Uptake of heavy metals and essential trace elements by crops grown on fly ash amended soils

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Overview of possible benefits (and risks) from FALSB (NVS):

- **Benefits the urban sector**: significant reduction of expenditures on WWTF construction and maintenance;
- **Benefits the Environment:** (i) reuse of byproducts, (ii) Conserves nonrenewable resources, maintains the recycling principal, (iii) reducing emissions of GHGs (on- and off-site); (iv) avoids composting derived emissions of GHGs, ammonia (40 kg N/ton!), odors and dust.
- **Direct agricultural benefits**:
  - **Fertilizer substitute, source of essential microelements and viable organic matter additive. Conserves the sludge N and renders it phyto-available!**
  - **Means to control soil-borne diseases (in light-textured soils);**
  - **Potentially improves sodic soils (acid soils) and other problematic soils (e.g., sandy, crust forming);**
  - **Potentially improves quality of agricultural products;**
- **The fly ash component (70-80% of the product) allegedly impairs soil and crop quality: high pH, salinity, phytoavailability of trace and heavy metals (especially oxyanions), diminishes the phytoavailability of P and essential micro-nutrients (especially Fe).**

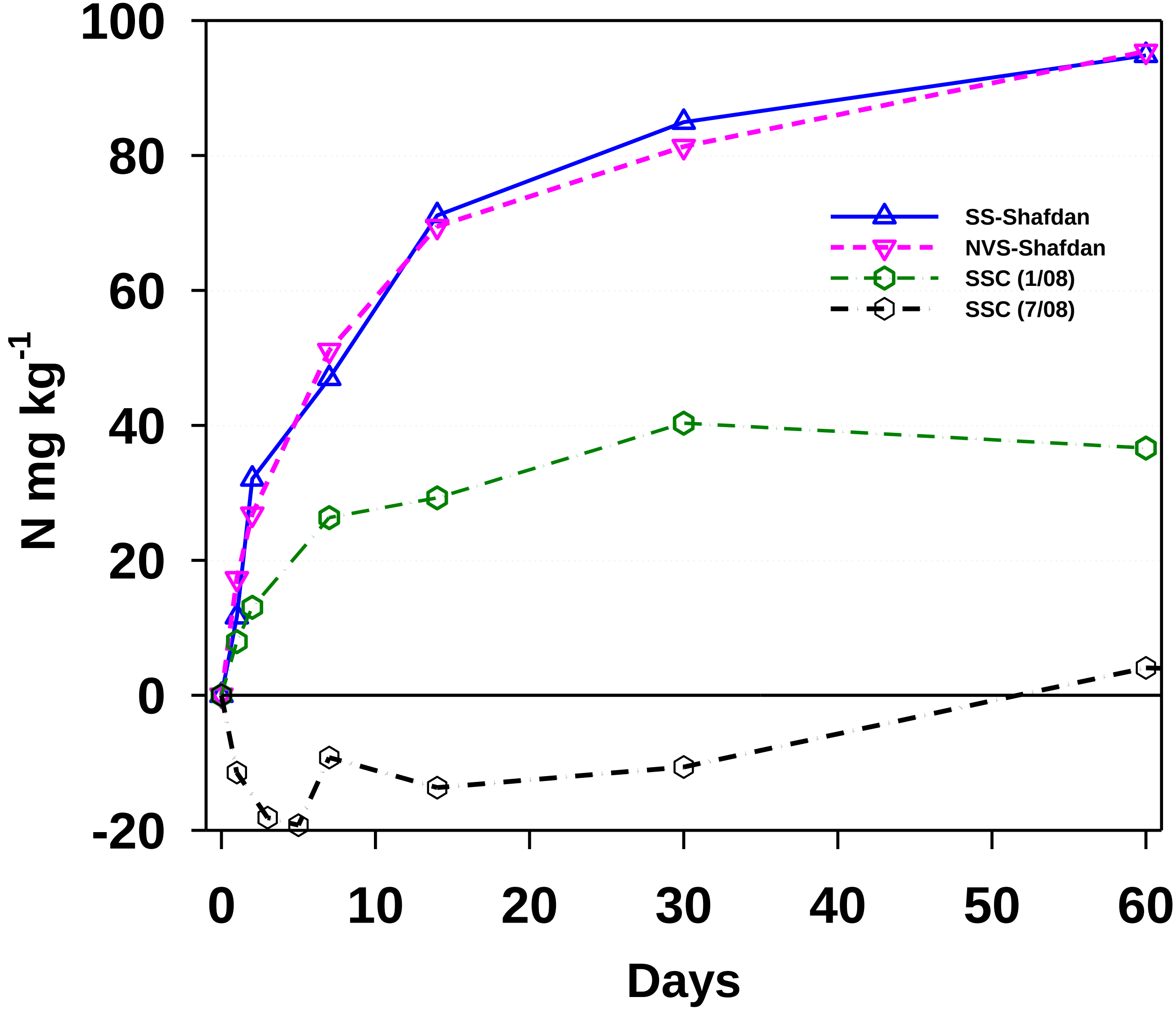
Composition of Israeli sludge types (2011 data)

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		5.8	12.2	6.6	
EC	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

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

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)



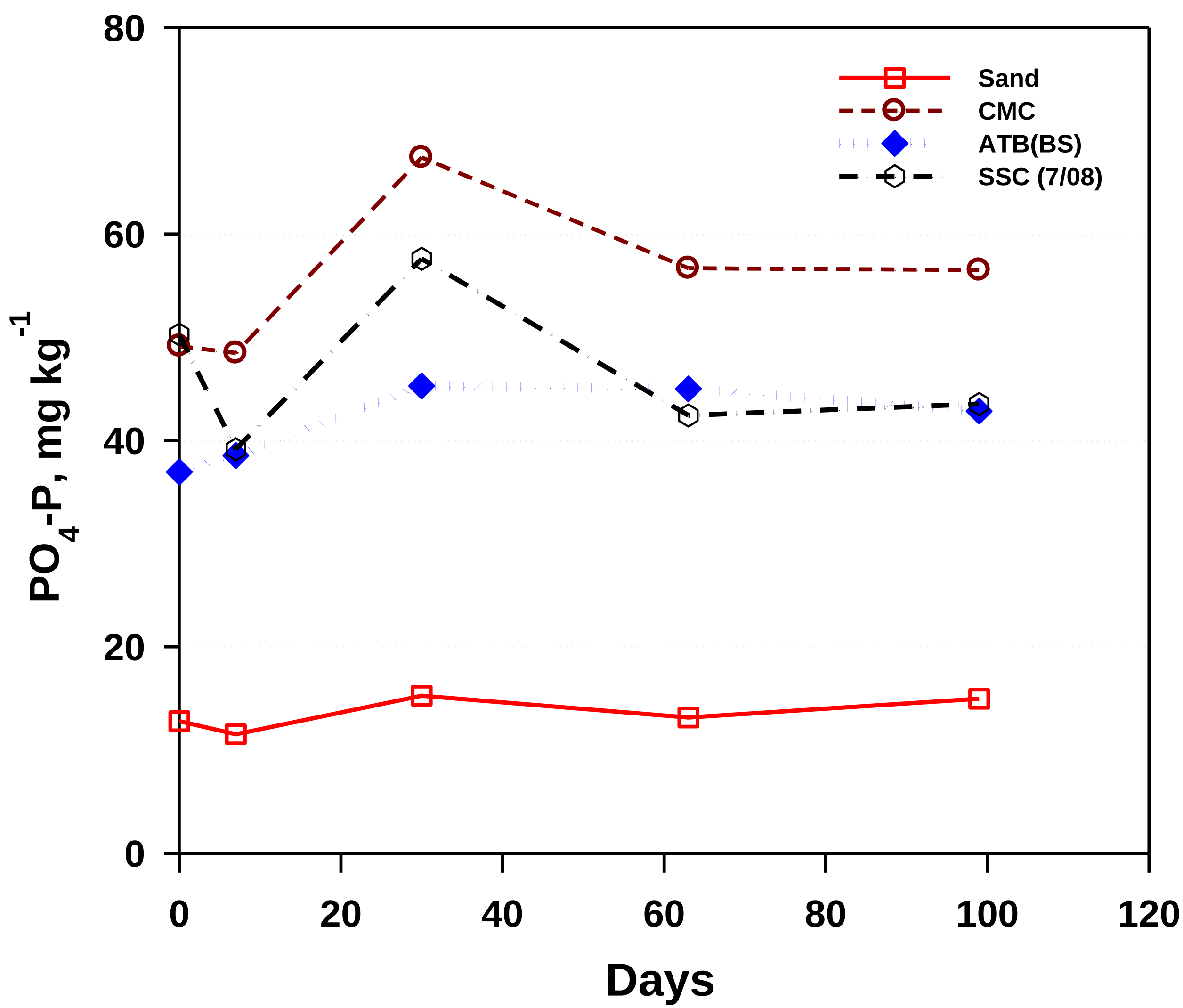
Mineralization parameters of sludge organic N in amended sand at a load equivalent to 500 kg total N_T ha^{-1}

