Understanding Cadmium Accumulation in Cacao and its Implications for Developing Tools for Mitigation of Cadmium in Cocoa Beans

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Objectives

- Identify the main junctures within the cacao plant that influence differential Cd transport between cacao genotypes.
- Develop an understanding of how the partitioning of biomass and Cd affects Cd concentration within the leaves and beans.
- Synthesise this information to develop tools for Cd mitigation in the short-, medium-, and long-term.

Experiment 1

Drip Irrigation study on Cd accumulation in cacao

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Factor	Macronutrient	Micronutrient	Cd (µM)
High	Sufficient	Sufficient	20
Low	Sufficient	Sufficient	0.2

Shade at 12 noon = 90%
EC of nutrient solution = 2500 µS
pH of nutrient solution = 6.5
Application rate = 34 ± 0.2 mL per minute

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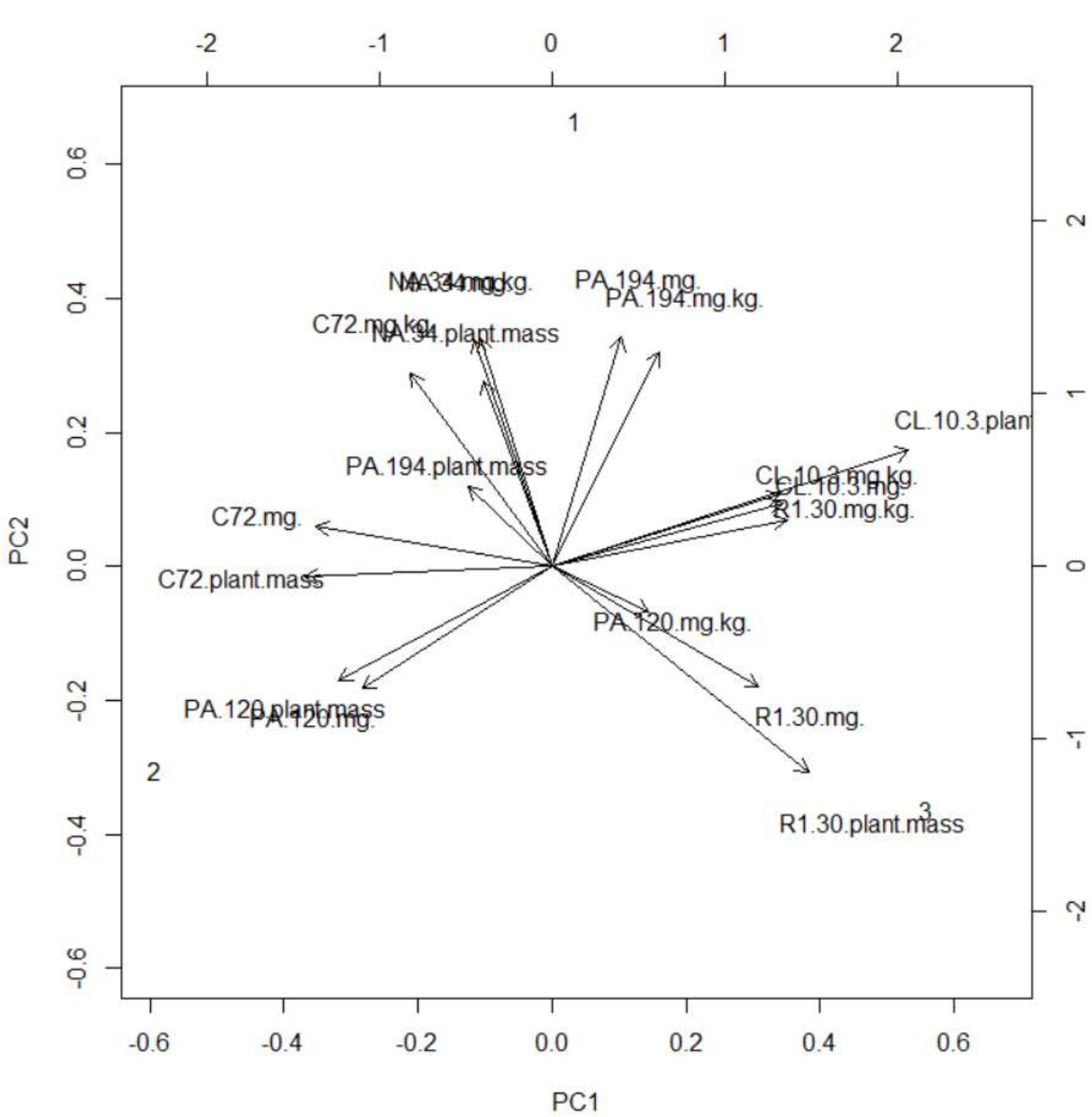
High Cd Accumulators	Low Cd Accumulators
CRU 72	CL 10/3
NA 34	PA 120
PA 194	Redamel 1/30

