Boron fertilizers: use, mobility in soils and uptake by plants

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Boron toxicity and deficiency in plants

- Boron is an essential micronutrient required for several functions in plants, particularly for cell walls and for reproduction (flowering)
- Uptake by plants is passive and unregulated, so toxicity can easily occur
- B is relatively immobile in most plant species, so crops are adversely affected by even short-term deficiencies

B toxicity

www.acpfg.com.au

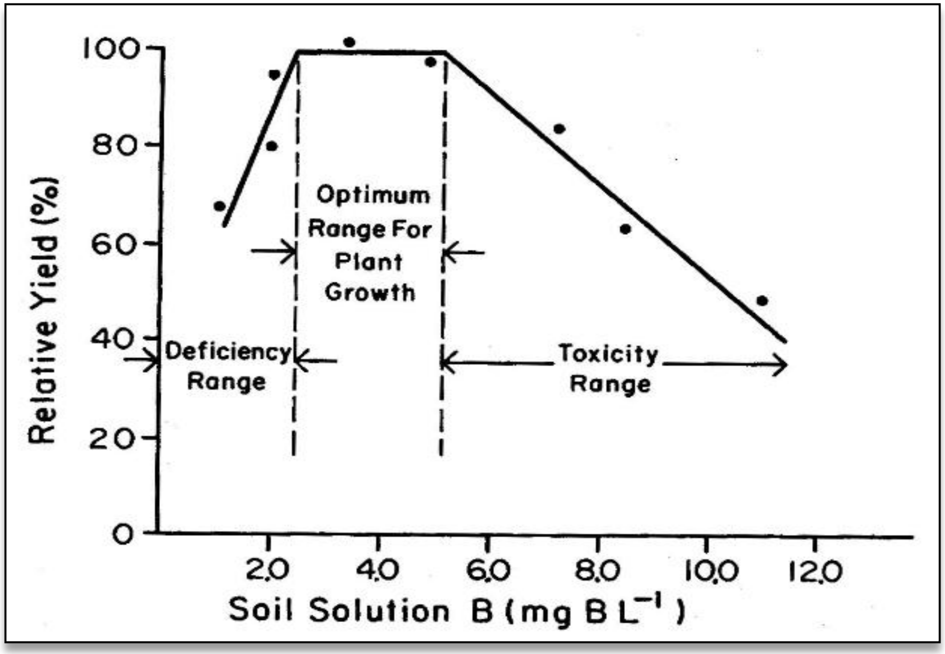
B deficiency

www.extension.umn.edu

www.agric.wa.gov.au

Boron toxicity and deficiency in plants

- The window between deficiency and toxicity for B is very narrow, e.g.



Gupta et al 1985, *Can J Soil Sci* 65: 381

- The optimal range in soil varies by crop, but is roughly 0.5-5 mg/kg hot water-extractable boron for most species

Boron toxicity and deficiency in plants

- Species sensitive to B deficiency: legumes, *Brassica*, fruit trees

Apium graveolens var. *dulce*	Celery	*Eucalyptus* spp.	Eucalypts
Arachis hypogaea	Groundnut	*Gossypium* spp.	Cotton
Beta vulgaris	Sugar beet	*Helianthus annuus*	Sunflower
Brassica spp.	Brassica	*Malus domestica*	Apple
B. rutabaga	Swede	*Medicago sativa*	Lucerne
Coffea spp.	Coffee	*Olea europaea*	Olive
Daucus carota	Carrot	*Pinus* spp.	Pines
Elaeis guineensis	Oil palm	*Vitis vinifera*	Grape

Shorrocks 1997, Plant Soil 193: 121

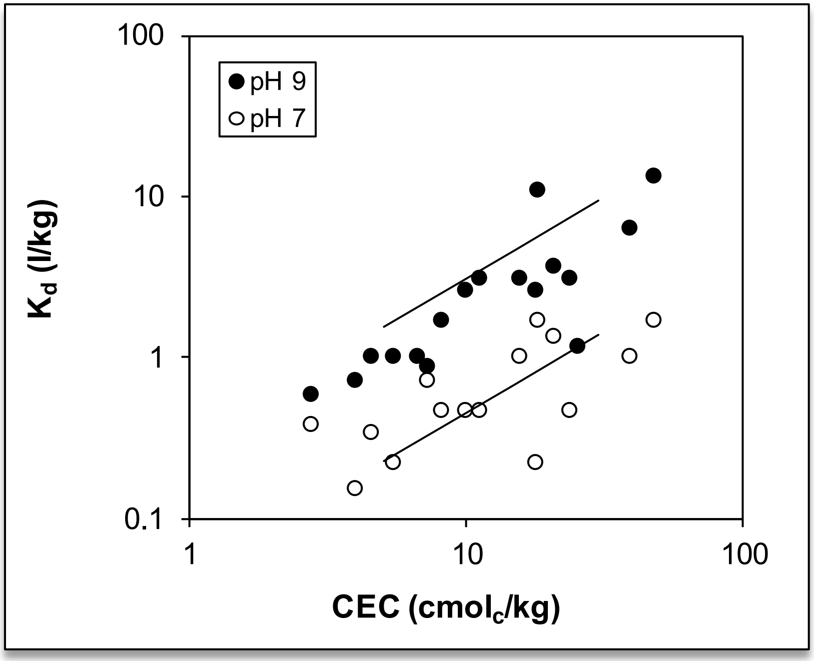
- Species sensitive to B toxicity:
  - Several cereal species (barley, wheat) (due to low pectin content?)
  - Stone and pome fruits

