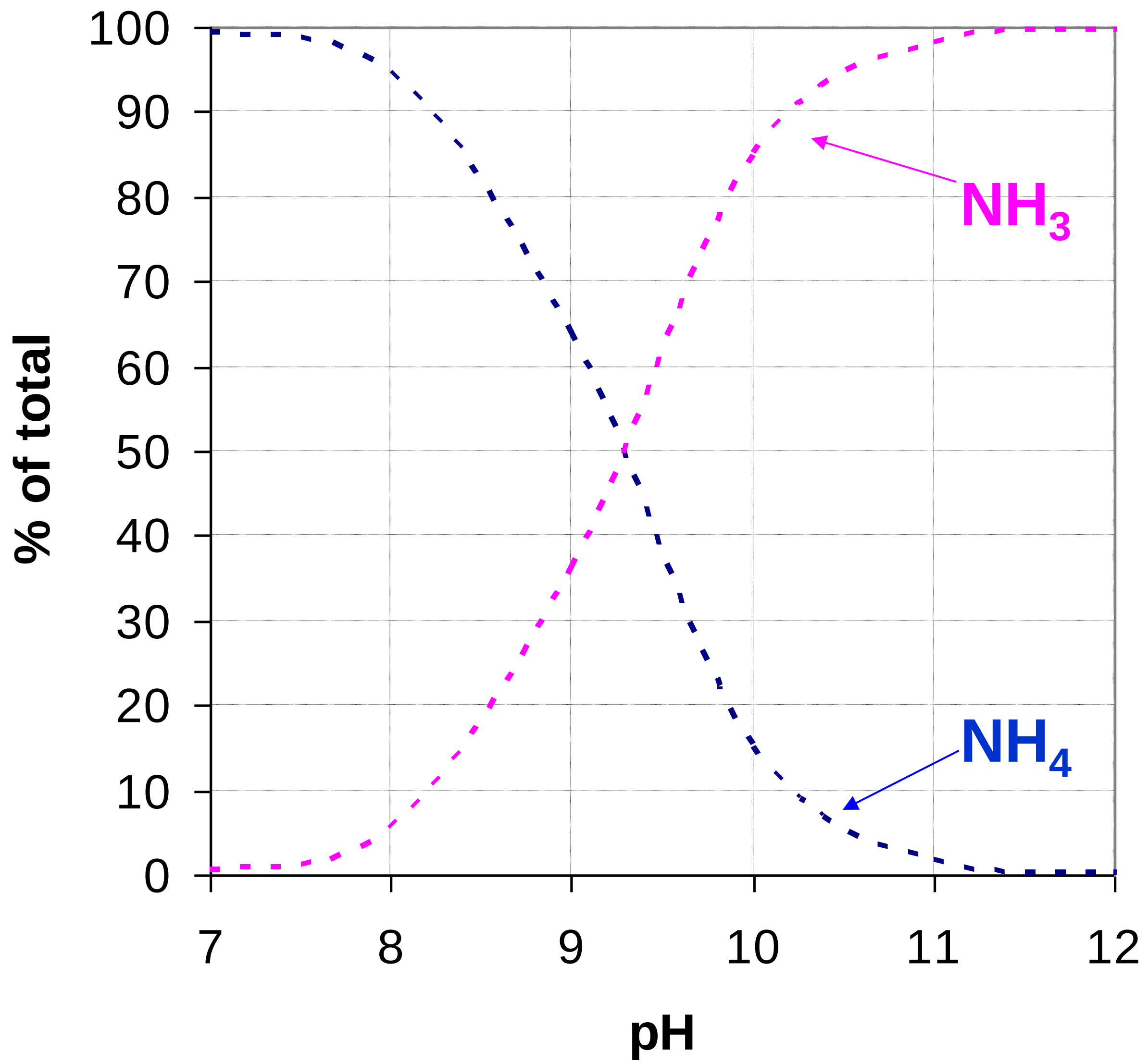
1. Gaseous ammonia is a biocide,

2. At given total ammonium concentration in soil, NH_3 concentration depends on soil solution pH as formulated by the Henderson-Hasselbalch equation:

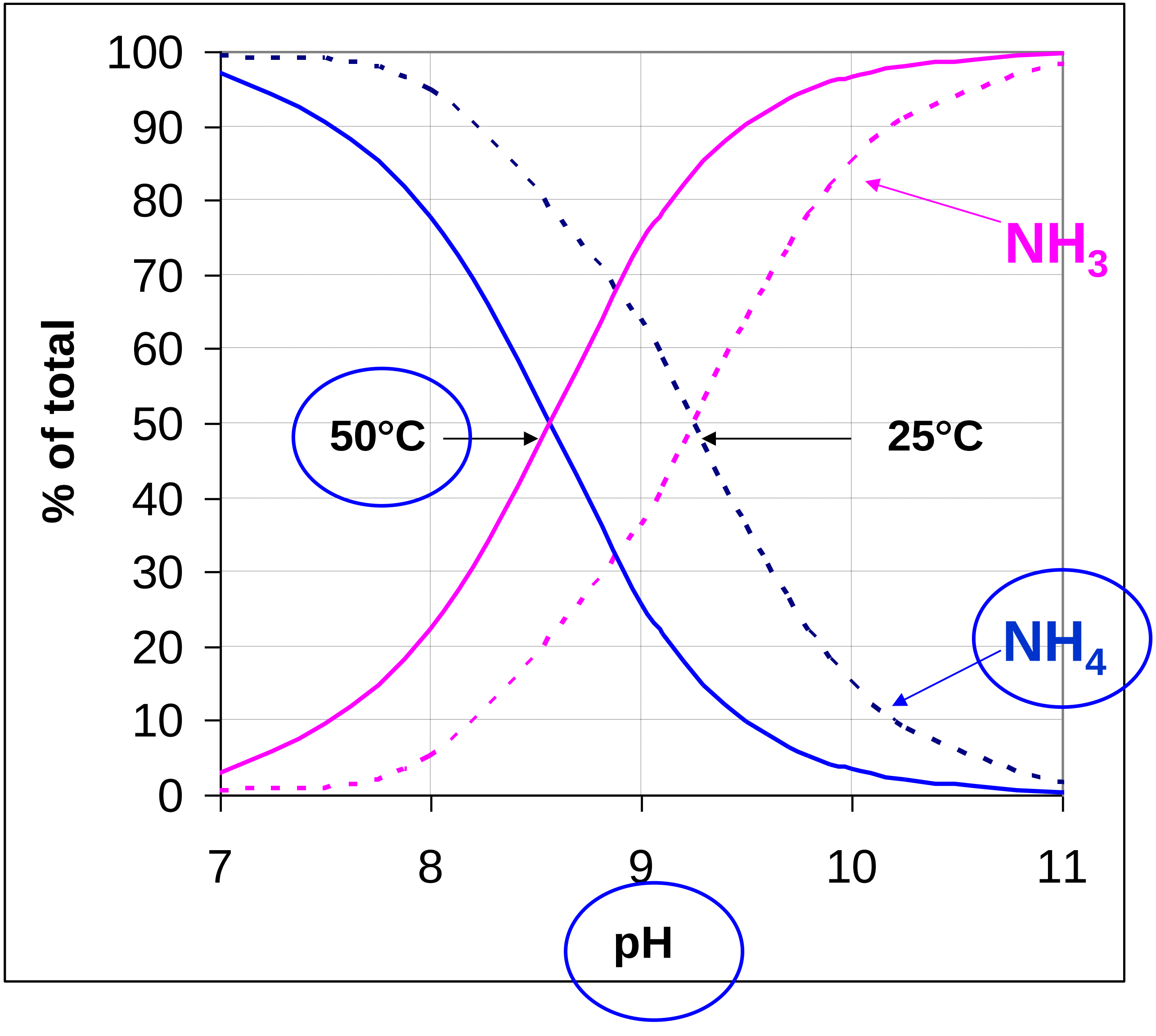
   $\text{Log}\ \{NH_{3(g)}/NH_4^+{}_{(aq)}\} = \text{pH} - 9.5;$ (at 25°C).

