

# *Enmiendas de suelo, efectividad, duración y accesibilidad para remediar el cadmio en fincas de cacao en Ecuador*

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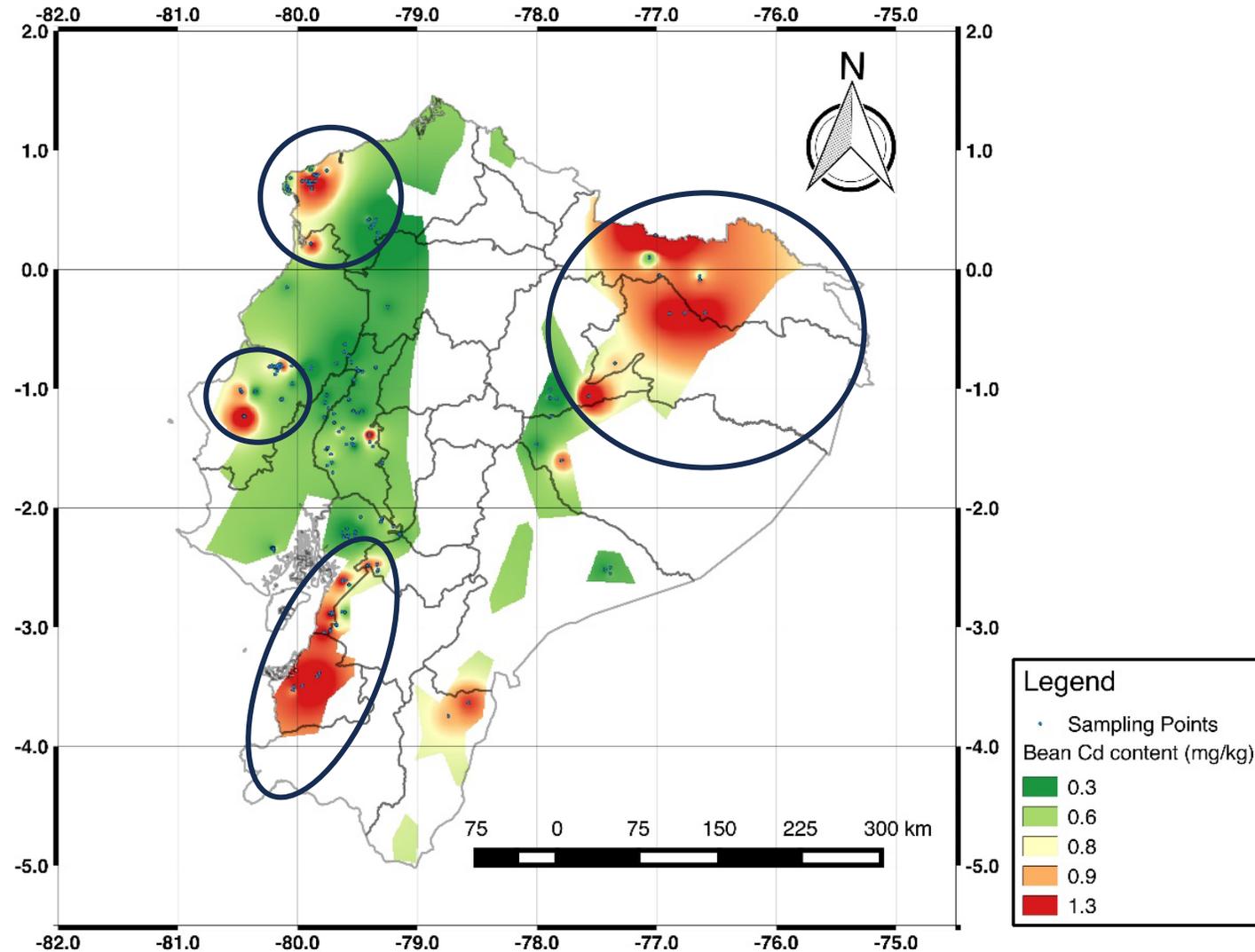
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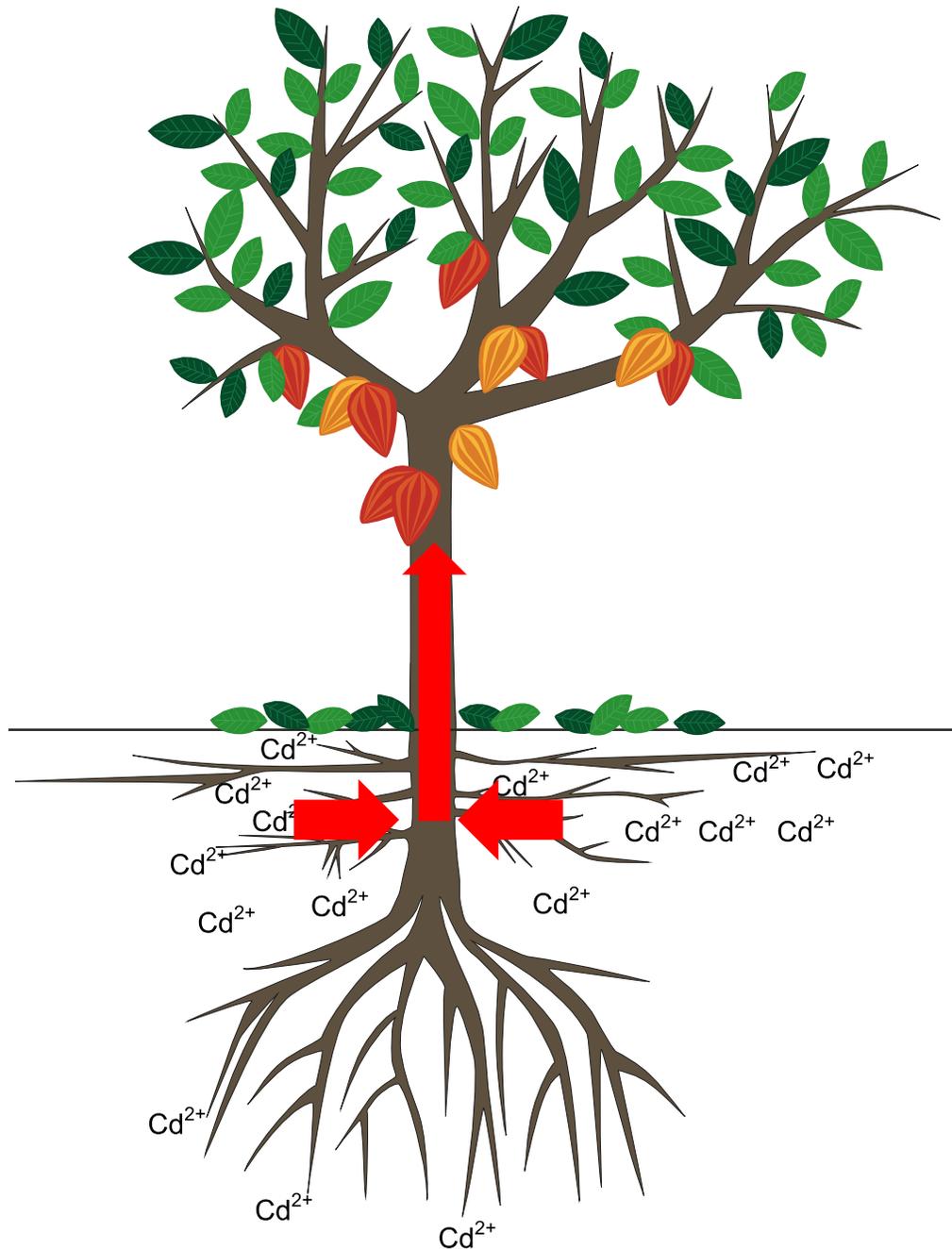
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**12 pilot farms – solutions are applied based on soil conditions. Farms have bean-Cd > 1.00 mg kg<sup>-1</sup>**

**Acid soil pH (<5.5):** liming materials to increase soil pH, increase plant-available Ca<sup>2+</sup>

**Neutral to alkaline soil pH (>6.5):** application of organic matter (compost and biochar), application of Zn, Mn or Fe.





## What needed to be understood first?

Soil to plant relationships – draft best possible treatments

- Cd - Leaf/soil ratio = 4.44 (average)
- Cd - Bean/soil ratio = 1.26 (average)

Conclusion – more Cd (concentration) in plant tissue as compared to soils

Search literature for field experiments – what has worked in other crops/soils

Conclusion – Lime and organic matter are the most applied soil conditioner, field results are highly variable.