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

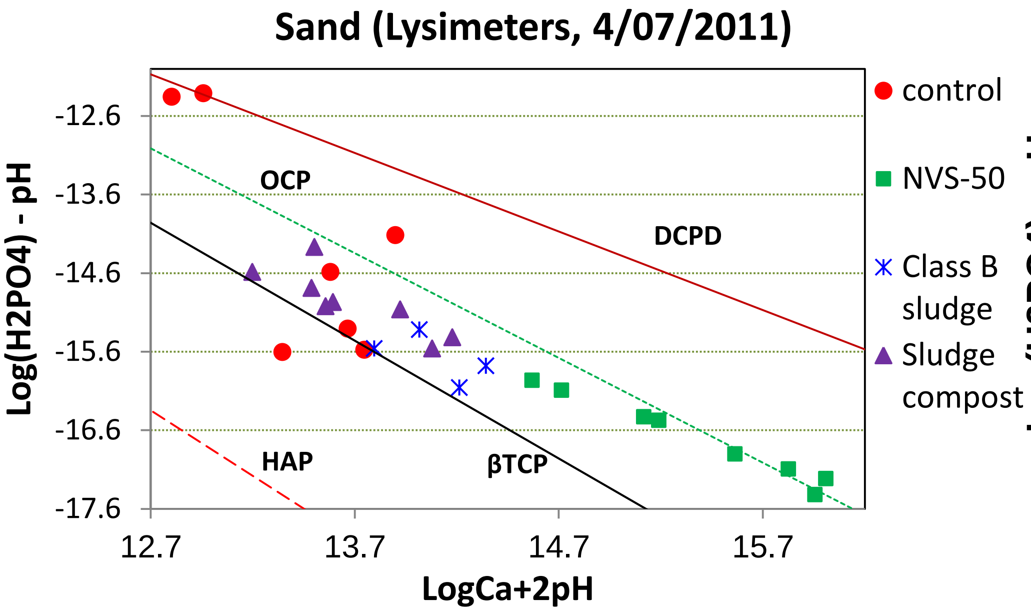
Sludge type	**N_0 (mg N kg^{-1})**	***p***	**N_0/N_T (%)**	**k (day^{-1})**	***p***	**r^2**
Untreated (Tel-Aviv)	90.5 ± 5.8	<0.0001	45	0.12 ± 0.02	0.008	0.97
NVS (Tel-Aviv)	88.5 ± 4.6	<0.0001	44	0.13 ± 0.02	0.002	0.98
Compost(Jan 08)	37.0 ± 2.0	<0.0001	19	0.18 ± 0.03	0.004	0.97
Compost(July 08)	-20	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

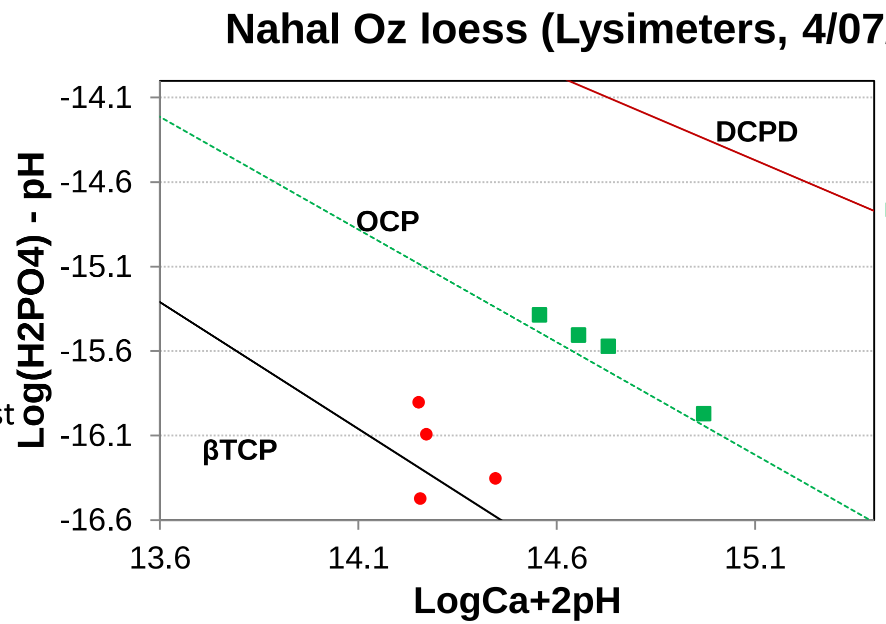
Potentially phyto-available P

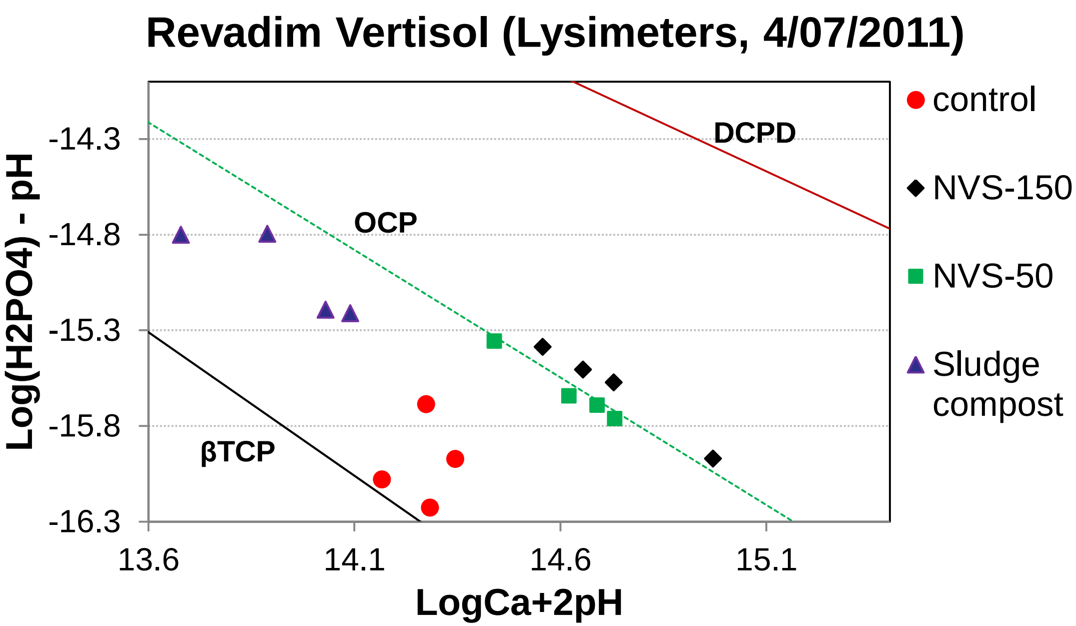
Incubation study - application rate 8-50 tons/ha, equivalent to application of 500 kg N/ha (incubation at optimal moisture content, 30ºC)