Boron in soil

- Total B concentrations in soil depend on parent material and the degree of weathering, with natural background concentrations usually ranging from 2 to 100 mg/kg (average ~ 20 mg/kg; Power & Woods 1997)
- Boron is never found as a single element and is usually found combined with oxygen as borates
- Boron may also be tightly bound in silicate minerals to produce very insoluble minerals, e.g. clay minerals or tourmalines
- Adsorption on oxides and association with organic matter occurs

Boron in soil

- Soluble B in soil exists as a neutral species, H_3BO_3, in most soils or also as $B(OH)_4^-$ in high pH soils (pK_a=9.2)
- The adsorption of B in soils is weak, though generally higher in high pH soils (pH>8)

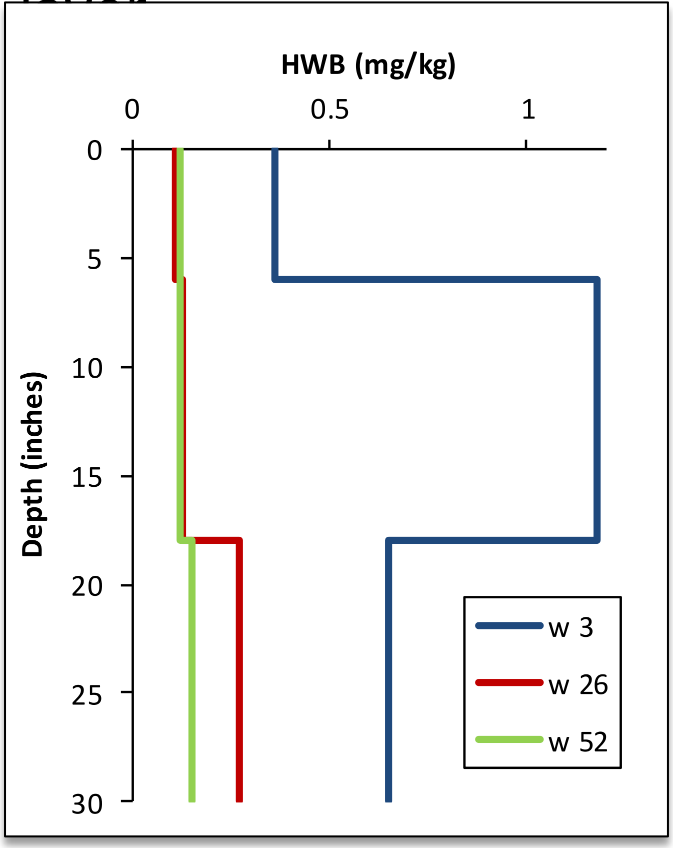


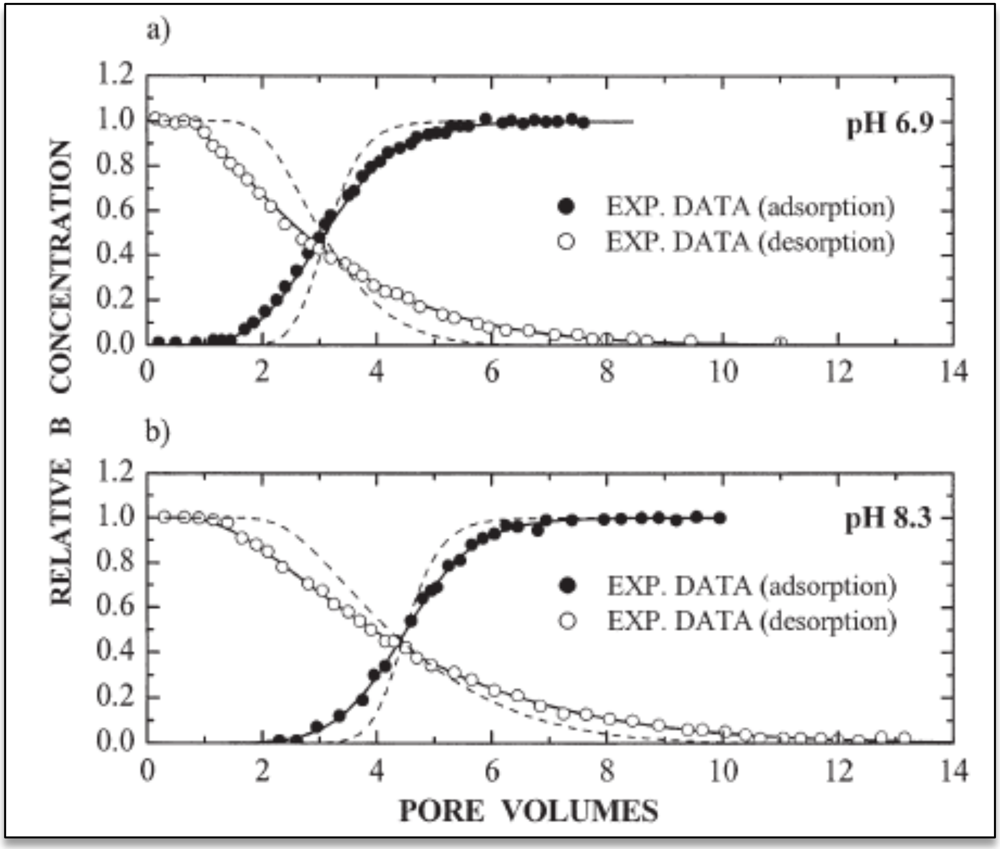
Data from Goldberg et al 2000, SSSAJ 64: 1356