# Soil to plant relationship



$$\log_{10}(Cd_{Bean}) = 1.66 + 0.94 \times \log_{10}(soil\ Cd_T) - 0.21 \times pH - 0.63 \times \log_{10}(\%OC) \quad (R^2 = 0.57)$$

Parameter	95 % CI
Intercept	1.42 – 1.90
Soil Cd <sub>T</sub>	0.86 – 1.01
pH	-0.24 – -0.17
%OC	-0.74 – -0.52

Assuming all the average values

Bean Cd = 0.67 mg kg<sup>-1</sup>

Increasing pH by 1 unit

Bean Cd = 0.42 mg kg<sup>-1</sup>

RF = 1.6

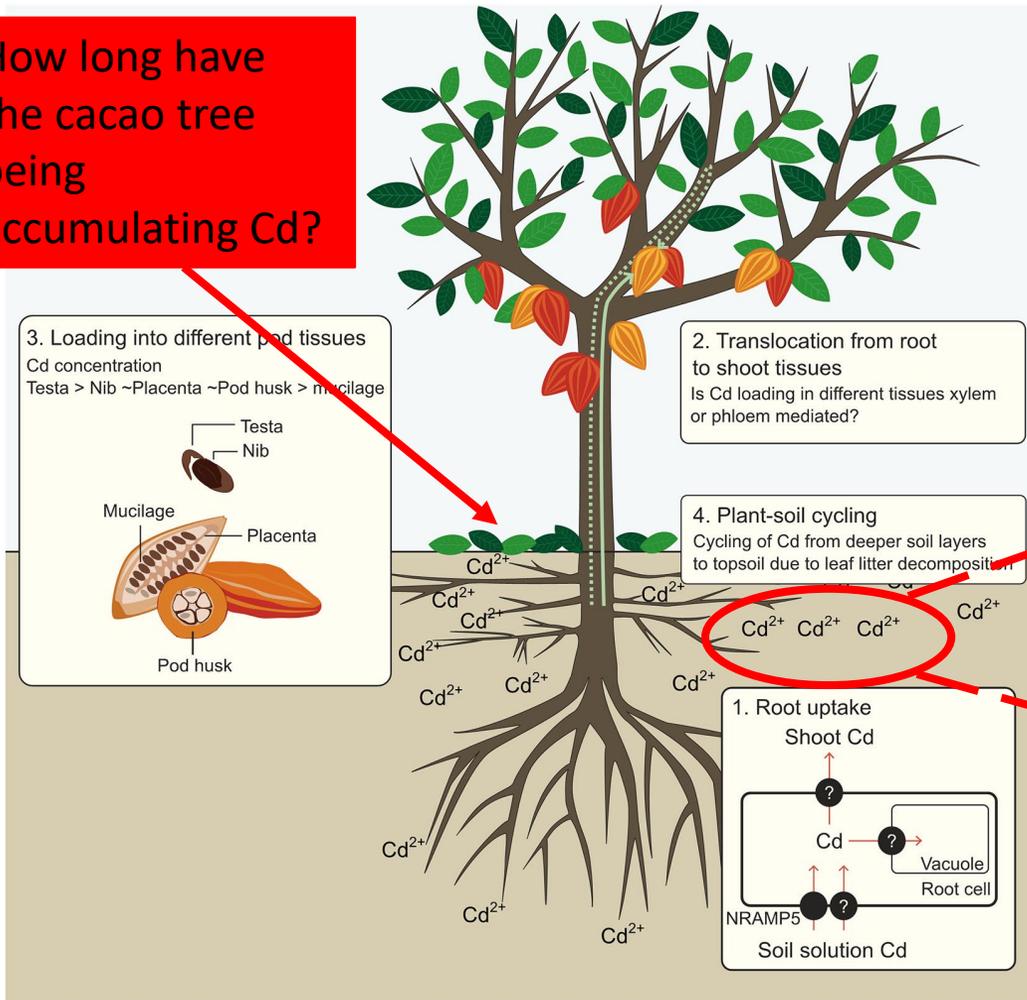
Double %OC

Bean Cd = 0.44 mg kg<sup>-1</sup>

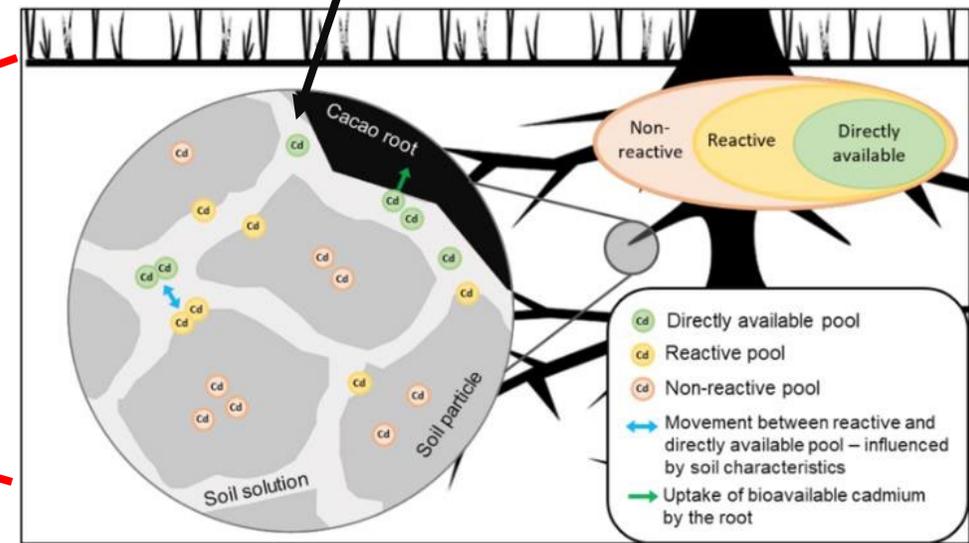
RF = 1.5

# What we try...

How long have the cacao tree been accumulating Cd?



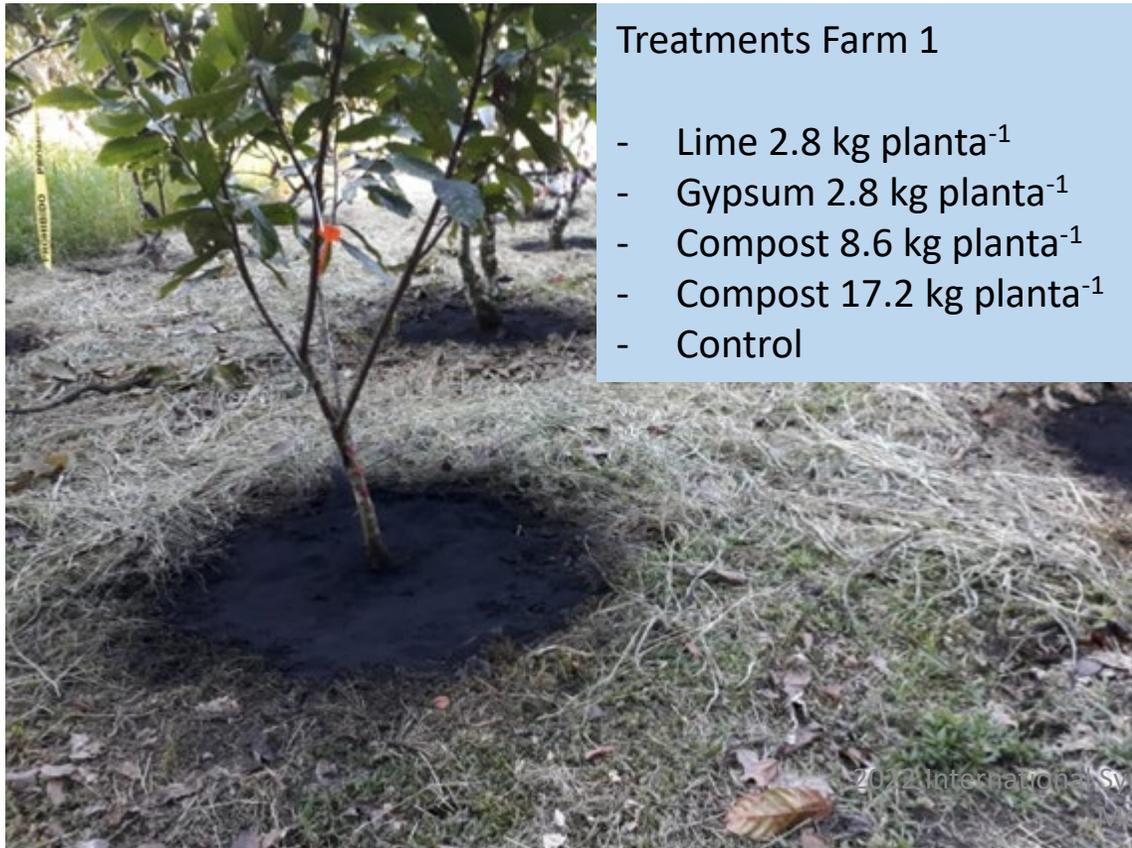
Is water-soluble Cd the only plant-available Cd for cacao trees



