

The role of slags and other by-products within circular economy in the steel industry

- Investigation of electric-arc-furnace slag for sustainable wheat and lettuce production
- Rifat Bugra Bildiri

5-6
MARCH
2025

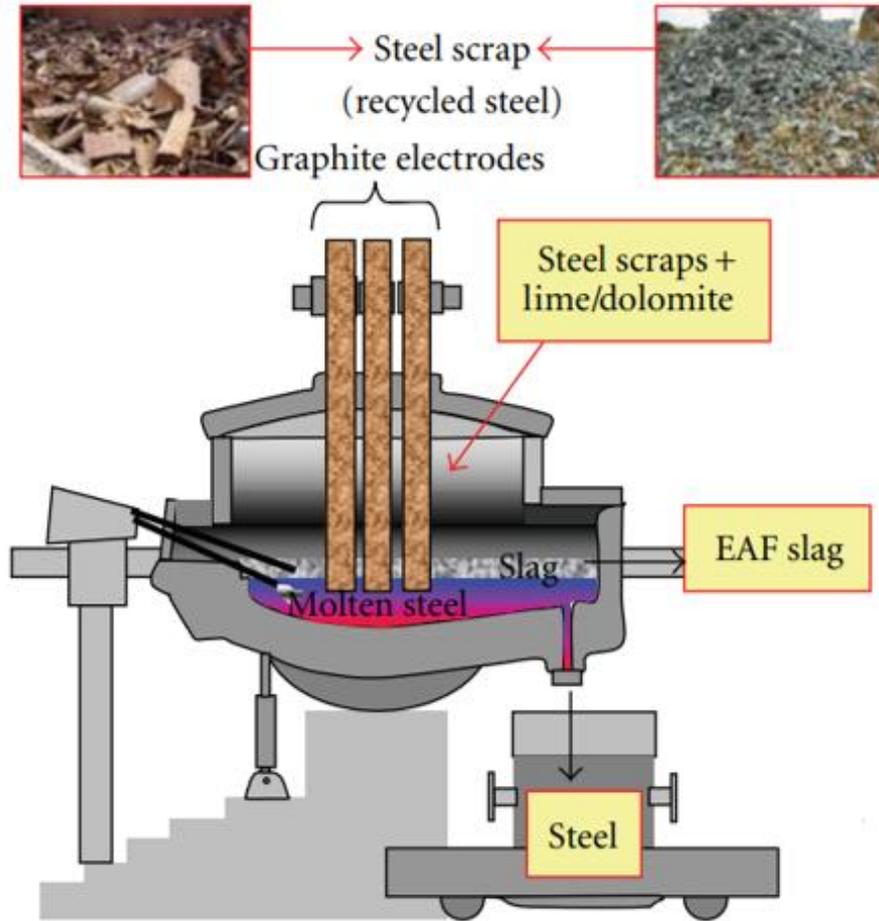
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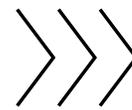
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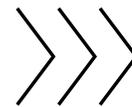
EAF Slag



Facility Type	Producers	Crude Steel Production (Mt - %)
BF/BOF Integrated Facilities	Kardemir	2,3 (%6)
	İsdemir	5,7 (%14)
	Erdemir	3,3 (%8)
	Sum of the Integrated Facilities	11,5 (%28)
EAF/IF Facilities	Sum of the EAF/IF Facilities	28,9 (%72)
Total	All Facilities	40,4 (%100)



1t of steel production → 150-200 kg of EAF slag



Approximately 6 Mt EAF slag production in 2021

Mineral Composition of Our Slag



Nutrients

Bioavailability?