- Organ mass – leaf, stem, root
- Cd partitioning – leaf, stem, root
- Cd content and concentration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C72.mg.kg.
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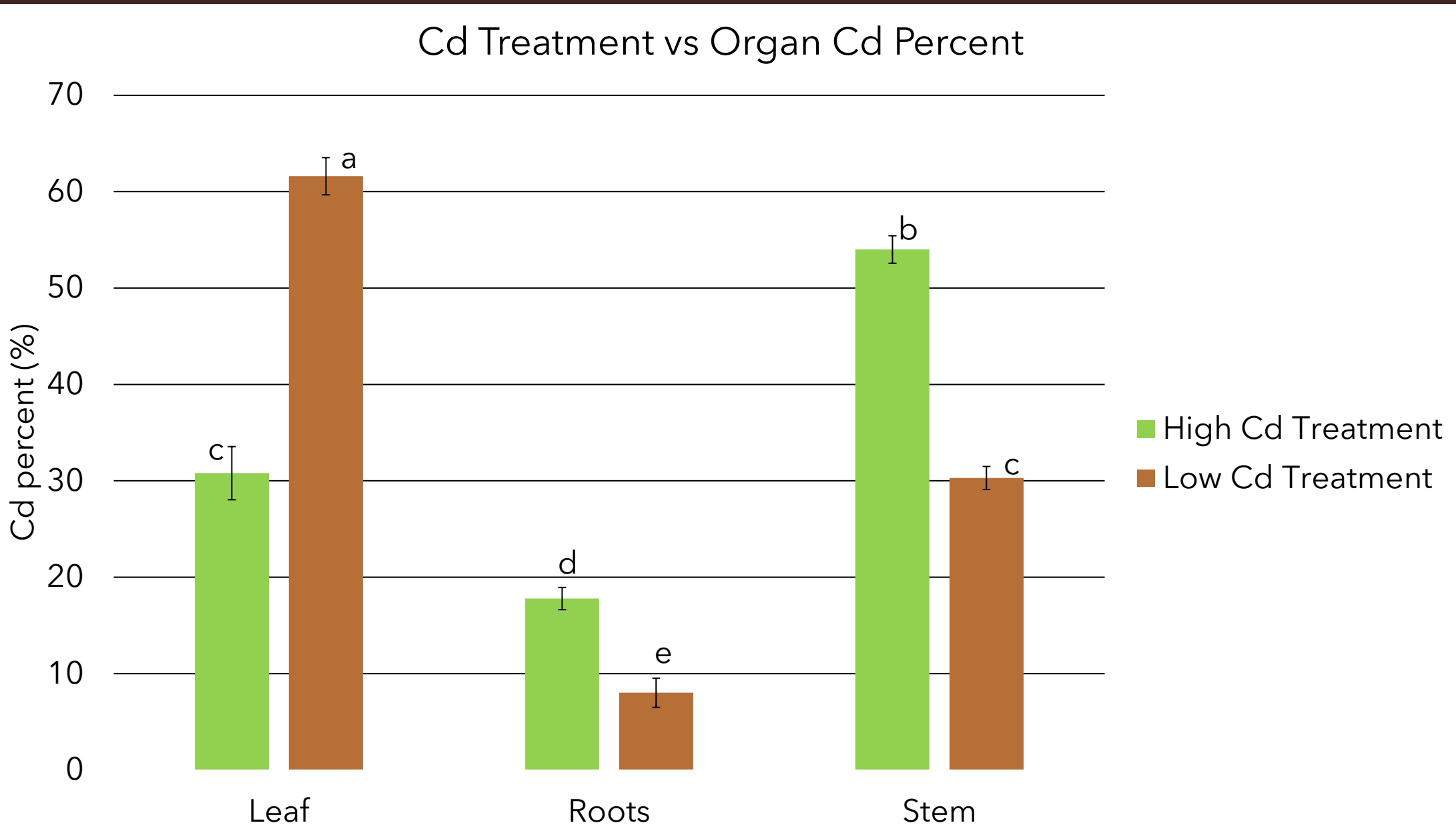