Meter et al., 2019

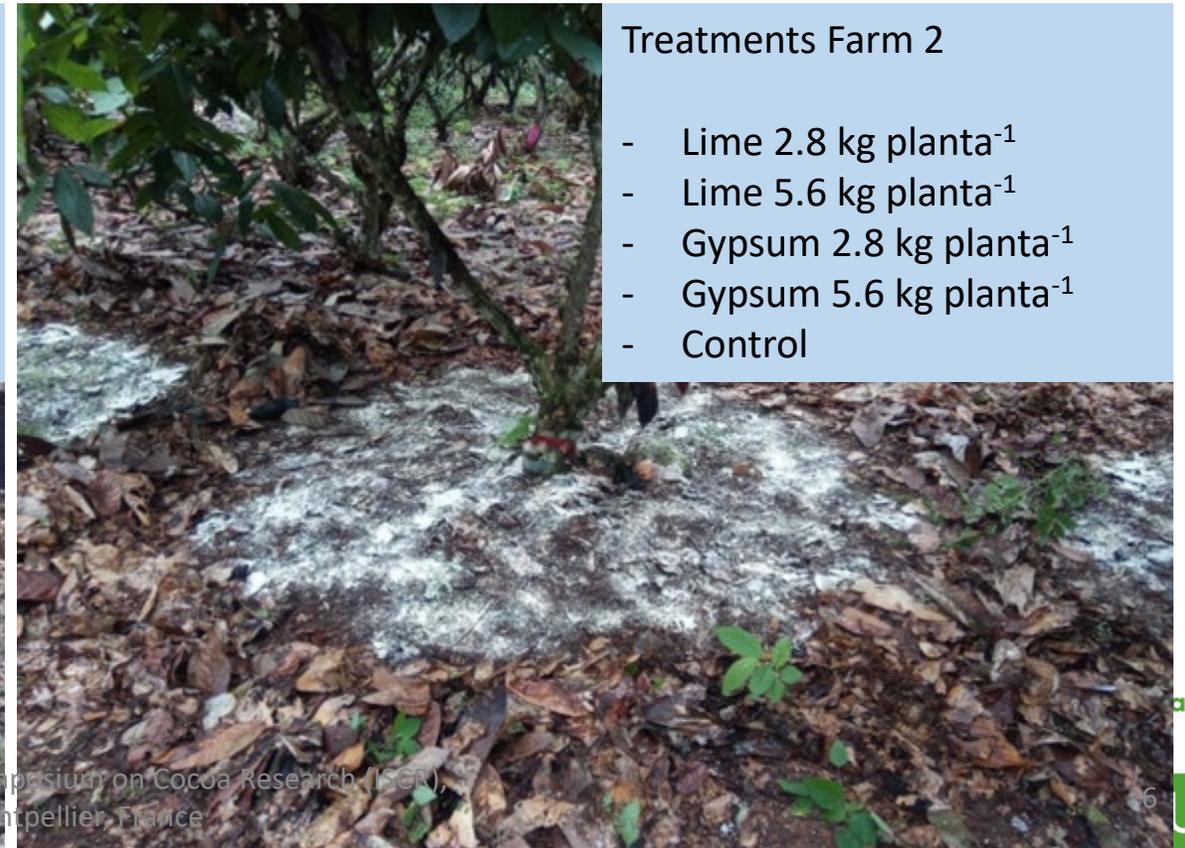
Vanderschueren, Argüello, Blommaert, et al., 2021

Description	pH <sup>‡</sup>	SOC %	WHC (ml kg <sup>-1</sup> )	Fe <sub>ox</sub> <sup>£</sup>	Al <sub>ox</sub> <sup>£</sup>	Mn <sub>ox</sub> <sup>£</sup>	eCEC	Ca-exc <sup>¶</sup>	Total Cc
				g kg <sup>-1</sup>			cmol <sub>c</sub> kg <sup>-1</sup>		mg kg <sup>-1</sup>
Field Trial Farm 1	6.6	1.18	380	4.02	1.01	0.40	14.5	13.3	1.01
Field Trial Farm 2	5.1	3.54	430	10.2	2.07	1.46	17.3	12.2	0.85
Incubation and column experiment	4.9	7.14	560	9.57	28.1	0.45	6.39	3.88	0.56



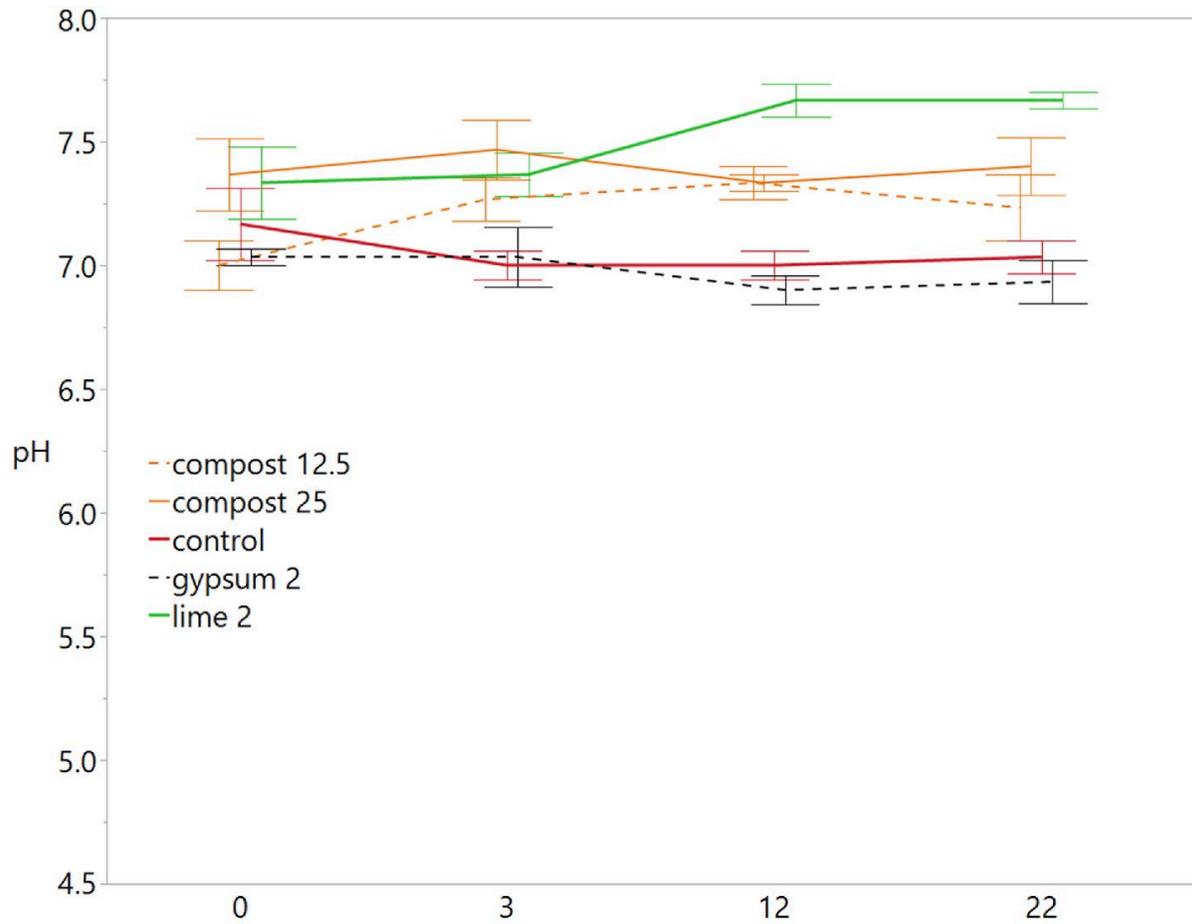
#### Treatments Farm 1

- Lime 2.8 kg planta<sup>-1</sup>
- Gypsum 2.8 kg planta<sup>-1</sup>
- Compost 8.6 kg planta<sup>-1</sup>
- Compost 17.2 kg planta<sup>-1</sup>
- Control