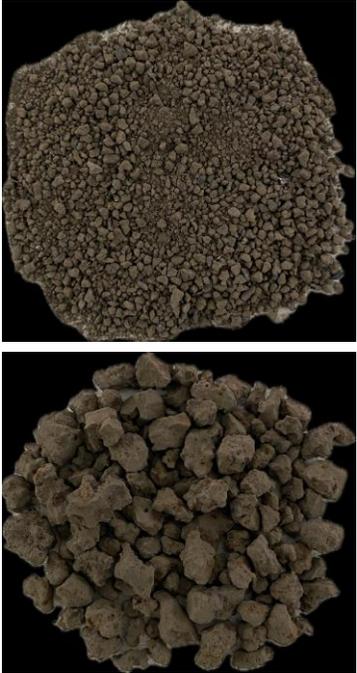


Low price

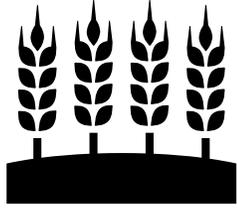


Sustainable

Macroelement Concentrations (g kg ⁻¹)						
Particle Size	[P]	[K]	[Ca]	[Mg]	[S]	
Fine (0-2 mm)	1.5	0.8	185	10.0	1.6	
Coarse (0-4 mm)	1.6	0.8	184	9.5	1.7	
Microelement Concentrations (mg kg ⁻¹)						
Particle Size	[Fe]	[Zn]	[Mn]	[Cu]	[B]	[Mo]
Fine (0-2 mm)	247	832	30	448	78	26
Coarse (0-4 mm)	289	713	28	635	99	47



Wheat Trial



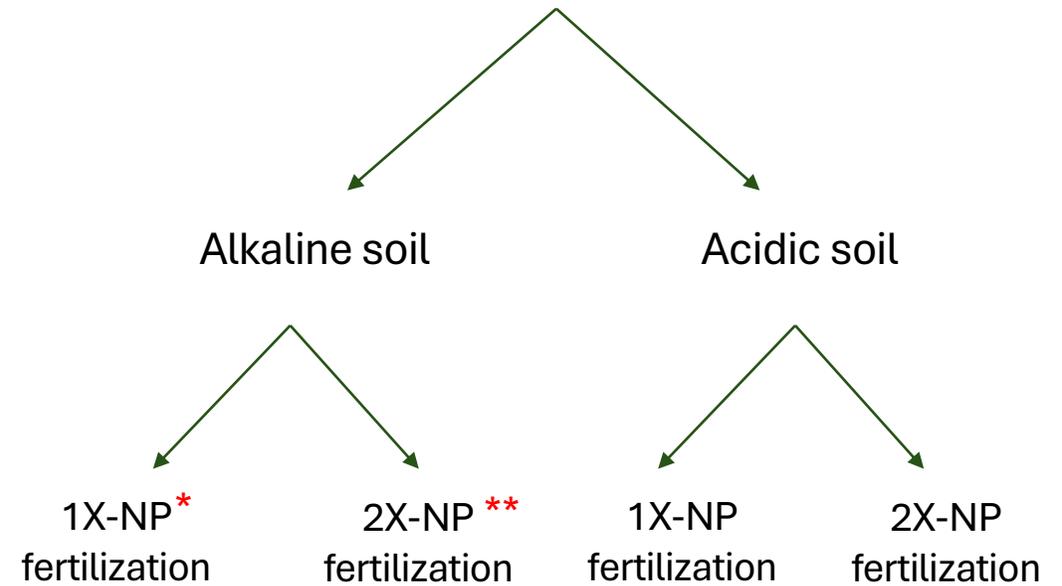
Investigation into effects of steel slag on:

»»» growth

»»» yield

»»» nutritional quality

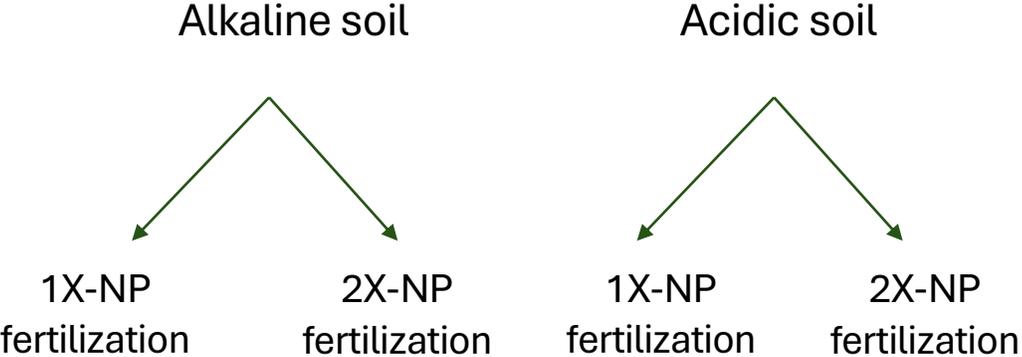
of bread wheat (*Triticum aestivum* cv. Nusrat).