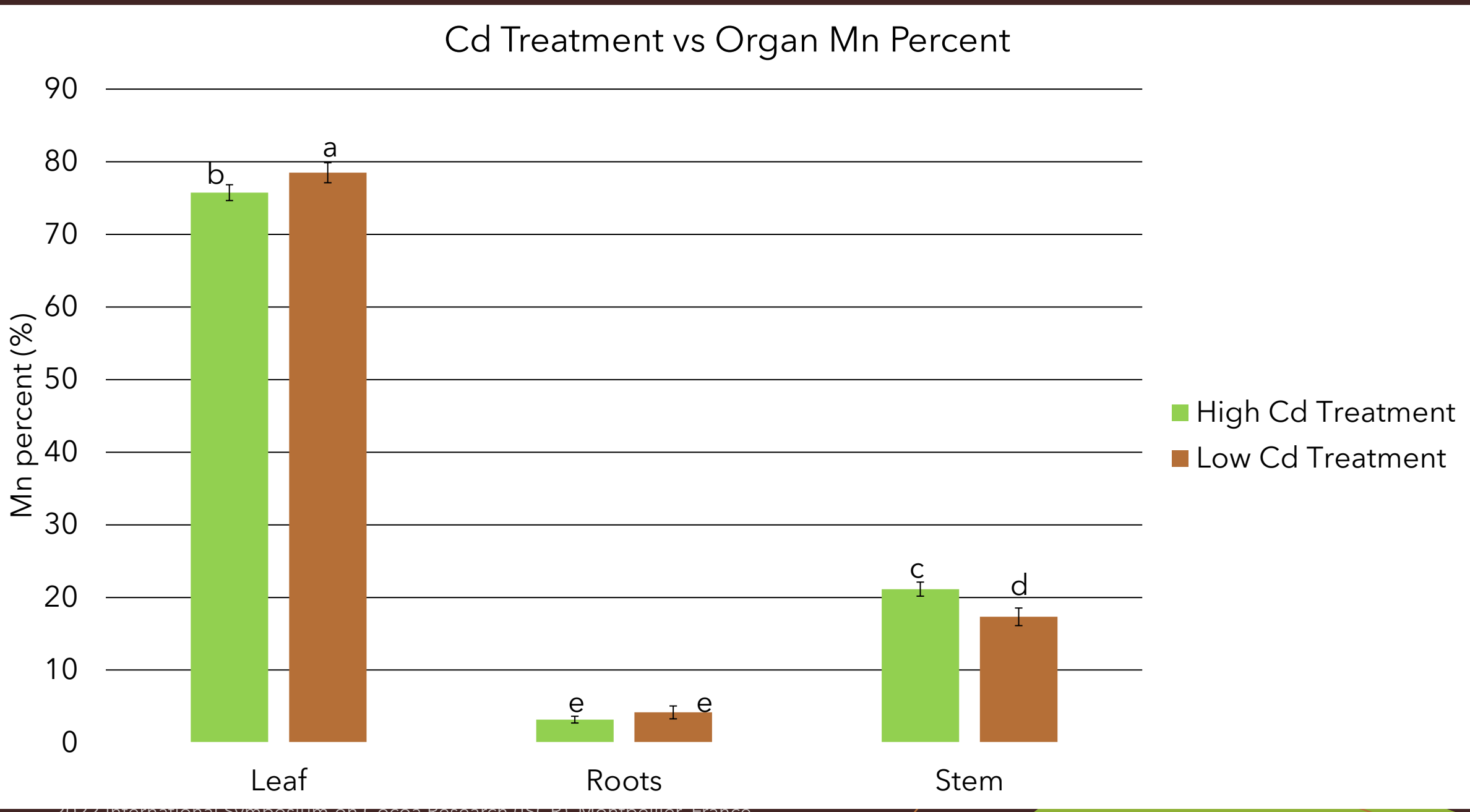
CL.10.3.plan
PA.194.plant.mass
CL.10.3.mg.kg.
CL.10.3.mg.
R1.30.mg.kg.
C72.mg.
C72.plant.mass
PA.120.mg.kg.
PA.120.plant.mass
PA.120.mg.
R1.30.mg.
R1.30.plant.mass
PC1
PC2


