Testing novel combinations of amendments for stabilization of metals in heavily contaminated soils

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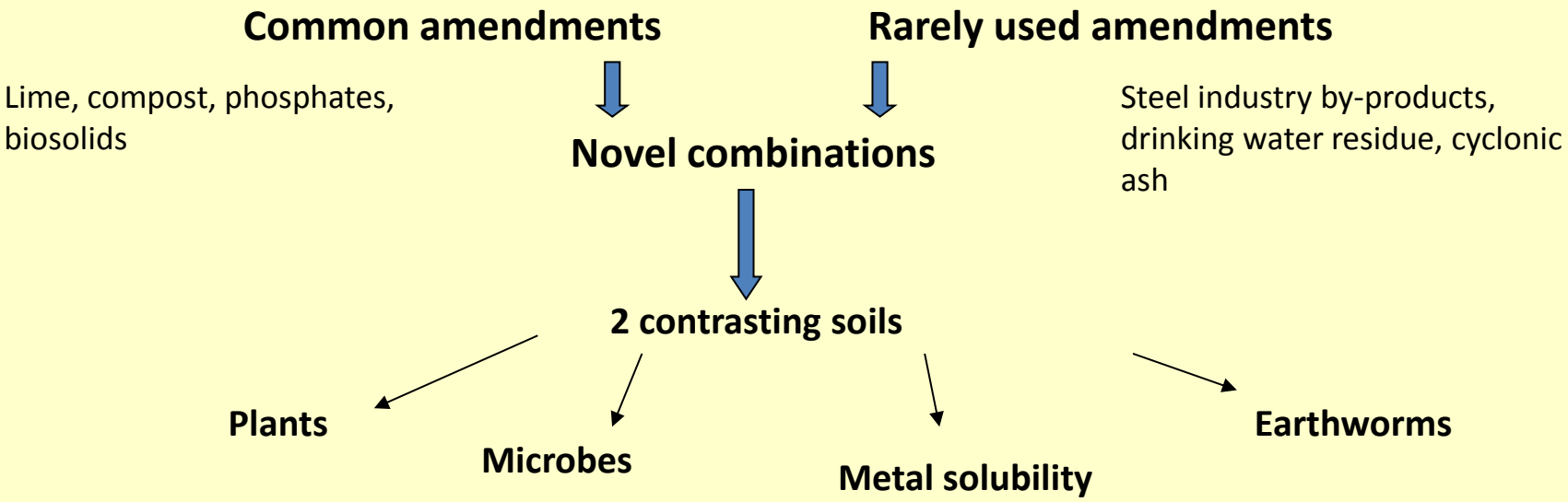
Cabernet 2014

1. Combining amendments



2. Involving bacterial inoculation

SOILS

- **soil A, less toxic agricultural soil contaminated through long-term Zn/Pb smelter emissions in Poland (pH 6.9, total Zn, Pb and Cd: 2670, 690 and 30 mg kg^{-1}, respectively); PHYTOEXCLUSION**

- **soil B, toxic soil contaminated 20 years ago through smelter dust spill in Poland (pH 6.9, total Zn, Pb and Cd: 4070, 1770 and 27 mg kg^{-1}, respectively, large pool of soluble Zn and Cd); PHYTOSTABILISATION**

Parameter		Soil A	Soil B
pH		6.9	6.9
Clay (%)		3	2
Soil texture		silt loam	sandy loam
Organic C (%)		0.56	0.56
Total metals (mg kg^{-1})	Zn	2670	4070
	Cd	30	27
	Pb	690	1770
1M NH_4-nitrate extractable metals (mg kg^{-1})	Zn	8.6	485
	Cd	0.4	5.4
	Pb	0.2	13.5

AMENDMENTS

CaCO3 – reagent grade

Drinking water residue
pH 7.8, OM 3%, Fe 1.8%, Mn 7.2%, Al 0.63%, Ca 1.6%,

Ca-phosphate – reagent grade CaHPO4

GWDA compost – municipal green waste and sludge as feedstock
pH 6.1, OM 27%, Fe 1.9%, Mn 0,03%, Al 1.3%, Ca 2.6%,

Thomas basic slag (TBS)- steel manufacture by-product
pH 11.9, high Fe, Mn, Al, Ca, rich in P

Linz-Donawitz slag (LD) – steel industry by-product
pH 13.2, Fe 22.9%, Mn 3%, Al 1.5%, Ca 7.4%,

Gravel sludge (GS)
pH 8.1, Fe 5.2%, Mn 0.1%, Al 2.4%, Ca 4.2%,

Siderite (SID) – iron carbonate
pH 8.2, Fe 26%, Mn 1.2%, Al 0.29%, Ca 7.4%,

Cyclonic ashes (CA) are a modified aluminosilicate, originating from the fluidized bed burning of coal refuse. The CA used in this experiment originate from a Spanish coal burning plant.
pH 13.1, Fe 4.7%, Mn 0.03%, Al 8%, Ca 30%,

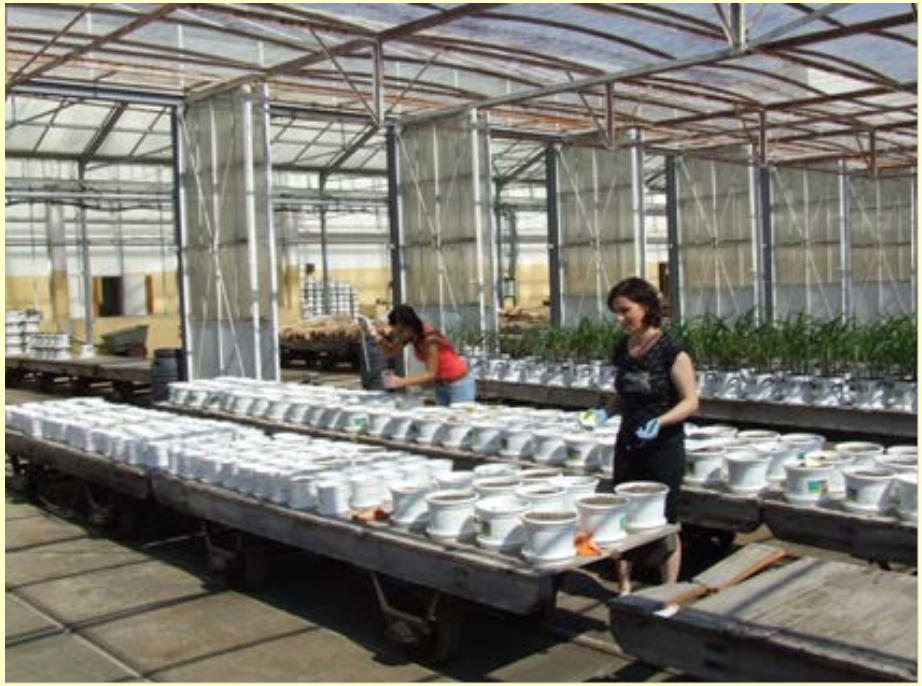
Iron grit (IG) - Steel shots are an industrial material intended for shaping metal surfaces prior to coating. They consist mainly of iron (Fe^0) and contain native impurities such as Mn, Ni or Cr
pH 8.5, Fe, Mn, Al, Ca,

Amendment characteristics

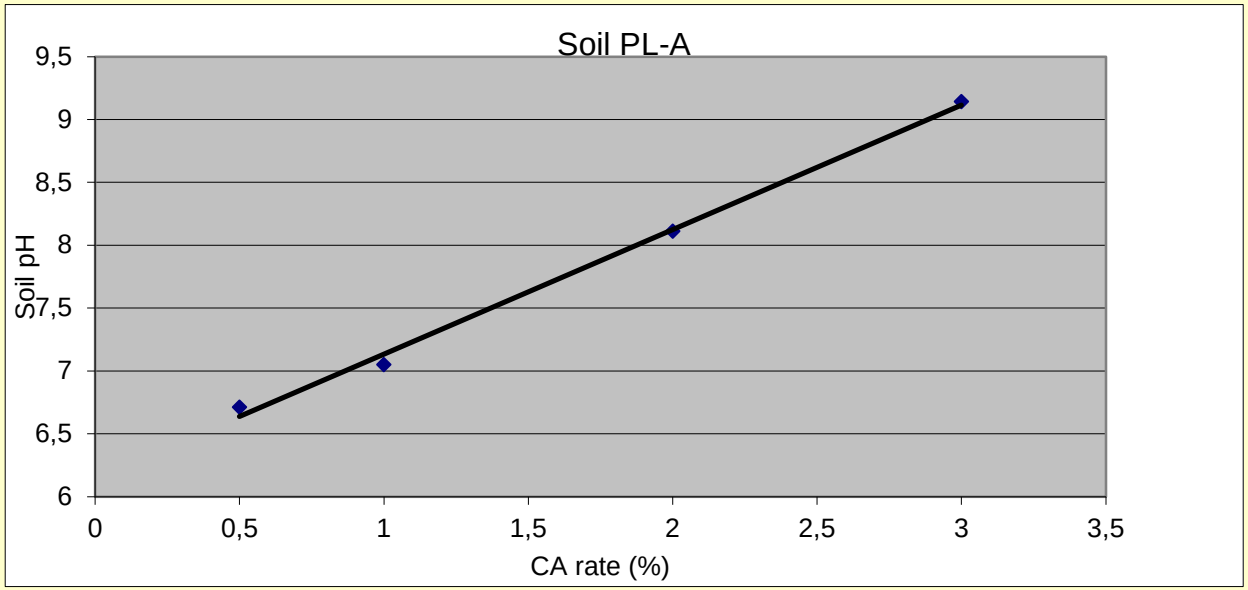
Amendment	pH	EC (mS/m)	OM (%)	Fe (%)	Mn (%)	Al (%)	Ca (%)
DWR	7.8	28	2.7	1.80	7.20	0.64	1.58
Compost GWDA	6.1	457	26.7	1.89	0.03	1.29	2.57
TBS	11.9	761	-	1.3	1.6	10	23.5
LD slag	13.2	598	-	22.9	3.01	1.49	30.7
Gravel sludge	8.1	14	1.4	5.25	0.11	2.40	4.19
Siderite	8.2	13	-	26.0	1.23	0.29	7.39
Cyclonic ash	13.1	968	-	4.73	0.03	7.97	7.40
Iron grit	8.5	4	-	97.3	0.77	0.06-0.1	-

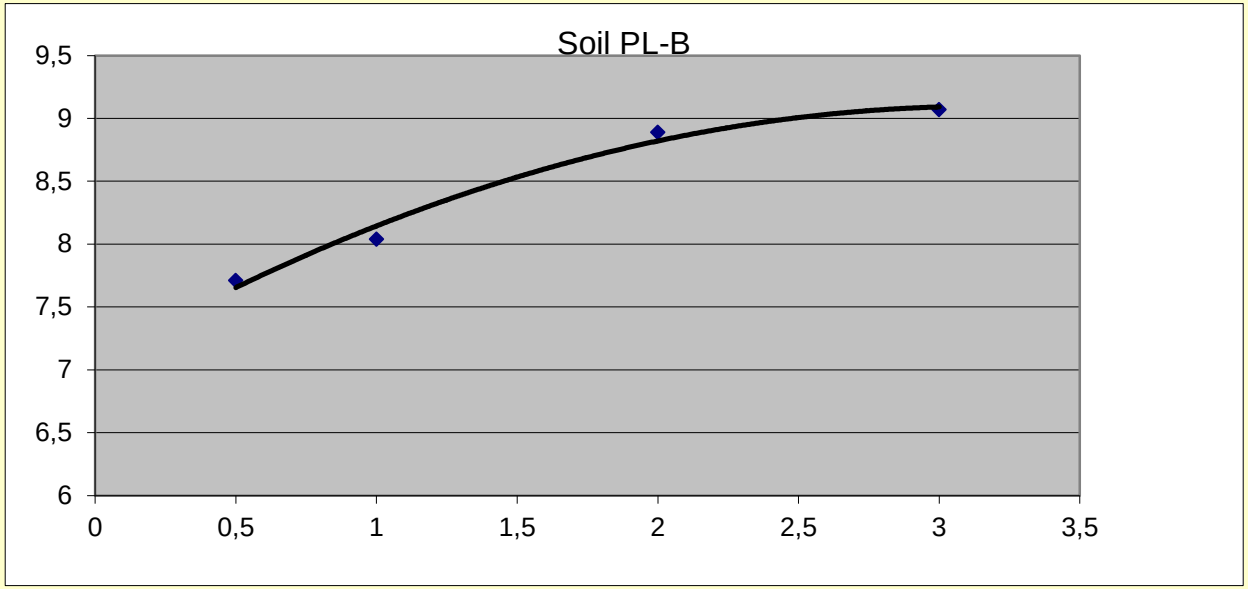
RATES

Untreated control
Drinking water residue (DWR) 5 %
Iron grit 0.5%+0.5%
Compost GWDA 5%
P as Ca-phosphate 2%
LD slag 0.5%
TBS 0.5%
Gravel sludge 2.5% + siderite 1%
DWR 5%+ GWDA 5%
Iron grit 0.5% 0.5%+ GWDA 5%
Iron grit 0.5% 0.5%+ LD slag
Iron grit 0.5% 0.5%+ LD slag + GWDA5%
TBS 0.5%+ GWDA 5%
GWDA 5%+ P as Ca-phosphate 2%+ DWR 5%
P as Ca-phosphate 2% + DWR 5%
Gravel sludge 2.5% + siderite 1%+ GWDA 5%
Cyclonic ash 1 or 1.5%
Iron grit 0.5% + 0.5%+ cyclonic ash 1 or 1.5%+ GWDA 5%
$CaCO_3$ 5%
Cyclonic ash 1.5% or 1%



pH batch test – Cyclonic ash





Application scheme

Control				
DWR 5%	**DWR**	**CaCO3**		
Iron grit 0,5%+0,5%	**1/2 Iron grit**	**1/2 Iron grit**	**CaCO3**	
GWDA 5%	**GWDA**	**CaCO3**		
CaHPO4 2%	**CaHPO4**	**CaCO3**		
LD slag	**LD slag**			
TBS 0,5%	**TBS**			
Gravel sludge 2,5% + siderite 1%	**Gravel sludge**	**Siderite**	**CaCO3**	
DWR 5%+ GWDA 5%	**DWR**	**GWDA**	**CaCO3**	
Iron grit 0,5% 0,5%+ GWDA 5%	**1/2 Iron grit**	**1/2 Iron grit**	**GWDA**	**CaCO3**
Iron grit 0,5% 0,5%+ LD slag	**1/2 Iron grit**	**1/2 Iron grit**	**LD slag**	
Iron grit 0,5% 0,5%+ LD slag + GWDA5%	**1/2 Iron grit**	**1/2 Iron grit**	**GWDA**	**LD slag**
TBS 0,5%+ GWDA 5%	**GWDA**	**TBS**		
GWDA 5%+ CaHPO4 2%+ DWR 5%	**CaHPO4**	**DWR**	**GWDA**	**CaCO3**
CaHPO4 2% + DWR 5%	**CaHPO4**	**DWR**	**CaCO3**	
Gravel sludge 2,5% + siderite 1%+ GWDA 5%	**Gravel sludge**	**Siderite**	**GWDA**	**CaCO3**
Iron grit 0,5% 0,5%+ cyclonic ash + GWDA 5%	**1/2 Iron grit**	**1/2 Iron grit**	**GWDA**	**Cyclonic ash**
CaCO3 5%	**CaCO3**			
Cyclonic ash 1,5% or 1%	**Cyclonic ash**			

METHODOLOGY DESCRIPTION

Reagent grade $CaCO_3$ was added to soils if needed in order to establish soil pH at comparable level in all treatments.