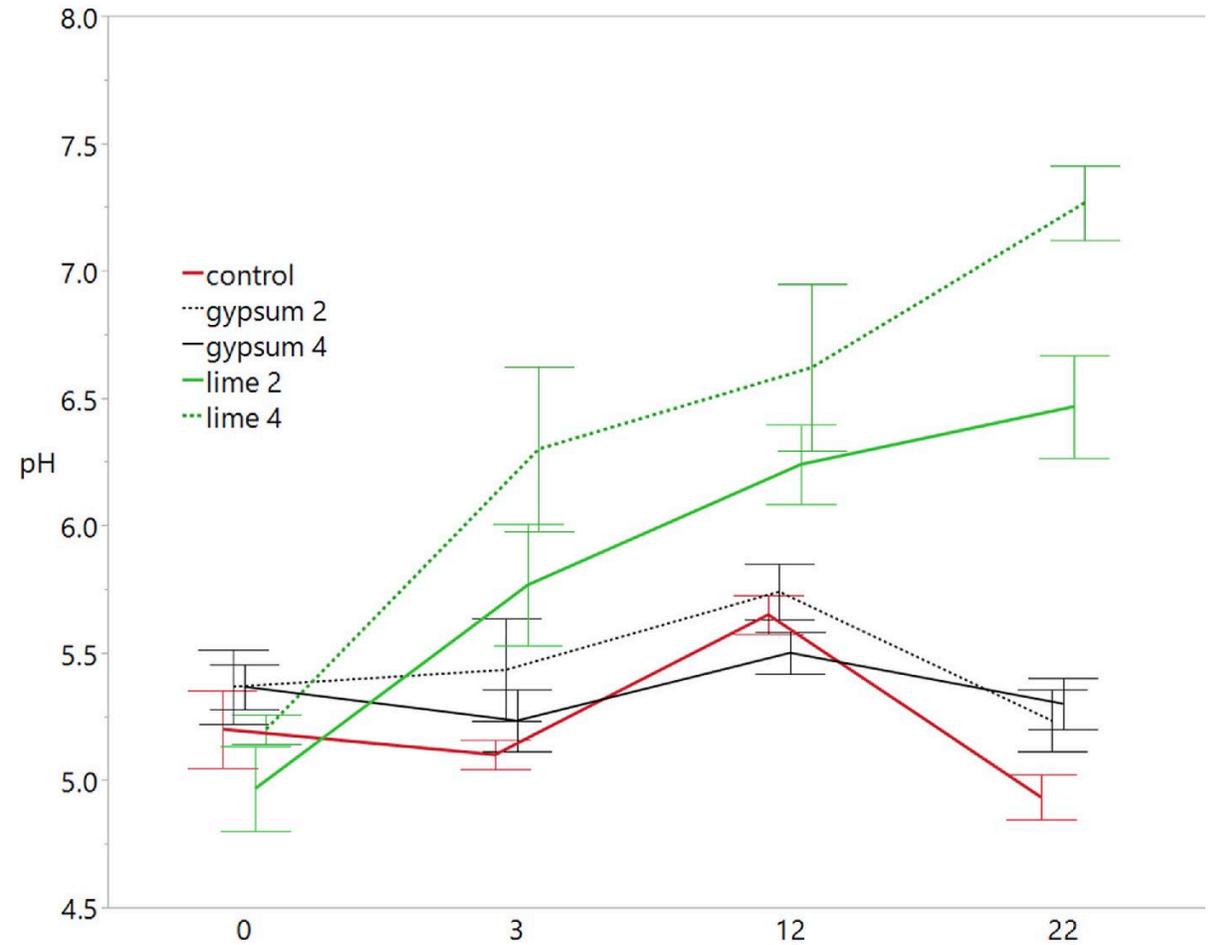


#### Treatments Farm 2

- Lime 2.8 kg planta<sup>-1</sup>
- Lime 5.6 kg planta<sup>-1</sup>
- Gypsum 2.8 kg planta<sup>-1</sup>
- Gypsum 5.6 kg planta<sup>-1</sup>
- Control



After 20 months of (last) application, soil pH is higher in limed soils by factors 1.07 to 1.4. These results were also observed in other farms with acid soil pH



Argüello et. al., 2023

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A major effect in more acid soil pH (< 5.5). What to expect?

**Farm 1 (pH 6.6)**

Months after 1st application	Control			Lime (2 Mg ha <sup>-1</sup> )		Gypsum (2 Mg ha <sup>-1</sup> )		Compost (12.5 Mg ha <sup>-1</sup> )		Compost (25 Mg ha <sup>-1</sup> )	
	Bean Cd	Bean Cd	RF	Bean Cd	RF	Bean Cd	RF	Bean Cd	RF	Bean Cd	RF
	[mg kg <sup>-1</sup> ]	[mg kg <sup>-1</sup> ]	[-]	[mg kg <sup>-1</sup> ]	[-]	[mg kg <sup>-1</sup> ]	[-]	[mg kg <sup>-1</sup> ]	[-]	[mg kg <sup>-1</sup> ]	[-]
12	0.99 ± 0.12	0.93 ± 0.17	1.1 ± 0.2	0.94 ± 0.10	1.1 ± 0.1	0.88 ± 0.03	1.1 ± 0.1	1.00 ± 0.20	1.0 ± 0.3		
22	1.45 ± 0.15	1.24 ± 0.04	1.2 ± 0.1	1.21 ± 0.18	1.2 ± 0.3	1.13 ± 0.12	1.3 ± 0.2	1.09 ± 0.48	1.5 ± 0.7		
30	0.91 ± 0.06	1.12 ± 0.13	0.8 ± 0.1	1.18 ± 0.15	0.8 ± 0.1	1.00 ± 0.28	1.0 ± 0.3	1.00 ± 0.25	1.0 ± 0.2		

**Effect<sup>s</sup> of**

<b>time</b>	n.s.								
<b>treatment</b>	-	n.s.	-	n.s.	-	n.s.	-	n.s.	-
<b>time*treatment</b>	-	n.s.	-	n.s.	-	n.s.	-	n.s.	-

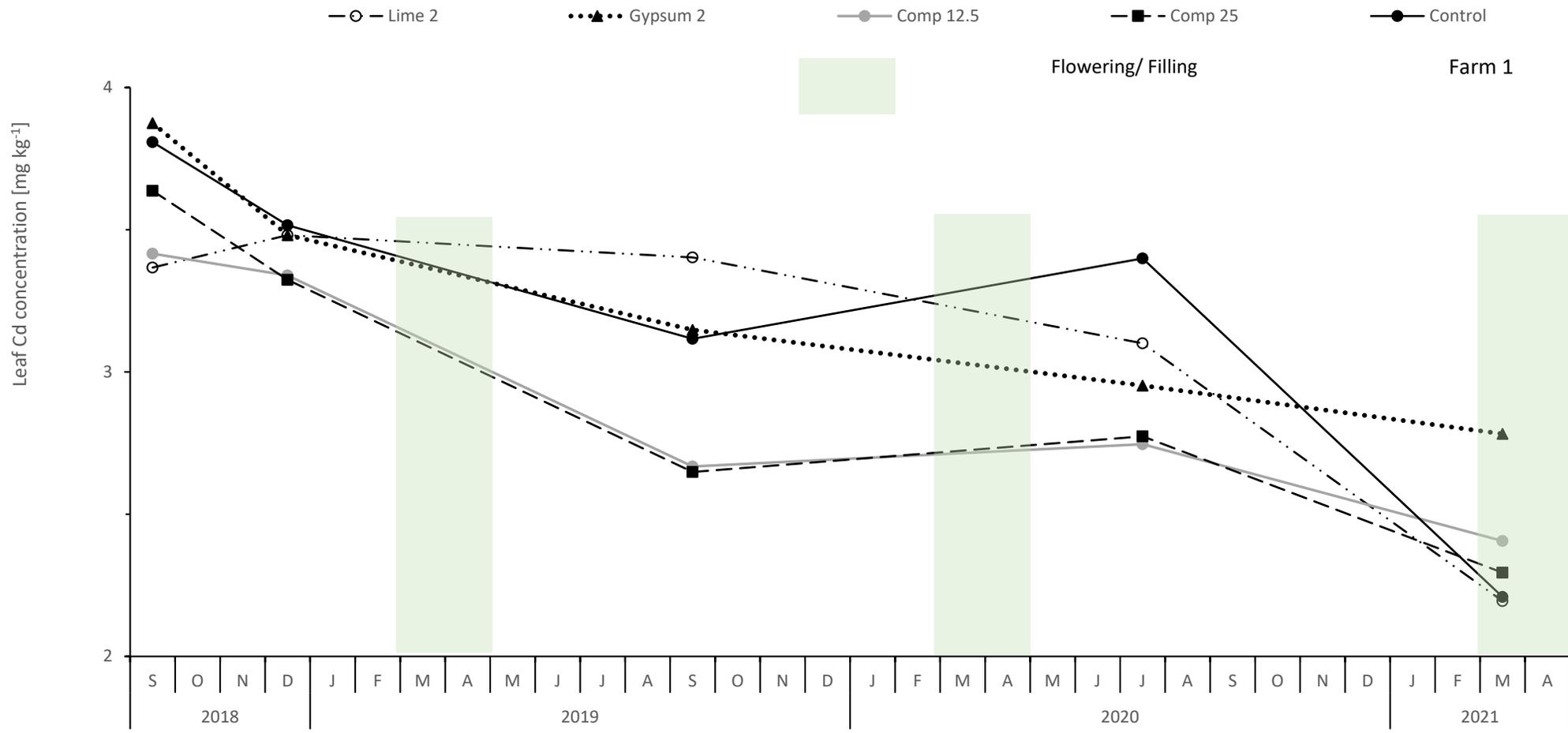
**Farm 2 (pH 5.1)**

	Control	Lime (2 Mg ha <sup>-1</sup> )		Lime (4 Mg ha <sup>-1</sup> )		Gypsum (2 Mg ha <sup>-1</sup> )		Gypsum (4 Mg ha <sup>-1</sup> )	
22	1.71 ± 0.80	1.65 ± 0.50	1.0 ± 0.3	1.54 ± 1.18	1.5 ± 1.0	1.63 ± 0.43	1.2 ± 0.7	2.87 ± 1.80	0.8 ± 0.5