3. We manipulate the soil to simultaneously and transiently increase the concentration of pH and ammonia

pH-dependence of NH_3/NH_4 ratio at 25°C

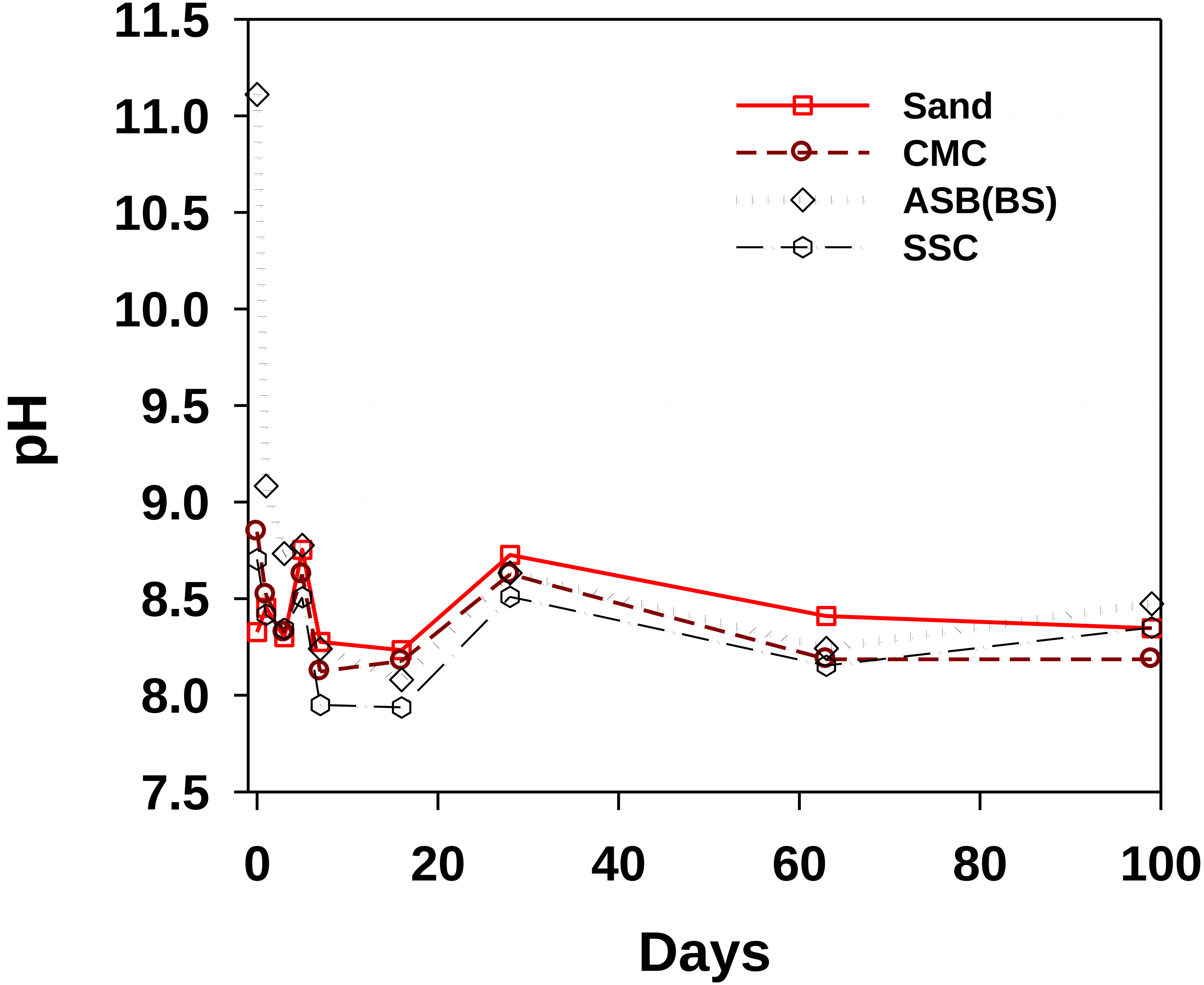


pH-dependence of NH_3/NH_4 ratio at 25°C and 50°C



Effect of lime-treated sludge on soil pH

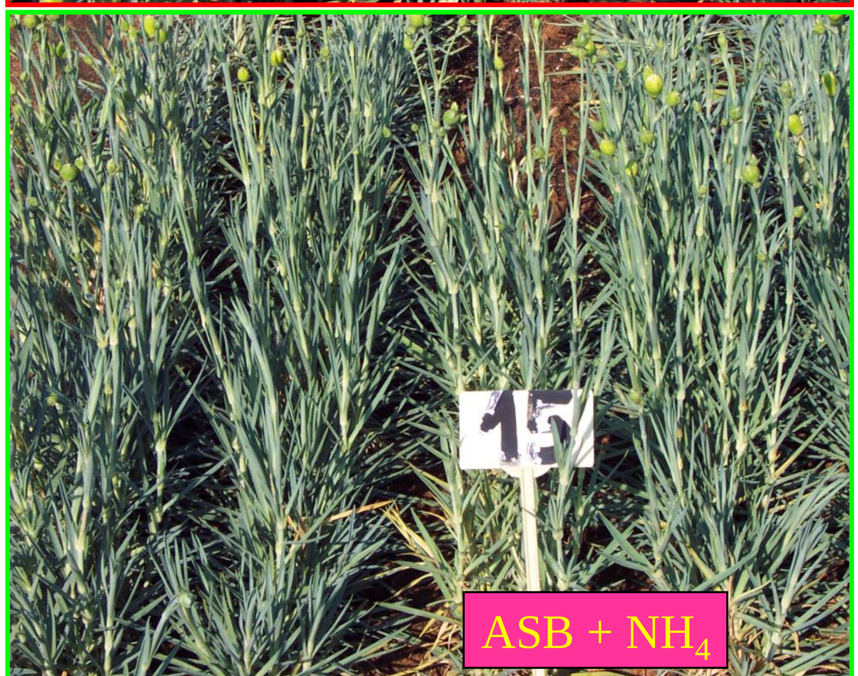
Incubation study in a sandy soil: 22-50 tons/ha which was equivalent to 500 kg N/ha (incubation at optimal moisture content, 30°C)



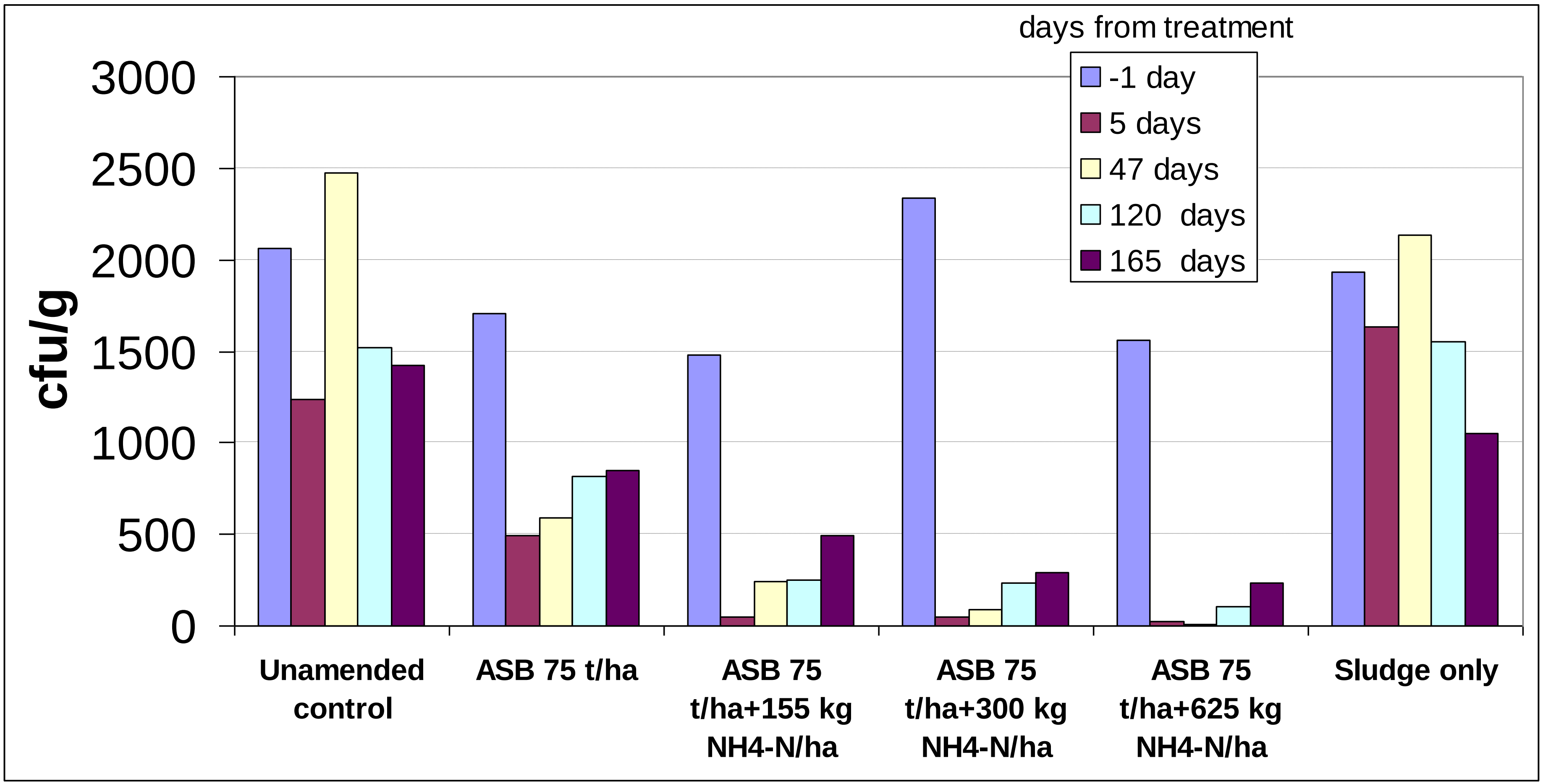

4. 8. 2011

Fusarium oxysporum reduction in soil and alleviation of fusarium wilt in carnations – a micro-plot experiment