Cd Treatment vs Organ Cd Percent
70
60
50
40
30
20
10
0
Cd percent (%)
a
b
c
c
d
e
Leaf
Roots
Stem
High Cd Treatment
Low Cd Treatment

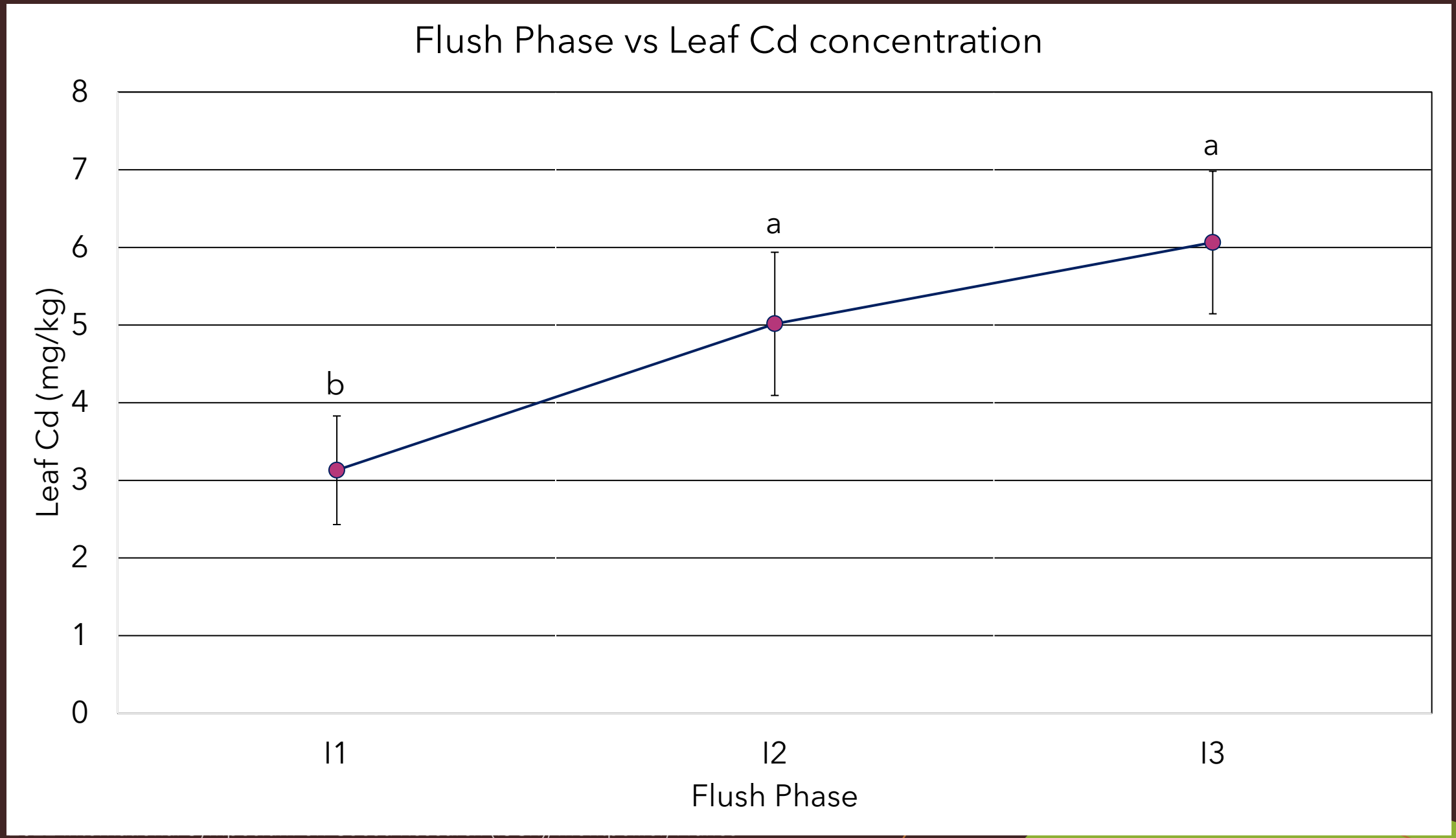

Cd Treatment vs Organ Mn Percent
Mn percent (%)
90
80
70
60
50
40
30
20
10
0
b
a
e
e
c
d
Leaf
Roots
Stem
High Cd Treatment
Low Cd Treatment