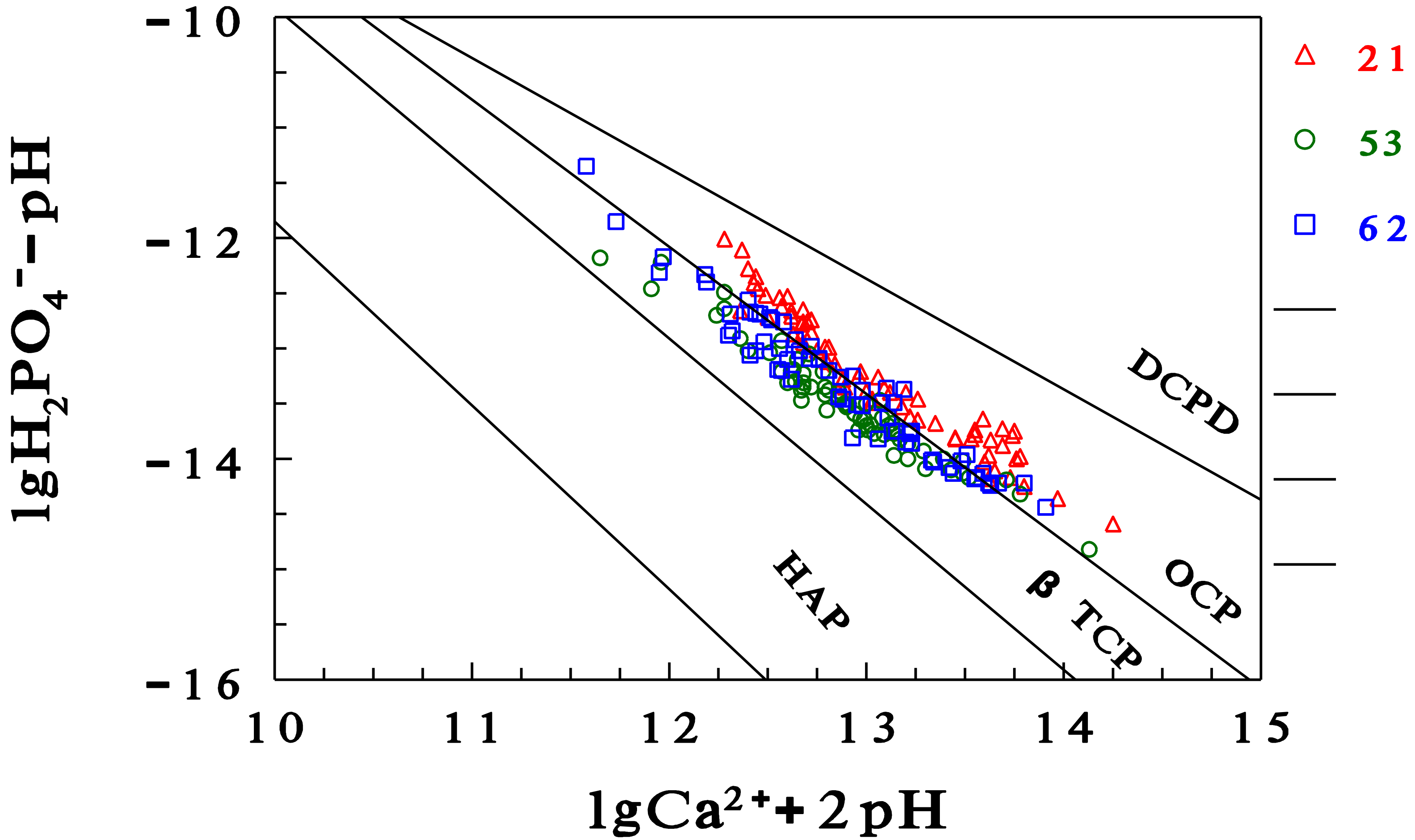
P-Phases in lysimeters soils one month after 1st application



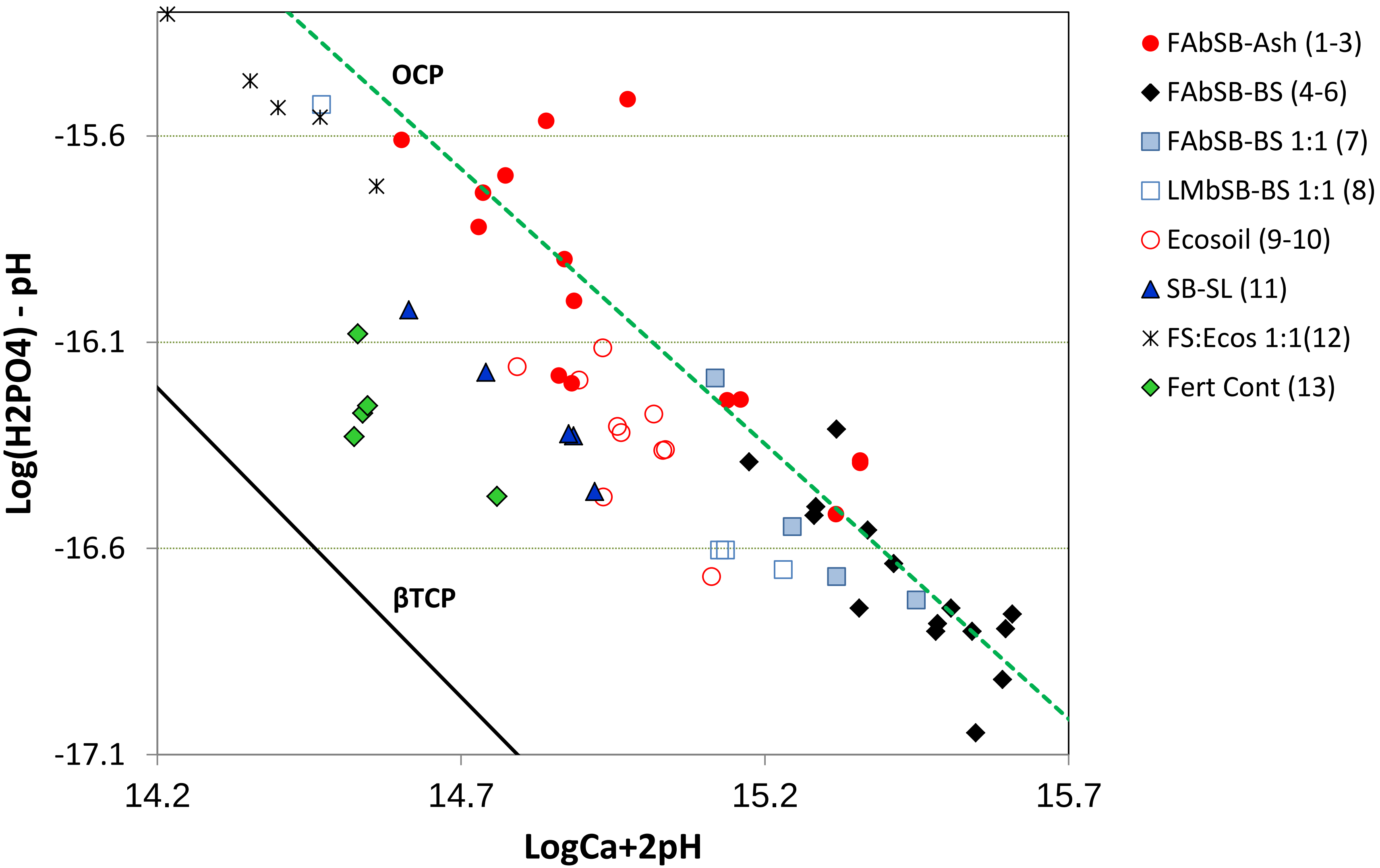




P-Phases in sandy soil under long-term organic regime following application of broilers litter