11
Unamended control


15
ASB + NH_4

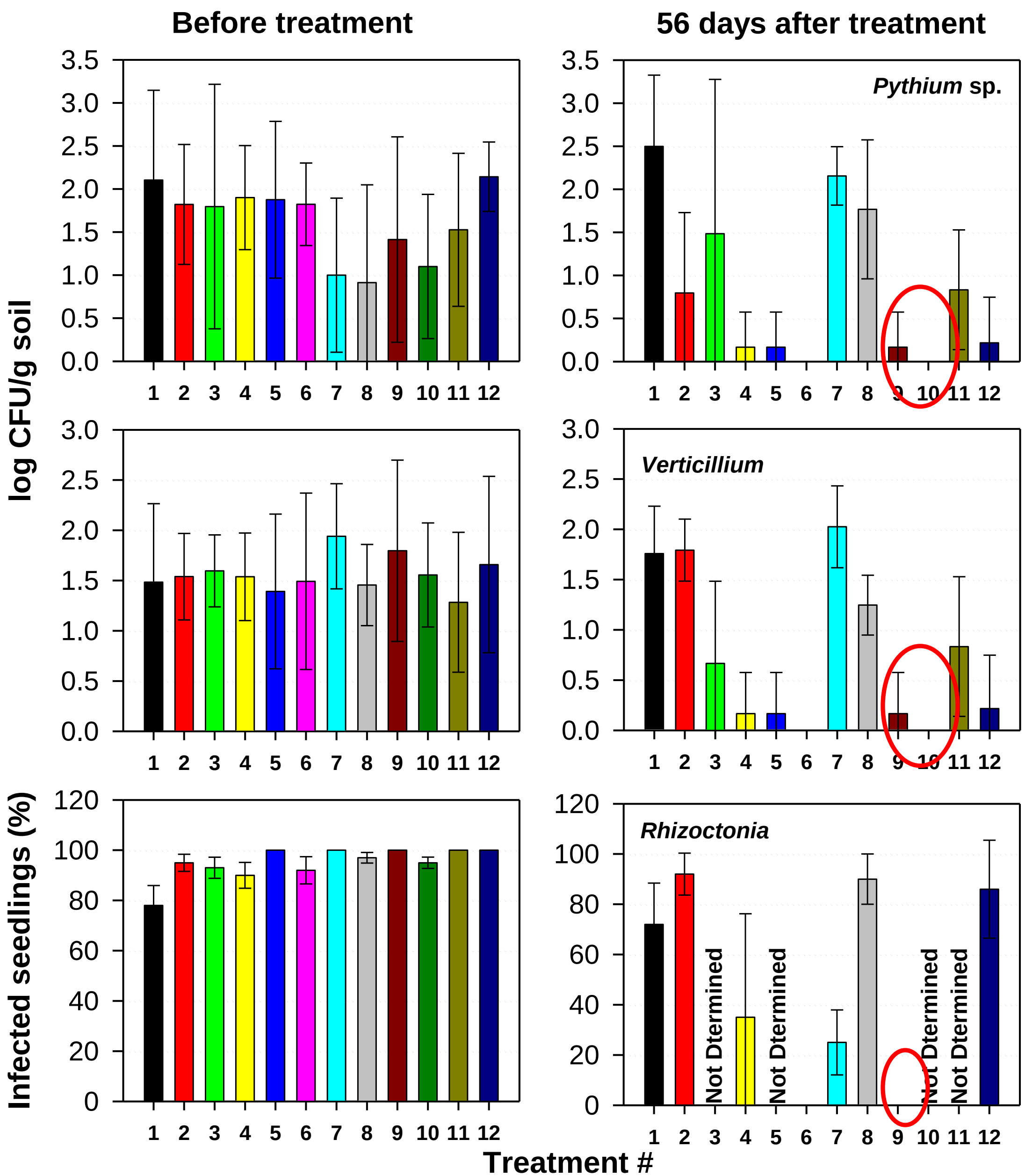
Effect of ASB+NH_4 application to the 0-20 cm layer of infested red Mediterranean sand on viability of *Fusarium oxysporum dianthi* (averages of 8 replicate plots)



הטיפולים בניסוי השדה בהפחתת גורמי מחלה שוכני קרקע בניר יצחק

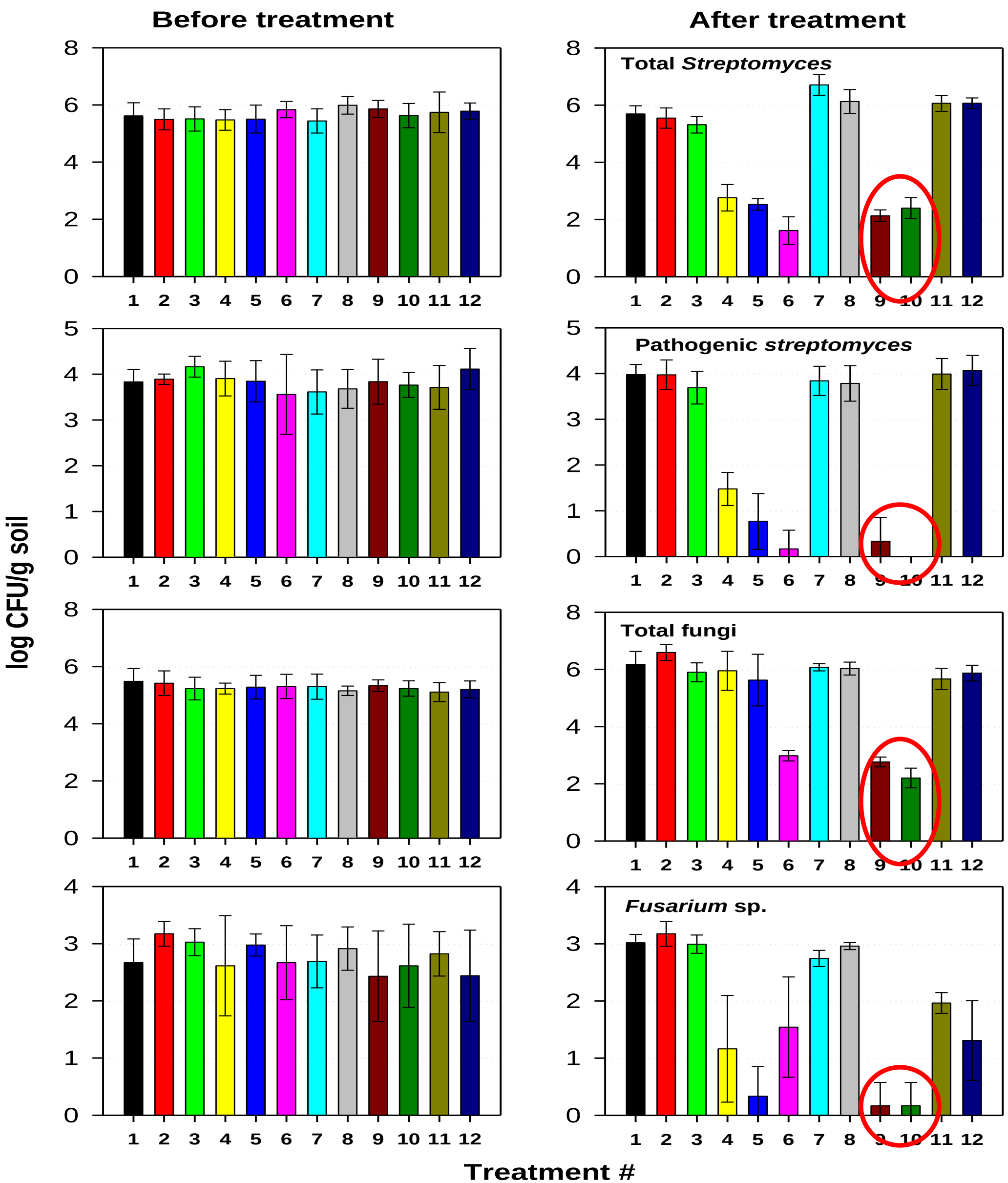
Treatment and (code)		ASB m^3/ha	SSC m^3/ha	BL t/ha	Slaked lime t/ha	$(NH_4)_2SO_4$ t/ha	Plastic Cover
1	Cont						
2	Cont-Plastic (Cont-P)						+
3	Cont-Lime (Cont-L)				5		
4	Cont-Lime-NH_4 (Cont-L-N)				5	1.8	
5	Cont-Lime-NH_4-Plastic (Cont-L-N-P)				5	1.8	+
6	Formalin (Form)						
7	SSC		50				
8	SSC-Plastic (SSC-P)		50				+
9	ASB-NH_4 (ASB-N)	100				1.8	
10	ASB-NH_4-Plastic (ASB-N-P)	100				1.8	+
11	Broiler litter-Lime (Bl-L)			30	5		
12	Broiler litter-Lime-Plastic (Bl-L-P)			30	5		+

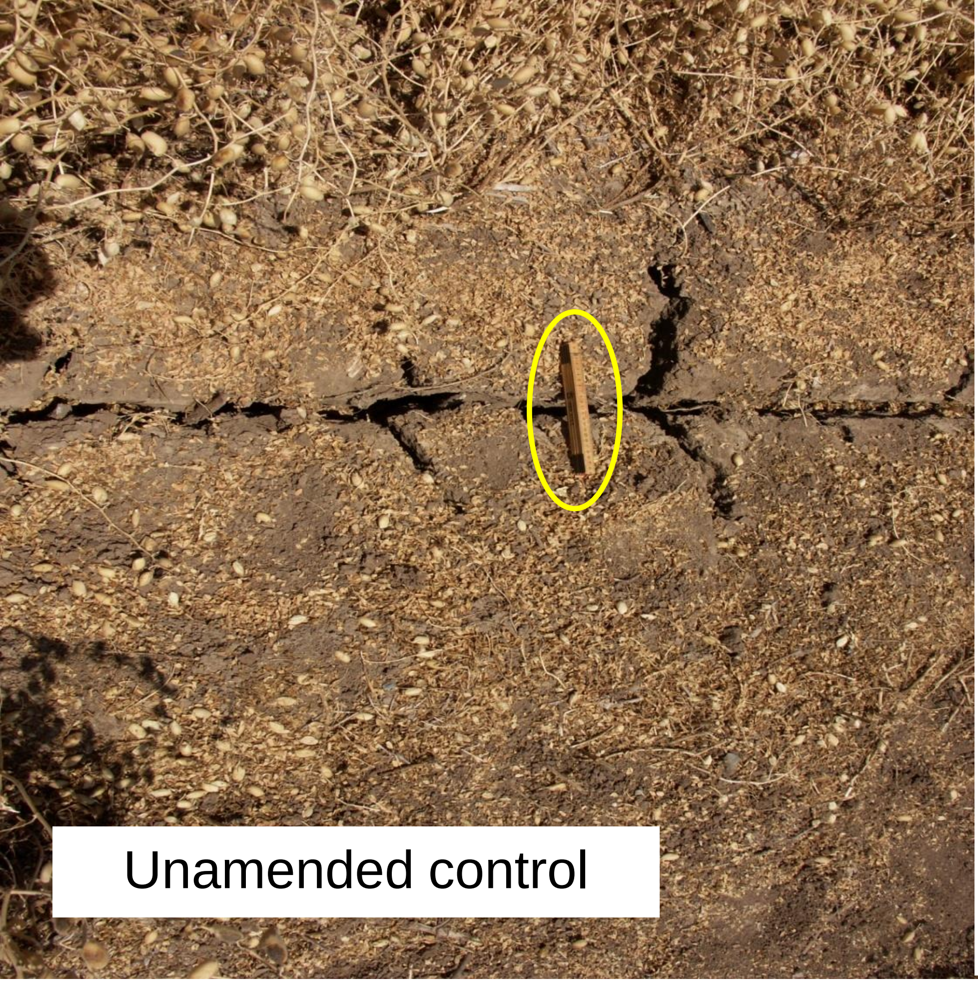
ה-CFU של אורגניזמים נבדקים בשכבה 20-0 ס"מ של קרקע חול משדה תפו"א
בניר יצחק לפני יישום התוספים ואחרי היישום.