* 1X-NP: 150 ppm $\text{Ca}(\text{NO}_3)_2$; 40 ppm KH_2PO_4

** 2X-NP: 300 ppm $\text{Ca}(\text{NO}_3)_2$; 75 ppm KH_2PO_4

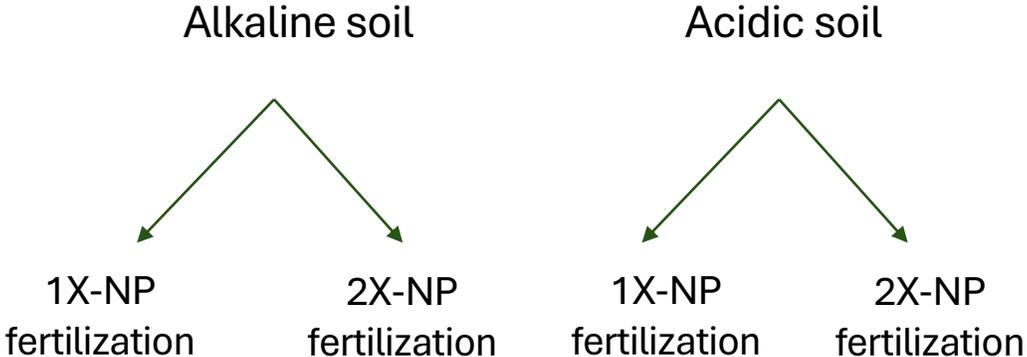
Wheat Trial



- 1** Fine Slag (0.5%)
- 2** Fine Slag (1.0%)
- 3** Fine Slag (2.0%)

- ① Coarse Slag (0.5%)
- ② Coarse Slag (1.0%)
- ③ Coarse Slag (2.0%)

Wheat Trial



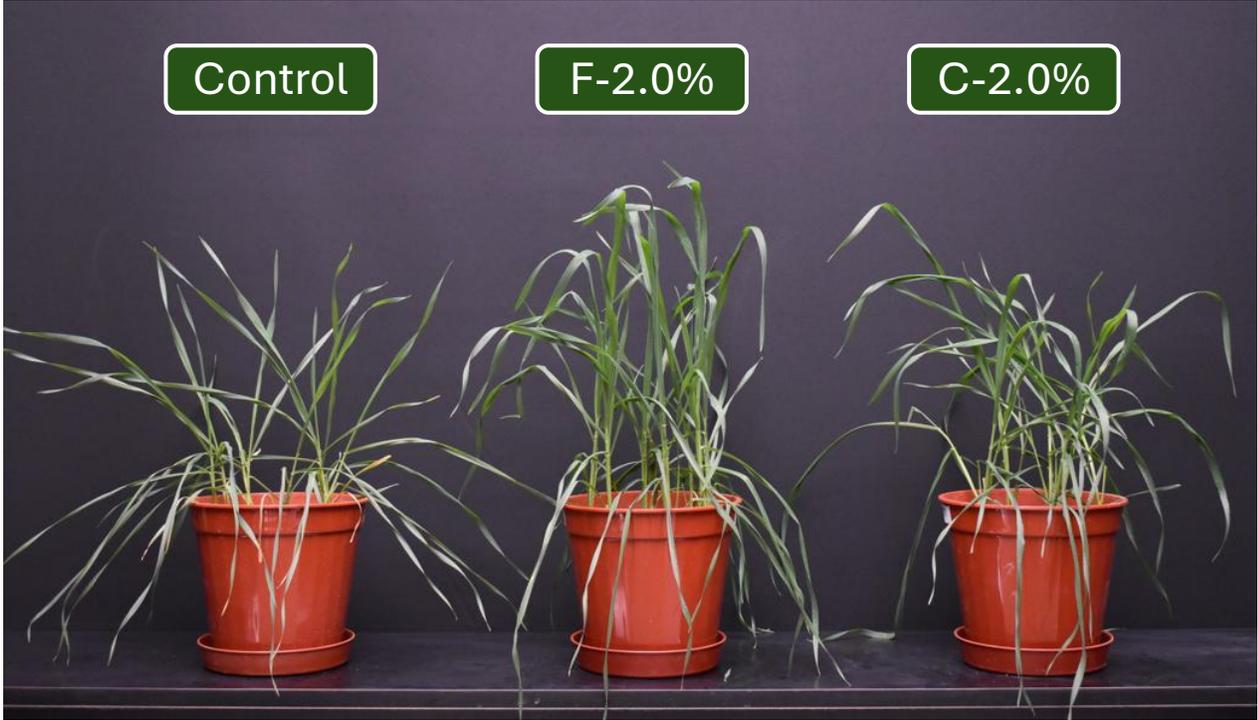
- Fine Slag (F-2.0%)

- Coarse Slag (C-2.0%)

- No Slag (Control)