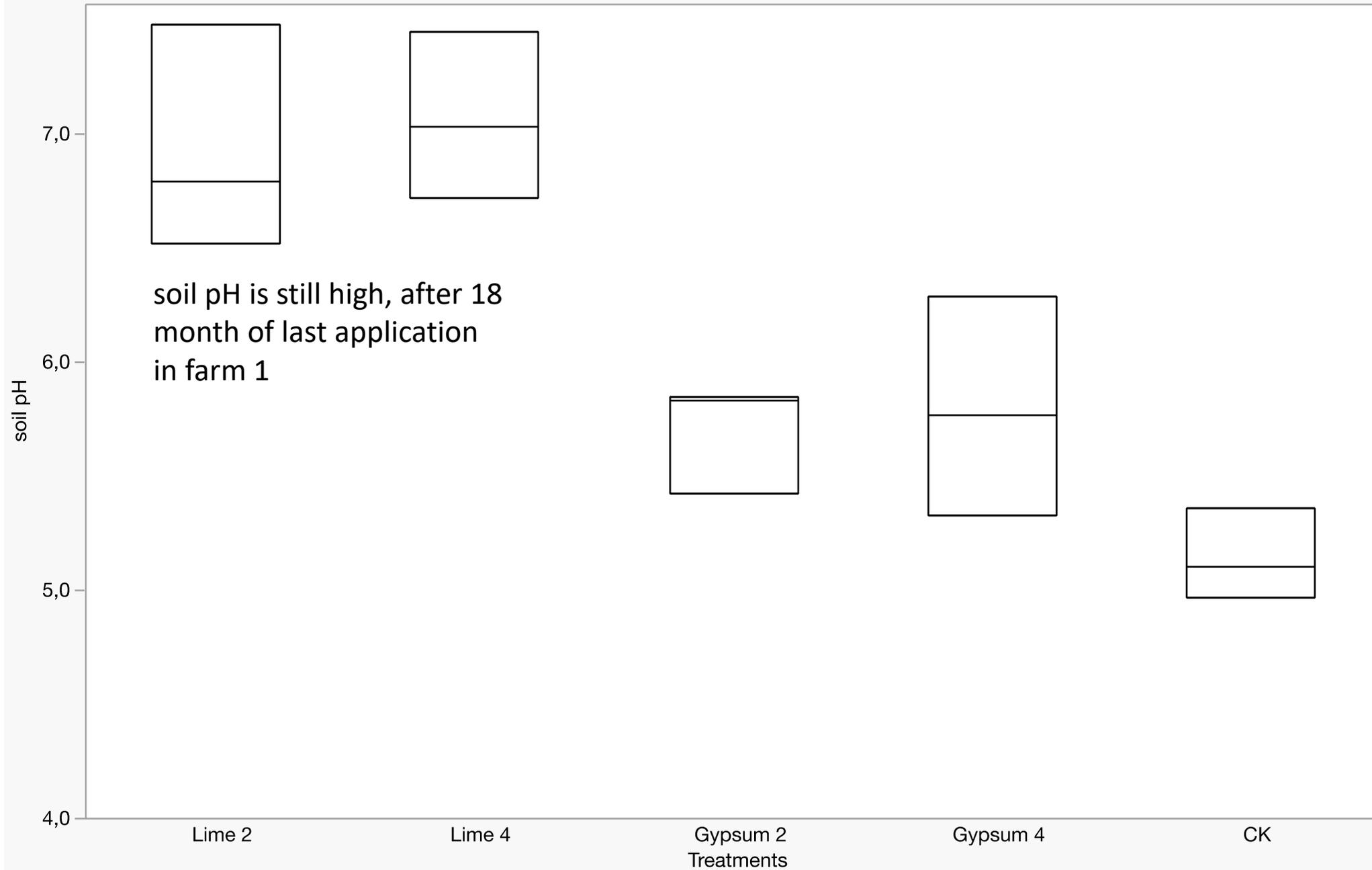
**Effect<sup>s</sup> of**

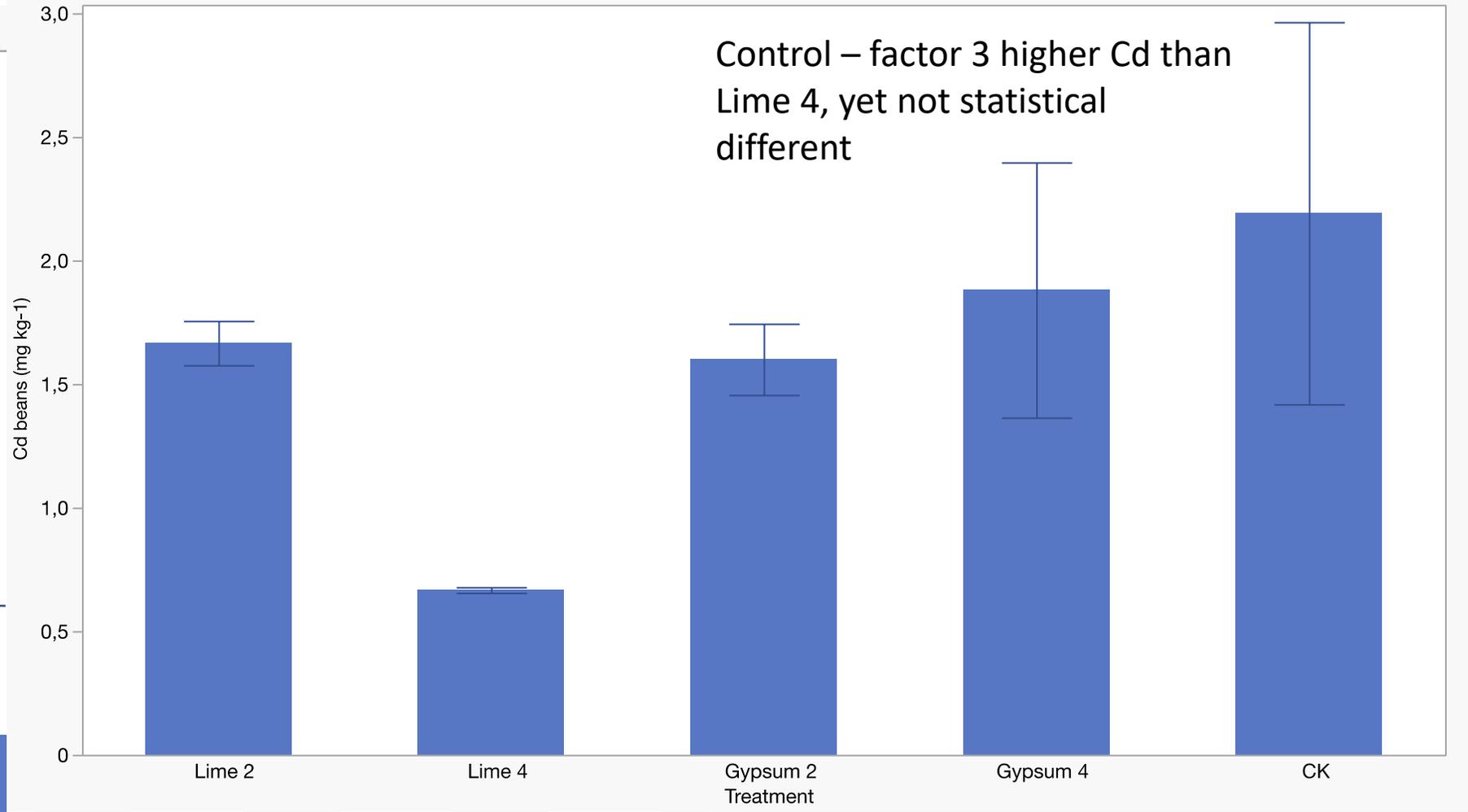
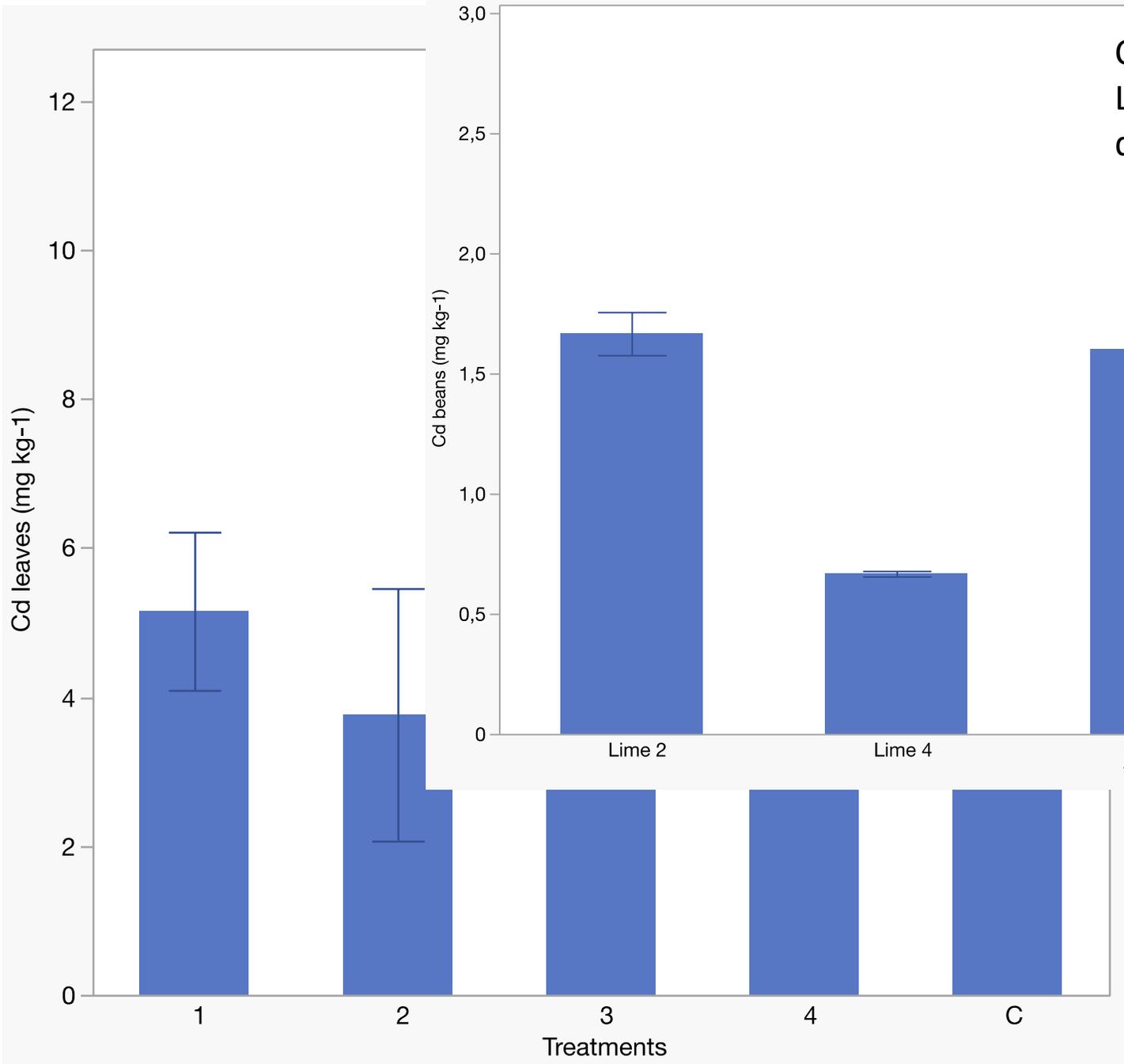
<b>treatment</b>	-	n.s.	-	n.s.	-	n.s.	-	n.s.	-
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Temporal variability of leaf-Cd in farm 1 – neutral soil pH. All treatments decreased with time, including control, why?