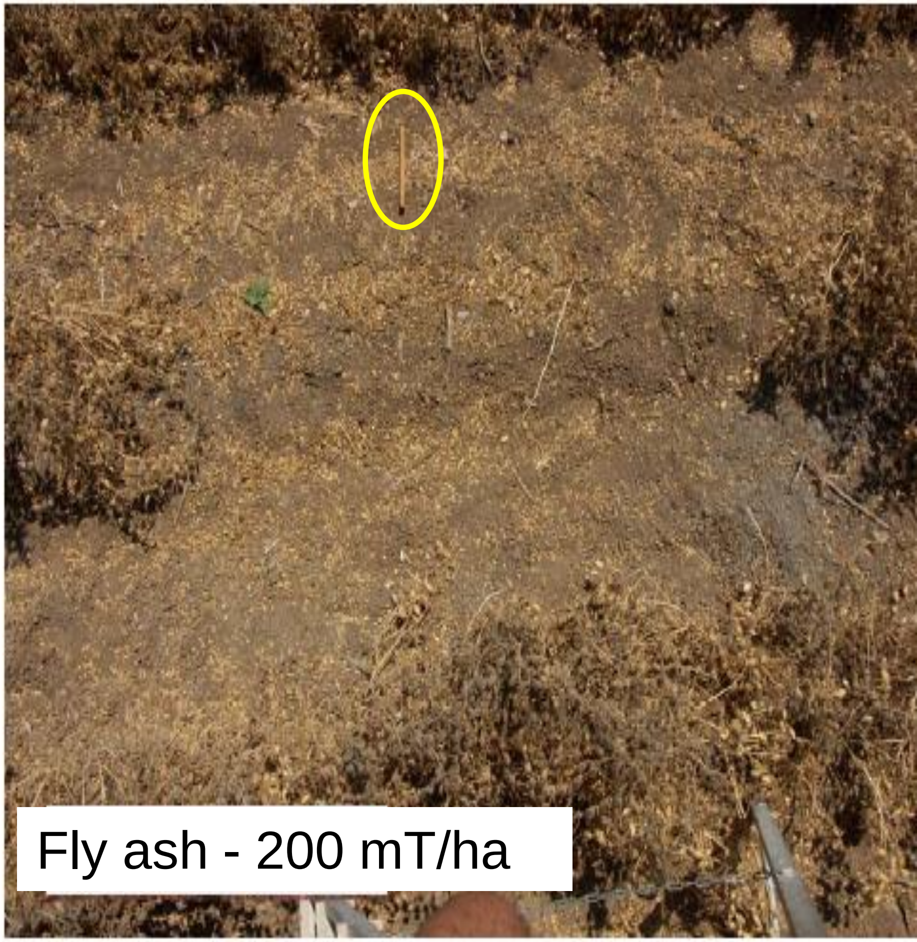


Treatment # & code	ASB	SSC	Broiler litter	Slaked lime	$(NH_4)_2SO_4$	Plastic

ה-CFU של אורגניזמים נבדקים בשכבה 0-20 ס"מ של הקרקע מהשדה בניר יצחק לפני טיפולי ההדברה ואחריהם.



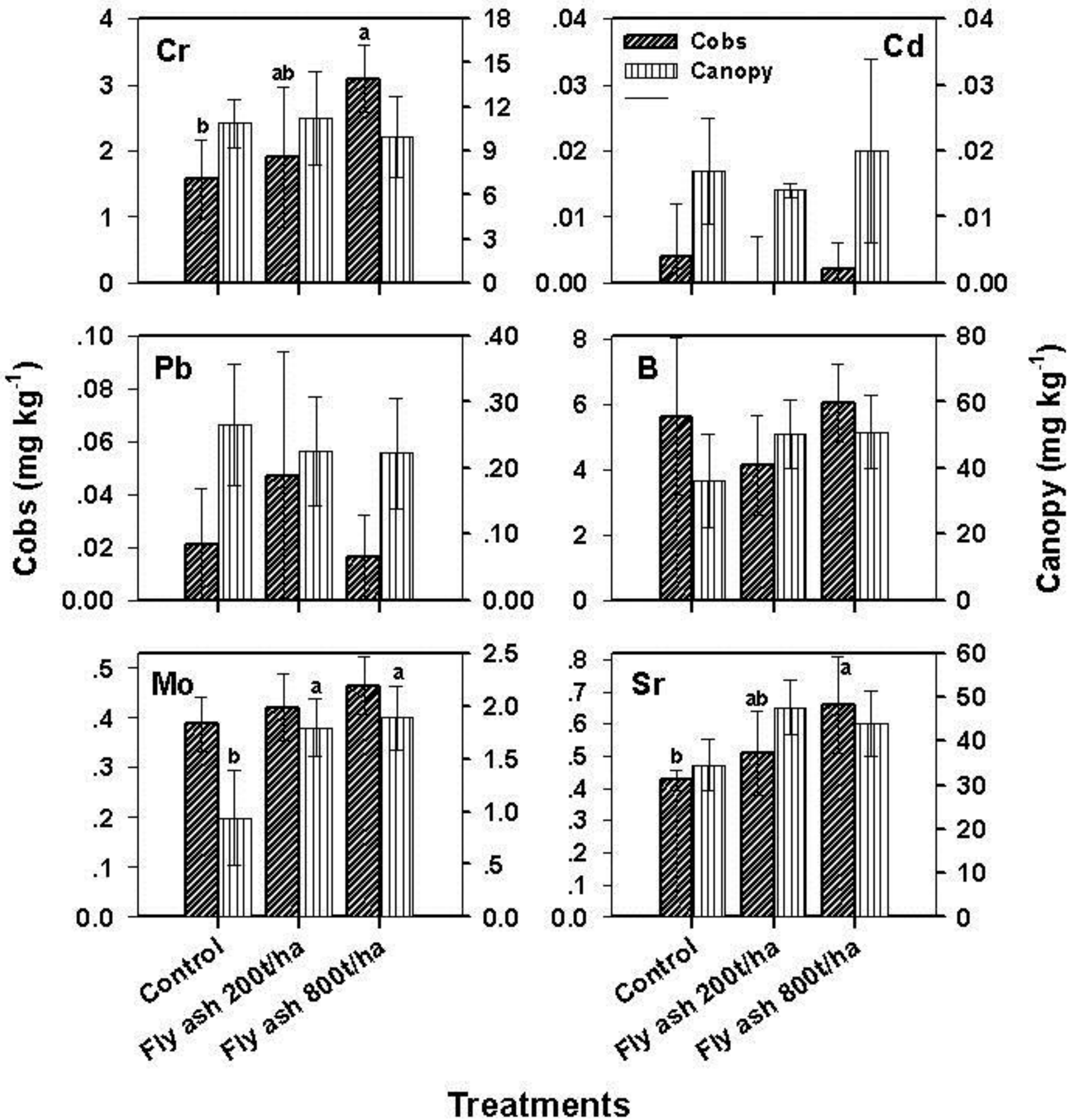




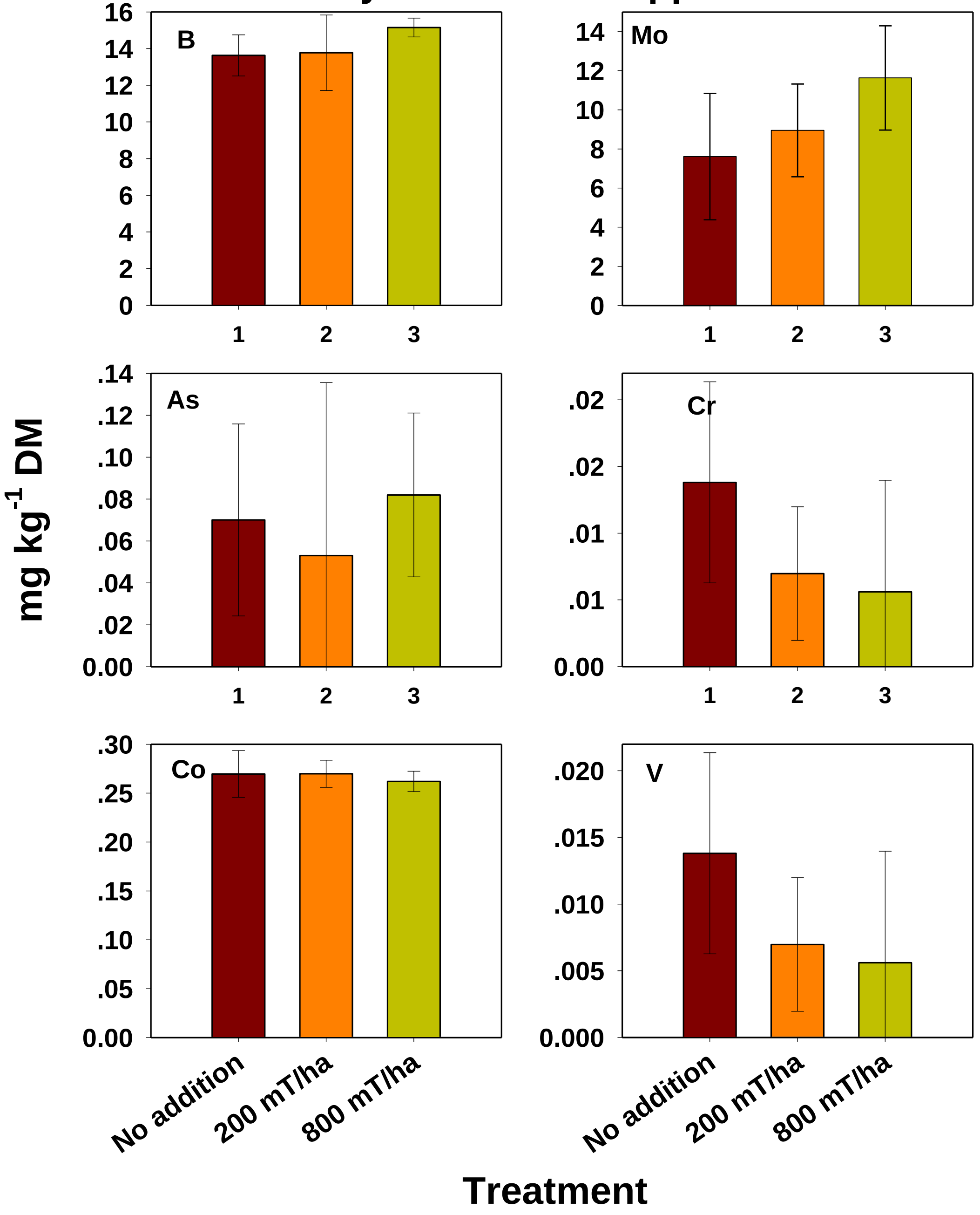
Effect of fly ash addition (200 and 800 tons/ha) on cracking of a sodic clayey soil