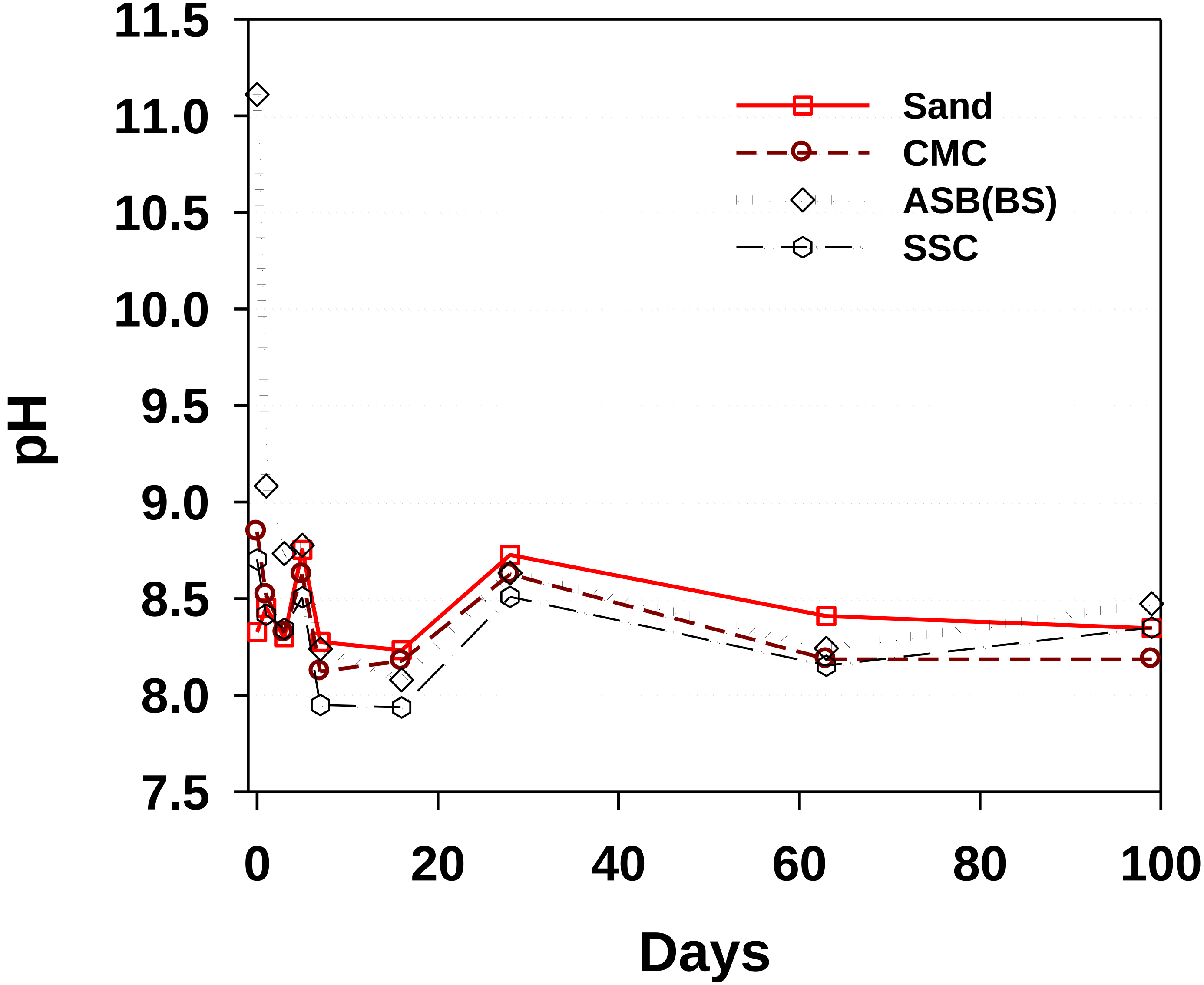


P-Phases in various NVS preparates - sand mixtures used for corn growing in pots (soils sampled ≈120 days after mixing)



Effect of lime-treated sludge on soil pH

Incubation study - application rate (22-50 tons/ha) equivalent to application of 500 kg N/ha (incubation at optimal moisture content, 30ºC)



Sites of field experiments with NVS (& other sludges

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

Yields of silage corn 2011 and 2012 (Revadim, plot 20)

Treatments		Nitrogen Base	Nitrogen Side	Times applied	2011 % of commercial	2012 % of commercial
1	Cont 0-0	0	0		100	69 d
2	Cont N-0	100	0		106	95 bc
3	Cont 0-N	0	150		100	84 c
4	Cont N-N	100	150		100	100 ab
5	SS-500+N	500	150	2	86	110 a
6	SC-500+N	500	150	2	94	99 ab
7	NVS-500+N	500	150	2	95	101 ab
8	MSW-500+N	500	150	2	102	92 bc
9	SS-500-0	500	0	2	103	103 ab
10	SC-500-0	500	0	2	104	94 bc
11	NVS-500-0	500	0	2	98	95 bc
12	MSW-500-0	500	0	2	105	87 c
13	SS-1500-0	1500	0	1	92	93 bc
14	SC-1500-0	1500	0	1	104	94 bc
15	NVS-1500-0	1500	0	1	82	86 c
16	MSW-1500-0	1500	0	1	-	86 c

Revadim 2012: elements in corn seeds (mg kg^{-1})

Treatment	Mg (Student t')		Ca (Stud. t)		Mn (Stud. t)		Ni (T-K HSD)		Cu (Stud. t)		Mo (T-K HSD)	
1 Cont 0-0	1,132	abcde	44	a	5.5	bcd	0.44	a	1.52	abcde	0.13	abcd
2 Cont N-0	1,030	e	31	bcd	4.8	d	0.29	ab	1.34	de	0.09	d
3 Cont 0-N	1,027	e	38	abc	4.8	d	0.21	b	1.46	bcde	0.11	bcd
4 Cont N-N	1,267	a	34	abcd	6.3	ab	0.17	b	1.75	a	0.10	d
5 SS-500+N	1,108	bcde	24	d	5.1	d	0.17	b	1.51	abcde	0.11	bcd
6 SC-500+N	1,204	abc	36	abcd	6.2	abc	0.17	b	1.66	abc	0.10	d
7 NVS-500+N	1,261	ab	40	abc	6.5	a	0.22	b	1.68	ab	0.15	ab
8 MSW-500+N	1,120	abcde	30	cd	5.4	cd	0.19	b	1.59	abcd	0.09	d
9 SS-500-0	1,041	de	34	abcd	4.9	d	0.28	ab	1.42	cde	0.09	d
10 SC-500-0	1,099	cde	42	ab	5.4	bcd	0.28	ab	1.50	abcde	0.10	cd
11 NVS-500-0	1,186	abcd	40	abc	5.5	bcd	0.22	b	1.66	abc	0.15	a
12 MSW-500-0	1,017	e	37	abc	5.2	cd	0.33	ab	1.32	e	0.10	d
13 SS-1500-0	1,114	bcde	33	abcd	4.9	d	0.29	ab	1.43	bcde	0.12	abcd
14 SC-1500-0	1,026	de	32	bcd	4.8	d	0.33	ab	1.49	abcde	0.11	abcd
15 NVS-1500-0	1,102	cde	35	abcd	5.1	d	0.29	ab	1.43	bcde	0.14	abc
16 MSW-1500-0	1,094	cde	42	ab	5.6	abcd	0.37	ab	1.54	abcde	0.13	abcd
AVERAGE	1,114		36		5.4		0.27		1.52		0.11	
p	*0.02*		*0.08*		*0.007*		*0.0002*		*0.06*		*<.0001*	