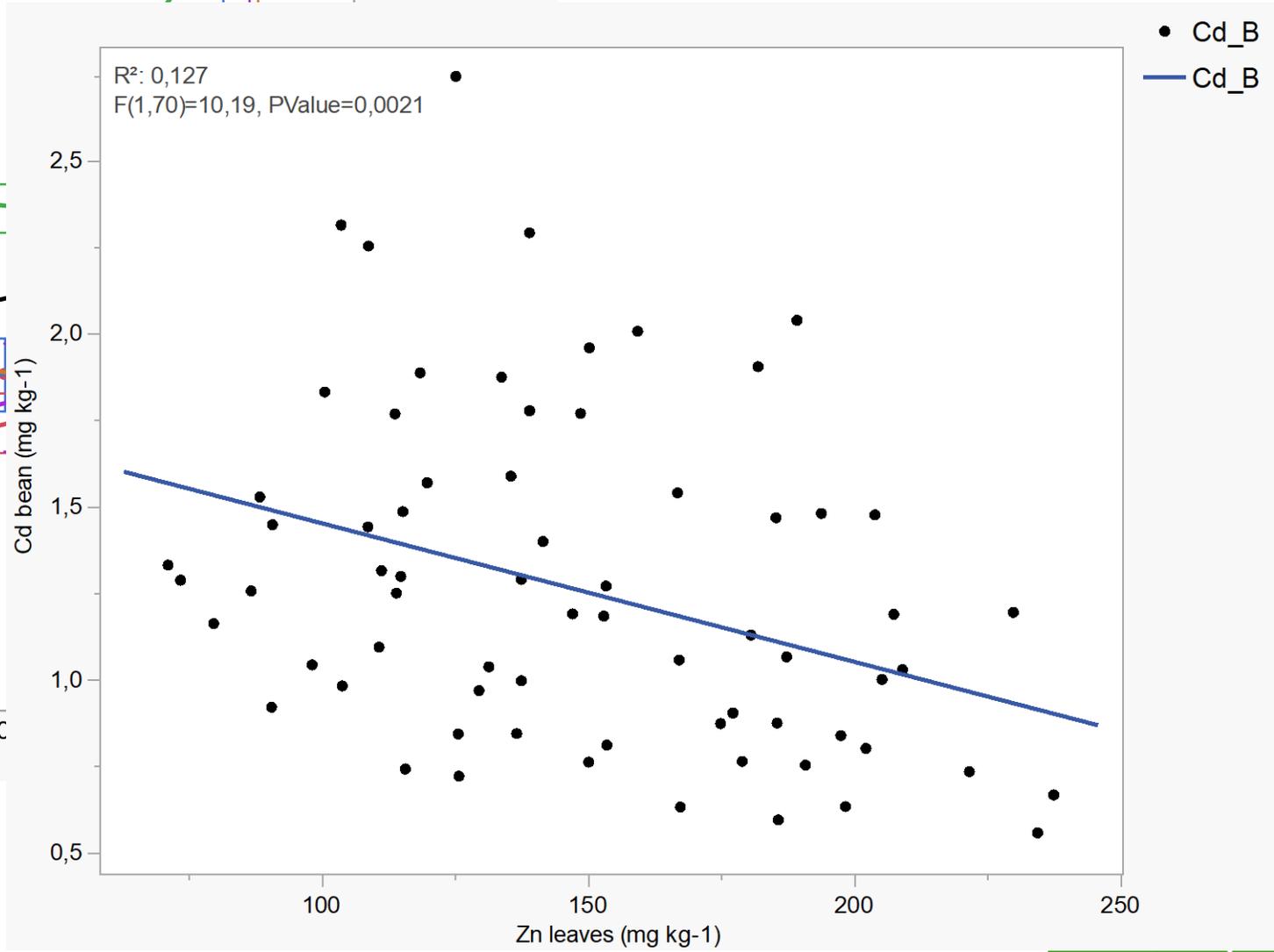
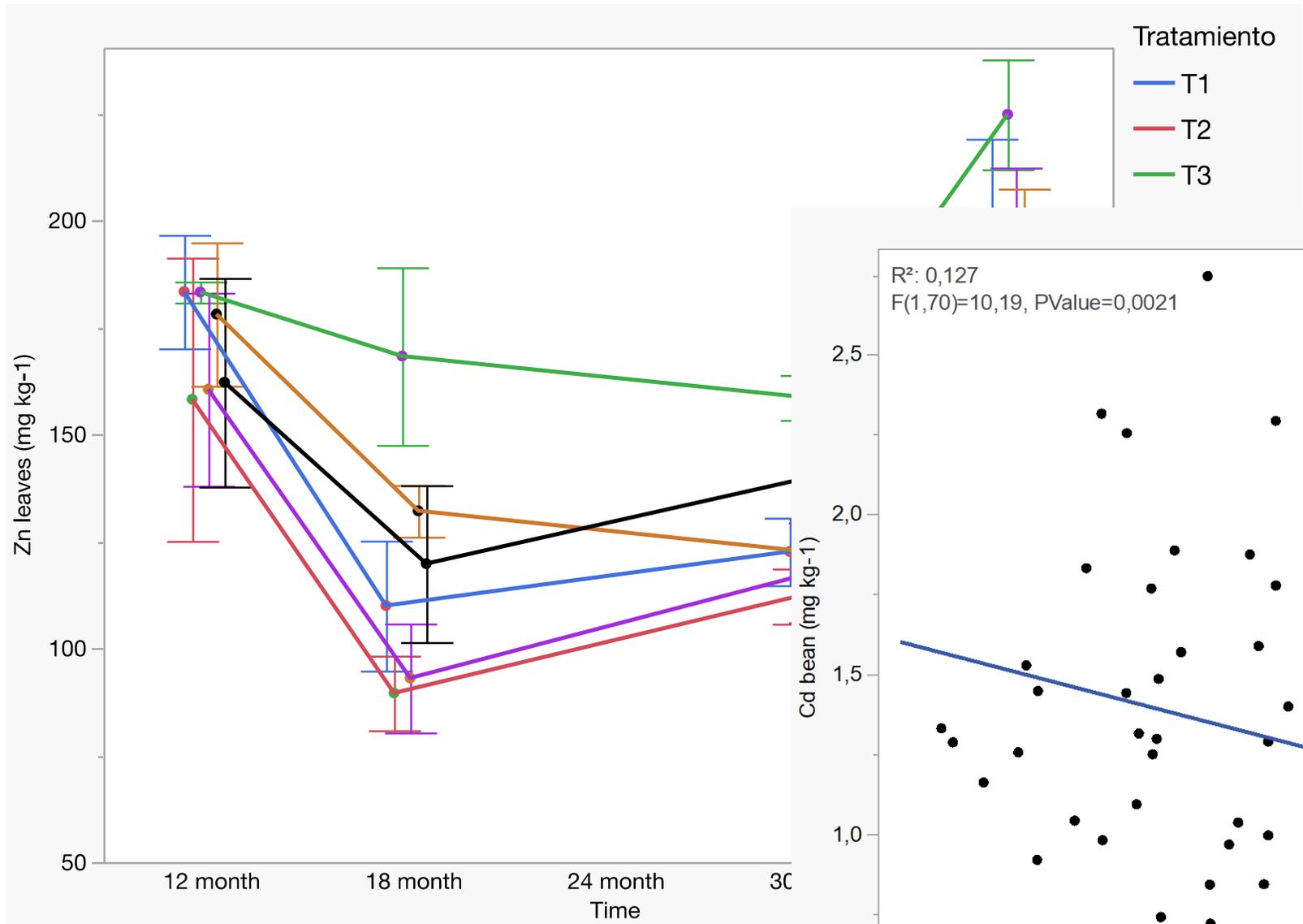
Foliar micronutrients were applied at doses (equivalent) to 6 kg ha<sup>-1</sup>.