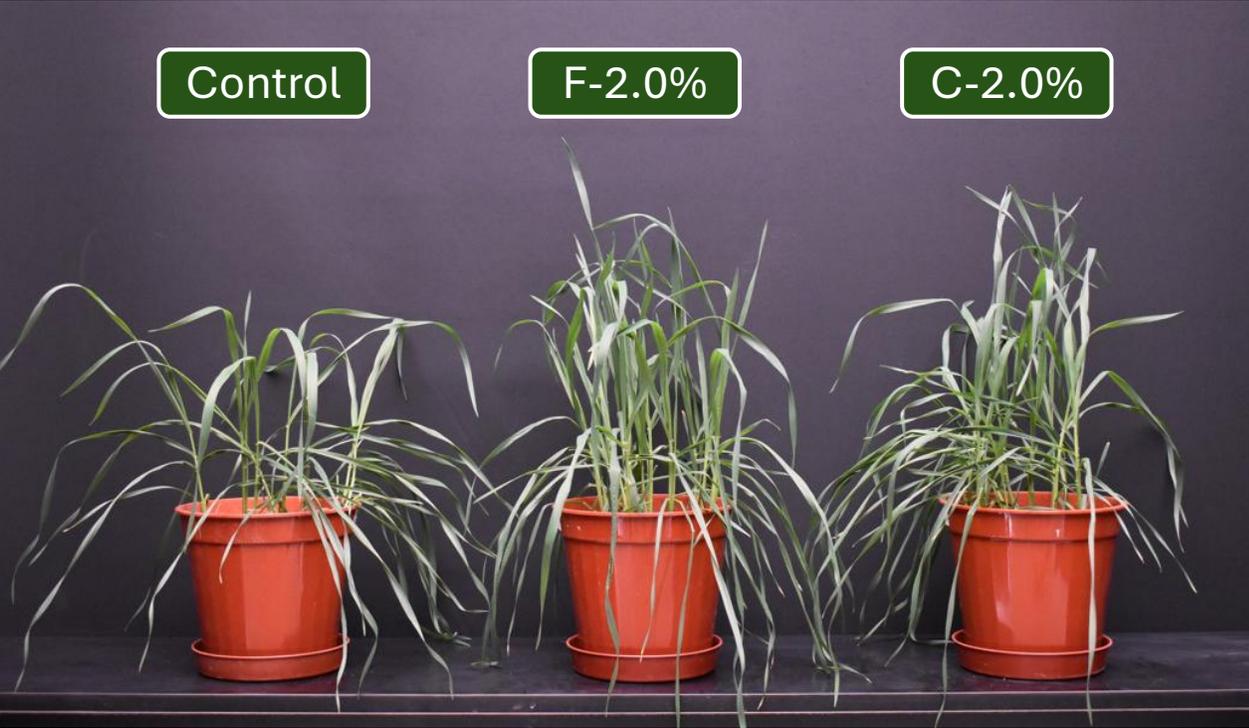
Biomass Results

Fertilization	Slag Treatment	Dry Biomass (g plant ⁻¹)	
		Alkaline Soil	Acidic Soil
1X-NP	Control	2.90 ± 0.18 bc	1.70 ± 0.09 d
	F-2.0%	2.72 ± 0.13 c	2.81 ± 0.31 b
	C-2.0%	3.04 ± 0.43 bc	1.95 ± 0.33 cd
2X-NP	Control	3.75 ± 0.18 a	1.95 ± 0.23 cd
	F-2.0%	3.55 ± 0.22 ab	3.48 ± 0.27 a
	C-2.0%	3.72 ± 0.46 a	2.51 ± 0.26 bc