Boron in soil

- The low retention makes B vulnerable to leaching

⇒ Excess rainfall can result in loss of applied B from the top layer





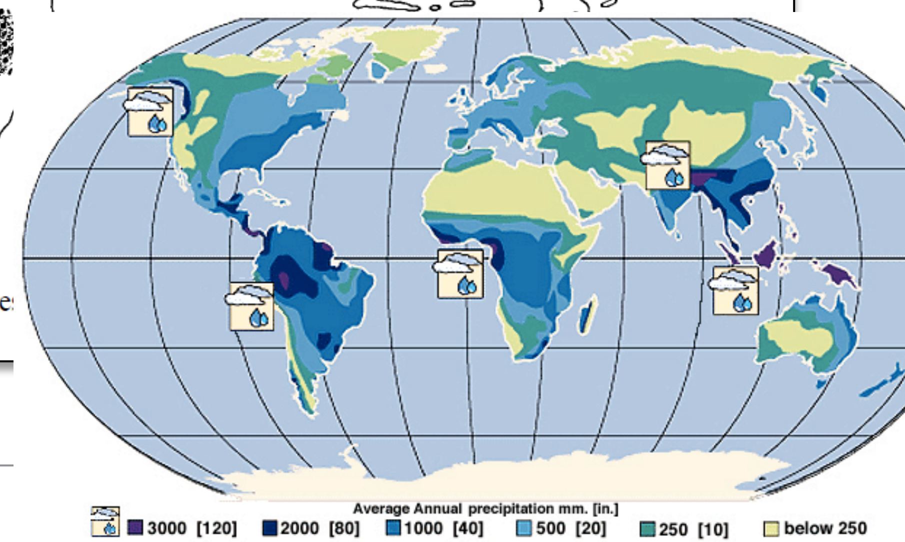
Data from Winsor 1951, Soil Sci 71: 91

Communar & Keren 2005, SSSAJ 69: 311

Boron in soil

Areas where B deficiency is most likely to occur

Figure 1. Boron deficient areas. Areas identified on the basis of crop re
boundaries have a firmer basis.



Shorrocks 1997, Plant Soil 193: 121

Boron in soil

- Toxic B levels are most likely to occur in dry areas, particularly in:
  - soils inherently high in B
  - soils irrigated with B-rich irrigation water
- High B is often found in association with salinity problems
- The highest B concentrations are often found at depth (>20 cm), so topsoil sampling may not reveal the issue
- “Detoxifying” the soil through excess irrigation is often not practical or economical, so selecting/breeding crop cultiv with tolerance is usually the only practical approach to increase or maintain yields on high-B soils

Boron in soil and plants - Summary

- Boron is highly mobile in soil (if not occluded in minerals/ organic matter)
- Boron deficiency is most commonly found in humid regions, as leaching removes plant-available B
- There is a narrow range between B deficiency and toxicity, with optimal soil concentrations generally between 0.5-5 mg/ kg hot-water extractable B
- The sensitivity to B deficiency or toxicity is plant species dependent

Boron fertilizer - Sources

- Boron is primarily obtained from mined B minerals, located mostly in arid regions of Turkey and the USA, and also in Argentina, Chile, Russia, China, and Peru
- Approximately 70% of the world supply comes from two corporate organizations – Eti Mine Works (Turkey) and Rio Tinto (US Borax)
- It is estimated that Turkey has 72% of the world's B reserves

Boron fertilizer - Sources

- Soluble borates/boric acid (borax and refined borates)

Compound (Common/commercial name)	Formula	% B
Disodium tetraborate decahydrate (Borax, tincal)	$Na_2B_4O_7.10H_2O$	11.3
Disodium tetraborate pentahydrate (Fertibor, Granubor)	$Na_2B_4O_7.5H_2O$	15.2
Disodium octaborate tetrahydrate (Solubor, Granubor)	$Na_2B_8O_{13}.4H_2O$	20.9
Anhydrous borax (Dehybor)	$Na_2B_4O_7$	21.5
Boric acid	H_3BO_3	17.5

Boron fertilizer - Sources

- Crushed or refined ores

Compound	Formula	% B
Colemanite	$Ca_2B_6O_{11}.5H_2O$	15.8
Ulexite	$NaCaB_5O_9.8H_2O$	13.3

Boron fertilizer - Sources

- Other sparingly soluble compounds

Compound	Formula	% B
Boron frits	(boric oxide glass)	2-11
Boron phosphate	BPO_4	10.2

  - Boron frits are produced by melting silicates with borates and have very low solubility
  - Boron phosphate is synthesized from boric acid and phosphoric acid and its solubility depends on the temperature of synthesis (Abat et al. 2014)

Boron fertilization

- Recommended rates depend on B crop requirements and generally range from 0.25 to 3 kg/ha
- Methods of application:
  - Soil application: mostly broadcast, banding not recommended because of toxicity risk
  - Foliar for selected crops

Boron fertilization - Foliar

Wild Type

Transgenic

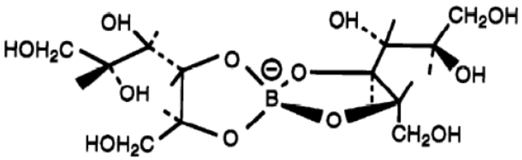
Brown et al 1999, *Plant Phys* 119:17

TABLE 2. Leaf B concentration (ppm dry wt.) along a shoot in various plant species.