Zn, Mn and Fe in alkaline (pH > 7) soils

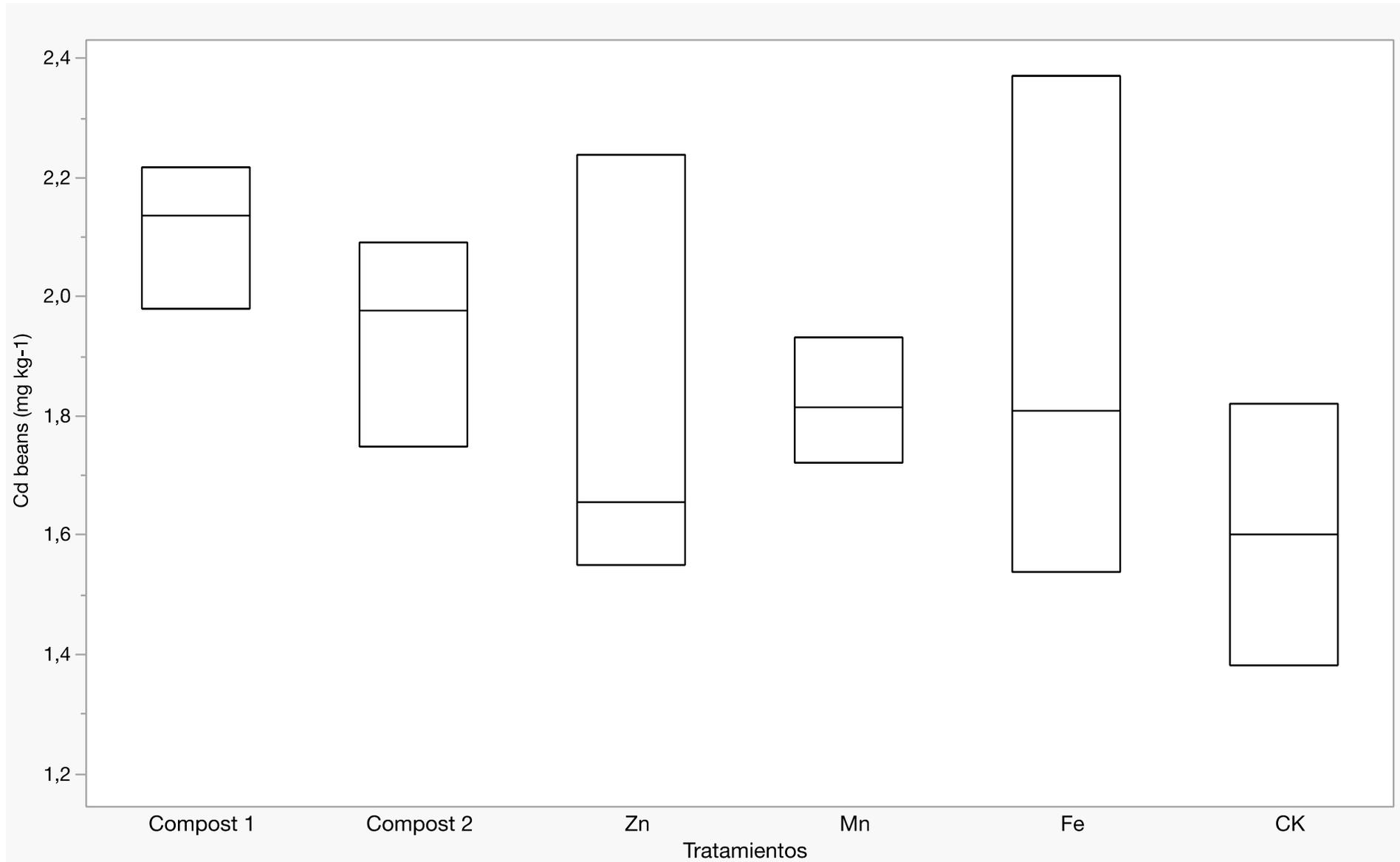
All micronutrients are applied as chelates (EDTA)

Finca	Tratamiento	pH (H <sub>2</sub> O)	Mat. Org (%)	Zn* mg kg <sup>-1</sup>	Mn* mg kg <sup>-1</sup>	Fe* mg kg <sup>-1</sup>
Farm 1	T1	6.1 ± 0.2	3.90 ± 1.27	183.4 ± .23	410 ± 110	53.7 ± 6.70
	T2	6.1 ± 0.2	4.00 ± 0.64	158.2 ± 57.4	367 ± 61.5	58.7 ± 20.3
	T3	6.2 ± 0.1	3.84 ± 0.47	183.3 ± 4.30	362 ± 59.8	60.1 ± 14.6
	T4	6.1 ± 0.1	3.15 ± 0.85	160.5 ± 39.1	400 ± 88.2	49.4 ± 13.3
	T5	6.1 ± 0.1	4.52 ± 0.83	178.2 ± 29.0	406 ± 157.5	51.3 ± 4.2
	TC	6.1 ± 0.4	4.82 ± 0.21	162 ± 42.2	386 ± 147.5	53.2 ± 7.45
Farm 2	T1	6.9 ± 0.2	2.13 ± 0.46	21.5 ± 1.20	427 ± 58.5	84.3 ± 8.11
	T2	7.2 ± 0.2	2.24 ± 0.48	23.7 ± 4.60	351 ± 75.2	113 ± 40.3
	T3	6.9 ± 0.5	2.05 ± 0.45	23.7 ± 7.60	375 ± 154	101 ± 28.8
	T4	7.2 ± 0.6	1.64 ± 0.17	22.2 ± 5.60	403 ± 156	103 ± 8.71
	T5	7.1 ± 0.6	1.89 ± 0.06	22.0 ± 6.80	376 ± 169	97.4 ± 30.5
	TC	7.2 ± 0.5	1.78 ± 0.41	19.2 ± 6.50	378 ± 176	72.2 ± 11.6
Farm 3	T1	6.1 ± 0.2	3.83 ± 0.27	95.1 ± 41.4	215 ± 8.80	93.1 ± 29.7
	T2	6.3 ± 0.3	3.89 ± 0.60	81.6 ± 48.4	273 ± 107	77.4 ± 12.7
	T3	6.2 ± 0.1	3.15 ± 0.71	124 ± 22.3	291 ± 102	66.2 ± 10.2
	T4	6.2 ± 0.1	3.20 ± 0.39	62.4 ± 4.30	168 ± 26.0	76.8 ± 15.2
	T5	6.3 ± 0.4	2.98 ± 0.41	101 ± 32.5	199 ± 45.5	57.8 ± 17.7
	TC	6.1 ± 0.1	3.60 ± 0.19	81.4 ± 16.7	180 ± 18.8	101 ± 26.5