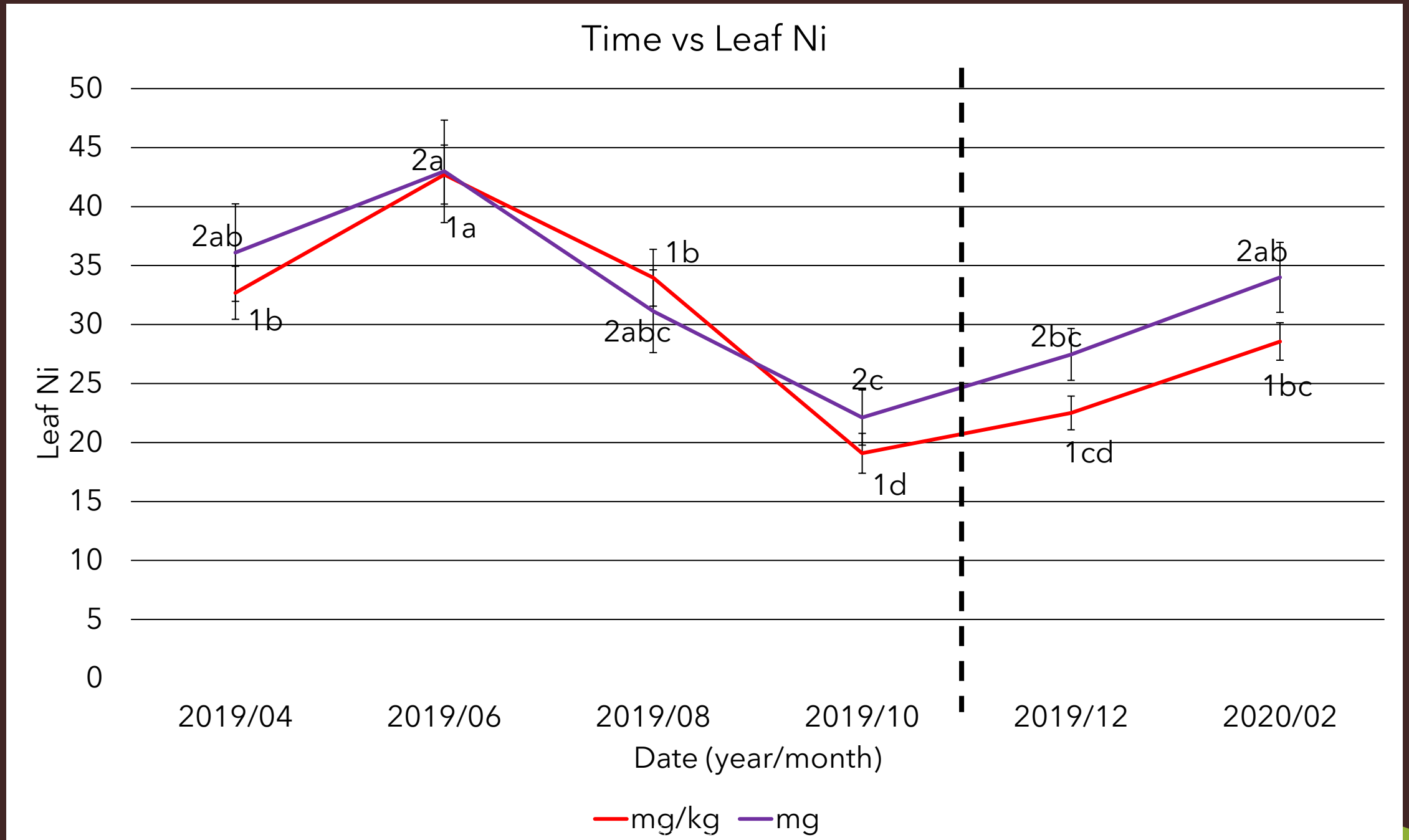
Experiment 2

Cd Accumulation through Plant Growth

Accessions
CRU 72
ELP 1/S-4
GU 335/P
PA 293
TRD 94

- Differences in leaf metal concentration and content between flush phases
- Differences in leaf interflush 2 metal concentration and content between dates over the period of a year


Flush Phase vs Leaf Cd concentration
Leaf Cd (mg/kg)
0
1
2
3
4
5
6
7
8
b
a
a
I1
I2
I3
Flush Phase


Time vs Leaf Ni
50
45
40
35
30
25
20
15
10
5
0
Leaf Ni
2ab
1b
2a
1a
1b
2abc
2c
1d
2bc
1cd
2ab
1bc
2019/04
2019/06
2019/08
2019/10
2019/12
2020/02
Date (year/month)
mg/kg
mg

Experiment 3

Effect of biomass and Cd partitioning on cotyledon Cd concentration

Morphological Traits

- Single pod mass
- Mass of beans per pod
- Single bean Mass
- Beans per pod/ single pod husk mass ratio
- Cotyledon/testa mass ratio

Elemental Traits

- Cd content per pod
- Bean Cd percent
- Cotyledon Cd percent
- Cotyledon Cd concentration

Results

Cotyledon Cd (mg/kg) ~ Pod Cd content – total bean mass + bean Cd % ⟶ $R^2 = 0.87$

Conclusions

- High and low Cd accumulators from field studies were grouped under controlled conditions but a significant biomass effect on Cd accumulation was observed.
- Leaves and stems were the main loading hubs for Cd in cacao.
- Under low Cd conditions, Cd was preferentially stored in the leaves, while it was preferentially stored in the stems under high Cd conditions.
- Increased Cd treatment conditions reduced leaf Mn accumulation and increased stem Mn accumulation – Zn accumulation in roots was also affected.
- Large variation in leaf Cd accumulation between I1, I2, and I3.
- No significant variation in leaf Cd accumulation over time.
- Significant variation in leaf Ni accumulation over time – likely as a result of pod development.
- Partitioning of Cd between the pod husk and beans, bean biomass, and pod Cd content explained most of the variation in cotyledon Cd concentration between genotypes.

Short-term

- Remove pruned stems from farm
- Apply ameliorants 3 months before pod maturity
- Clearly identify leaf developmental stage for analysis
- Use both Cd concentration and Cd content during field diagnosis

Medium-term

- Propagate farms with low Cd accumulating commercial varieties
- Assess the root-stock effect for grafting commercial varieties on low Cd rootstocks

Long-term

- Breed new commercial varieties for low Cd uptake, large total bean biomass, and low partitioning of Cd from pod husk to beans.