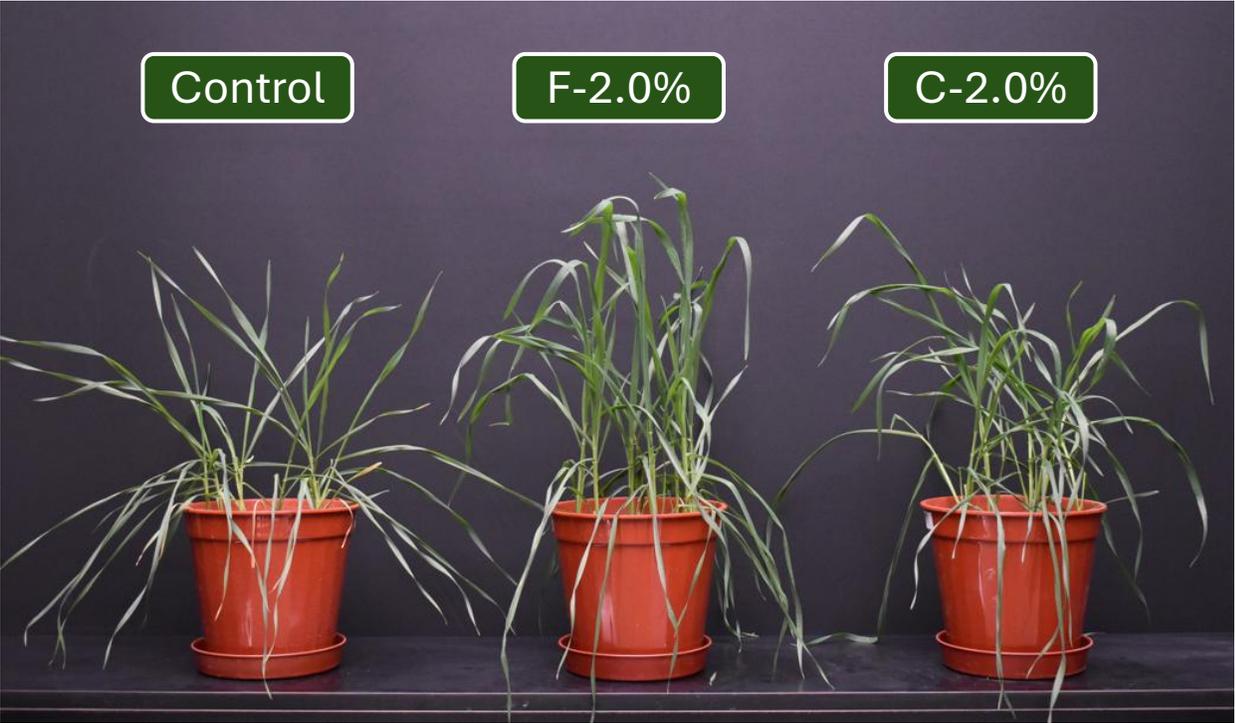
Biomass Results

Fertilization	Slag Treatment	Dry Biomass (g plant ⁻¹)	
		Alkaline Soil	Acidic Soil
1X-NP	Control	2.90 ± 0.18 bc	1.70 ± 0.09 d
	F-2.0%	2.72 ± 0.13 c	2.81 ± 0.31 b
	C-2.0%	3.04 ± 0.43 bc	1.95 ± 0.33 cd
2X-NP	Control	3.75 ± 0.18 a	1.95 ± 0.23 cd
	F-2.0%	3.55 ± 0.22 ab	3.48 ± 0.27 a
	C-2.0%	3.72 ± 0.46 a	2.51 ± 0.26 bc



Biomass Results

Fertilization	Slag Treatment	Chlorophyll Content ($\mu\text{g cm}^{-2}$)	
		Alkaline Soil	Acidic Soil
1X-NP	Control	42.1 \pm 1.6 a	32.9 \pm 2.8 c
	F-2.0%	41.1 \pm 1.0 a	38.7 \pm 0.6 ab
	C-2.0%	42.2 \pm 1.7 a	35.6 \pm 2.7 bc
2X-NP	Control	42.5 \pm 2.1 a	37.6 \pm 1.2 ab
	F-2.0%	40.3 \pm 1.0 a	41.3 \pm 1.4 a
	C-2.0%	43.1 \pm 0.5 a	41.0 \pm 0.9 a



Mineral Composition of Wheat Leaves

Macronutrients

Fertilization	Slag Treatment	pH	[P]		[K]		[Mg]		[S]	
			Alkaline Soil	Acidic Soil	Alkaline Soil	Acidic Soil	Alkaline Soil	Acidic Soil	Alkaline Soil	Acidic Soil
1X-NP	Control	4.3 ± 0.1	2.7 ± 0.2 b	1.4 ± 0.1 c	44.5 ± 0.8 a	53.5 ± 1.8 b	0.09 c	1.19 ± 0.04 ab	3.7 ± 0.2 b	3.0 ± 0.1 ab
	F-2.0%	4.1 ± 0.0	2.7 ± 0.1 b	2.6 ± 0.1 a	46.2 ± 0.6 a	57.7 ± 2.3 a	0.06 c	1.31 ± 0.10 a	3.4 ± 0.1 b	2.9 ± 0.1 b
	C-2.0%	4.1 ± 0.2	2.5 ± 0.1 b	2.6 ± 0.2 a	45.3 ± 0.8 a	58.1 ± 0.8 a	0.07 c	1.12 ± 0.01 b	3.6 ± 0.1 b	3.2 ± 0.1 a
2X-NP	Control	4.6 ± 0.2	2.8 ± 0.2 ab	2.5 ± 0.2 a	44.1 ± 1.4 ab	53.7 ± 1.3 b	0.06 a	1.31 ± 0.07 a	4.4 ± 0.1 a	3.0 ± 0.1 ab
	F-2.0%	4.3 ± 0.1	3.2 ± 0.1 a	1.8 ± 0.1 b	45.7 ± 0.5 a	51.0 ± 1.4 b	0.08 ab	1.24 ± 0.03 a	3.7 ± 0.2 b	3.1 ± 0.1 ab
	C-2.0%	4.4 ± 0.1	3.1 ± 0.3 a	2.5 ± 0.2 a	42.0 ± 1.4 b	51.7 ± 1.4 b	0.04 bc	1.21 ± 0.04 ab	3.6 ± 0.1 b	3.2 ± 0.1 ab