3rd year after application

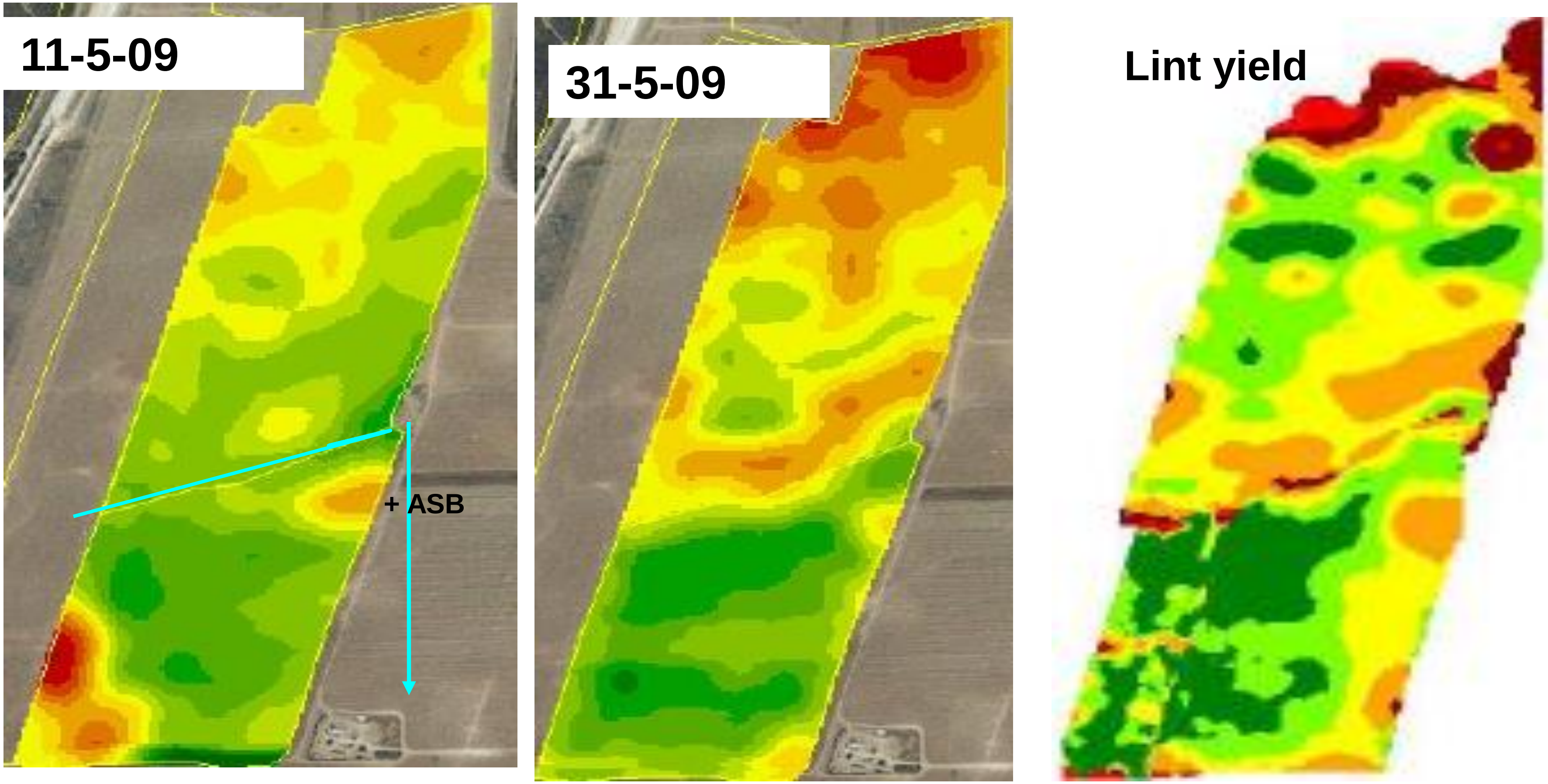
Concentration of trace elements in corn plants (cobs and canopy) grown of a clayey soil heavyly amended with fly ash



Metals in chikpea seeds - Revadim 2007
3 years after FA application



Cotton response to ASB application at 50 m³/ha (2009)



במהלך עונת הגידול (כותנה) נערך מעקב אחר התפתחות הנוף בשיטות של חישה מרחוק. בוצעו הדמאות לווין ברזולציה קרקעית גבוהה שנוצלו לשם חישה ספקטרלית באורכי גל בתחומי הירוק, האדום ובקרבת האינפרא-אדום המוחזרים מהצמח, ומייצגים את מצב הצמח. רמת ההחזר היחסית של הצבעים תלויה בביומסה ובפעילות הכלורופיל בצמח. הניתוח נעשה ע"י חברת סתיו-ממ"ג בע"מ באמצעות מערכת המידע פרמסט (*FarmSat*) של חברת גיאוסיס שהיא יישום GIS-י בסביבת האינטרנט.

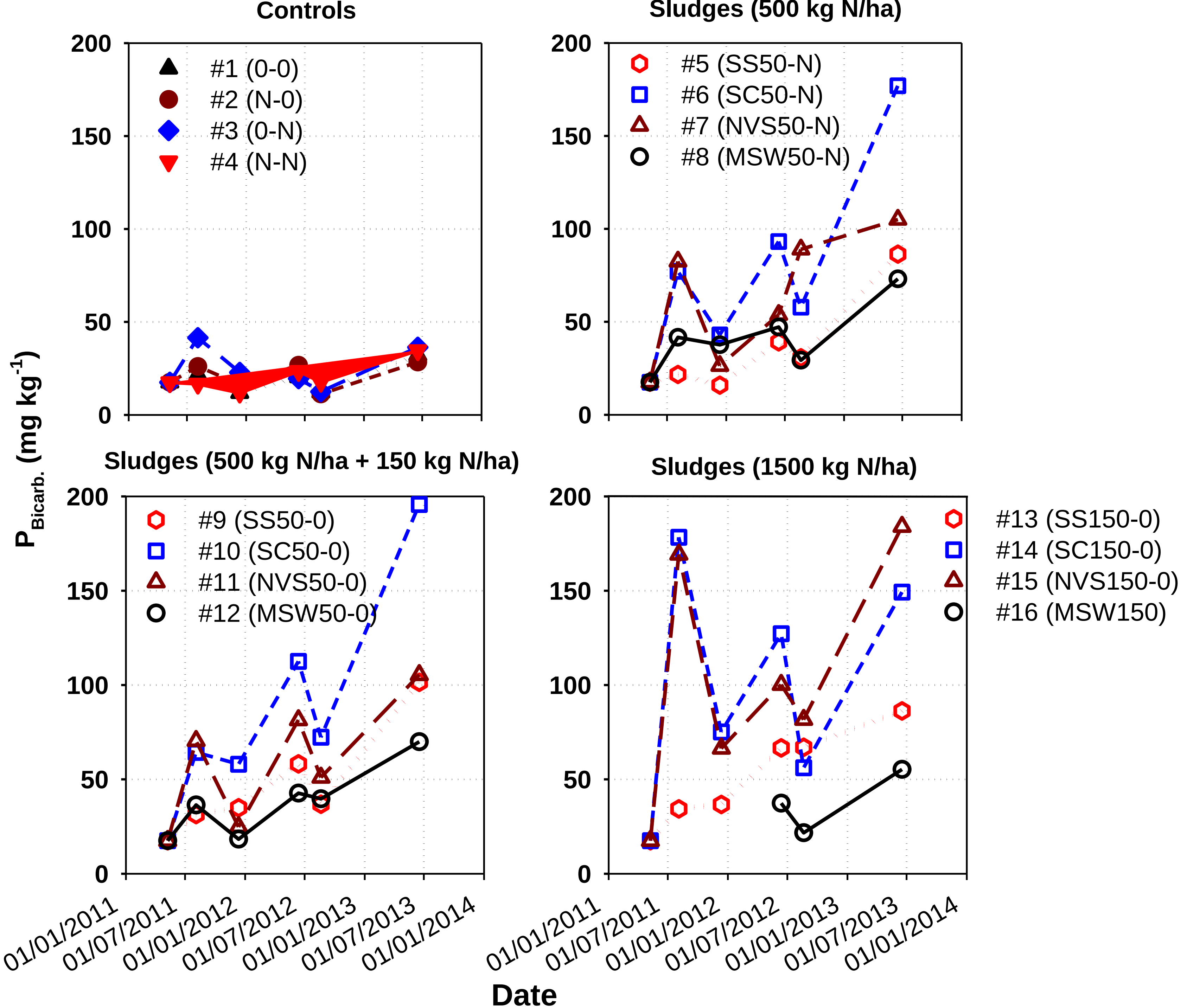
Conclusions:

- Coal fly ash and FA-based ASB do not add to soil significant loads of priority pollutants (and other oxyanions and heavy metals).
- NVS did not increase the concentrations in plant parts of priority pollutant trace and heavy metals (As, Cd, Pb).
- NVS positively affected crop nutrition of essential micro-elements and with oxyanions essential for human nutrition.
- NVS replaced base application of fertilizer N, P and K. To some extent also side application of N.
- The data thus far collected strongly suggests that incremental FA addition to soils via FA-based ASB loading has no foreseen short or long-term risks to soil and crop quality.
- Potential pitfalls are mainly with respect to high initial pH and salinity which under aridity might become detrimental to crops.
- More research is always needed...especially for the longer term.