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

Element (Quant.)	Commer cial	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

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 500 or 1500 kg N/ha/y (in (): loads in dry tons/ha)

Dune sand	As	Cd	Pb	B	Mo	Zn	P	Cu
Unamended	**0.12**	**0.50 ab**	**0.09**	**46 b**	**0.30 b**	**37 b**	**4,867 c**	**4.2 c**
NVS-50	**0.17**	**0.29 b**	**0.11**	**75 a**	**1.01 a**	**48 b**	**5,166 bc**	**7.5 a**
Sludge-8	**0.13**	**0.98 a**	**0.08**	**44 b**	**0.20 b**	**110 a**	**6,594 ab**	**6.5 ab**
Sl comp.-22	**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)								
Unamended	**0.02 b**	**0.07 b**	**0.08**	**37 b**	**0.54 b**	**32**	**4,805**	**8.0**
NVS-50	**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)								
Unamended	**0.13**	**0.20**	**0.29**	**35**	**0.30 b**	**46 bc**	**6,490**	**9.3**
NVS-50	**0.22**	**0.27**	**0.23**	**47**	**0.80 a**	**40 c**	**5,140**	**8.4**
NVS-150	**0.13**	**0.27**	**0.32**	**46**	**0.76 a**	**53 ab**	**6,920**	**11.7**
Sl comp. - 22	**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**

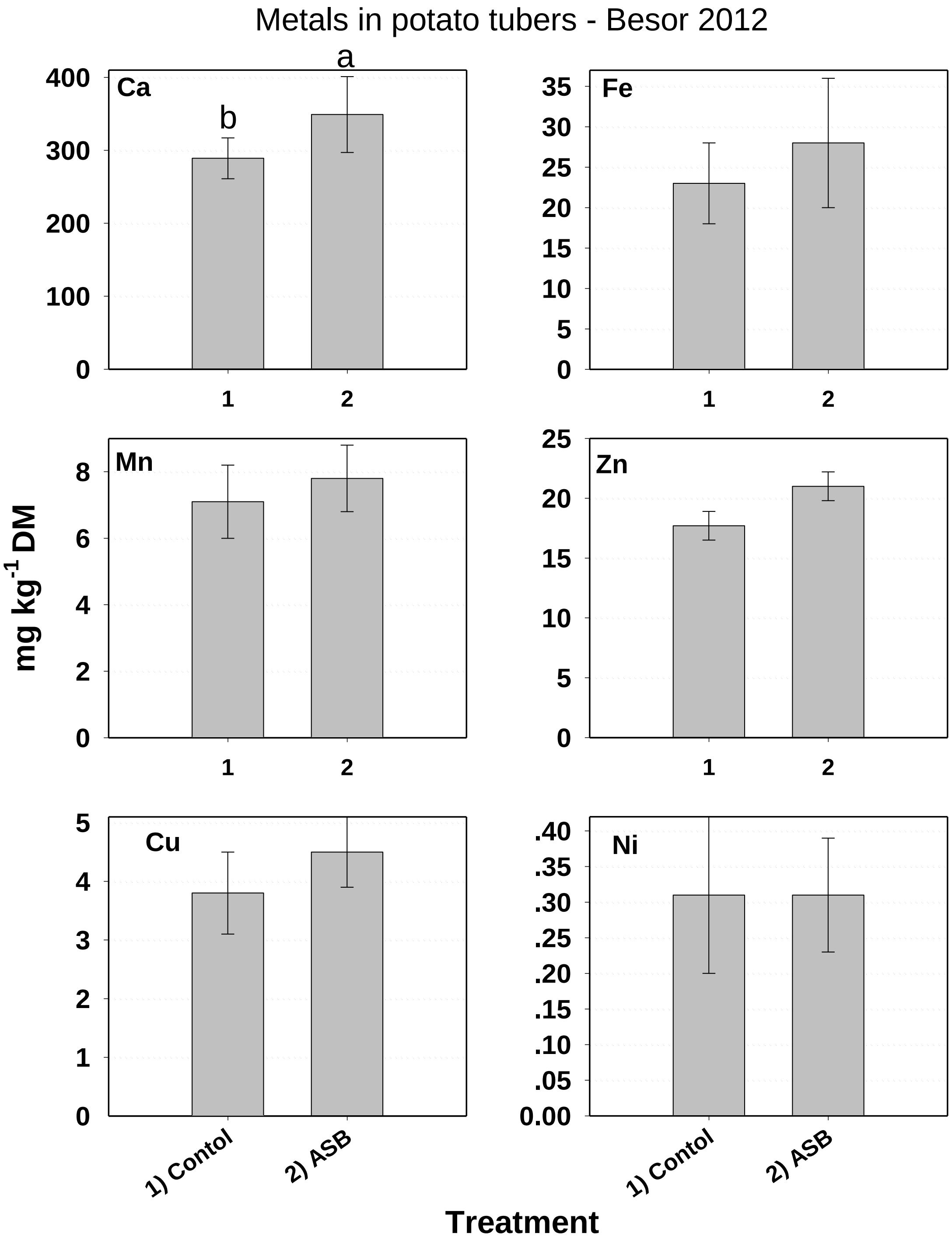
Quantification levels (mg/kg): Cd: 0.035; Pb: 0.30; As: 0.7