Species	Basal	Middle	Apical	Remarks
Pecan	303	119	30	B-immobile
Tomato	721	318	94	B-immobile
Strawberry	512	176	68	B-immobile
Walnut	304	127	48	B-immobile
Apple	50	56	70	B-mobile
Apricot	45	60	81	B-mobile
Pear	42	57	62	B-mobile
Celery	32	49	104	B-mobile
Grape	74	55	88	B-mobile
Loquat	72	101	162	B-mobile
Olive	42	51	56	B-mobile
Peach	53	57	208	B-mobile
Pomegranate	21	20	111	B-mobile

Brown & Hu 1998, *Better Crops* 82:28

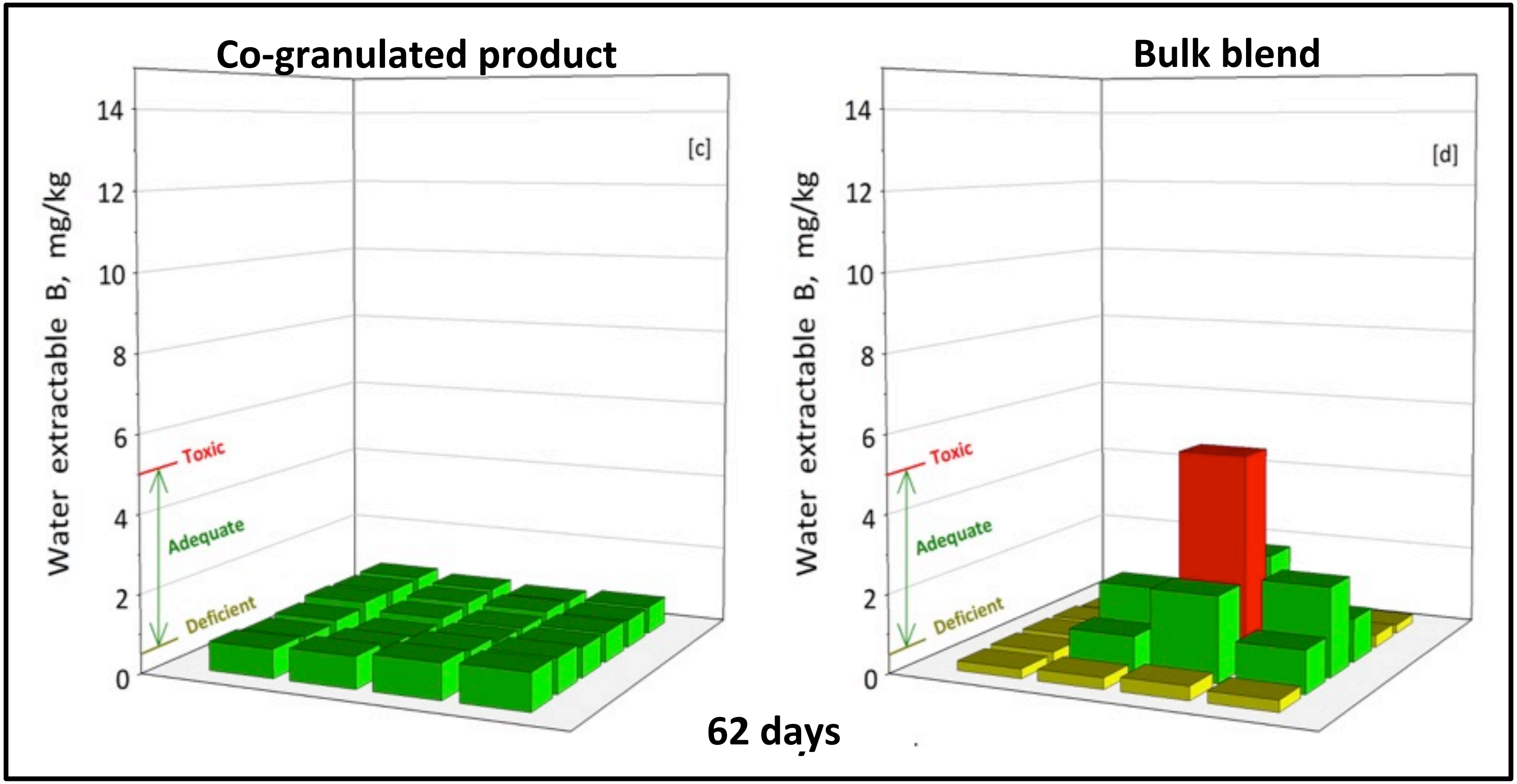
- Boron is phloem-mobile in sorbitol-rich species, e.g. several fruit crops
- In most species, B is not phloem-mobile and hence foliar fertilization is not effective



Boron fertilization

- Recommended rates depend on B crop requirements and generally range from 0.25-3 kg/ha
- Methods of application:
  - Soil application: mostly broadcast, banding not recommended because of toxicity risk
  - Foliar for selected crops
- Types of soil-applied fertilizer:
  - Granular fertilizer bulk blended with granular NPK sources
  - Boronated NPK fertilizer