Mineral Composition of Wheat Leaves

Micronutrients

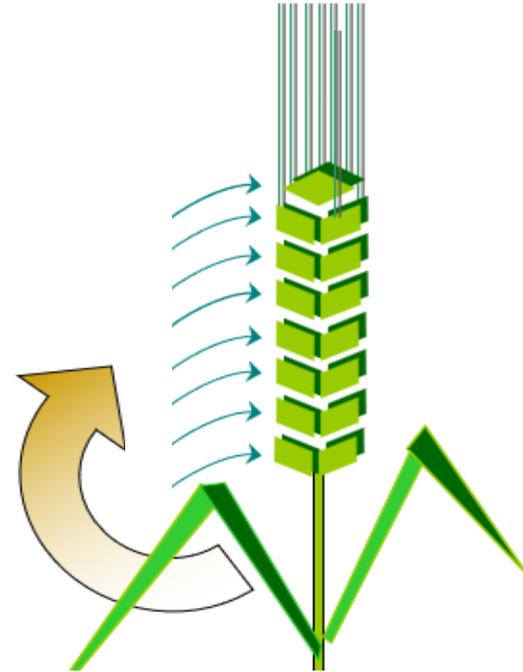
Fertilization	Slag Treatment	[Zn]		[B]		[Mo]		[Mo]				
		Alkaline Soil	Acidic Soil									
1X-NP	Control	32 ± 2	c	55 ± 4	a	3.3 ± 0.2	c	3.9 ± 0.3	d	0.7 ± 0.1	c	<i>n.d</i>
	F-2.0%	45 ± 4	a	54 ± 8	a	12.2 ± 1.8	ab	14.2 ± 0.3	a	1.9 ± 0.3	a	0.51 ± 0.05
	C-2.0%	43 ± 2	a	58 ± 1	a	10.0 ± 1.2	b	6.2 ± 0.6	c	1.2 ± 0.1	bc	<i>n.d</i>
2X-NP	Control									0.6 ± 0.1	c	<i>n.d</i>
	F-2.0%	32 ± 1	c	59 ± 9	a	5.6 ± 0.3	c	4.5 ± 0.6	cd	0.6 ± 0.1	c	<i>n.d</i>
	C-2.0%	37 ± 1	b	53 ± 3	a	13.0 ± 1.7	a	16.0 ± 1.2	a	1.5 ± 0.5	ab	0.26 ± 0.05
		34 ± 0	bc	64 ± 12	a	5.5 ± 1.1	c	8.3 ± 1.4	b	0.9 ± 0.4	c	<i>n.d</i>

Mineral Composition of Wheat Leaves

Others

		[Cd]	
		Alkaline Soil	Acidic Soil
Fertilization	Slag Treat	0.16 ± 0.02 a	0.25 ± 0.02 a
	Control	0.12 ± 0.03 ab	0.17 ± 0.04 b
	1X-NP	0.14 ± 0.01 ab	0.10 ± 0.01 c
Fertilization	Slag Treat	0.16 ± 0.03 a	0.17 ± 0.03 b
	Control	0.11 ± 0.01 b	0.13 ± 0.02 bc
	2X-NP	0.11 ± 0.01 b	0.16 ± 0.04 bc