N-Viro – 43 tons/ha
4. 1. 2012

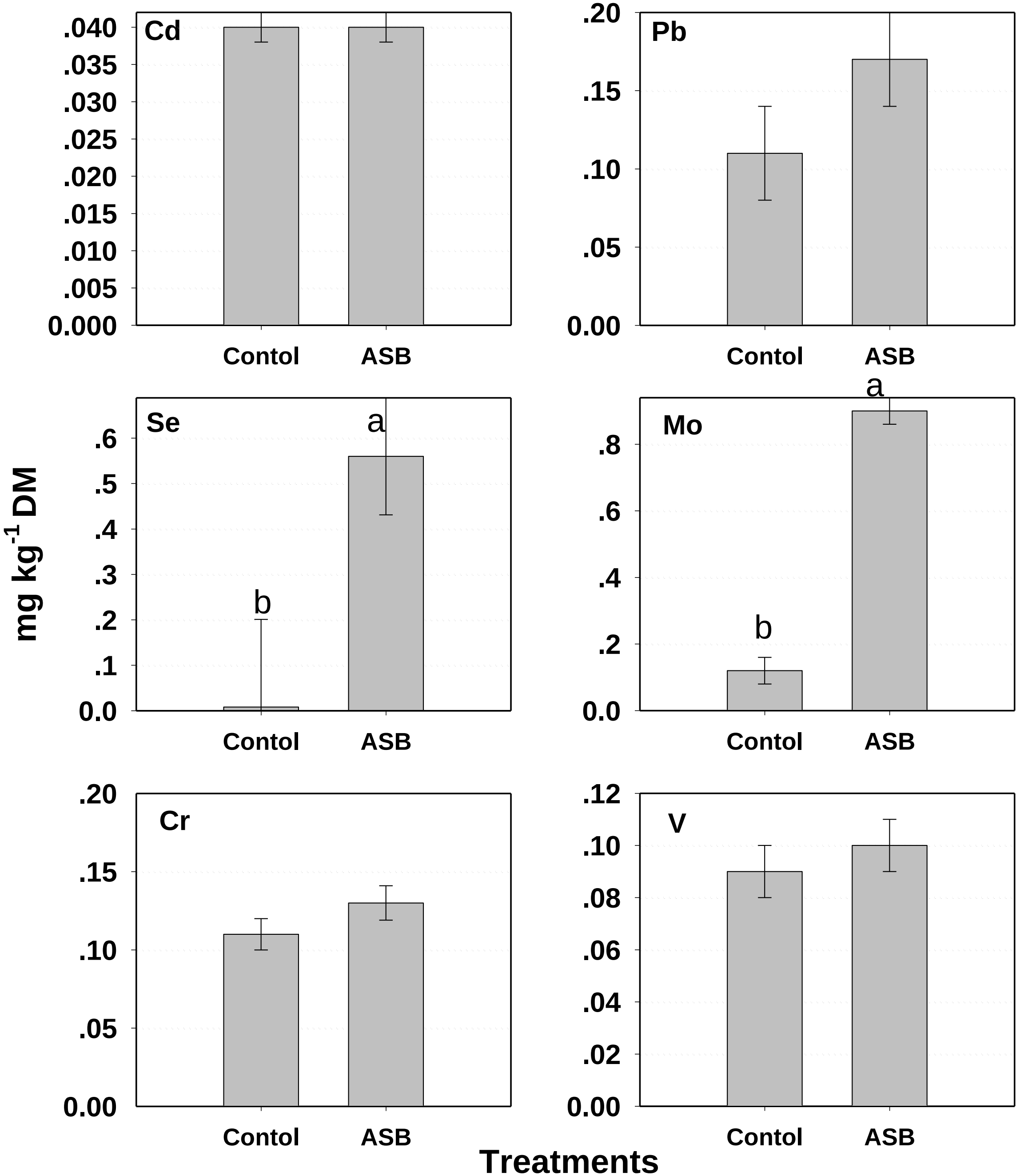
Control

Yield of potatoes – Besor 2011/2012

Treatments	Tubers yield (tons/ha)	Mean tuber weight (gr)	Tubers number (/m^2)
Control (all)	37 b	212 b	68 b
N-Viro (all)	54 a	272 a	77 a
p	<.0001	<.0001	0.004


Metals in potato tubers - Besor 2012
mg kg-1 DM
Ca
a
b
Fe
Mn
Zn
Cu
Ni
1) Contol
2) ASB
Treatment

Metals in potato tubers - Besor 2012



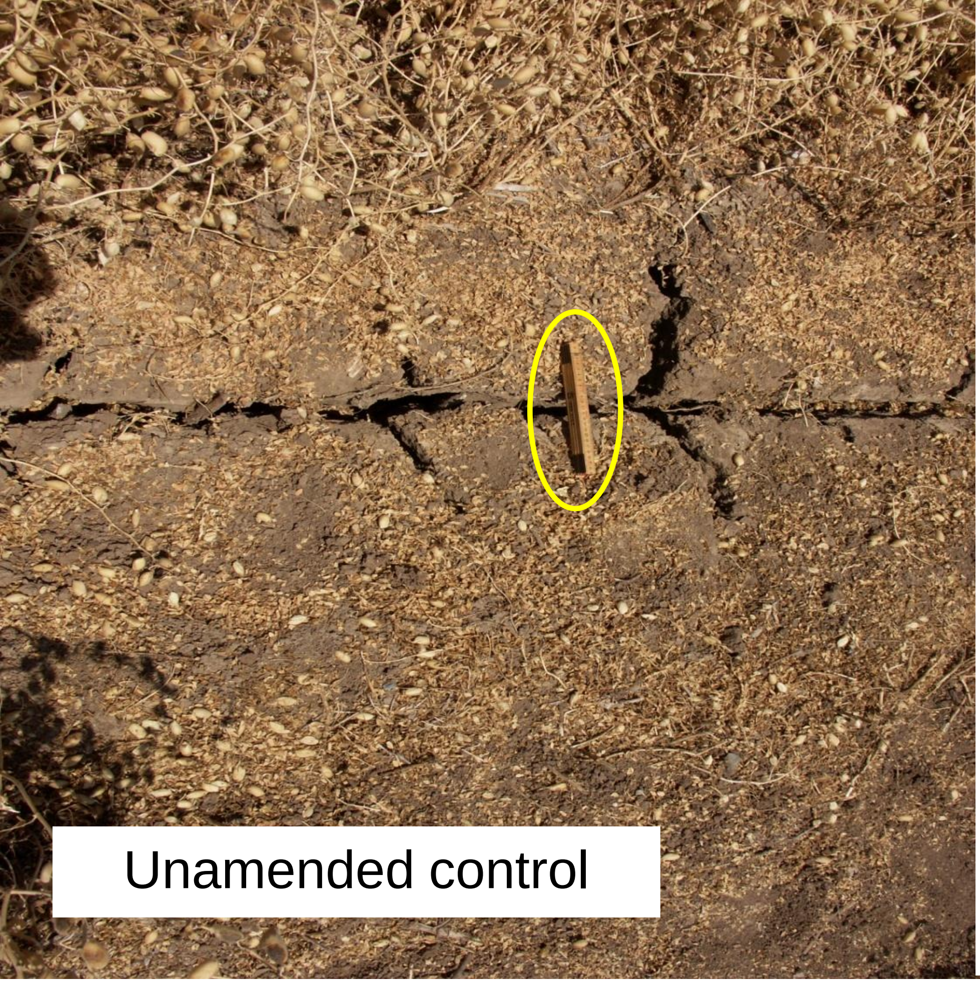
Nutrient	EAR	RDA or AI	UL	Unit/day
Boron	NE	-	20	mg
Calcium	NE	1000	2500	mg
Chloride	NE	2300	3600	mg
Chromium	NE	35	ND	µg
Copper	700	900	10000	µg
Fluoride	NE	4	10	mg
Iodine	95	150	1100	µg
Iron	6	8	45	mg
Magnesium	330	420	350[a]	mg
Manganese	NE	2.3	11	mg
Molybdenum	34	45	2000	µg
Nickel	NE	-	1.0	mg
Phosphorus	580	700	4000	mg
Potassium	NE	4700	ND	mg
Selenium	45	55	400	µg
Sodium	NE	1500	2300	mg
Sulfate	NE	-	ND	-
Zinc	9.4	11	40	mg