The more toxic soils (B and C) were planted with **grasses** (tall fescue) whereas soil A was seeded with **lettuce**.

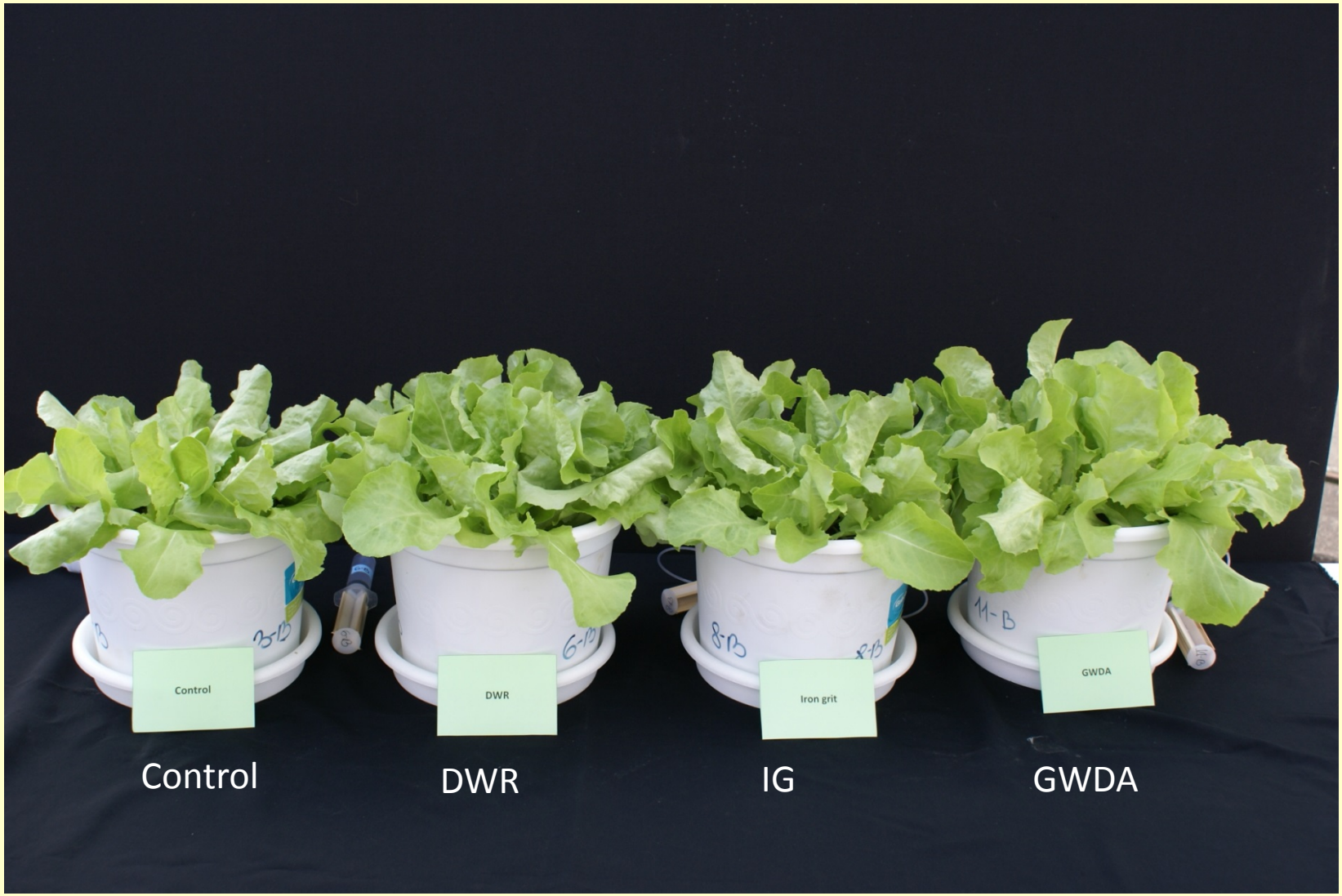
The experiment was run for 1-year, and plants were periodically harvested, the **yields** recorded and samples analyzed for metal content.

Soil samples were collected for analysis of **metal extractability, soil pH, electric conductivity and enzymatic activity**.

Soil **pore waters** were collected periodically to determine trace element and nutrient concentrations

Planted and unplanted

PHYTOEXCLUSION – soil A, 1st lettuce



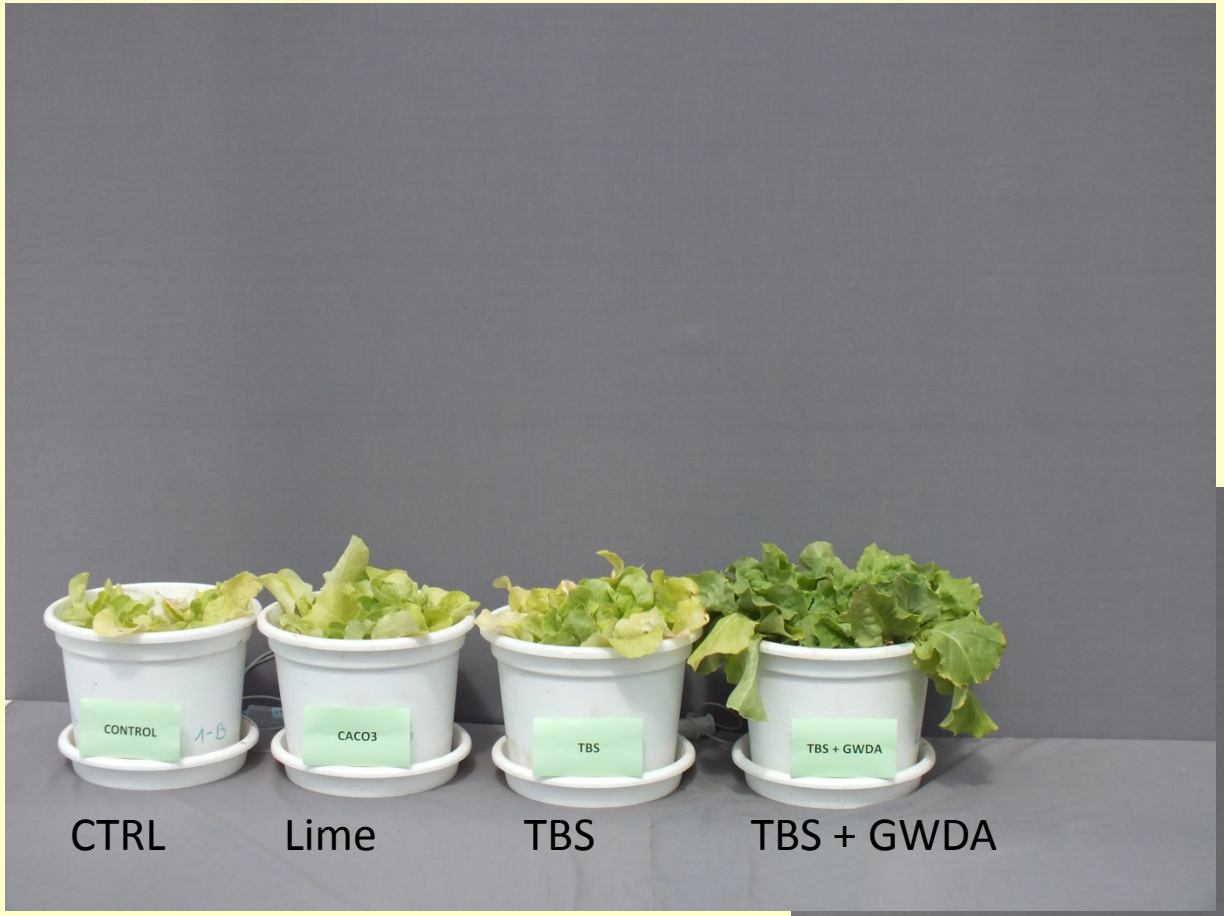
Single vs combined amendments – Soil A (phytoexclusion) 2nd lettuce