Conclusions:

- Many!
- Being strictly scientific?

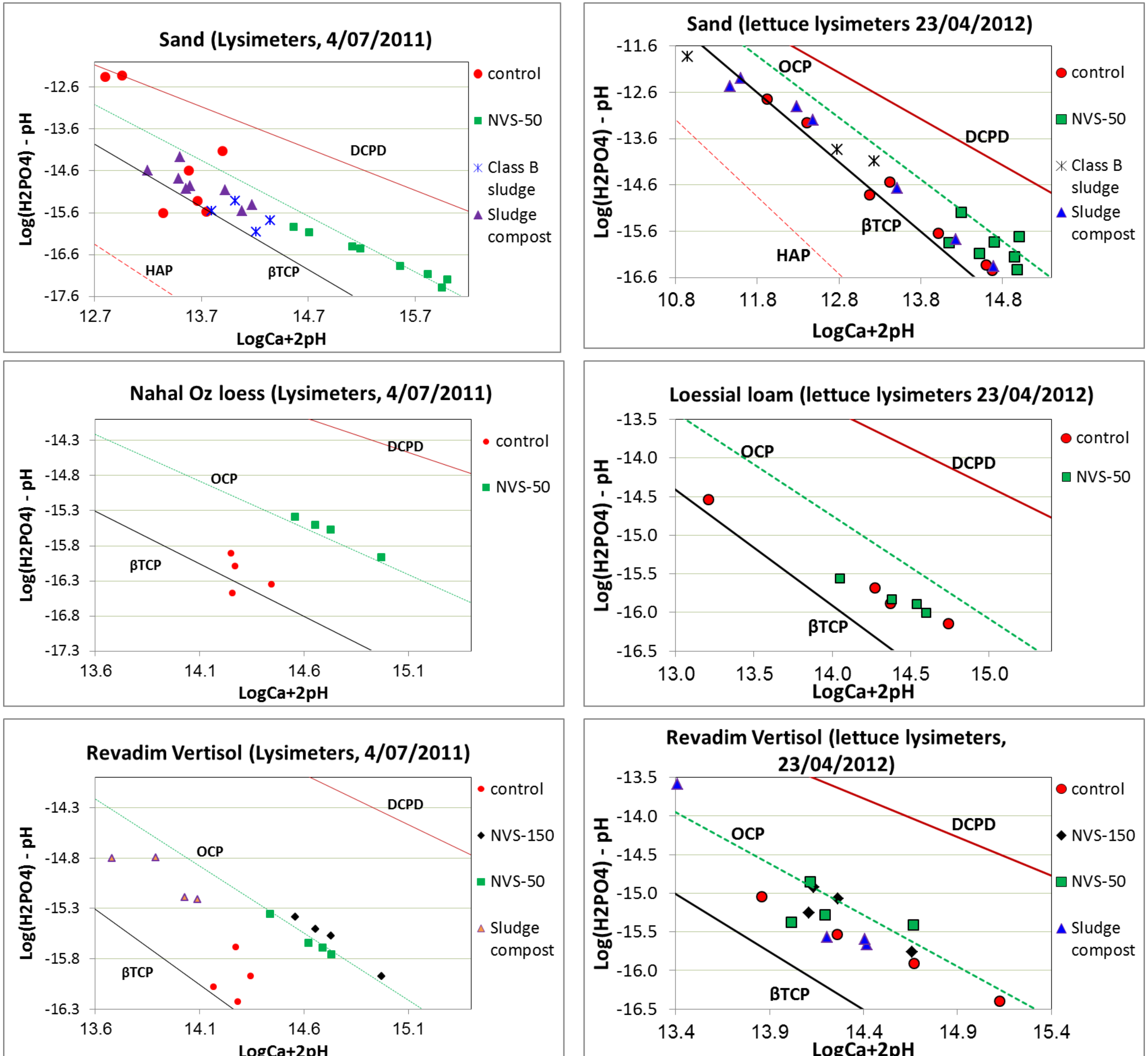

Thank you
29/05/2014


Controls
#1 (0-0)
#2 (N-0)
#3 (0-N)
#4 (N-N)
Sludges (500 kg N/ha)
#5 (SS50-N)
#6 (SC50-N)
#7 (NVS50-N)
#8 (MSW50-N)
Sludges (500 kg N/ha + 150 kg N/ha)
#9 (SS50-0)
#10 (SC50-0)
#11 (NVS50-0)
#12 (MSW50-0)
Sludges (1500 kg N/ha)
#13 (SS150-0)
#14 (SC150-0)
#15 (NVS150-0)
#16 (MSW150)
P Bicarb. (mg kg-1)
0
50
100
150
200
01/01/2011
01/07/2011
01/01/2012
01/07/2012
01/01/2013
01/07/2013
01/01/2014
Date

ASB (Bet-Shem.) effect on soil pH

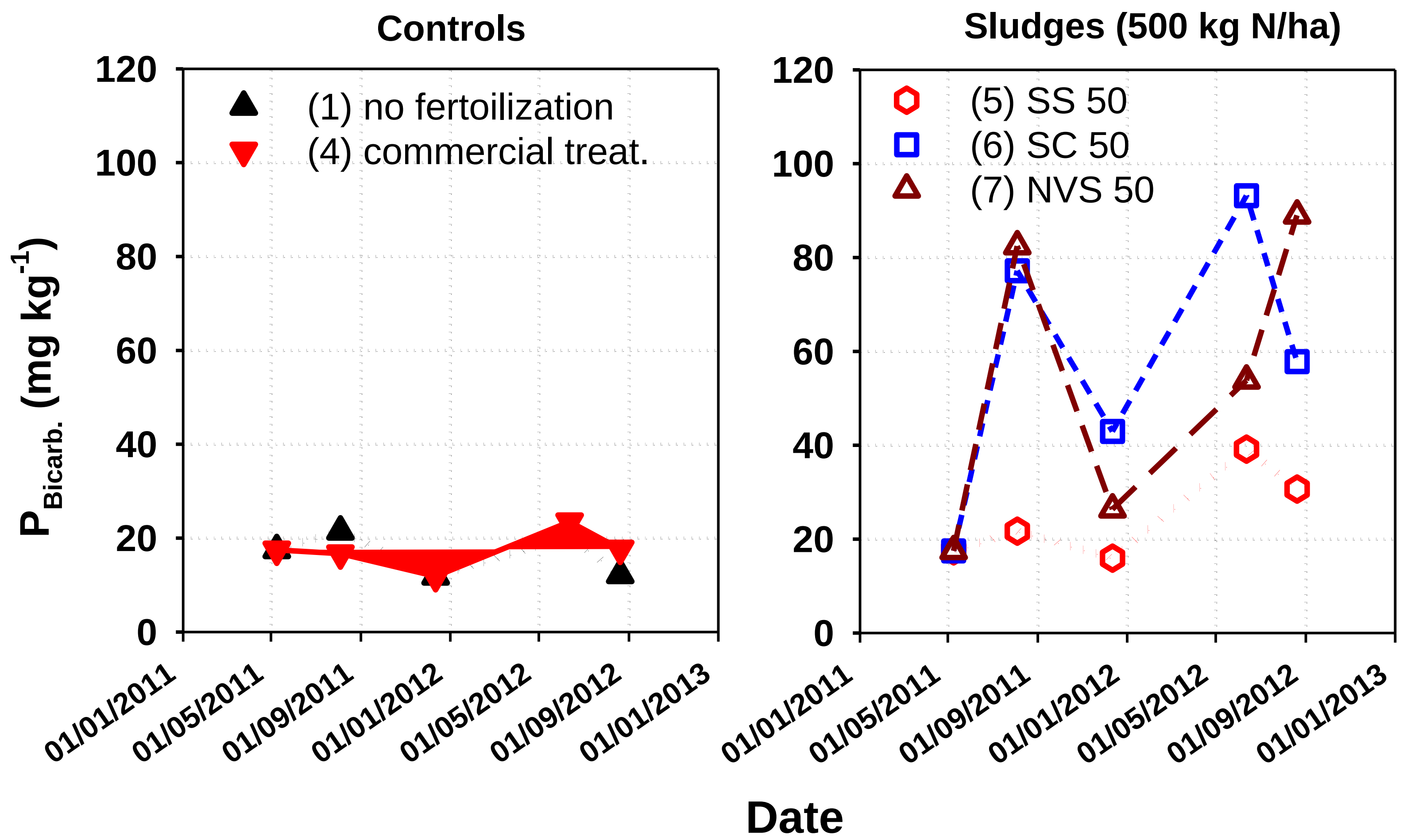
ASS (tons ha^{-1})	Soil pH (after incubation of)			
	1 day	4 days	8 days	16 days
Red Mediterranean sand (7.5% clay)				
0	8.53	8.50	8.47	8.42
25	9.03	8.41	8.31	8.31
37.5	9.50	8.52	8.47	8.39
50	10.02	8.83	8.44	8.33
75	10.66	9.85	8.90	8.42
light-brown loessial loam (18% clay)				
0	8.53	8.50	8.47	8.42
25	9.03	8.41	8.31	8.31
37.5	9.50	8.52	8.47	8.39
50	10.02	8.83	8.44	8.33
75	10.66	9.85	8.90	8.42
Vertisol (60% clay)				
0	8.42	8.40	-	8.29
100	9.77	9.64	-	8.35
150	10.20	10.00	-	9.12
200	10.56	10.26	-	10.16

§ Values are averages of 4 replicates, each of which plated in 3 replicates.