Boron fertilization – Bulk blend vs boronated

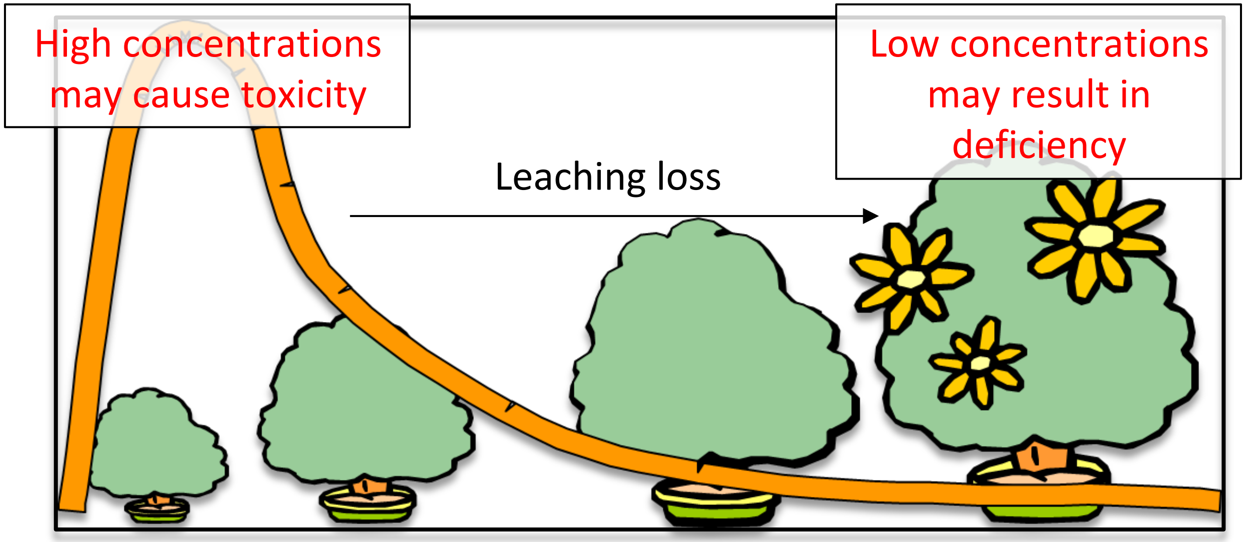


da Silva et al, in preparation

- Bulk blending results in poorer field distribution and hence higher risk of toxicity/deficiency than co-granulated fertilizers

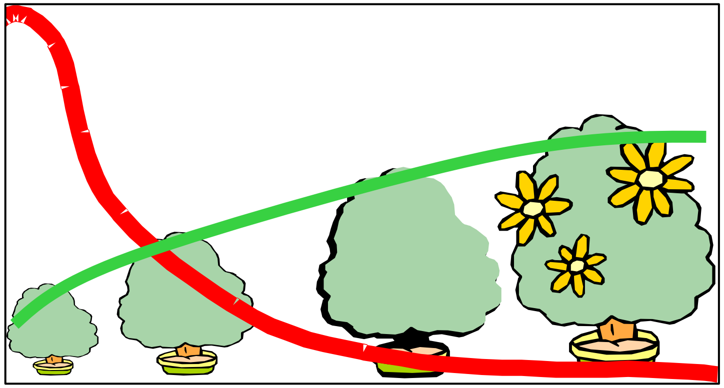
Issues with soluble B fertilizer

- Soluble B may cause toxicity initially with sensitive crops
- Retention of B in most soils is negligible, so B leaches easily, which may result in deficiency later in the season



Slow release fertilizers

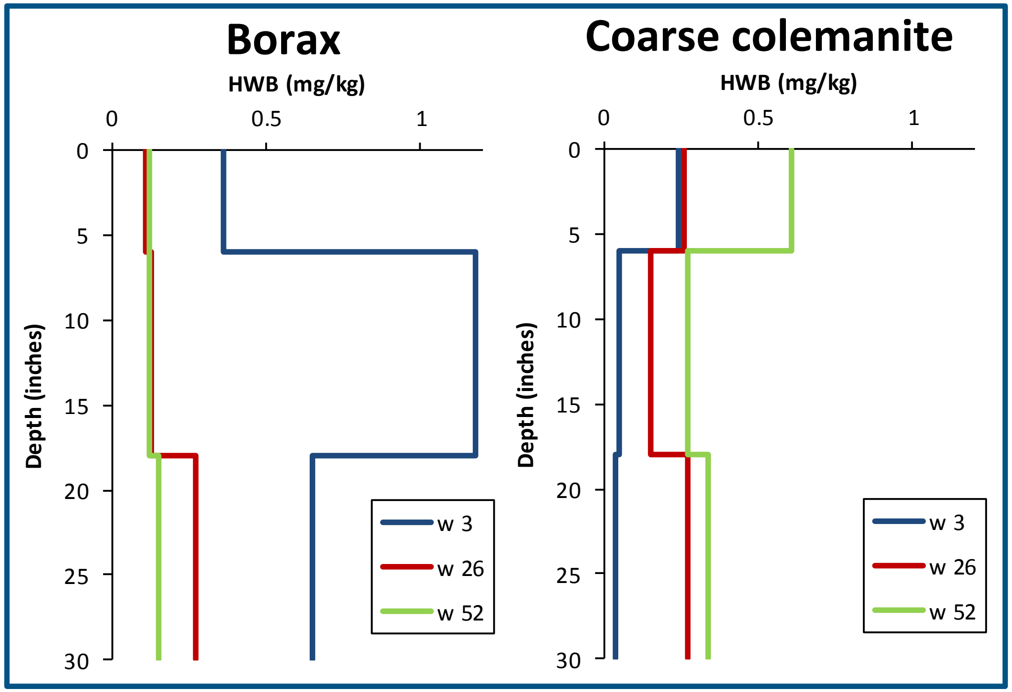
- Slow release fertilizer reduce the risk of both leaching losses (possibly resulting in deficiency) and of seedling toxicity
- The release should be slow enough to protect against leaching and harmful concentrations, but fast enough to supply the nutrients within a reasonable timeframe



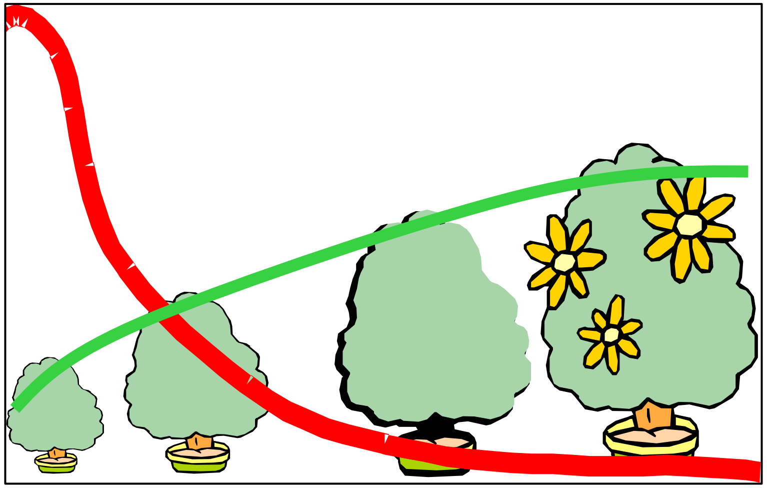
Slow release fertilizers – Reduced leaching