# What happens in the beans?

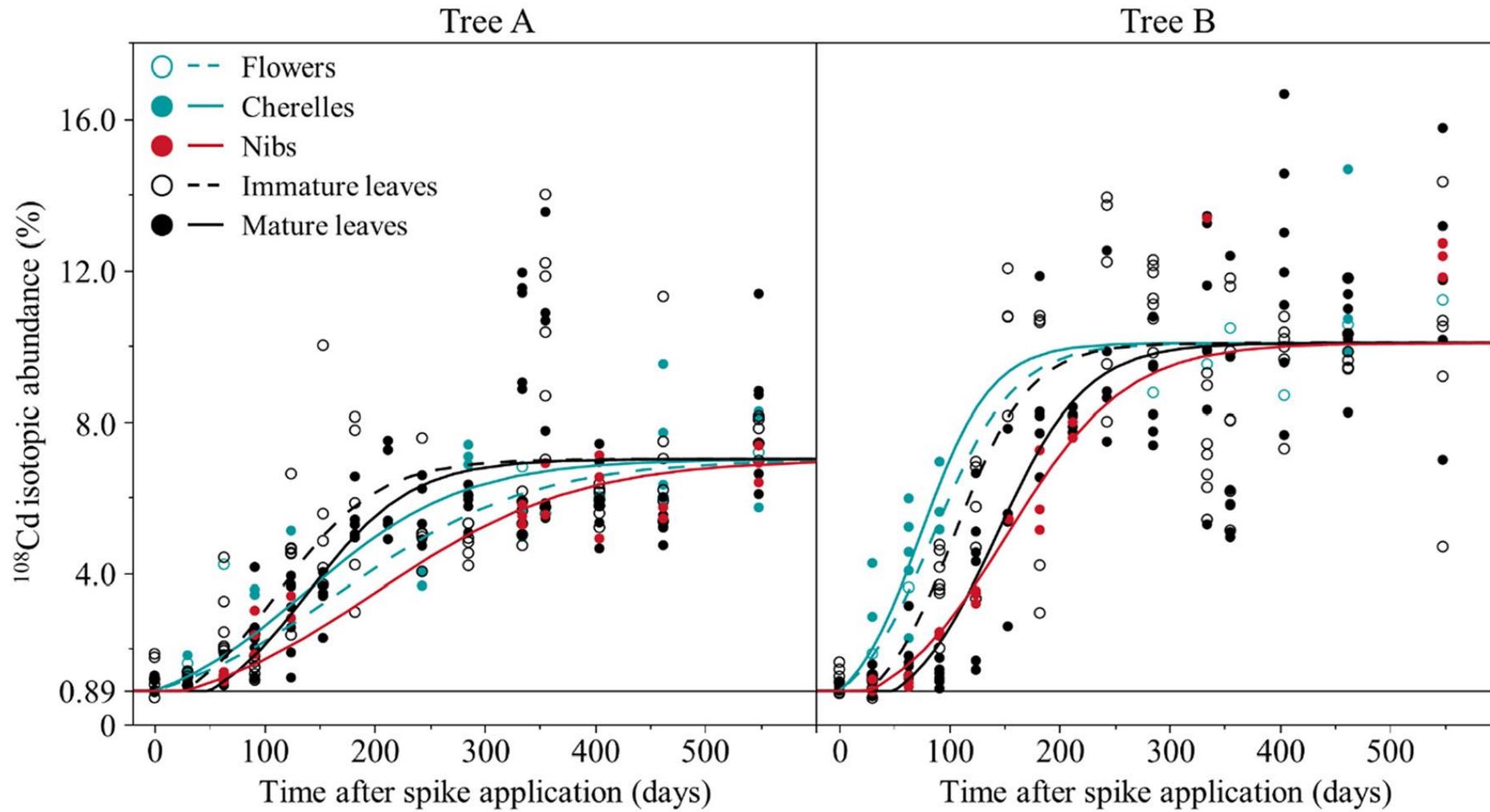


# Possible explanations?



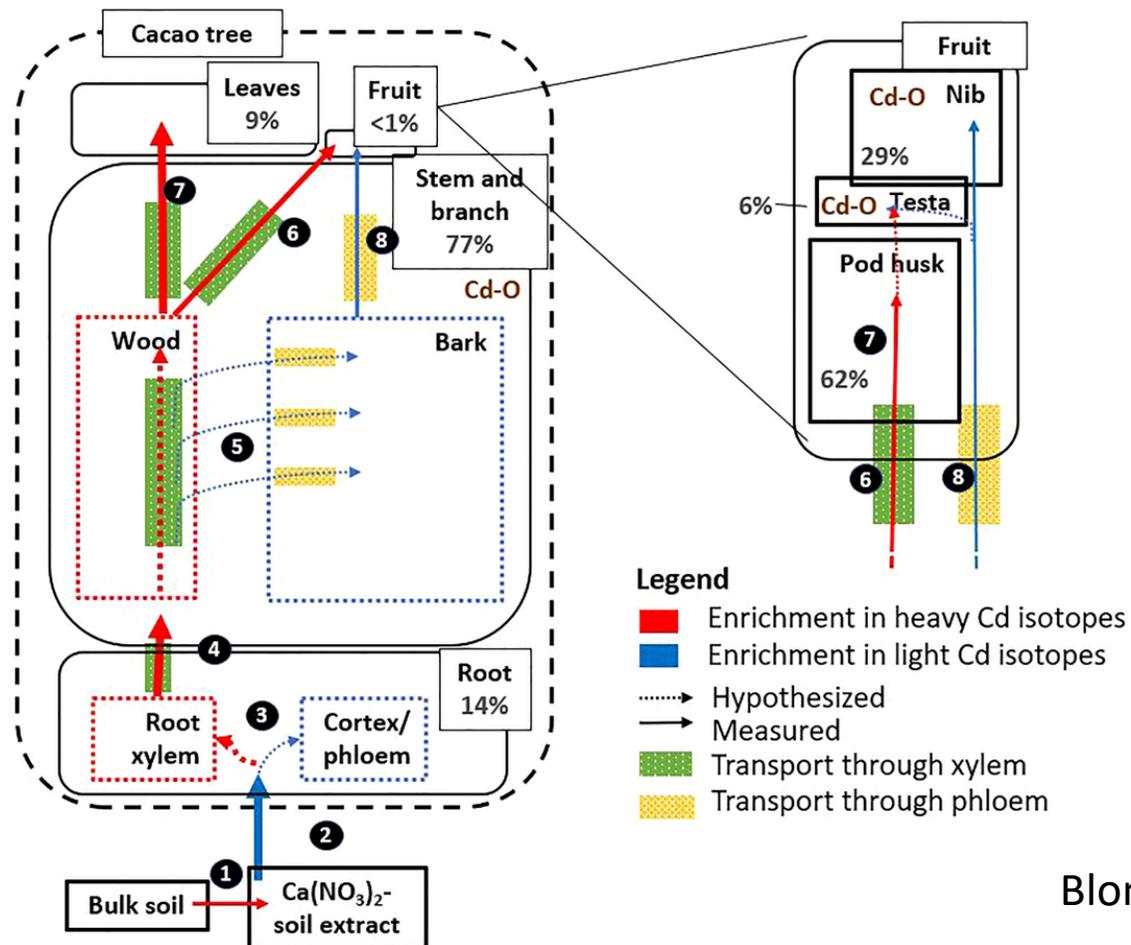
Estimated time to reach half of background corrected equilibrium IA (day)<sup>b</sup>

	Tree A		Tree B	
	Estimate	95 % CL	Estimate	95 % CL
Immature leaves	124	104–145	111	98–124
Mature leaves	152	131–173	<b>151<sup>a</sup></b>	137–164
Flowers	191	67–316	93	– 25–210
Cherelles	156	91–222	80	61–99
Nibs	<b>225<sup>a</sup></b>	152–299	<b>163<sup>a</sup></b>	135–190



**Fig. 1.** Increase of the isotopic abundance of  $^{108}\text{Cd}$  in the different plant tissues after spike application (symbols) and logistic model fits for the different tissues. The parameter estimates can be found in Table 2. The natural abundance of  $^{108}\text{C}$  is 0.89 % and indicated by the horizontal line.

# Remobilization from trunk and branches



Blommaert et al., 2022

# Conclusiones finales

1. Se pueden modificar las propiedades de suelo, de tal forma que (teóricamente) exista menos Cd “fitodisponible”.
2. El incremento de pH es el cambio más significativo que afecta la acumulación de Cd en almendras. La materia orgánica o el yeso no generan ningún cambio en la planta.
3. Esta medida es aplicable SOLO en suelos con  $\text{pH} < 5.5$ , ¿qué hacemos en otras condiciones?
4. La aplicación de micronutrientes, particularmente Zn, tiene un efecto pero es intermitente. Es necesario pruebas de invernadero y estudiar rutas de absorción a nivel de raíces.
5. Cadmio en hojas y granos no solo proviene del suelo, evidencia muestra remobilización de troncos y ramas.