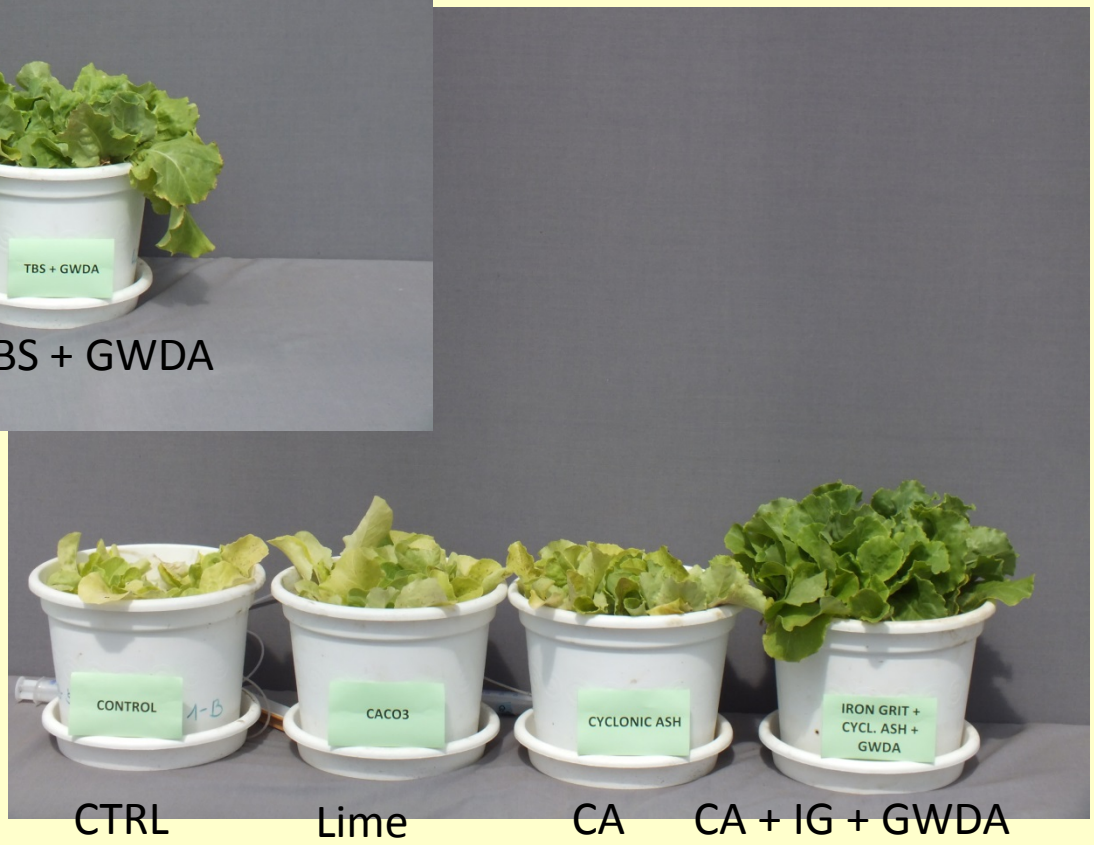
Iron grit combinations

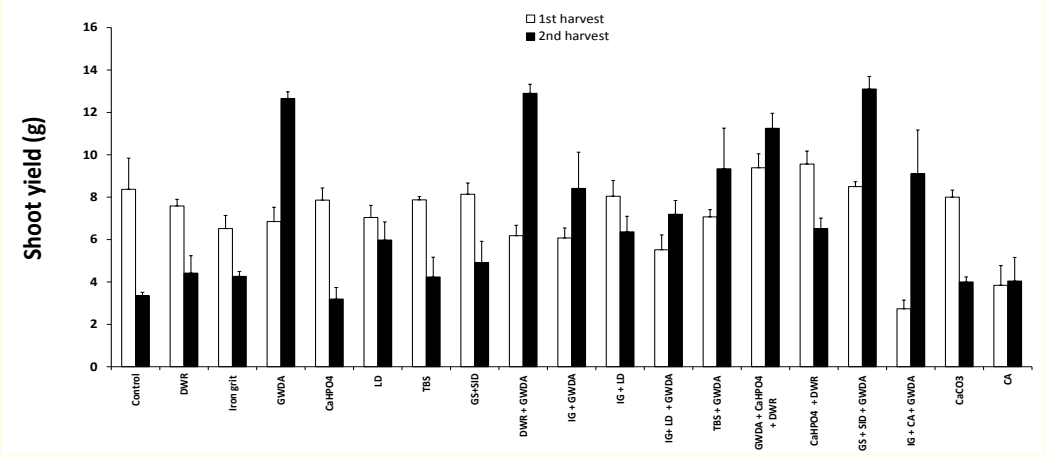
Compost combinations

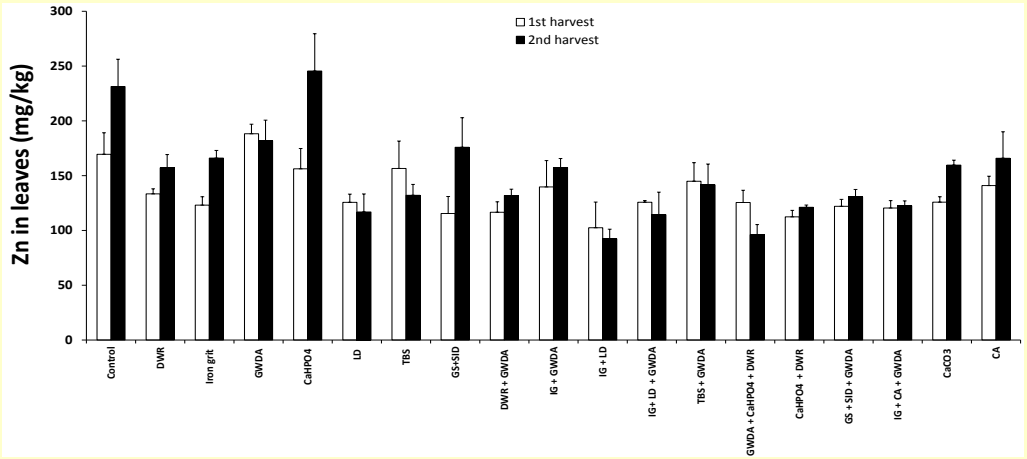
DWR combinations

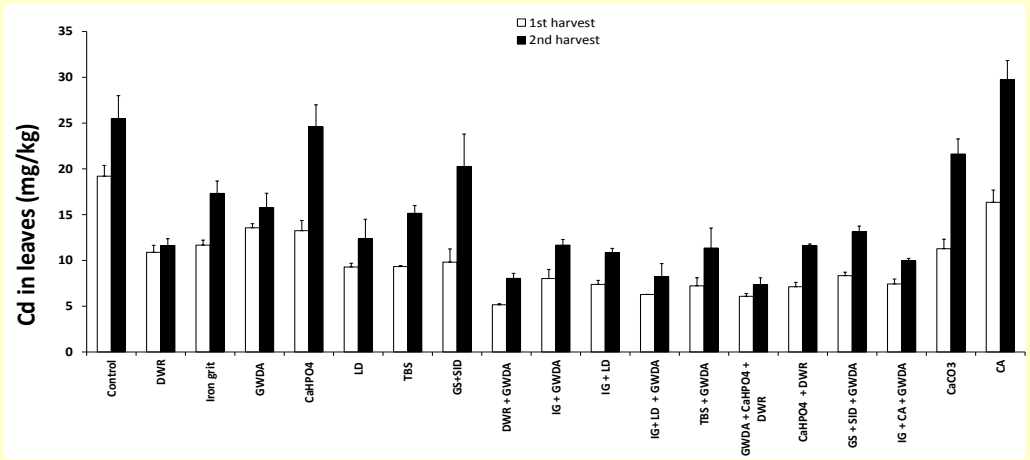
LD slag combinations


CONTROL
CACO3
TBS
TBS + GWDA
CTRL
Lime
TBS
TBS + GWDA


CONTROL
CACO3
CYCLONIC ASH
IRON GRIT + CYCL. ASH + GWDA
CTRL
Lime
CA
CA + IG + GWDA





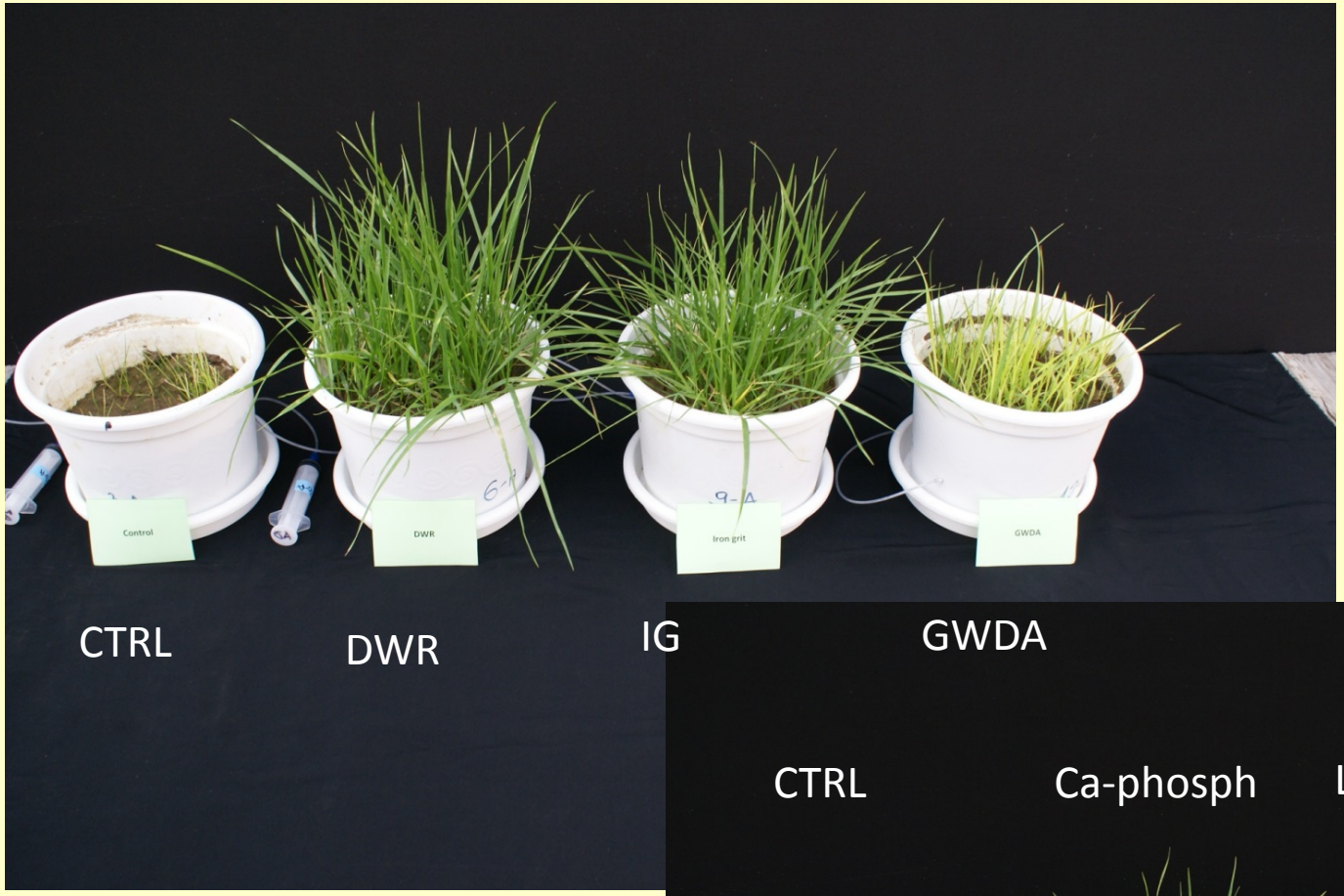


Effect of treatments on:

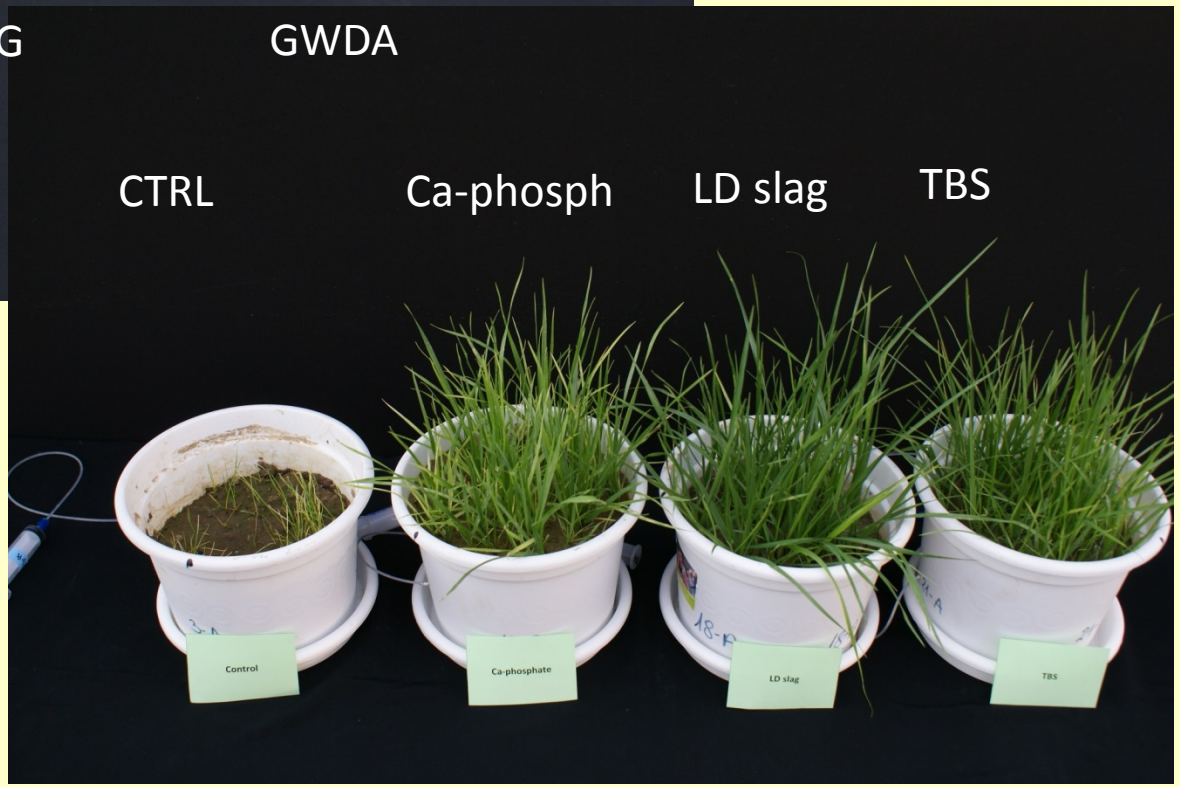
Lettuce yield

Zn in leaves

Cd in leaves



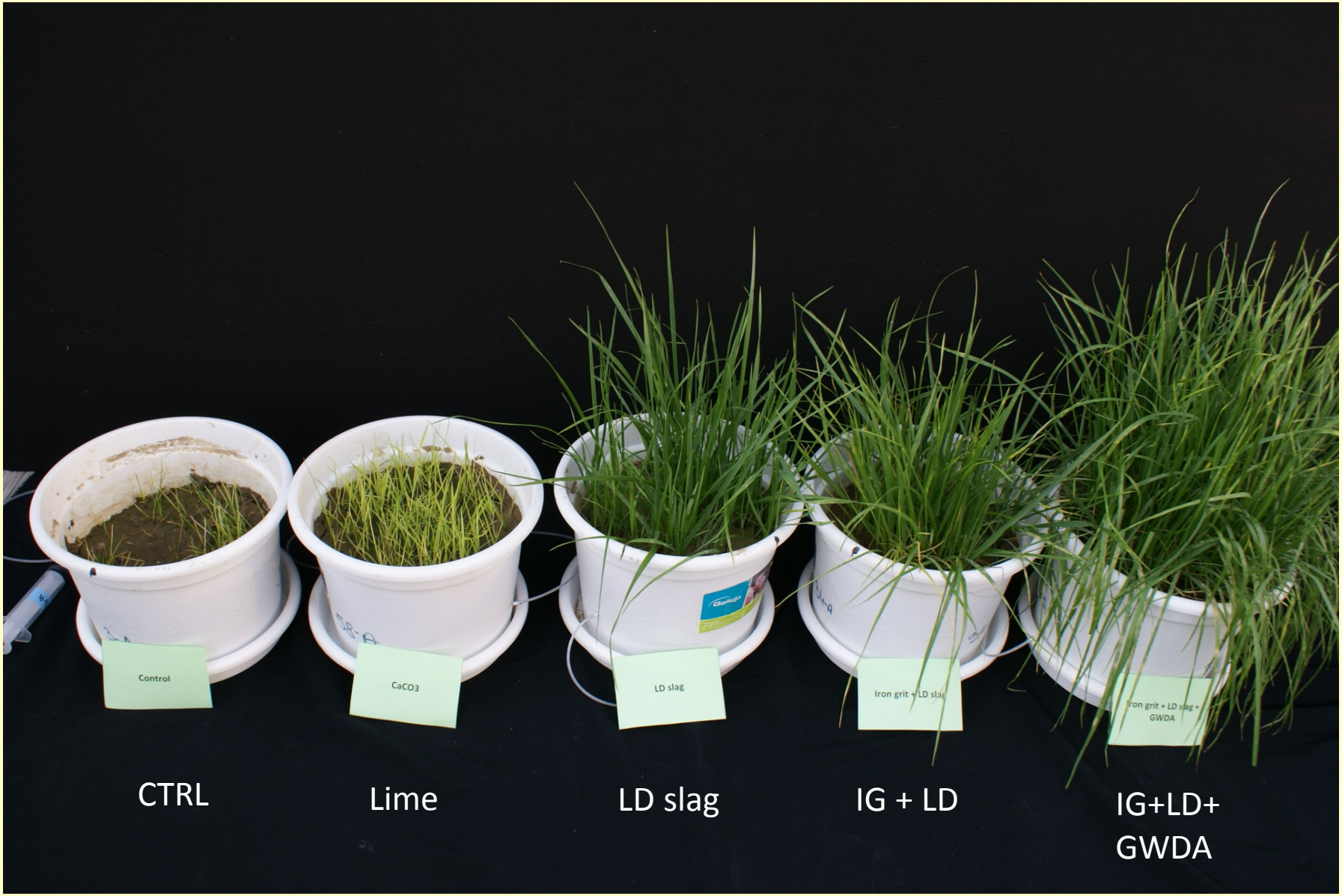
CTRL DWR IG GWDA



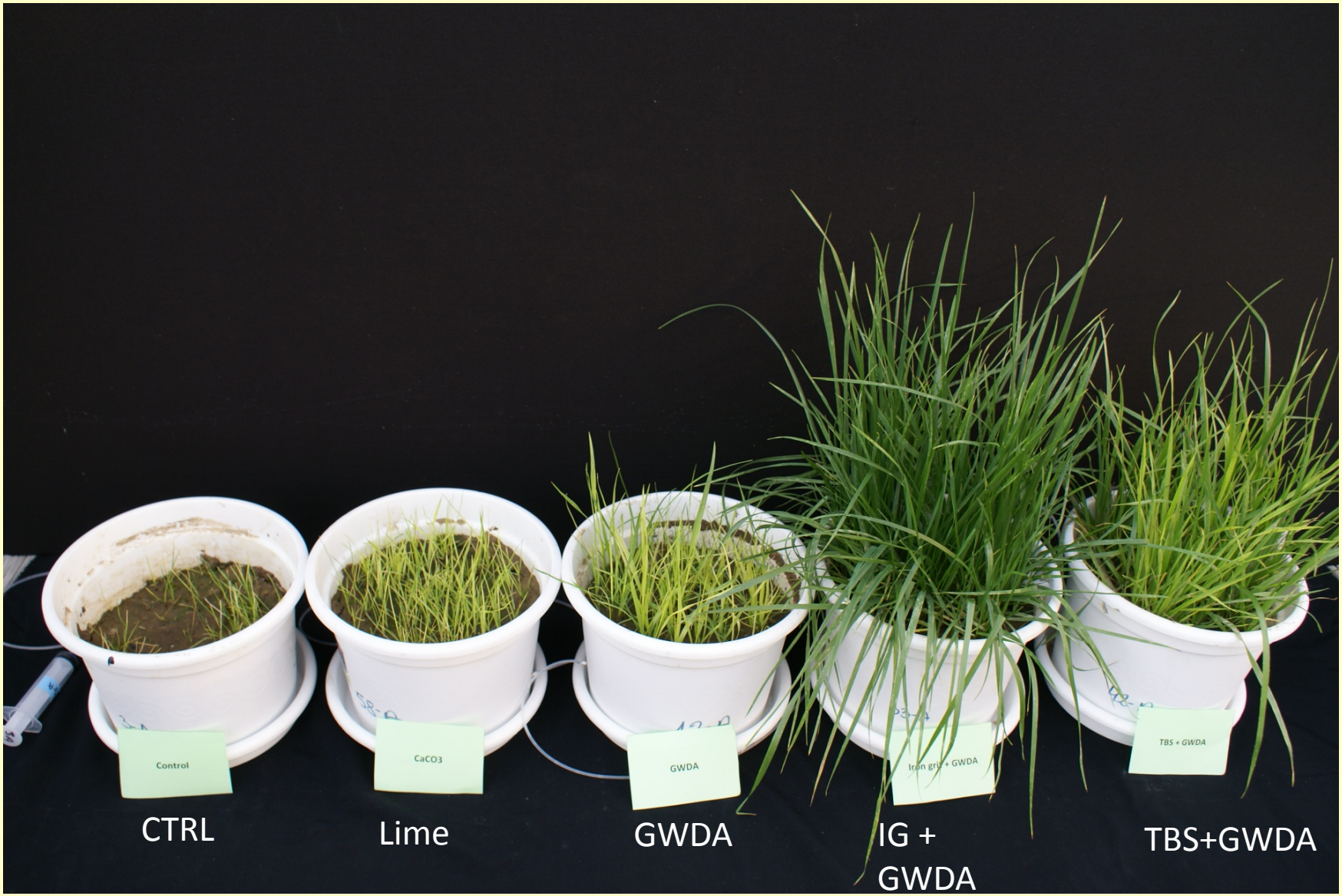
CTRL Ca-phosph LD slag TBS

Single amendments- Soil PL-B

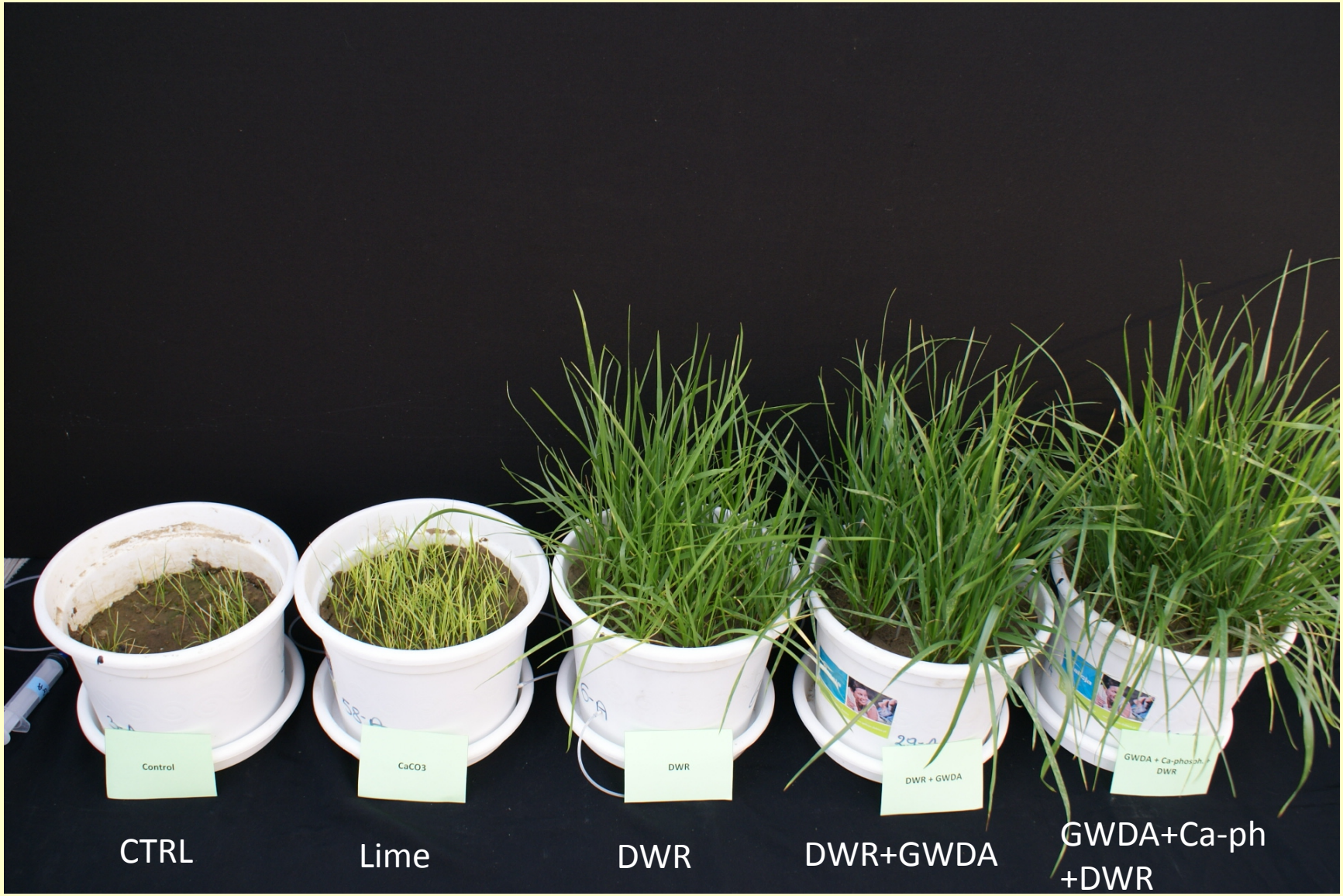
1st harvest



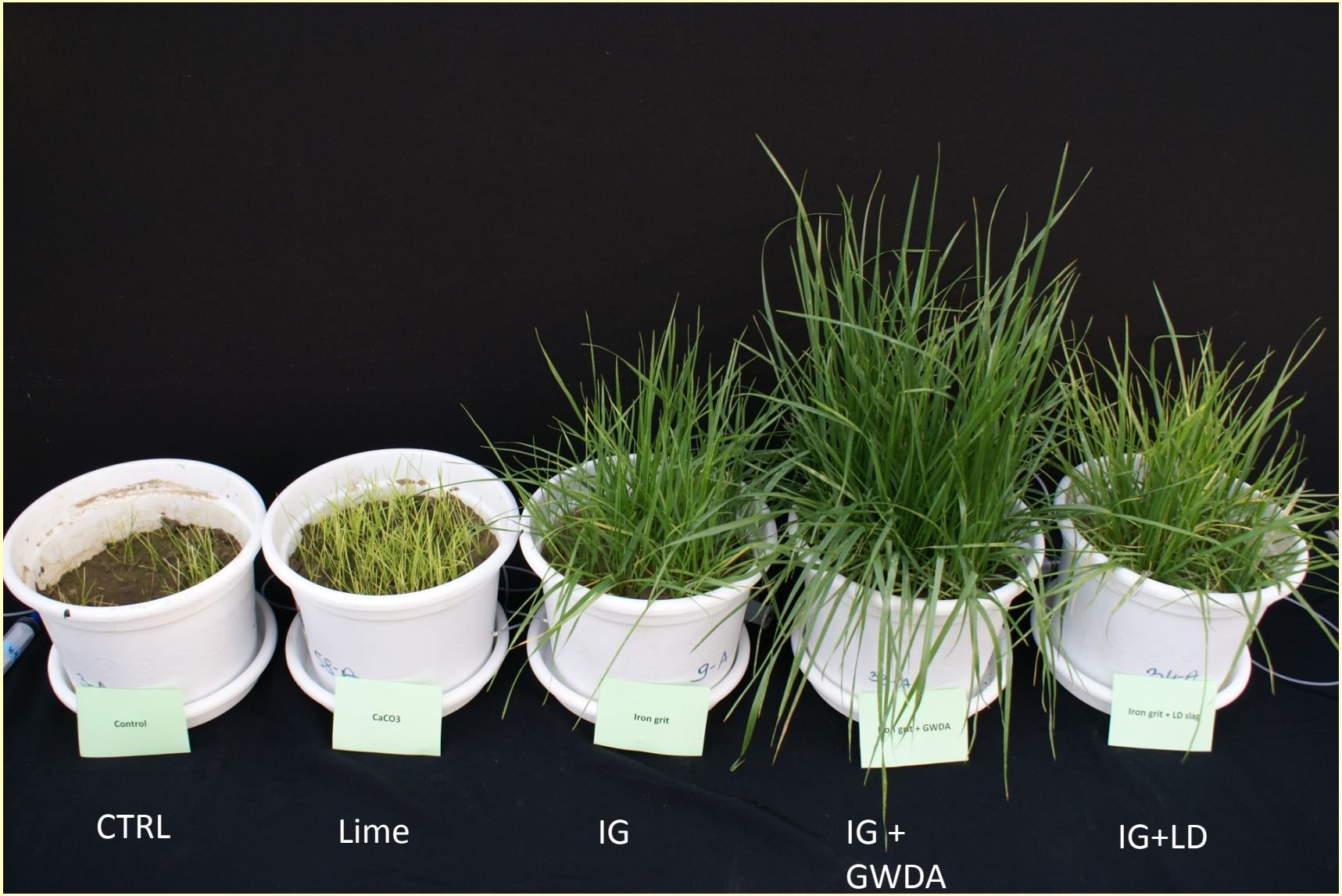
LD slag single vs. in combination (Soil PL-B)



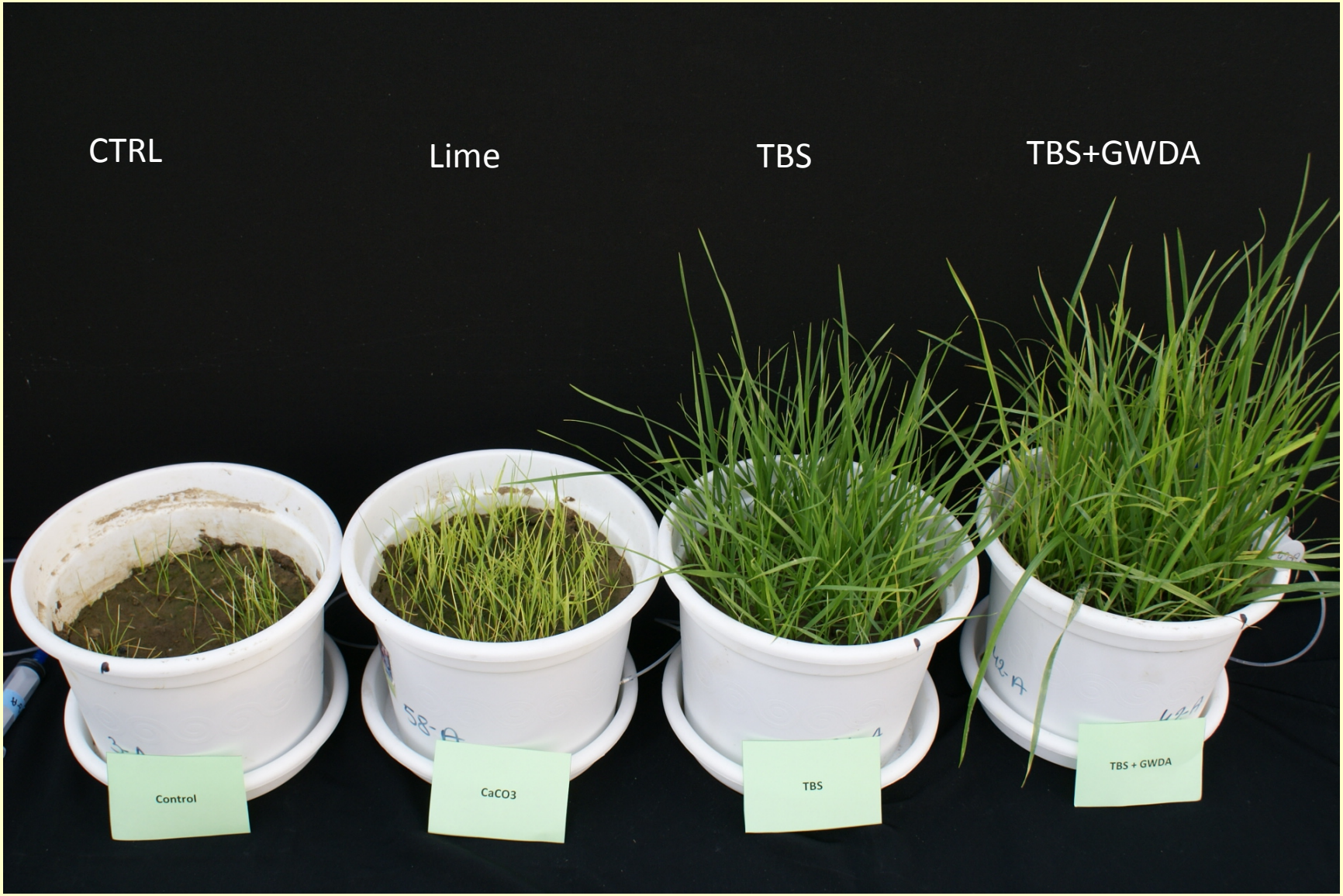
Compost as single amendment vs. Combined with other materials (Soil PL-B)