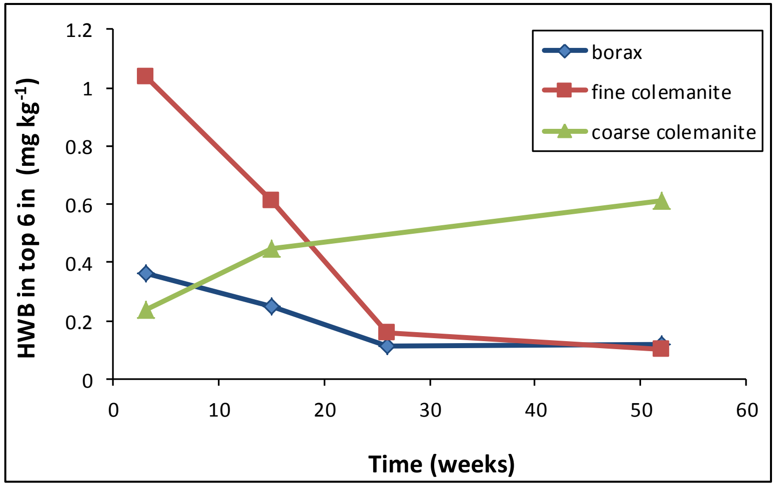
Less leaching for coarse colemanite

⇒ Available B maintained at optimal levels over longer period



Winsor 1951, Soil Sci 71:99

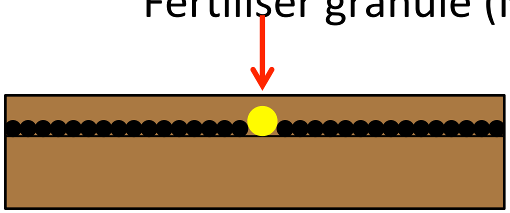




Slow release fertilizers – Reduced toxicity

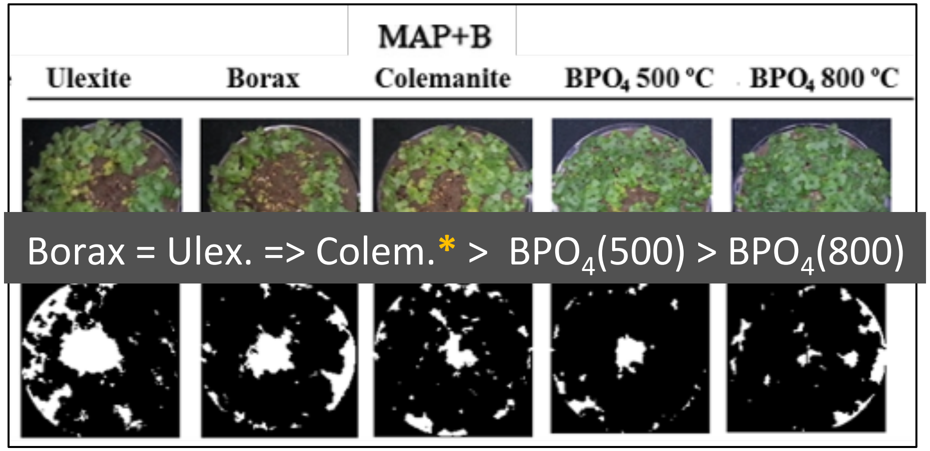
Seedling toxicity test (Abat et al. 2015)

- Petri dish filled with soil
- Fertilizer granule (MAP or MOP with 2% B) in centre
- Seeds germinated under controlled conditions (23/15°C, day/night)
- Pictures taken 7 and 11 days after germination and processed using imaging analysis software (GIMP)

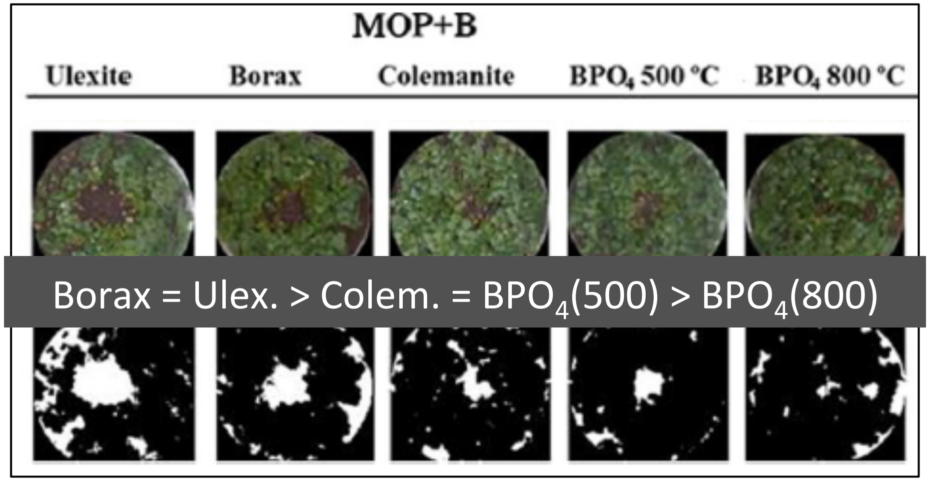


Slow release fertilizers – Reduced toxicity

Toxicity and HWB concentrations around MAP/MOP+2% B granules



Borax = Ulex. => Colem.* > BPO_4(500) > BPO_4(800)