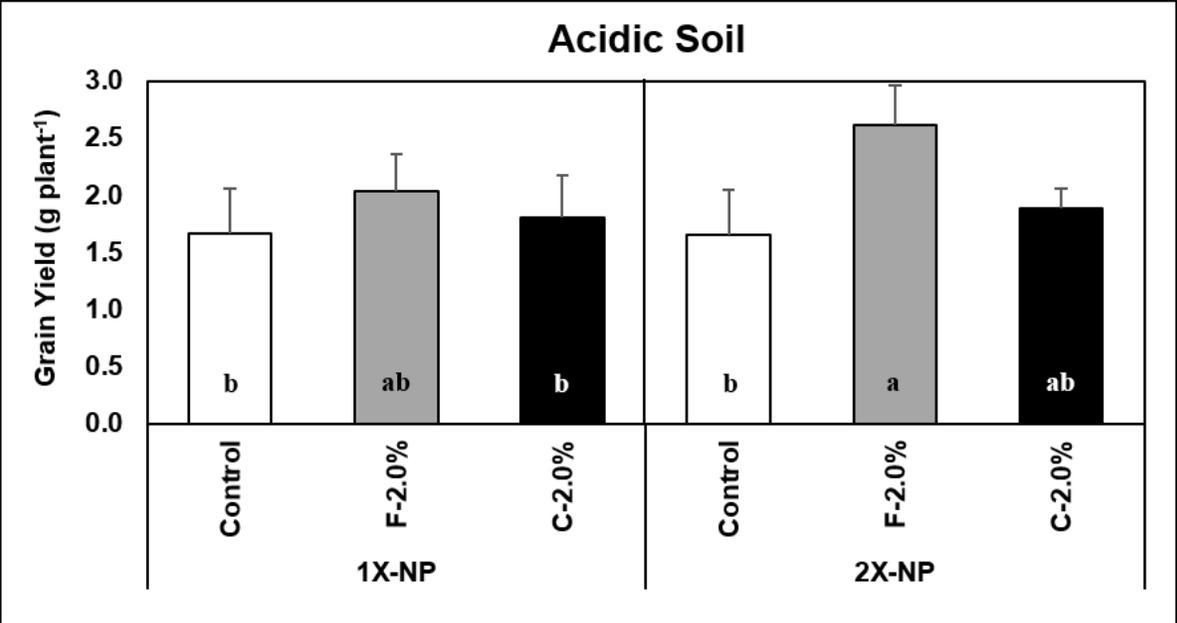
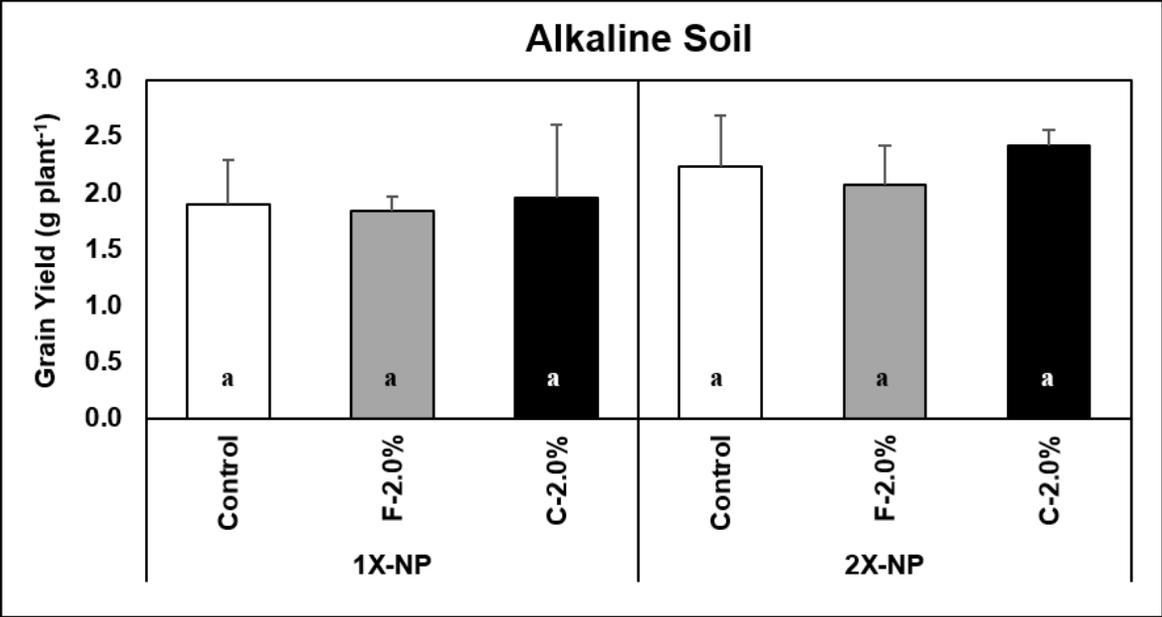
DILUTION EFFECT