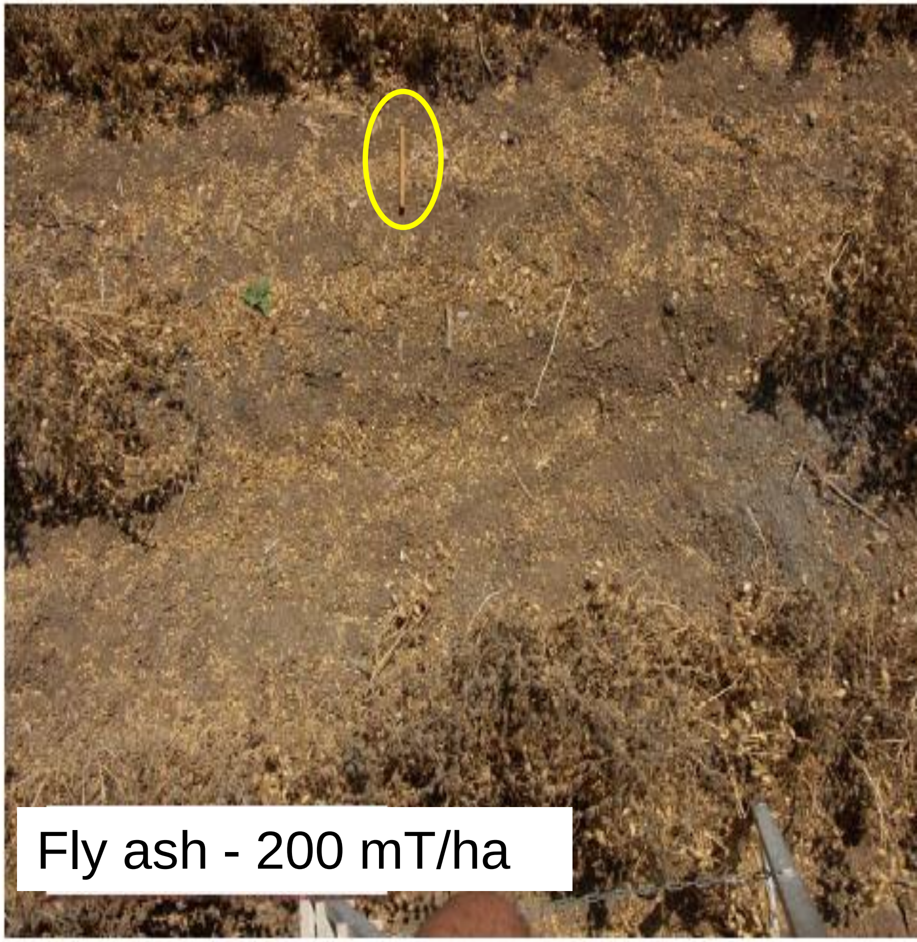
- **ERA** – Estimated average requirement;
- **RDA** - Recommended Dietary Allowances
- **AI** - Adequate Intake
- **UL** - Tolerable upper intake levels

Kg Besor potatoes/day to provide:		
	RDA	UL
Cu	1.3	
Cr	1.7	
Mn	1.9	
Fe	2.1	
Mo	3.3	
Zn	3.5	
Se	6.1	
Ca	19.0	
B		38.1
Ni		33.3