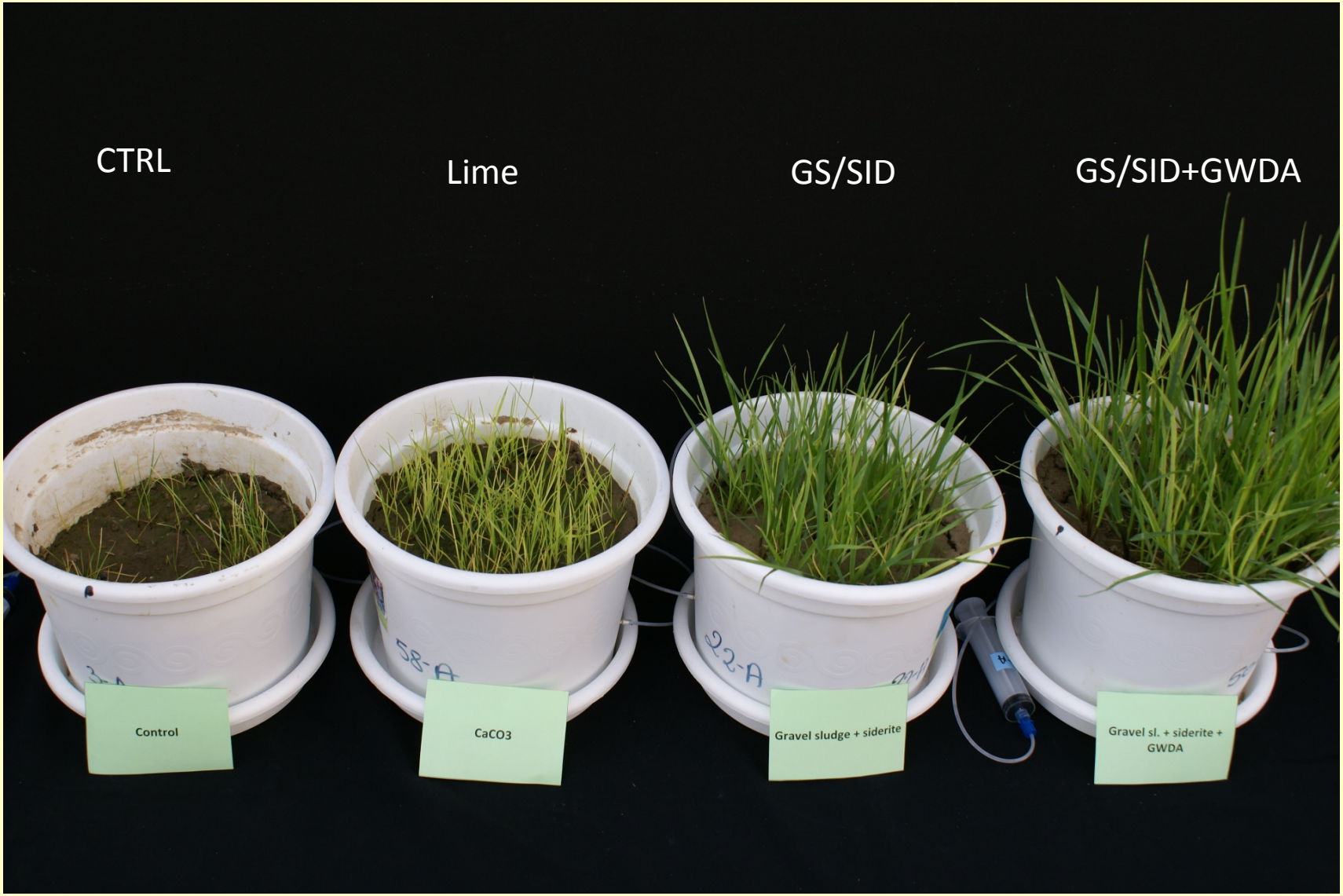
DWR as single amendment vs. Combined with other materials (Soil PL-B)



Iron grit as single amendment vs. Combined with other materials (Soil PL-B)

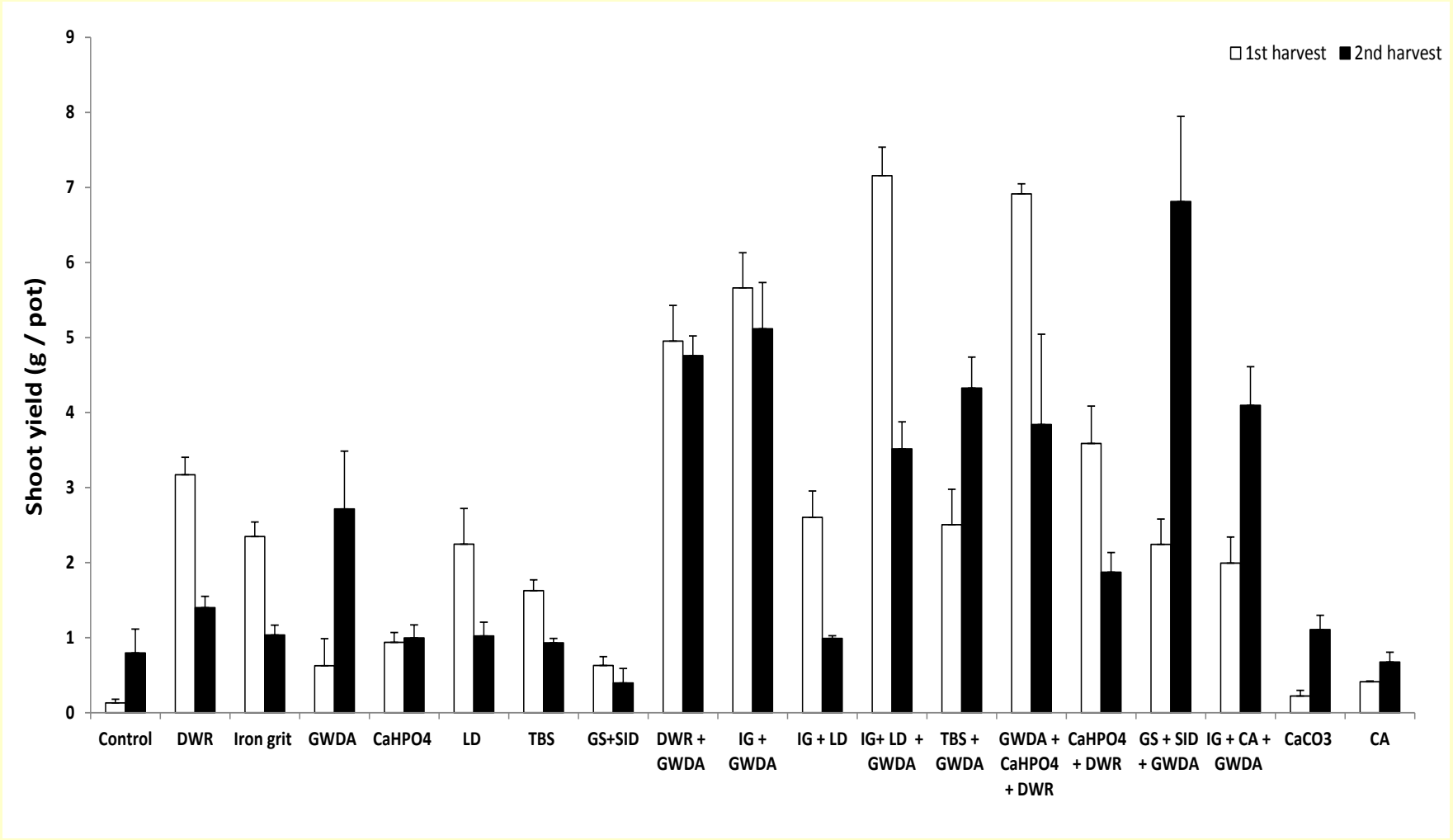


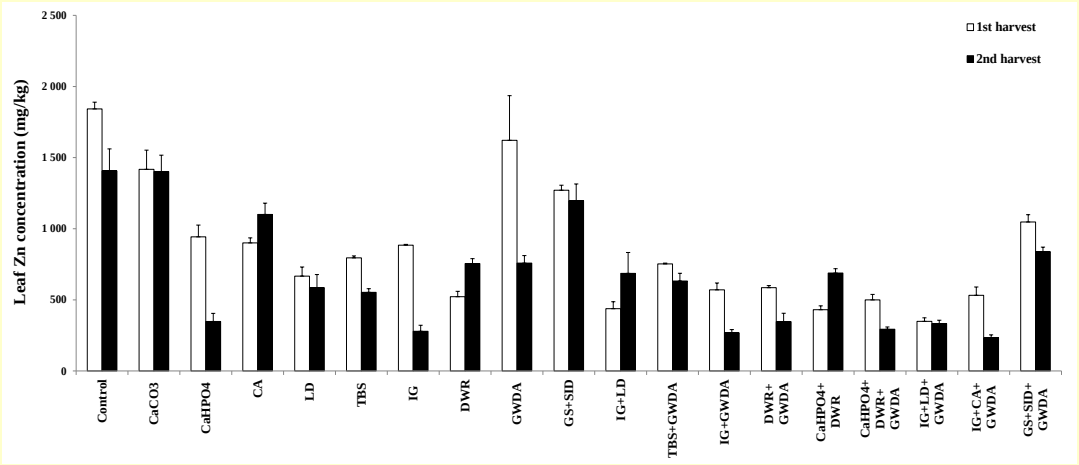
TBS as single amendment vs. Combined with other materials (Soil PL-B)



GS/SID as single amendment vs. Combined with other materials (Soil PL-B)

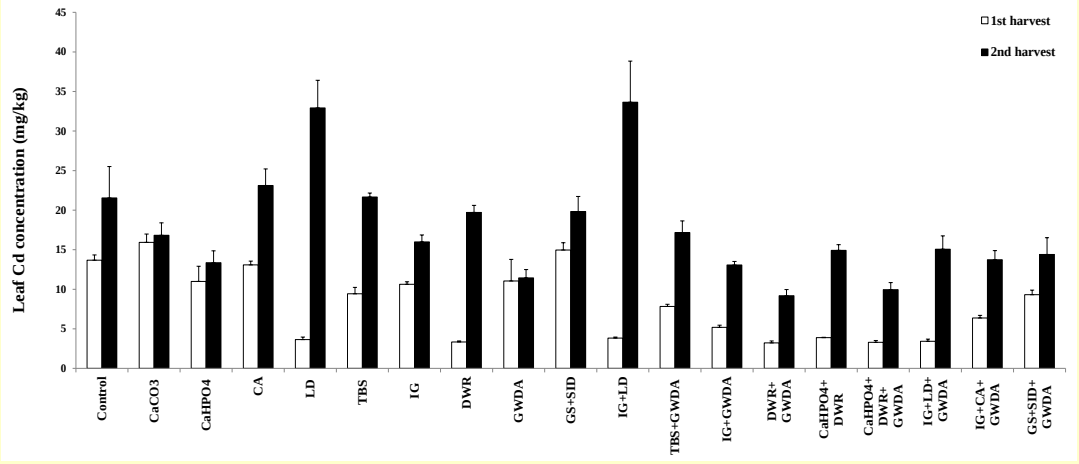
Effect of treatments on grass yield



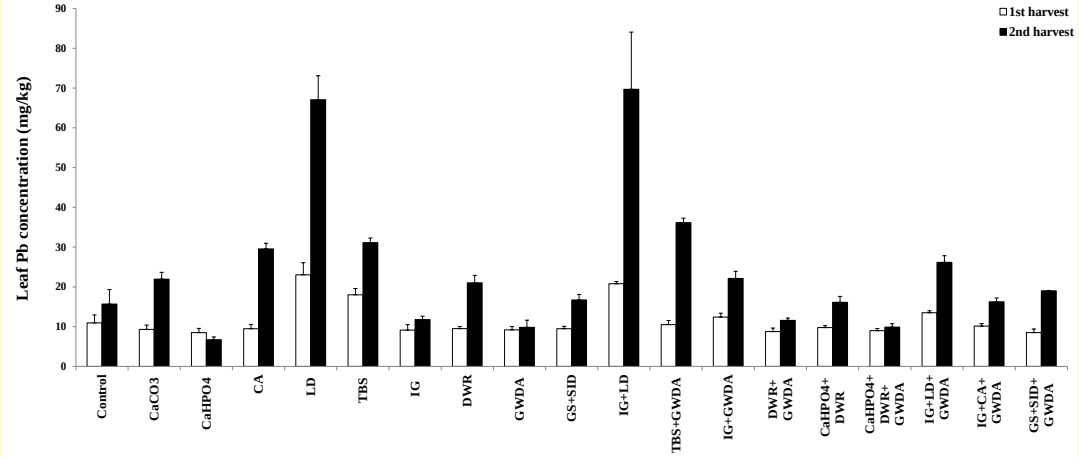


Effect of treatments on:

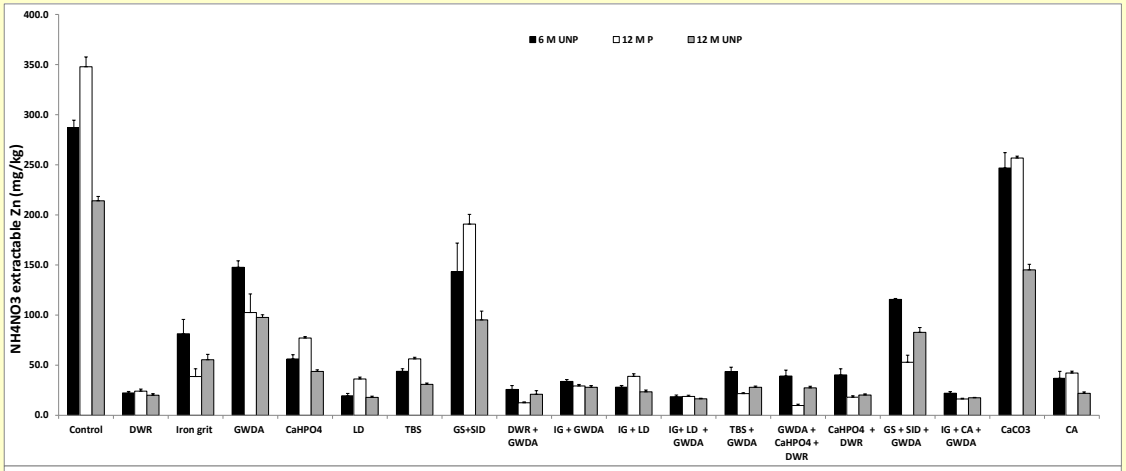
Zn in shoots

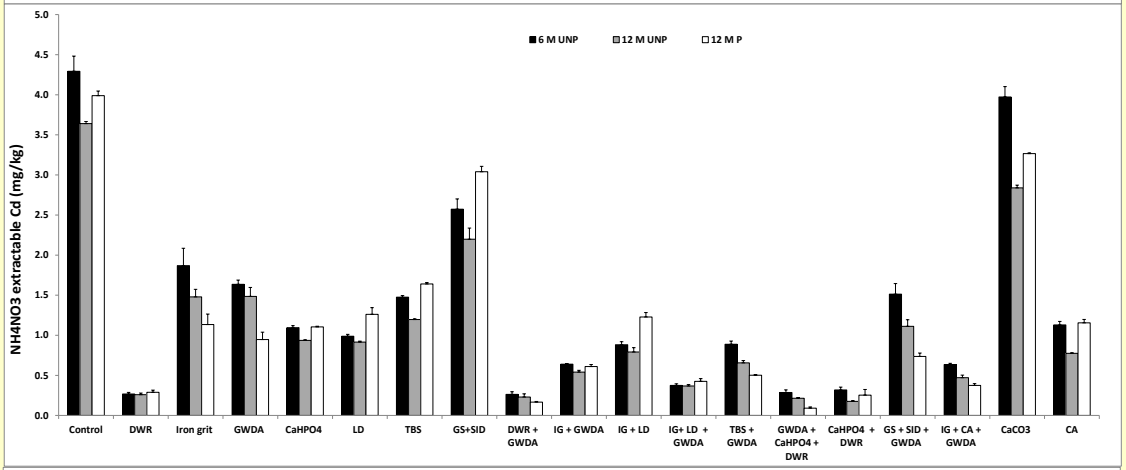


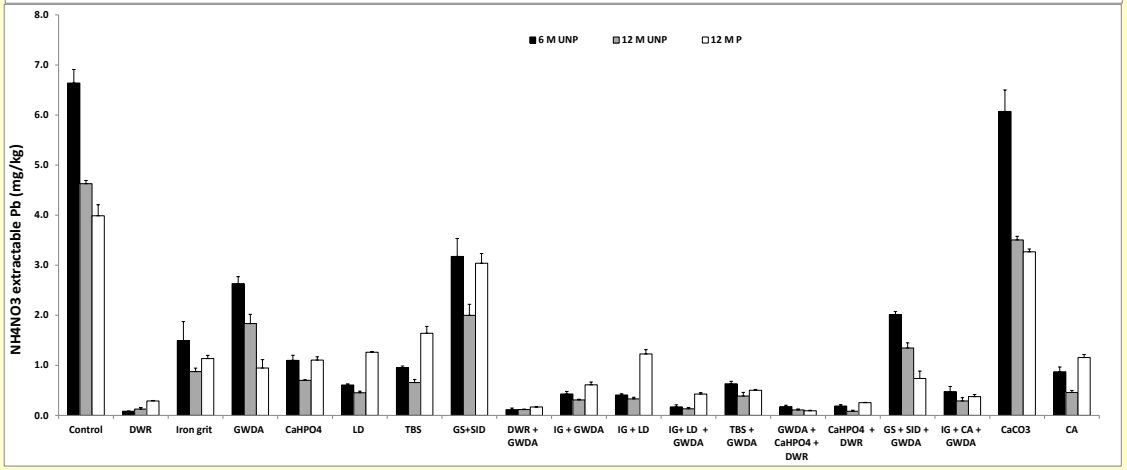
Cd in shoots



Pb in shoots







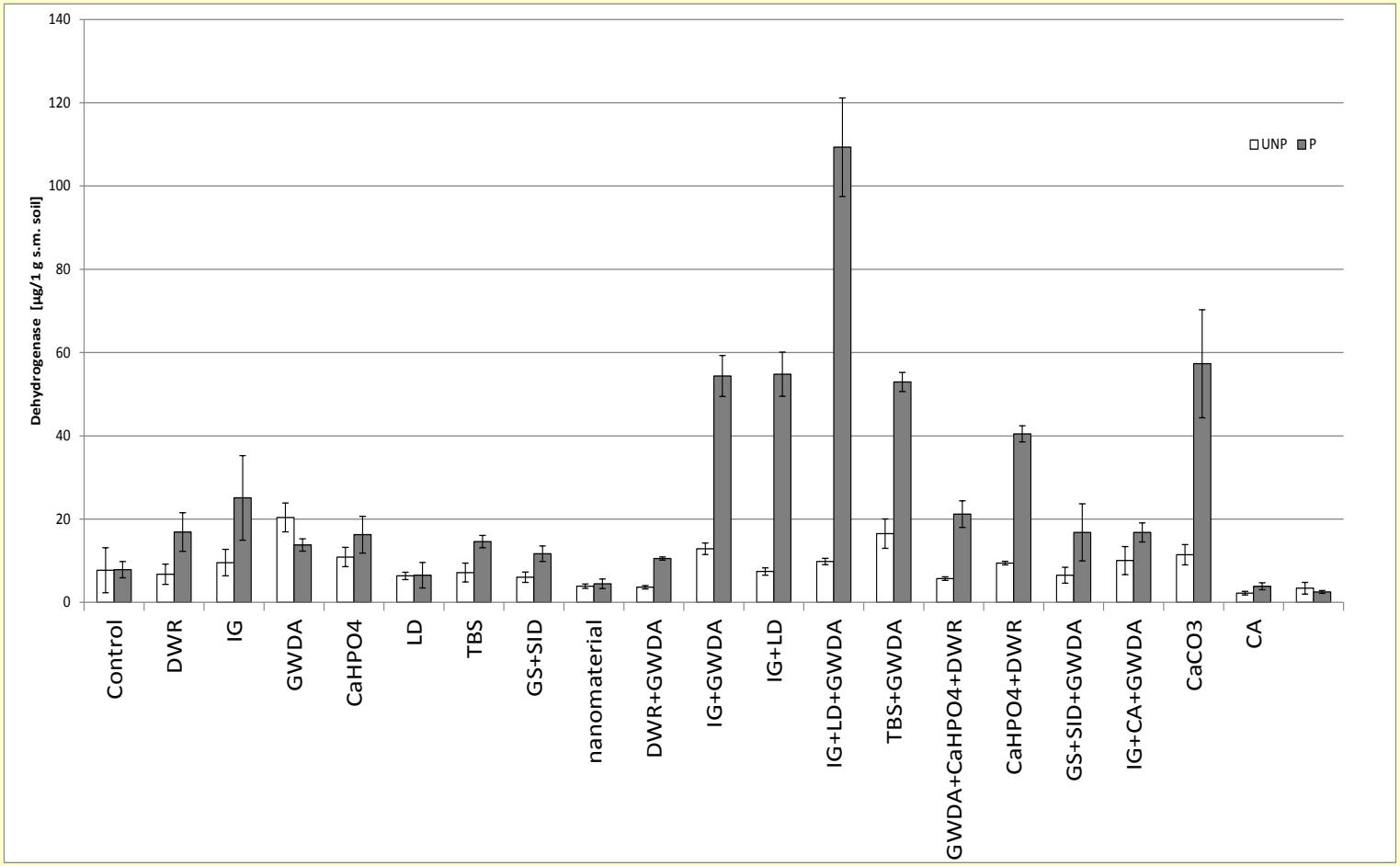
Effect of treatments on:

NH_4NO_3 extr. Zn

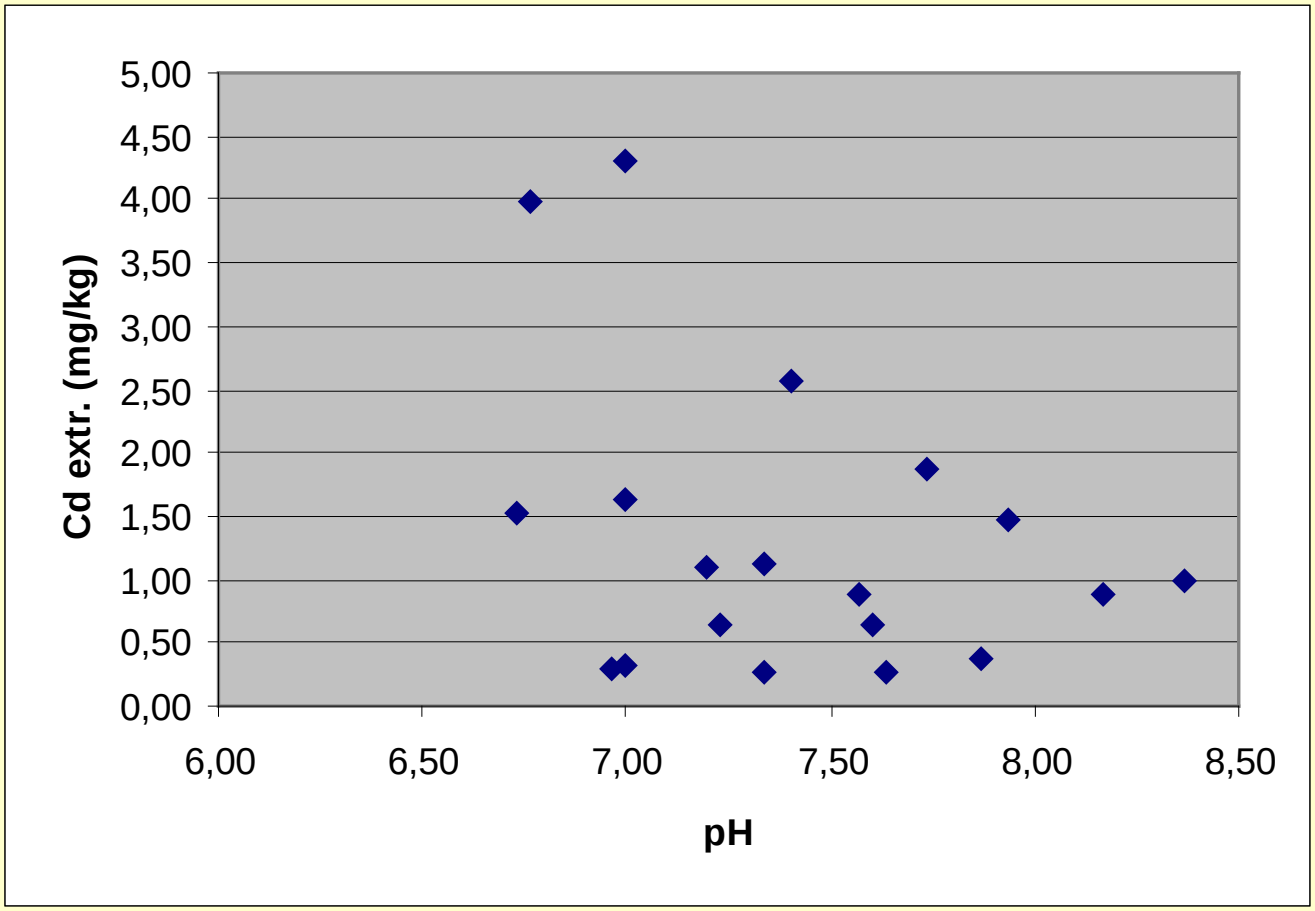
NH_4NO_3 extr. Cd

NH_4NO_3 extr. Pb

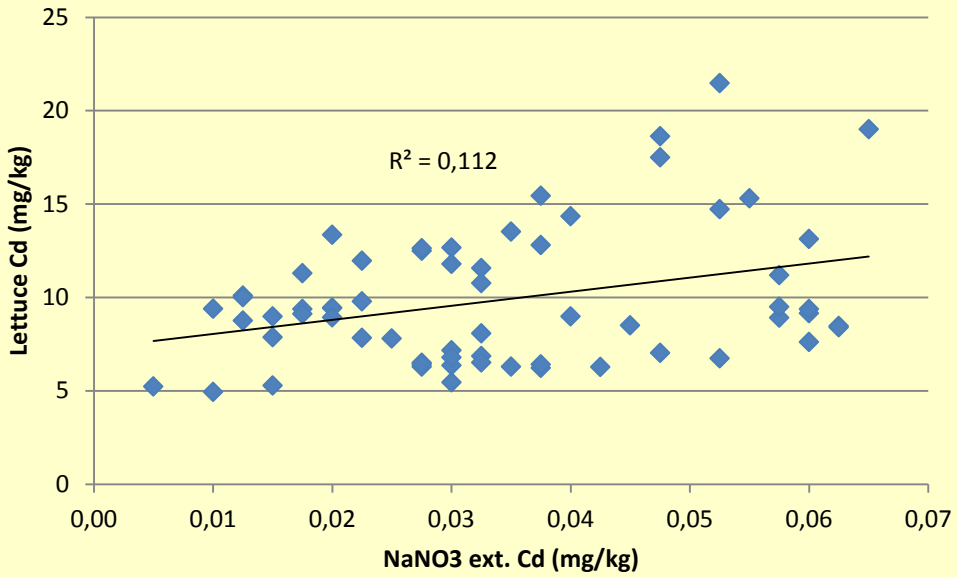
Effect of treatments on dehydrogenase activity of soil B:

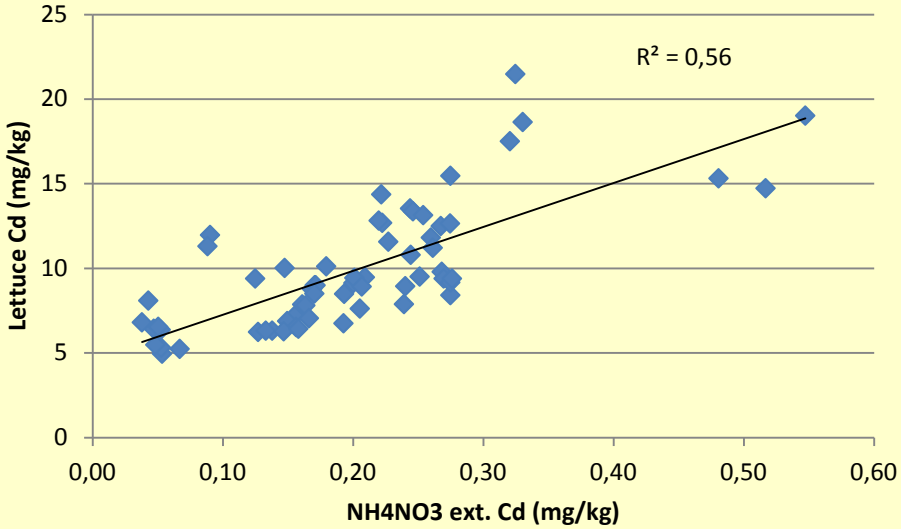


Metal solubility not a simple effect of pH



Soil PL-B – Ammonia nitrate extraction

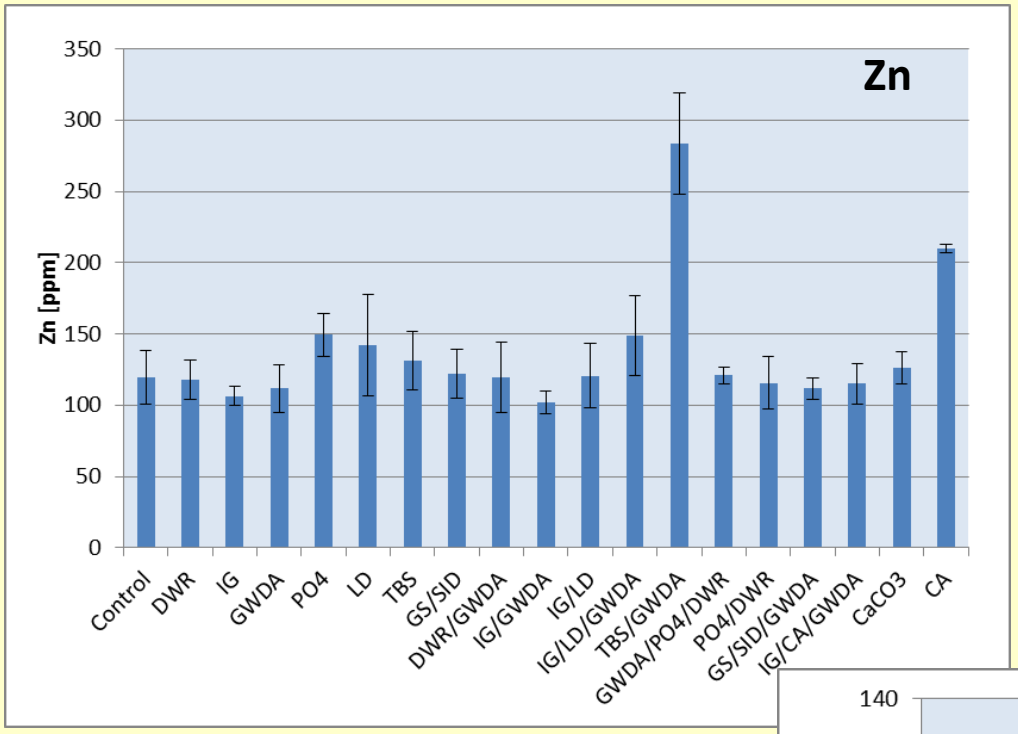


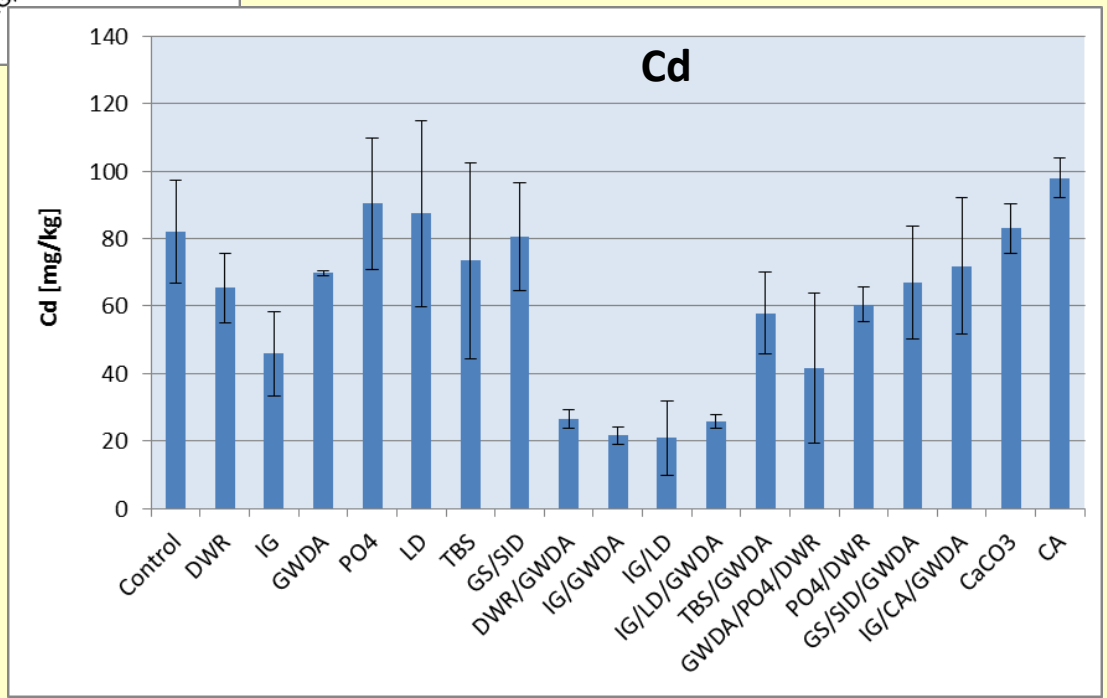


Relationship between 0.1M $NaNO_3$ or 1MNH_4NO_3 extractable Cd and Cd in lettuce (soil PL-A; Month 6)

Effect of treatments on metal accumulation in earthworm (*Eisenia veneta)*

TE in earthwoms





Inoculation study

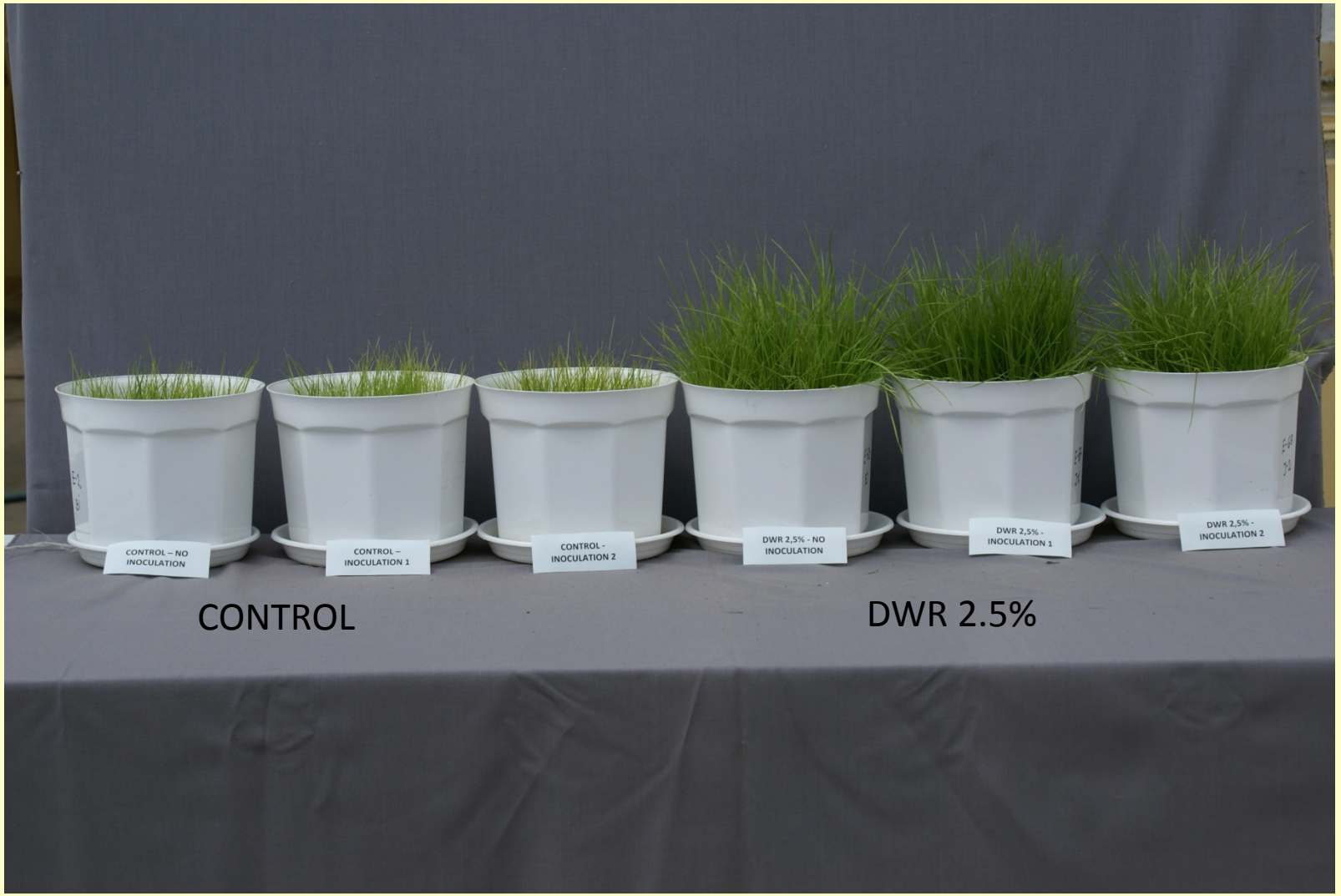
We tested whether effect of selected amendment combinations can be enhanced by bacterial inoculation of plants (Festuca arundinacea). Eight amendment combinations were tested at 2 rates and with 2 types of inoculants.

Amendment	Rate of addition
Control soil	Unamended
DWR	2.5%
DWR	5.0%
DWR + GWDA	2.5% (DWR), 2.5% (GWDA)
DWR + GWDA	5% (DWR), 5% (GWDA)
LD slag	0.25%
LD slag	0.5%
LD slag + IG + GWDA	0.25% (LD slag), 0.5% (IG), 2.5% (GWDA)
LD slag + IG + GWDA	0.5% (LD slag), 1.0% (IG), 5% (GWDA)

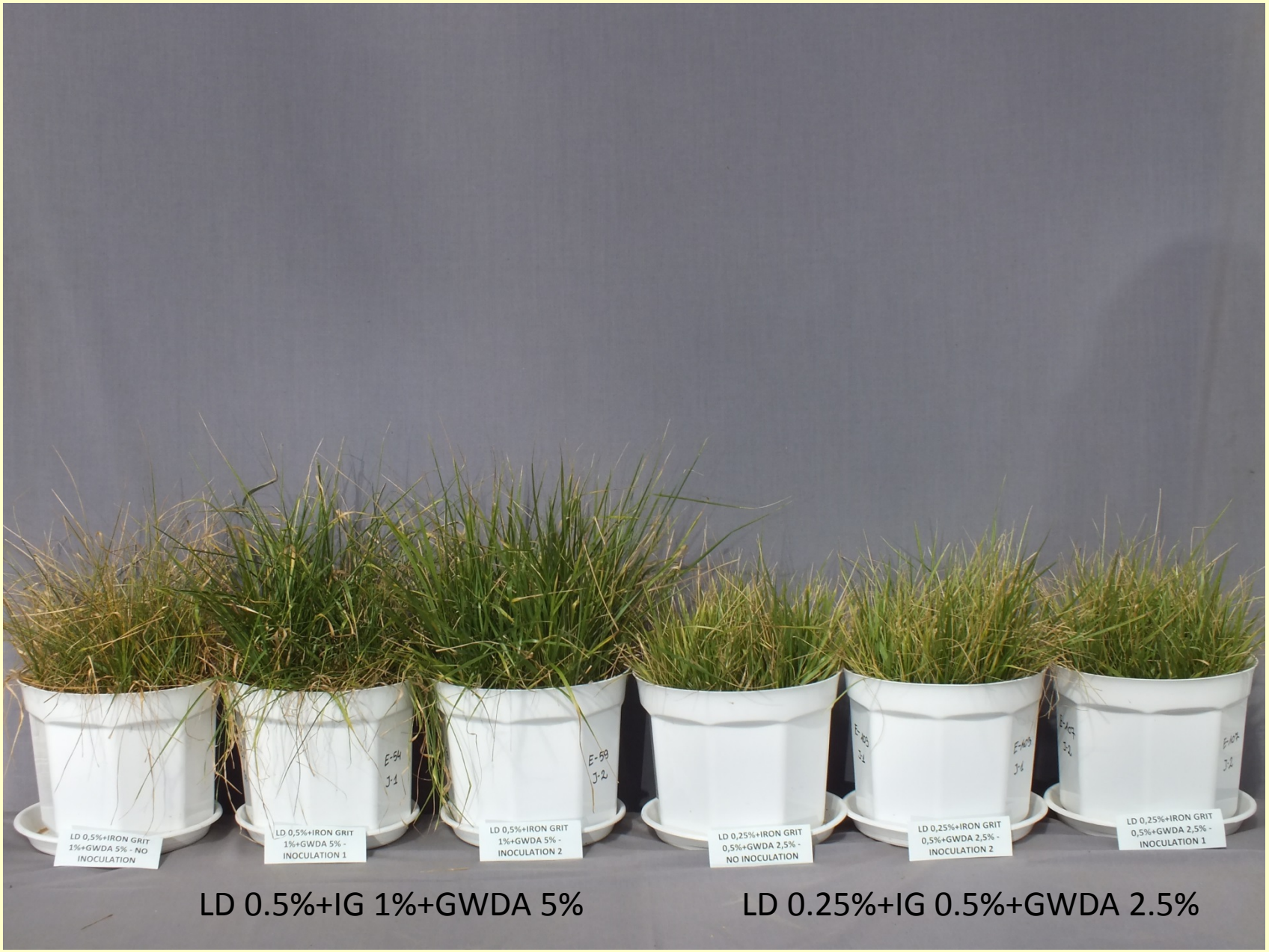
For each treatment:

- No inoculation
- Strain P87 (*Massilia niastensis*)
- P35 (*Pseudomonas koreensis)*