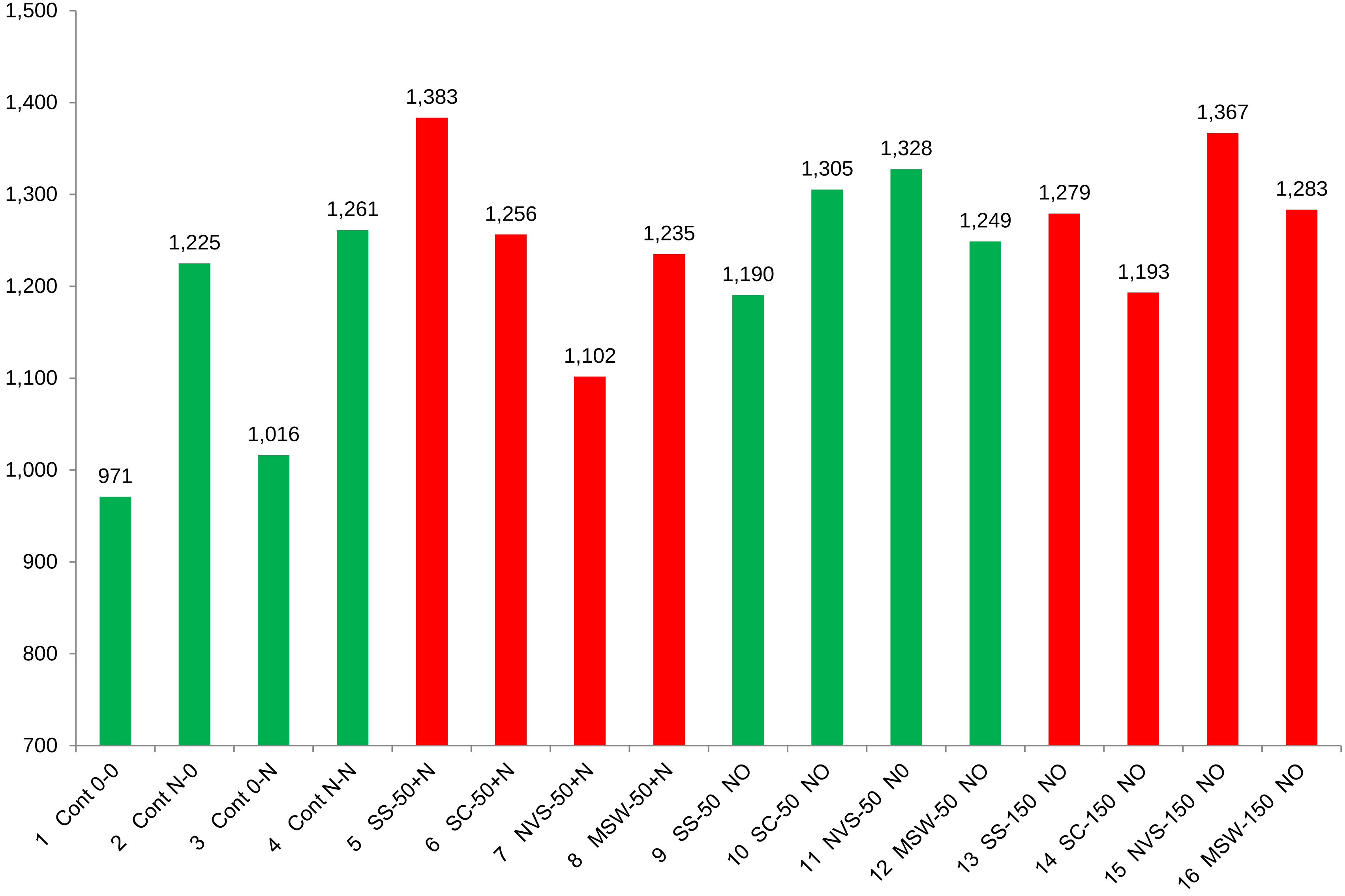


Sand (Lysimeters, 4/07/2011)
Log(H2PO4) - pH
-12.6
-13.6
-14.6
-15.6
-16.6
-17.6
12.7
13.7
14.7
15.7
LogCa+2pH
DCPD
HAP
βTCP
control
NVS-50
Class B sludge
Sludge compost
Sand (lettuce lysimeters 23/04/2012)
Log(H2PO4) - pH
-11.6
-12.6
-13.6
-14.6
-15.6
-16.6
10.8
11.8
12.8
13.8
14.8
LogCa+2pH
OCP
DCPD
βTCP
HAP
control
NVS-50
Class B sludge
Sludge compost
Nahal Oz loess (Lysimeters, 4/07/2011)
Log(H2PO4) - pH
-14.3
-14.8
-15.3
-15.8
-16.3
-16.8
-17.3
13.6
14.1
14.6
15.1
LogCa+2pH
DCPD
OCP
βTCP
control
NVS-50
Loessial loam (lettuce lysimeters 23/04/2012)
Log(H2PO4) - pH
-13.5
-14.0
-14.5
-15.0
-15.5
-16.0
-16.5
13.0
13.5
14.0
14.5
15.0
LogCa+2pH
OCP
DCPD
βTCP
control
NVS-50
Revadim Vertisol (Lysimeters, 4/07/2011)
Log(H2PO4) - pH
-14.3
-14.8
-15.3
-15.8
-16.3
13.6
14.1
14.6
15.1
LogCa+2pH
DCPD
OCP
βTCP
control
NVS-150
NVS-50
Sludge compost
Revadim Vertisol (lettuce lysimeters, 23/04/2012)
Log(H2PO4) - pH
-13.5
-14.0
-14.5
-15.0
-15.5
-16.0
-16.5
13.4
13.9
14.4
14.9
15.4
LogCa+2pH
OCP
DCPD
βTCP
control
NVS-150
NVS-50
Sludge compost

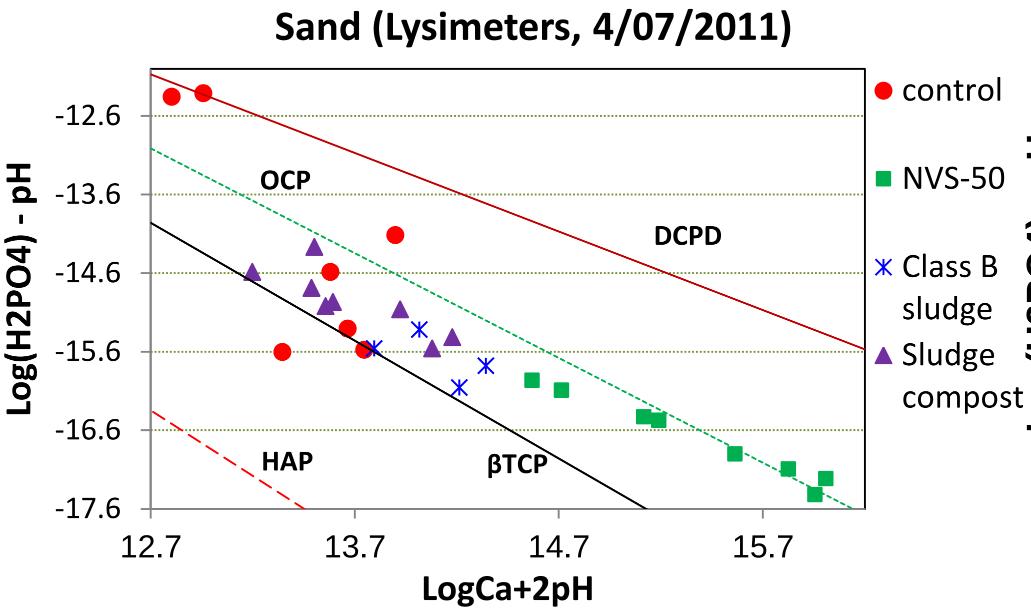
'Available' P in Revadim Vertisol (0-15 cm layer) after two consecutive seasons of manure application to silage corn