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	
Cd	0.04	0.05	
Pb	bd	bd	

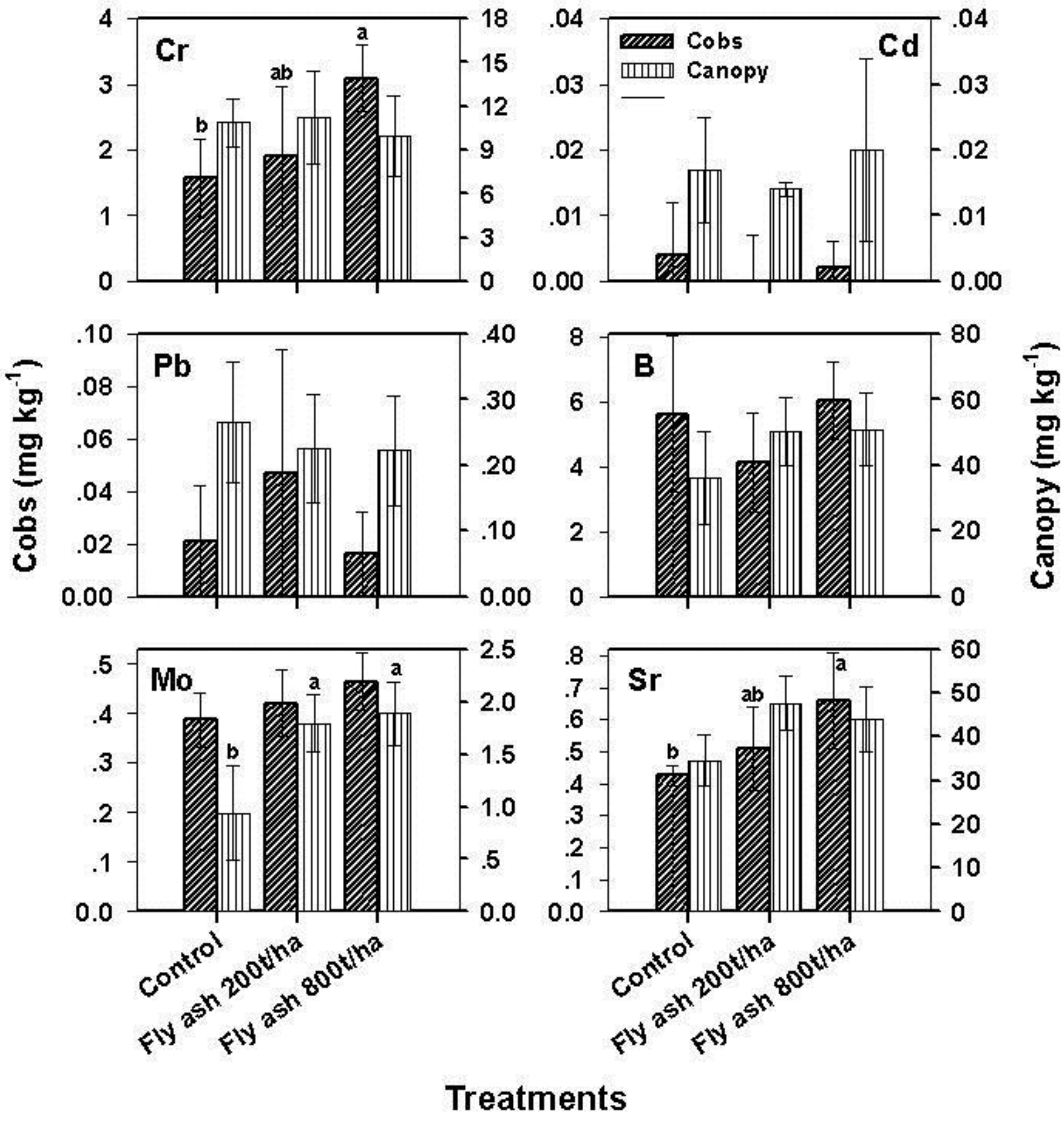




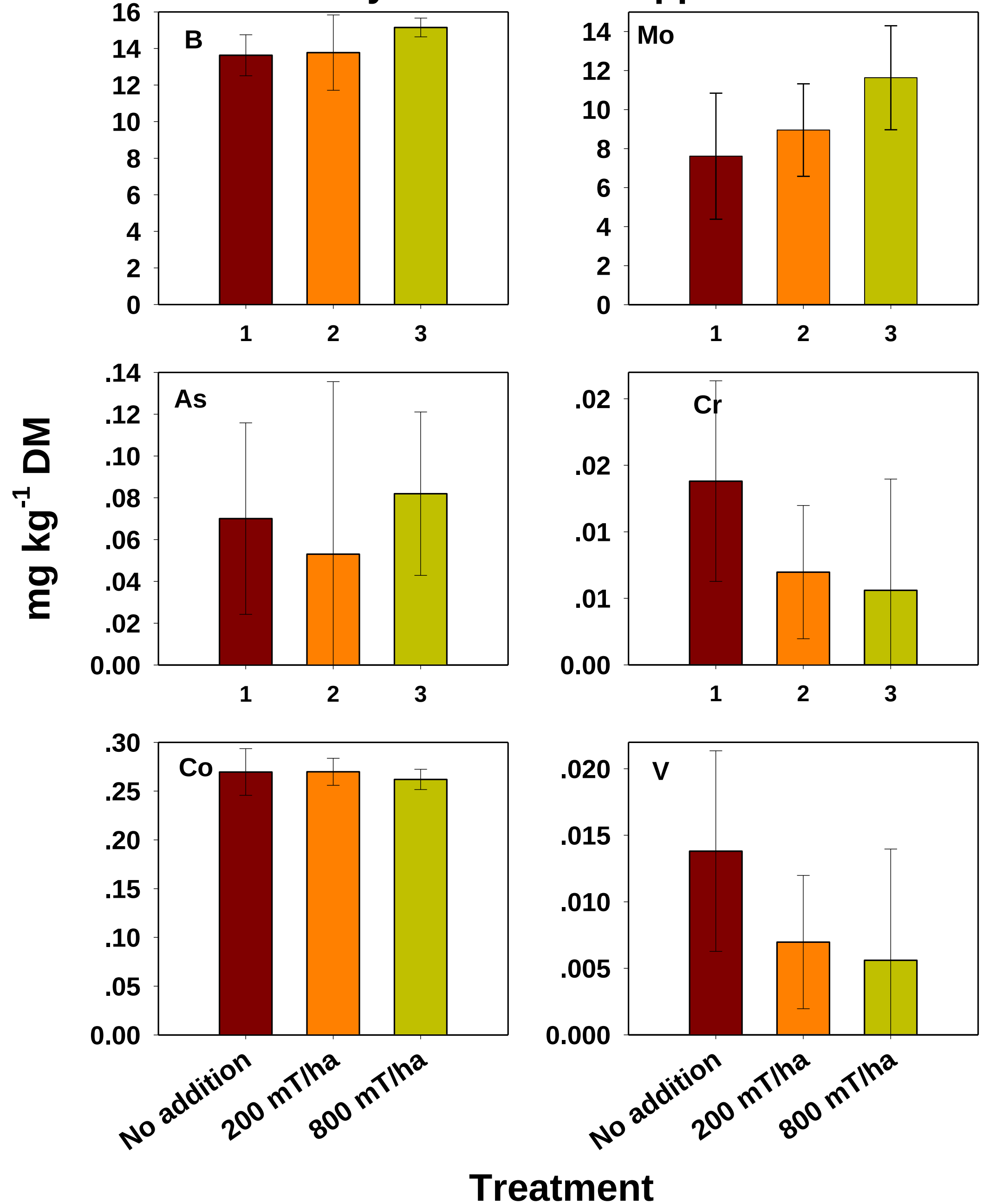
Effect of fly ash addition (200 and 800 tons/ha) on cracking of a sodic clayey soil

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



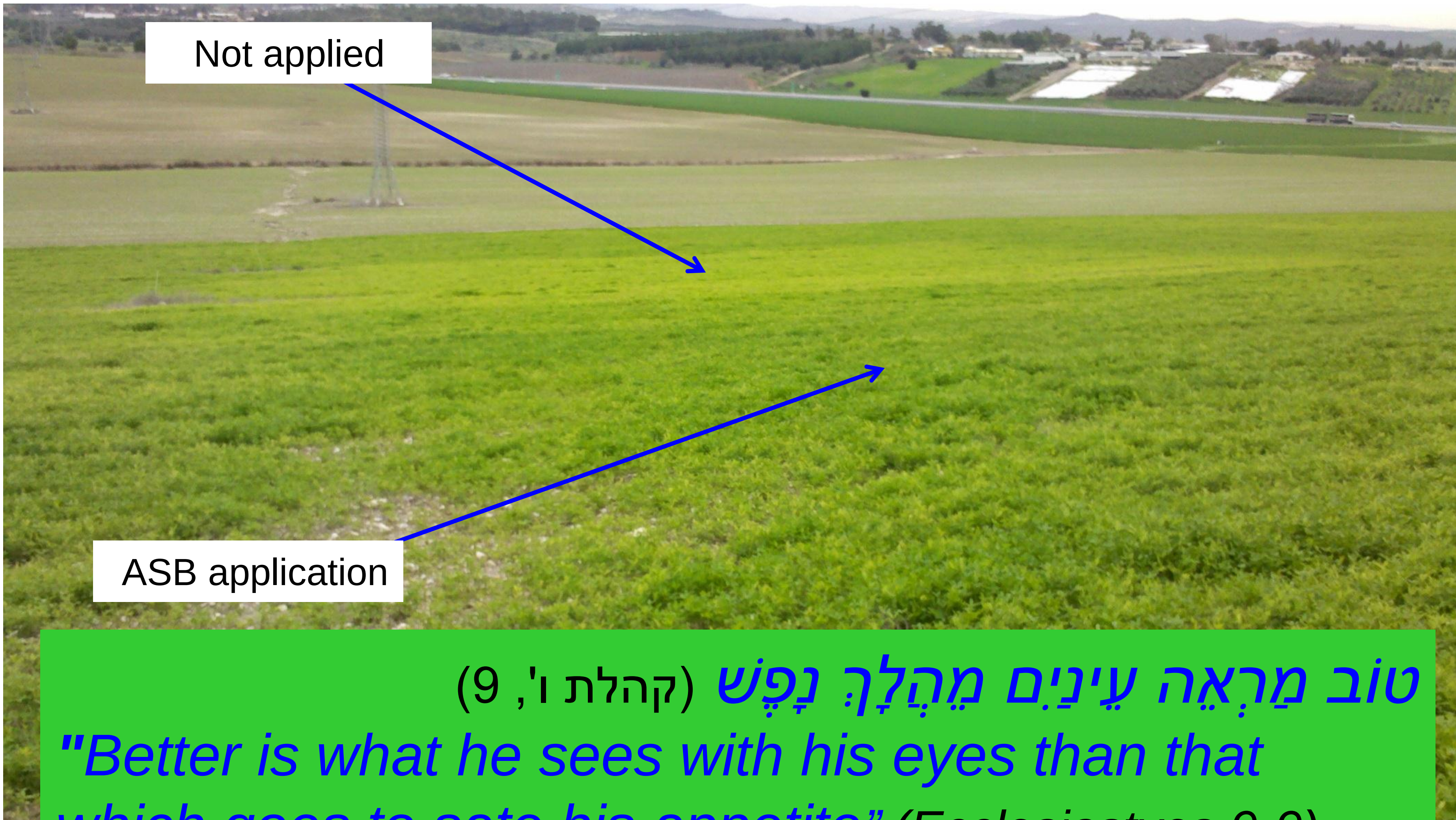
Content of priority metals in fly ash, N-Viro Soil and FA-amended Revadim soil (5 months after application)

Element (mg/kg)	N-Viro Soil	FA at Revadim (& FA IGS)	Revadim soil	Revadim +800 tons FA ha^{-1}	Sludge - Ceiling conc. (pH≥6)	
					EU	Israel
Cd	0.3-1.0	**bdl** (0.44 – 1.50)	bdl	bdl	40	20
Cr	50-51	**90** (110 – 205)	52	56	-	400
Cu	71-77	**44** (60 – 110)	58	38	1750	600
Hg	0.6*	(<0.2 – 0.30)			25	5
Ni	28-31	**56** (73 – 240)	36	35	-	90
Pb	15-25	**30** (40 – 140)	2	2.4	1200	200
Zn	247-260	**60** (70 – 190)	53	50	4000	2500

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.

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}



טוֹב 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)


Thank you
11/12/2012