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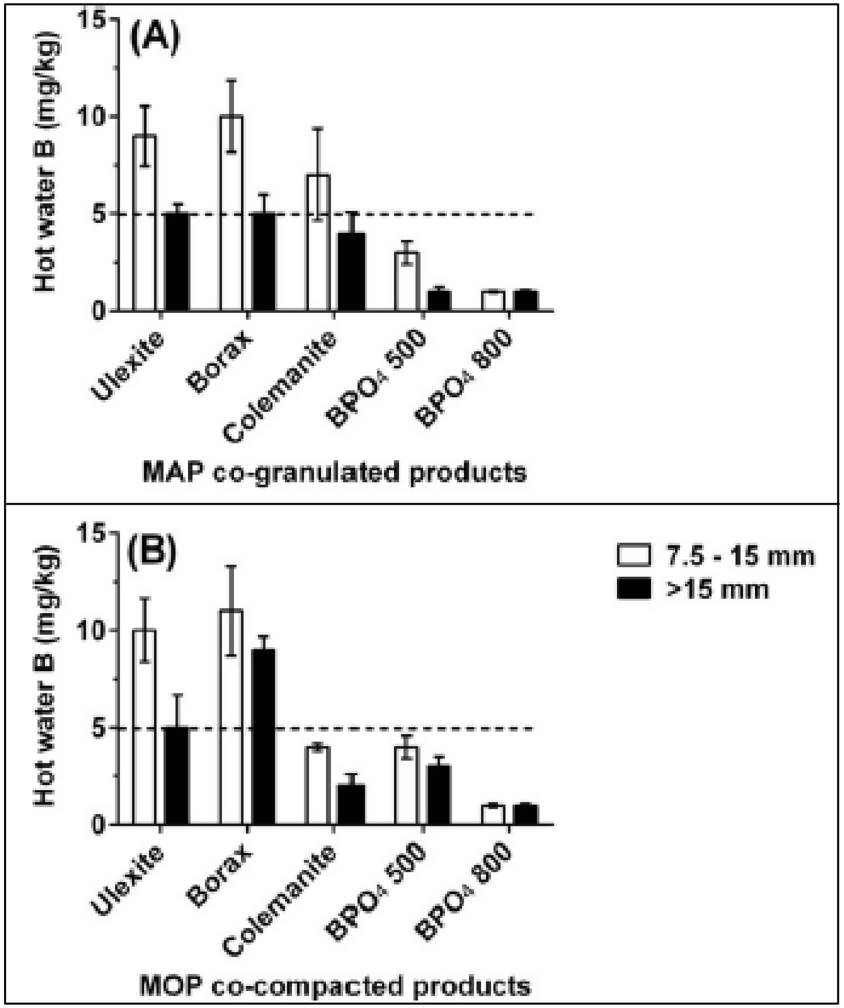


* Colemanite more soluble due to Ca ppt (Ca phosphates) and lower pH around MAP

Abat et al. 2015, Plant Soil 391:153

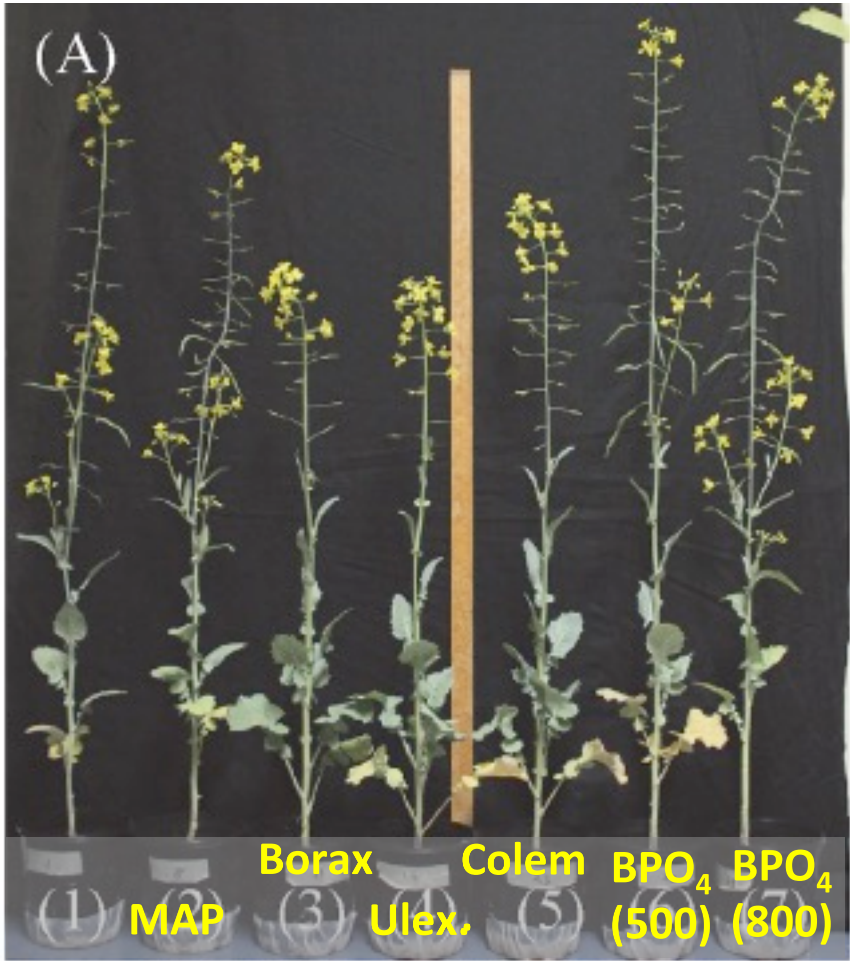
Slow release fertilizers – More optimal nutrient supply