1 harvest

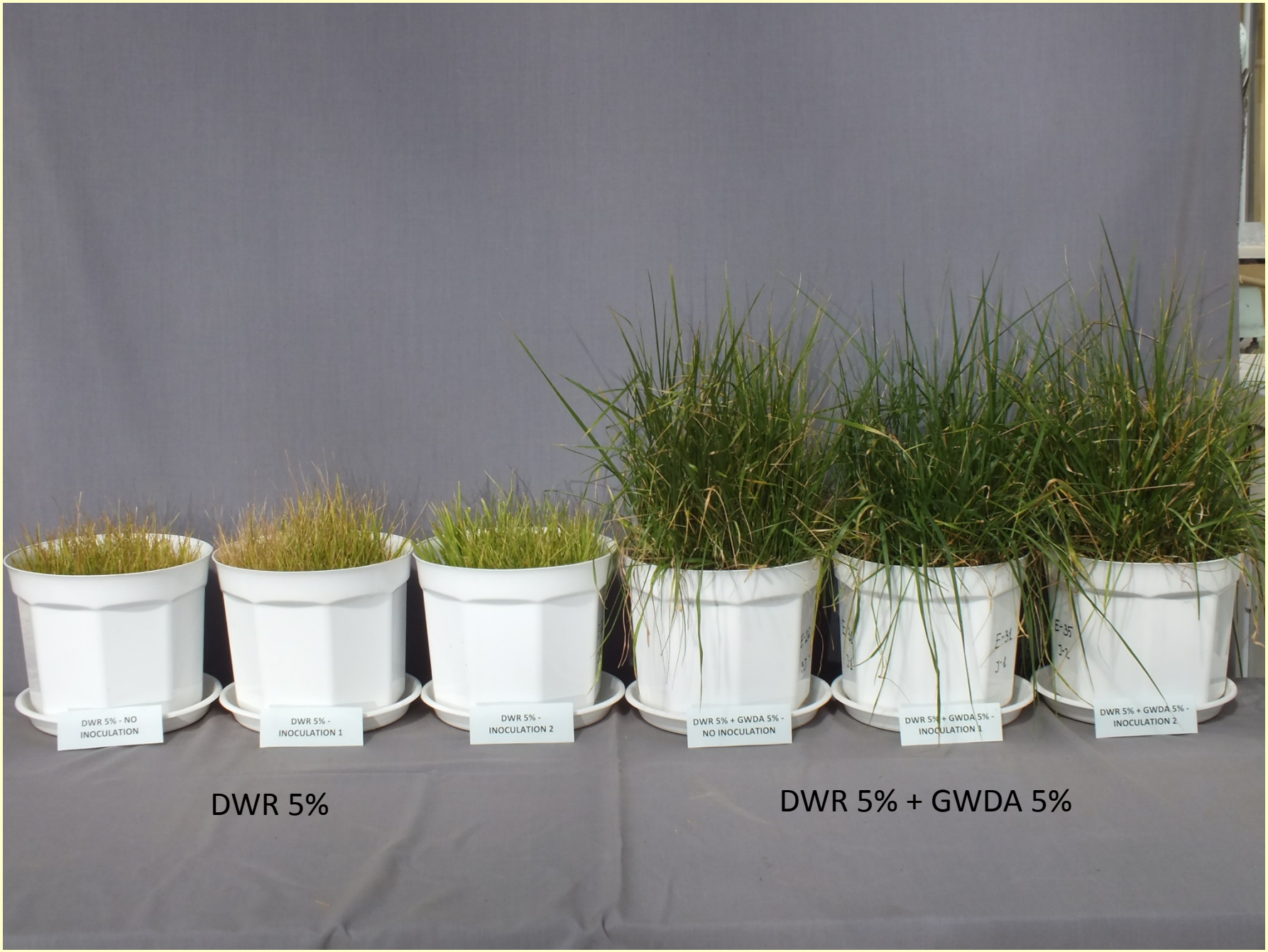

CONTROL – NO INOCULATION
CONTROL – INOCULATION 1
CONTROL - INOCULATION 2
DWR 2,5% - NO INOCULATION
DWR 2,5% - INOCULATION 1
DWR 2,5% - INOCULATION 2
CONTROL
DWR 2.5%

2 harvest

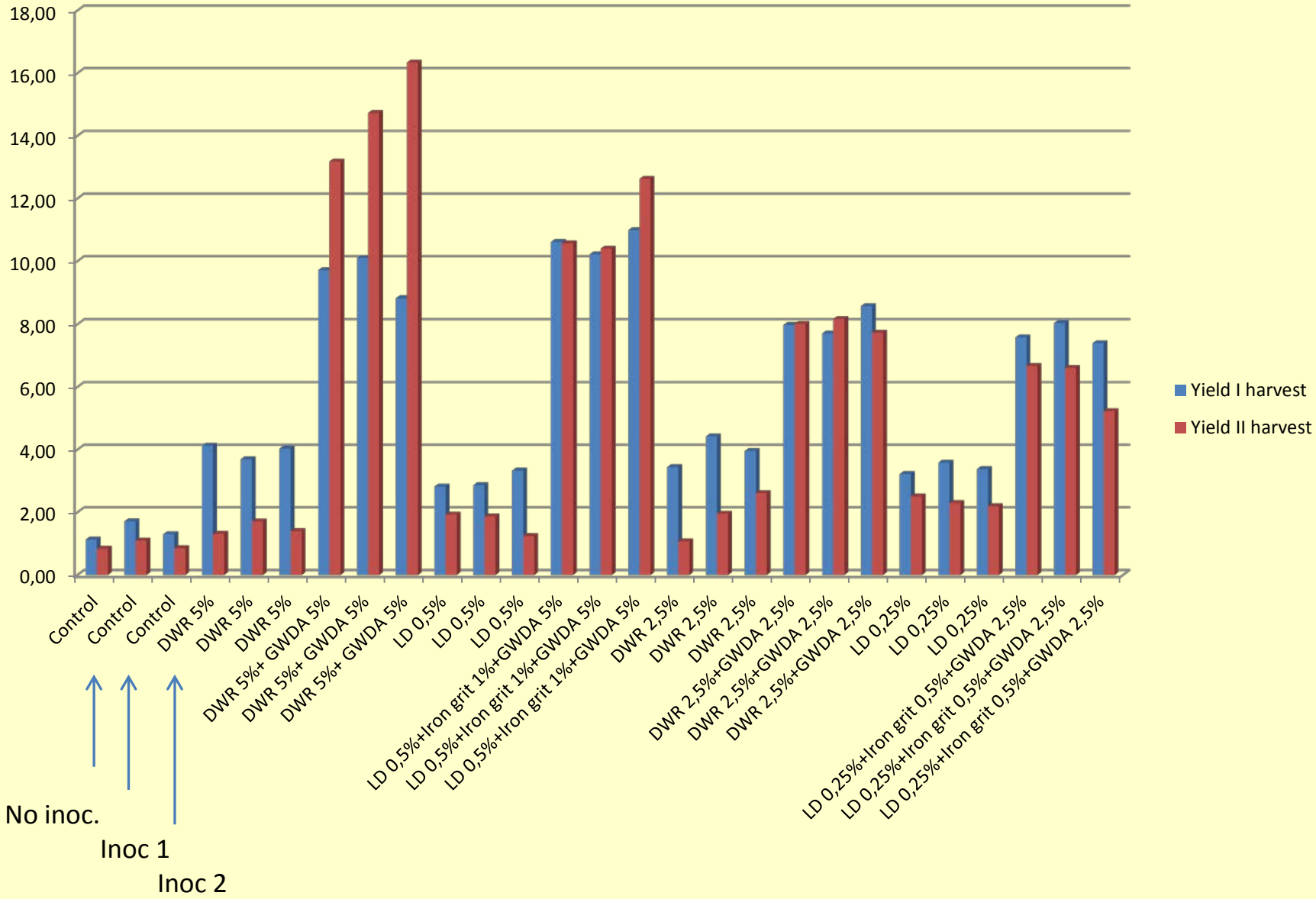


LD 0.5%+IG 1%+GWDA 5%

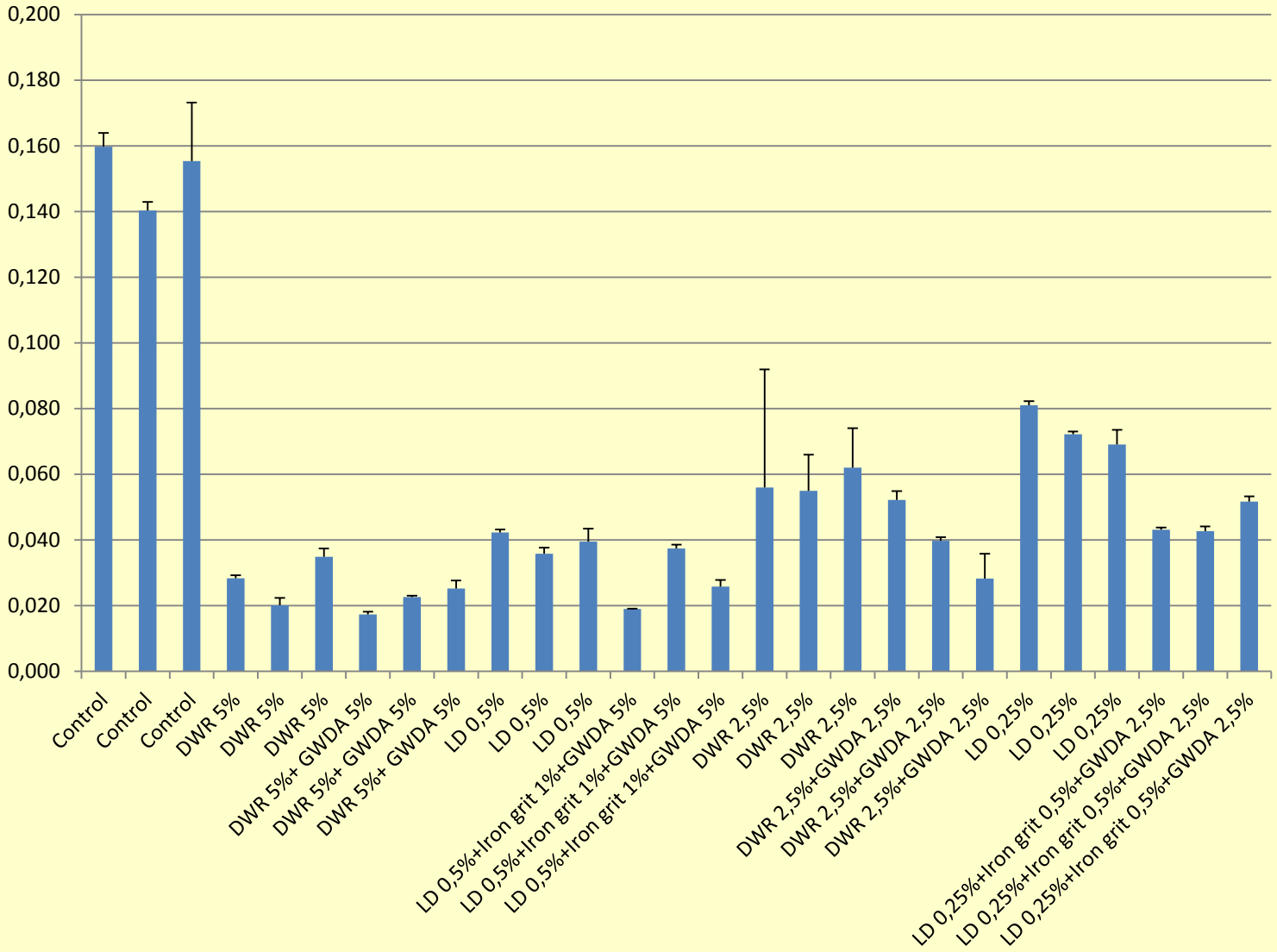
LD 0.25%+IG 0.5%+GWDA 2.5%


DWR 5% - NO INOCULATION
DWR 5% - INOCULATION 1
DWR 5% - INOCULATION 2
DWR 5% + GWDA 5% - NO INOCULATION
DWR 5% + GWDA 5% - INOCULATION 1
DWR 5% + GWDA 5% - INOCULATION 2
DWR 5%
DWR 5% + GWDA 5%

Effect of inoculation and rate on grass yield



Effect of inoculation and rate on Cd water solubility at 1 harvest



Tagetes patula, no sediment, no inoculation 22.09.2014

Tagetes patula, no sediment (RP92) 22.09.2014

Tagetes patula, no sediment (P87) 22.09.2014

Tagetes patula, sediment, no inoculation 22.09.2014

Tagetes patula, sediment (RP92) 22.09.2014

Tagetes patula, sediment (P87) 22.09.2014

Bottom sediment contaminated soil

SOIL A – Summary table

Treatment	Plant growth	Plant metal bioaccumulation		Soil metal availability			Soil enzymes	Metal leaching	Earthworm metal bioaccumulation		Scoring
		Cd	Pb	Zn	Cd	Pb			Cd	Pb	
Control	2	2	1	2	2	0	2	1	2	1	**15**
$CaCO_3$	2	2	1	1	2	0	1	2	2	1	**14**
$CaHPO_4$	2	2	1	2	2	1	2	1	2	1	**16**
IG	2	1	0	1	1	1	1	0	1	0	**8**
CA	2	2	2	1	2	0	0	2	2	2	**15**
LDslag	1	1	1	1	1	1	1	0	2	1	**10**
TBS	2	1	1	1	1	1	1	0	2	1	**11**
DWR	2	1	1	0	0	1	2	0	2	0	**9**
GWDA	0	1	0	1	1	1	1	1	2	0	**8**
GS+SID	2	2	1	1	2	1	1	0	2	1	**13**
IG+GWDA	1	1	1	1	1	1	0	1	0	0	**7**
IG+LDslag	1	1	0	1	1	1	1	0	0	1	**7**
TBS+GWDA	1	1	0	1	1	0	0	1	1	2	**8**
DWR+GWDA	0	0	0	0	0	1	0	1	0	0	**2**
$CaHPO_4$+DWR	1	1	1	0	0	0	1	0	1	0	**5**
GS+SID+GWDA	0	1	1	1	1	0	0	2	2	0	**8**
IG+LDslag+GWDA	1	0	1	1	1	0	0	1	0	1	**6**
IG+CA+GWDA	1	0	0	1	1	0	0	2	2	0	**7**
$CaHPO_4$+DWR+GWDA	0	0	0	0	0	0	0	0	1	0	**1**

SOIL B – Summary table

Treatment	Plant growth	Plant metal bioaccumulation			Soil metal availability			Soil enzymes	Metal leaching	Scoring
		Zn	Cd	Pb	Zn	Cd	Pb			
Control	2	2	2	1	2	2	2	2	2	**17**
$CaCO_3$	1	2	1	1	2	2	2	2	2	**15**
$CaHPO_4$	2	0	1	0	0	2	1	2	1	**9**
IG	2	0	1	1	0	1	1	0	1	**7**
CA	2	0	1	1	0	2	1	1	1	**9**
LDslag	2	1	2	2	0	2	1	0	0	**10**
TBS	2	1	2	2	0	2	1	0	0	**10**
DWR	1	1	1	1	0	0	0	0	0	**4**
GWDA	1	1	1	0	1	1	0	0	2	**7**
GS+SID	2	2	1	1	1	2	2	2	1	**14**
IG+GWDA	0	0	1	1	0	1	0	0	1	**4**
IG+LDslag	0	1	0	0	0	2	1	0	0	**4**
TBS+GWDA	0	1	1	1	0	0	0	0	1	**4**
DWR+GWDA	0	0	0	1	0	0	0	0	0	**1**
$CaHPO_4$+DWR	1	1	1	1	0	0	0	0	0	**4**
GS+SID+GWDA	2	2	1	1	0	1	0	0	2	**9**
IG+LDslag+GWDA	0	0	1	1	0	0	0	0	0	**2**
IG+CA+GWDA	0	0	1	1	0	0	0	0	1	**3**
$CaHPO_4$+DWR+GWDA	0	0	0	0	0	0	0	0	0	**0**

Conclusions

- Among single amendments Drinking Water Residue, compost GWDA and Iron Grit were the most effective in improving plant growth and reducing metal solubility and bioavailability
- In the phytoexclusion strategy where TE bioavailable pool in soil is smaller: only combinations give any effect
- In the phytostabilisation strategy single treatments reduce risk but combinations of treatments are much more effective
- The most effective combinations: DWR/compost combinations, IG/compost combinations

Thank you for your attention
and GREENLAND friends for the collaboration

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