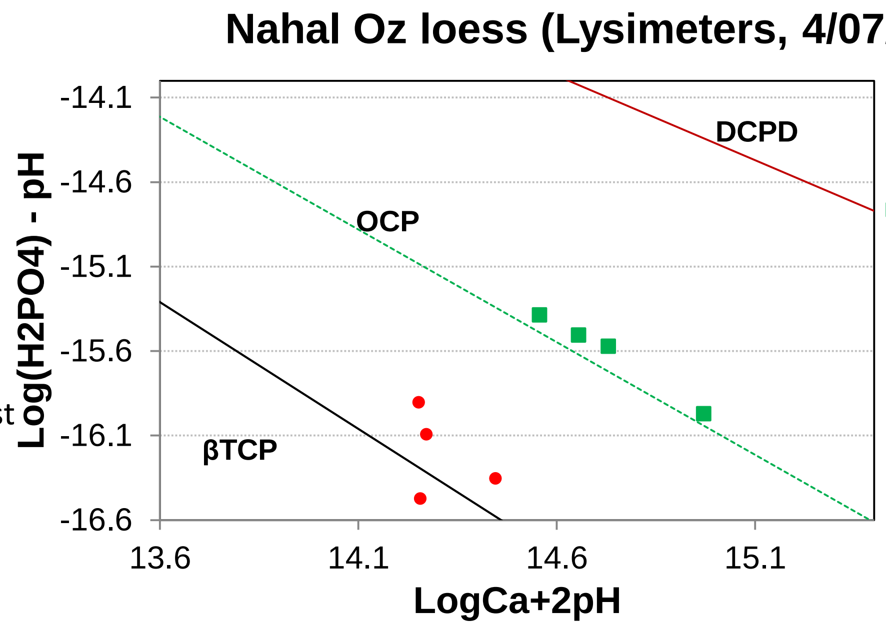


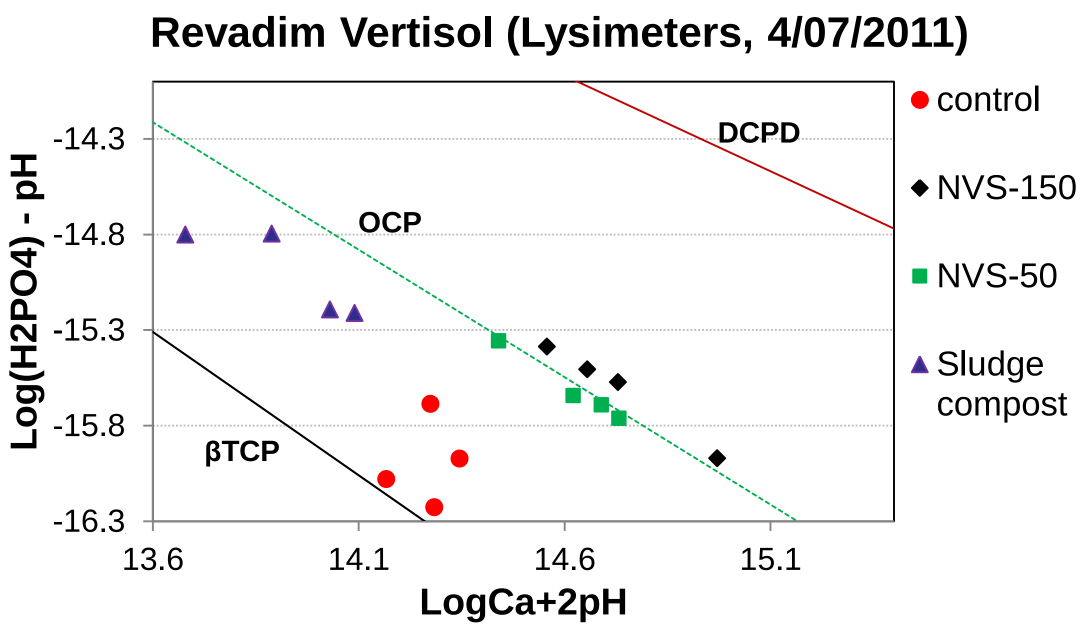
יבול חיטה ח"י על גבי שנתיים תירס (ק"ג\ד')

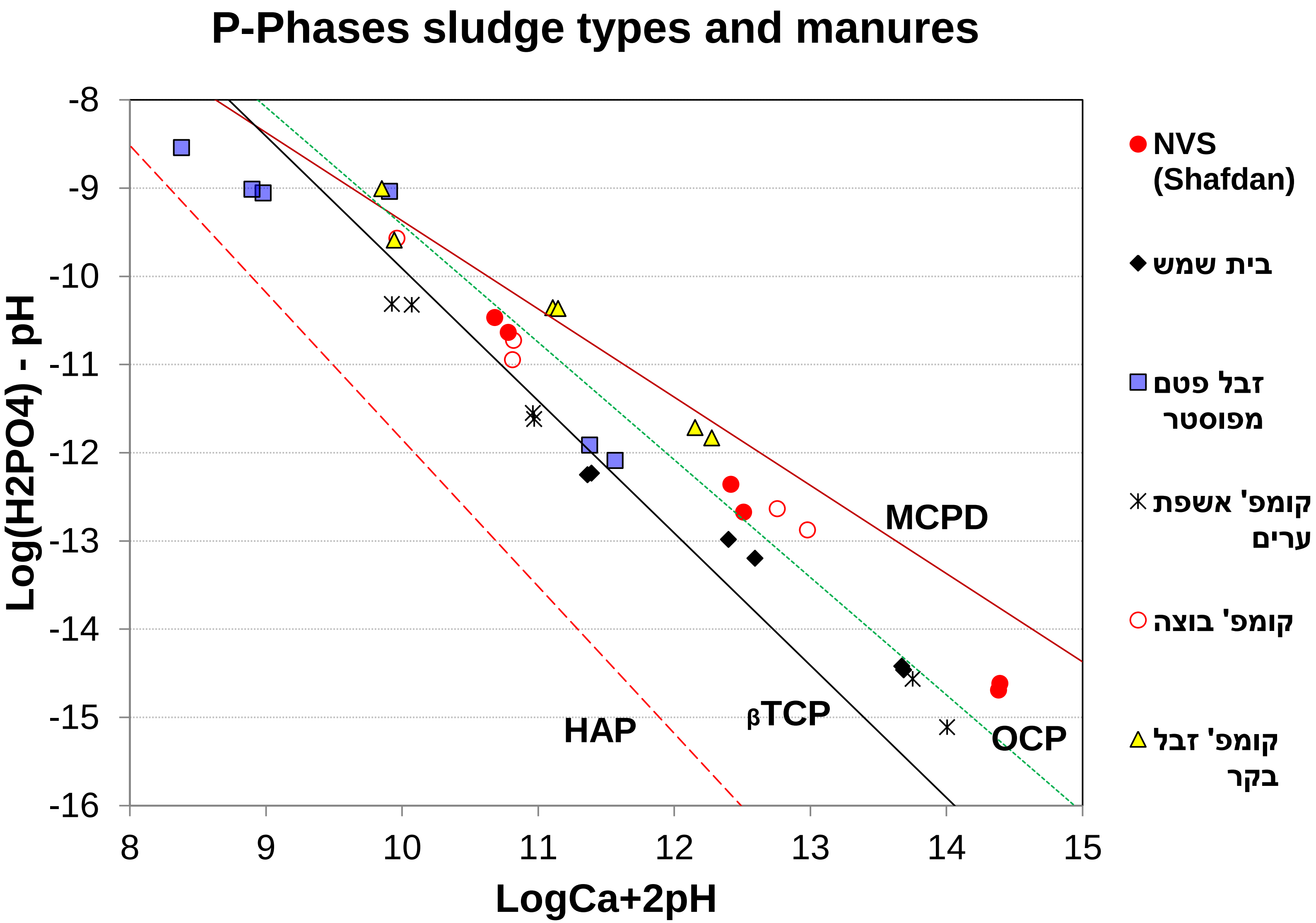


P-Phases in lysimeters soils one month after 1st application









P-Phases sludge types and manures
Log(H2PO4) - pH
LogCa+2pH
-8
-9
-10
-11
-12
-13
-14
-15
-16
8
9
10
11
12
13
14
15
MCPD
βTCP
HAP
OCP
NVS (Shafdan)
בית שמש
זבל פטם מפוסטר
קומפ' אשפת ערים
קומפ' בוצה
קומפ' זבל בקר

Average concentrations (mg kg^{-1}) of elements in corn seeds (Revadim, plot #32; 6 replicates, 2007)

Element (Quant.)	Commercial	Gypsum (5 t/ha)	Fly ash 150 tons/ha	SSC 150 t/ha	NVS (B.Sh.) 150 t/ha	*p*
As (0.6)	bd	bd	bd	bd	bd	
Co (0.11)	0.06	0.04	0.03	0.03	0.03	
Cr (0.05)	0.65	0.60	0.59	0.46	0.53	
Mo (0.08)	0.38	0.38	0.52	0.46	0.53	
Se (0.08)	0.14	1.20	< 0.08	0.70	< 0.08	
V (0.08)	0.01	0.01	0.02	0.02	0.01	
B	10	10	10	9	8	
Cd	<< 0.05	<< 0.05	<< 0.05	<< 0.05	<< 0.05	
Pb (0.3)	0.06	0.07	0.06	0.06	0.10	
Cu	1.40	1.51	1.51	1.57	1.62	
Ni	0.43 a	0.44 a	0.43 ab	0.30 b	0.35 ab	0.014
Zn	18 b	20 b	19 b	24 a	21 b	<.001
Mn	5.7	5.8	5.7	6.1	5.9	
Fe	18	17	16	19	17	
P	2922	3062	2961	2933	2961	
K	5228	5359	5355	5243	5073	

bd – מתחת לסף הגילוי.

הבמס"א יוצרה במט"ש בית-שמש: 10 אפר : 2 CKD: 11 בוצה סחוטה

Average concentrations (mg kg^{-1}) of elements in corn canopy (Revadim, plot #32; 6 replicates, 2007)

Element	Commercial	Gypsum (5 t/ha)	Fly ash 150 tons/ha	SSC 150 t/ha	NVS (B.Sh.) 150 t/ha	*p*
As	0.70	0.35	0.49	0.47	0.42	
B	65 b	58 b	141 a	80 b	95 ab	0.003
Co	0.27	0.26	0.34	0.27	0.30	
Cr	9.0	6.8	8.9	12.3	9.8	
Mo	1.7 bc	1.5 c	3.3 a	3.2 a	3.0 ab	0.001
Se	bdl	bdl	bdl	bdl	bdl	
V	0.51	0.60	0.84	0.69	0.77	
Cd	<< 0.05	<< 0.05	<< 0.05	<< 0.05	<< 0.05	
Pb	0.29	0.34	0.57	0.42	0.35	
Cu	10	10	10	13	13	
Ni	3.1	2.3	3.0	4.4	3.1	
Zn	20 b	24 ab	25 ab	38 a	32 ab	0.026
Fe	217	234	302	284	300	
Mn	69	60	70	77	78	
P	2,659	2,433	2,750	2,952	2,373	
K	24,308	24,024	25,081	29,118	24,429	

6 חזרות (חלקות של 48 מ^2, 8X6) בבלוקים באקראי. α=0.05 (Tukey HSD).

דישון מסחרי: 10 יחידות אשלגן K_2O, 10 יחידות זרחן P_2O_5; בכל הטיפולים: 25 יחידות חנקן: 10ביסוד ו-15 בראש.

במס"א: הכנה במט"ש בית שמש: 10 ט' אפר : 2 ט' CKD : 11 ט' בוצה סחוטה (20% מוצקים) = כ-10% ח"א

Sites of field experiments with NVS (& other sludges