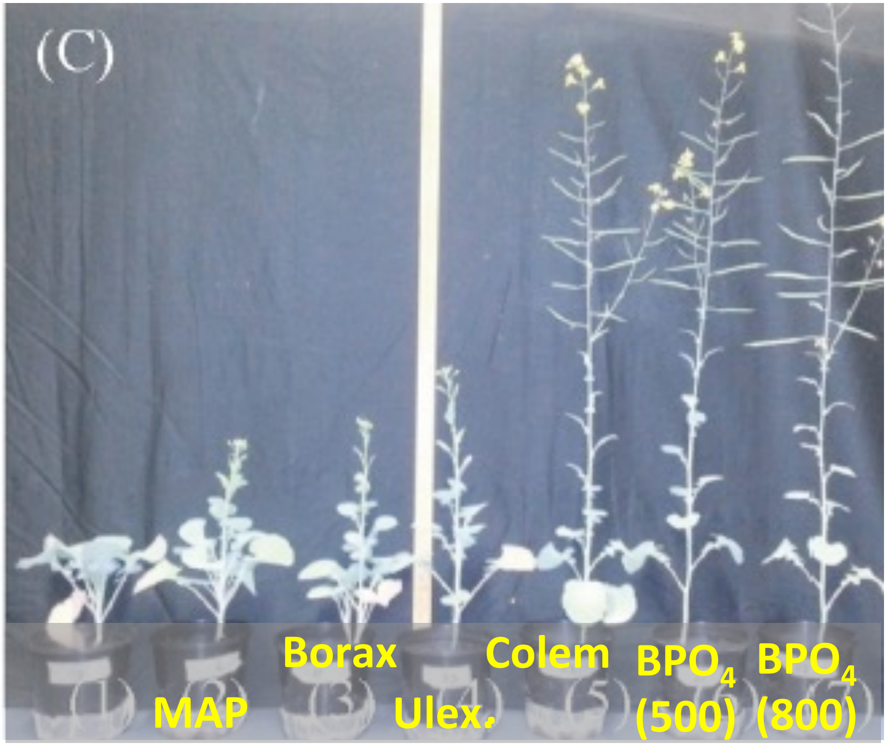
Pot trial (Abat et al. 2015)

- Sandy acid soil with low hot-water B concentration (0.2 mg/kg)
- Five B sources: borax, ulexite, colemanite, BPO_4(500) and BPO_4(800) co-granulated with MAP at 1% B
- Canola grown for 12 weeks in 1-kg pots
- After 3 months, leaching with 1400 ml of water, and second canola crop (12 weeks) grown
- Yield and tissue analysis

Slow release fertilizers – More optimal nutrient supply

First crop **Second crop**





Abat et al. 2015, SSSAJ 79: 97

Slow release fertilizers – More optimal nutrient supply

Treatment	First crop					
	Yield			Concentration		
	Shoot	Seed	Root	Shoot	Seed	Root
	g plant^{-1}			mg B kg^{-1}		
Control	3.60 c†	0.169 ns‡	0.384 a	24 d	18 d	12 cd
MAP¶	5.06 a	0.192	0.251 b	29 d	21 d	11 d
Borax	4.33 bc	0.074	0.224 b	97 a	72 a	20 ab
Ulexite	4.10 bc	0.081	0.202 b	108 a	68 ab	23 a
Colemanite	4.72 ab	0.163	0.205 b	101 a	48 bc	18 abc
BPO_4 500°C	4.77 ab	0.189	0.195 b	78 b	27 cd	18 ab
BPO_4 800°C	5.39 a	0.207	0.215 b	59 c	23 d	16 bcd

- With most soluble sources, toxicity symptoms and yield reduction in first crop

Abat et al. 2015, SSSAJ 79: 97

Slow release fertilizers – More optimal nutrient supply

Treatment	First crop						Second crop			
	Yield			Concentration			Yield		Concentration	
	Shoot	Seed	Root	Shoot	Seed	Root	Shoot	Seed	Shoot	Seed
	g plant^{-1}			mg B kg^{-1}			g plant^{-1}		mg B kg^{-1}	
Control	3.60 c†	0.169 ns‡	0.384 a	24 d	18 d	12 cd	2.38 b	0.0	14 d	NA§
MAP¶	5.06 a	0.192	0.251 b	29 d	21 d	11 d	3.10 a	0.0	12 d	NA
Borax	4.33 bc	0.074	0.224 b	97 a	72 a	20 ab	2.77 ab	0.003	15 cd	3.60 ns
Ulexite	4.10 bc	0.081	0.202 b	108 a	68 ab	23 a	2.46 b	0.067	20 cd	5.50
Colemanite	4.72 ab	0.163	0.205 b	101 a	48 bc	18 abc	2.59 ab	0.097	29 b	9.20
BPO_4 500°C	4.77 ab	0.189	0.195 b	78 b	27 cd	18 ab	2.63 ab	0.115	40 a	7.86
BPO_4 800°C	5.39 a	0.207	0.215 b	59 c	23 d	16 bcd	2.71 ab	0.091	24 bc	5.72

- With most soluble sources, toxicity symptoms and yield reduction in first crop
- With most soluble sources (borax and ulexite), deficiency symptoms in second crop

Abat et al. 2015, SSSAJ 79: 97

Conclusions

- Boron is an uncharged ion and is not strongly retained in soils
- Boron is therefore very mobile and deficiencies are most common in high rainfall environments, especially on sandy soils
- The ‘window’ between deficiency and toxicity is narrow for B, so care is needed in fertilizer formulation and placement to avoid B toxicity
- Only small amounts of B are required to alleviate deficiency (~0.5-3 kg/ha)

Conclusions

- Due to poor spatial distribution of B, bulk blends containing B salts are less effective than co-granulated products
- The use of highly soluble B sources can result in leaching losses in high rainfall environments, and also poses a higher risk of toxicity
- Slow release sources have most potential to supply adequate B throughout the entire plant cycle or multiple crop cycles

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Thank You