		[V]		[Pb]	
		Alkaline Soil	Acidic Soil	Alkaline Soil	Acidic Soil
Fertilization	Slag Treat	<i>n.d.</i>	<i>n.d.</i>	1.85 ± 0.81 a	1.00 ± 0.33 a
	Control	<i>n.d.</i>	<i>n.d.</i>	1.71 ± 0.41 a	0.77 ± 0.32 a
	1X-NP	<i>n.d.</i>	<i>n.d.</i>	0.87 ± 0.28 a	1.23 ± 0.25 a
Fertilization	Slag Treat	<i>n.d.</i>	<i>n.d.</i>	1.73 ± 0.40 a	1.34 ± 0.42 a
	Control	<i>n.d.</i>	<i>n.d.</i>	1.71 ± 0.58 a	1.13 ± 0.59 a
	2X-NP	<i>n.d.</i>	<i>n.d.</i>	1.50 ± 0.08 a	1.19 ± 0.20 a

Biomass is high, but content does not change correspondingly.

Grain Yield Results



Wheat Growth at Harvest Time (4-month-old)

Acidic Soil / 2X-NP



Control

F-2.0%

C-2.0%

Acidic Soil / 1X-NP



Control

F-2.0%

C-2.0%

Mineral Composition of Wheat Grains

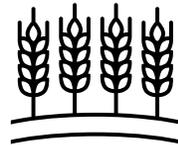
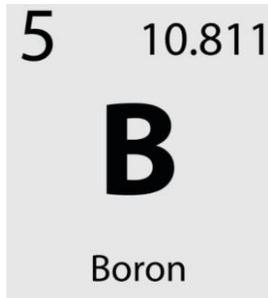
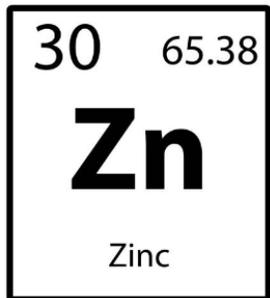


Fertilization	Slag Treatment	[Fe]	[Zn]		[Mo]		[B]	[Mo]		
			Alkaline Soil	Acidic Soil	Alkaline Soil	Acidic Soil				
1X-NP	Control	44.6 ± 3.3 bc	47 ± 4 c	102 ± 5 a	0.49 ± 0.06 c	<i>n.d</i>	0.34 ± 0.11 ab	0.57 ± 0.04 c	0.49 ± 0.06 c	<i>n.d</i>
	F-2.0%	45.3 ± 3.6 bc	60 ± 6 ab	77 ± 4 b	0.71 ± 0.10 ab	0.36 ± 0.04	0.56 ± 0.16 a	0.71 ± 0.07 ab	0.71 ± 0.10 ab	0.36 ± 0.04
	C-2.0%	47.0 ± 5.9 bc	62 ± 6 a	88 ± 5 ab	0.62 ± 0.07 a-c	<i>n.d</i>	0.27 ± 0.07 b	0.66 ± 0.03 bc	0.62 ± 0.07 a-c	<i>n.d</i>
2X-NP	Control	56.3 ± 1.0 a	50 ± 3 bc	78 ± 7 b	0.74 ± 0.10 a	0.29 ± 0.06	0.50 ± 0.08 ab	0.74 ± 0.10 ab	0.54 ± 0.12 bc	<i>n.d</i>
	F-2.0%	51.2 ± 1.7 ab	42 ± 4 c	88 ± 11 ab	0.54 ± 0.12 bc	<i>n.d</i>	0.49 ± 0.09 ab	0.83 ± 0.06 a	0.74 ± 0.10 a	0.29 ± 0.06
	C-2.0%	43.1 ± 2.0 c	41 ± 5 c	89 ± 12 ab	0.56 ± 0.03 a-c	<i>n.d</i>	0.40 ± 0.15 ab	0.81 ± 0.02 a	0.56 ± 0.03 a-c	<i>n.d</i>

Conclusion



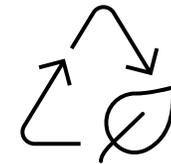
Beneficial role of slag
in improvement of
fertilizer use efficiency



Effective strategy in
increasing plant
growth, grain yield,
and nutritive quality



Safe soil amendment that
showed no accumulation
of toxic metals in plant
tissues



Effective application
strategy in terms of
sustainability

Acknowledgement



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