Supplemental Information

Graphite Nanoparticle Addition to Fertilizers Reduces Nitrate Leaching in Growth of Lettuce (*Lactuca sativa)*

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Fertilizer Treatments

The required amount of nutrients per treatment (six pots for trial 1 and four pots for trials 2 and 3) were dissolved into tap water and then sonicated and stirred on a stir plate for 30 minutes each. The dissolved nutrient solution was then constantly stirred to maintain homogeneity and distributed into centrifuge tubes on a per pot basis. The contents of the centrifuge tubes were poured onto the soil surface of each pot. The tube was rinsed with water to remove any residual nutrients/CNPs and added to the pots. The nutrients were split into two doses over the growing period, with one dose applied when seeds were planted and one dose mid-way through the growing period.

Nutrient Balance Calculations

The initial N values for the trial 1 growing season were calculated by summing the initial amount of nitrogen in the soil and the amount of nitrogen added from fertilization. Soil data was only collected for the trial 1 experiment and, therefore, is only applicable to the trial 1 nutrient balance. Trials 2 and 3 were only partial nutrient balances because only leachate and plant tissue were considered. The initial N values for the trial 2 and trial 3 growing seasons were calculated based on the amount of nitrogen added from fertilizer. Part A: Initial N is the average amount of nitrogen applied through fertilizer, and found naturally in the soil (trial 1 only). Part A: Post-Harvest is the average N content in the leachate, plant tissue, and post-harvest soil. Table S13 Part B is the percent of the total nitrogen within leachate, plant tissue, and soil at the end of the harvest. This was calculated by separately dividing the total nitrogen of the leachate, plant tissue, and soil by the initial amount of nitrogen. Subsequently, the percentage of added nitrogen from fertilizer was then calculated for leachate and plant tissue in Part C of Table S13 and Part B of Tables S15 and S18. The values in Table S13 Part C and Table S15 and S18 Part B represent how much of the nitrogen applied from fertilization ended up in the leachate and plant tissue. The plant tissue percentages represent the efficiency of nitrogen uptake for each treatment. Table S13 Part C and Table S15 and S18 Part B was calculated using Equation 1 by subtracting the no treatment data from the fertilizer treatment data then dividing by the total amount of nitrogen applied from fertilizer for each treatment.

Equation 1 $$\boldsymbol{Mass\ or\ Percent\ of\ applied\ N} = \frac{\boldsymbol{N - N_o}}{\boldsymbol{TF}}$$

N: amount of nitrogen in the leachate or plant tissue, N_o: amount of nitrogen in the no fertilizer (NT) leachate or NT plant tissue, TF: total amount of nitrogen added from fertilizer

Table S1. The cultivation period and experiment goal for each season.

Season	Start Date	Harvest Date	Experiment Goal
Trial 1	June 13, 2017	August 3, 2017	Vary fertilizer dose
Trial 2	September 8, 2017	November 29, 2017	Vary fertilizer dose
Trial 3	January 19, 2018 Transplanted February 9, 2018	April 10, 2018	Vary soil hydraulic conductivity

Table S2: Average monthly temperature (°F) and relative humidity (%) inside the greenhouse for all growing periods.

Month	Temperature (°F)	Relative Humidity (%)
June	26.1	31.5
July	26.2	45.8
September	24.7	37.8
October	24.3	33.3
November	23.6	39.7
February	23.5	30.3
March	22.4	28.6
April	24.6	28.6

Table S3. Summary of initial soil composition before planting. All nutrients are in mg/kg, cation exchange capacity (CEC) is in meq/100 g, and k_{sat} is in m/s.

Soil Type	P	K	Mg	Ca	Zn	Mn	Cu	Fe	B	TKN	NO_3	pH	CEC	k_{sat}	Organic Matter
AZ[1]	60.5	484	361	5210	3.50	159	3.35	40	2.93	1000	6.0	8.40	31.5	$4.6x10^{-6}$	0.54%
30S	66.0	484	401	5300	3.80	177	3.55	42	3.10	600	25	8.50	32.7	$5.2x10^{-6}$	
70S	54.0	176	253	2350	1.45	73.0	1.50	41	1.25	400	12	8.90	15.1	$3.4x10^{-5}$	

[1]Organic matter was only measured for the Arizona soil sample

Table S4. Analytical methods summary.

Analyte	Matrix	Method	Instrument	Lab
Nitrate	Leachate	EPA 300.1	Dionex ICS-5000	Arizona State University
Phosphate	Leachate	EPA 300.1	Dionex ICS-5000	Arizona State University
Chloride	Leachate	EPA 300.1	Dionex ICS-5000	Arizona State University
Sulfate	Leachate	EPA 300.1	Dionex ICS-5000	Arizona State University
Sodium	Leachate	ASTM D6919-19	Dionex ICS-5000	Arizona State University
Ammonium	Leachate	ASTM D6919-19	Dionex ICS-5000	Arizona State University
Potassium	Leachate	ASTM D6919-19	Dionex ICS-5000	Arizona State University
Magnesium	Leachate	ASTM D6919-19	Dionex ICS-5000	Arizona State University
Calcium	Leachate	ASTM D6919-19	Dionex ICS-5000	Arizona State University
Phosphorus	Soil	Mehlich 3 acid extraction	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA

Zinc	Soil	Mehlich 3 acid extraction	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA
Manganese	Soil	Mehlich 3 acid extraction	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA
Potassium	Soil	Mehlich 3 acid extraction	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA
Magnesium	Soil	Mehlich 3 acid extraction	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA
Calcium	Soil	Mehlich 3 acid extraction	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA
TKN	Soil			Waters Agricultural Labs Inc Camilla, GA
Nitrate	Soil	KCl-Cadmium Reduction	Flow injection analysis	Waters Agricultural Labs Inc Camilla, GA
pH	Soil		Hydrogen probe	Waters Agricultural Labs Inc Camilla, GA
CEC	Soil			Waters Agricultural Labs Inc Camilla, GA
TN	Plant tissue		LECO Nitrogen Gas analyzer	Waters Agricultural Labs Inc Camilla, GA
Phosphorus	Plant tissue	Wet digestion Digi Block 3000	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA
Potassium	Plant tissue	Wet digestion Digi Block 3000	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA
Magnesium	Plant tissue	Wet digestion Digi Block 3000	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA
Calcium	Plant tissue	Wet digestion Digi Block 3000	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA

Sulfur	Plant tissue	Wet digestion Digi Block 3000	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA
Boron	Plant tissue	Wet digestion Digi Block 3000	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA
Zinc	Plant tissue	Wet digestion Digi Block 3000	iCAP TQ ICP-MS	Waters Agricultural Labs Inc Camilla, GA

Table S5 Surface charge of CNP using zeta potential at pH 4, 7, and10

pH	Zeta Potential (mV)
4	-23.9
7	-36.7
10	-36.7

Table S6. Average lettuce leaf yield for the *trial 1* growing season.

Treatment	Average Yield (kg/ha)	Average Yield (g/pot)
NT	4,710 ± 2,983	19.3 ± 12
CNP	1,949 ± 1,053	8.00 ± 4.3
100	39,471 ± 9,697	162 ± 40
100+CNP	40,283 ± 10,856	165 ± 45
70+CNP	38,171 ± 3,690	157 ± 15

Table S7. Average lettuce leaf yield for the *trial 2* growing season. Due to germination issues, some trial 2 treatments had only two replicates indicated by the * symbol.

Treatment	Average Yield (kg/ha)	Average Yield (g/pot)
NT	6,335 ± 1,289	26.0 ± 5.3
CNP	9,989 ± 4,331	41.0 ± 18
100*	38,740 ± 2,412	159 ± 9.9
100+CNP	22,090 ± 7,570	90.7 ± 31
70	25,989 ± 7,184	107 ± 30
70+CNP*	30,456 ± 3,101	125 ± 13
50	20,141 ± 7,050	83.0 ± 29
50+CNP	12,507 ± 7,877	51.0 ± 32
30	15,350 ± 7,491	63.0 ± 31

Table S8. Combined average lettuce leaf yield for the *trial 1* and *trial 2* growing seasons for statistical analysis.

Treatment	Average Yield (kg/ha)	Statistical Relationships for $p>0.10$
NT	5,252 ± 2,576	b
CNP	5,969 ± 5,195	b
100	39,227 ± 7,598	a
100+CNP	31,187 ± 13,013	a
70	25,989 ± 7,184	a
70+CNP	35,085 ± 5,203	a
50	20,141 ± 7,050	a
50+CNP	12,507 ± 7,877	ab
30	15,350 ± 7,491	ab

Table S9. Average lettuce leaf yield for the *trial 3* growing season. Yields followed by the same superscript letter indicate no statistical difference ($p>0.10$).

Treatment	Average Yield (kg/ha)	Average Yield (g/pot)
NT AZ	2,680 ± 1,014 ^{b}	11.0 ± 4.2
NT 30S	2,558 ± 613 ^{b}	10.5 ± 2.5
NT 70S	393 ± 103 ^{a}	1.61 ± 0.42
CNP AZ	4,142 ± 281 ^{bc}	17.0 ± 1.2
CNP 30S	2,924 ± 487 ^{b}	12.0 ± 2.0
CNP 70S	454 ± 66 ^{a}	1.86 ± 0.27
30 AZ	11,573 ± 3,500 ^{d}	47.5 ± 14
30+CNP AZ	11,695 ± 4,340 ^{d}	48.0 ± 18
30 30S	11,533 ± 4,528 ^{d}	47.3 ± 19
30+CNP 30S	14,253 ± 1,924 ^{d}	58.5 ± 7.9
30 70S	8,771 ± 3,732 ^{cd}	36.0 ± 15
30+CNP 70S	9,502 ± 2,337 ^{d}	39.0 ± 9.6

Table S10. Average nutrient leached for *trial 1* experiment with one standard deviation. # of replicates that grew was out of 6 planted.

Treatment	# Replicates Grown	Na kg/ha	K kg/ha	Ca kg/ha	NO_3 kg/ha	Cl kg/ha	SO_4 kg/ha
NT	6	223±60	7.1±1.8	63±18	0.87±1.1	279±79	173±44
CNP	4	246±21	9.0±0.88	71±13	0.31±0.31	311±37	165±9.1
100	4	130±60	5.0±1.9	65±39	28±17	162±92	74±22
100+CNP	3	155±24	17±8.1	76±19	34±8.0	188±28	93±30
70+CNP	3	101±37	4.0±0.35	40±20	11±3.0	111±38	53±16

Table S11. Average nutrient leached for *trial 2* experiment with one standard deviation. # of replicates that grew was out of 4 planted.

Treatment	# Replicates Grown	Na kg/ha	K kg/ha	Mg kg/ha	Ca kg/ha	NO_3 kg/ha	Cl kg/ha	SO_4 kg/ha
NT	3	175±42	6.9±3.2	17±7.4	54±17	6.09±6.0	269±38	100±40
CNP	4	153±89	5.4±3.7	16±8.7	46±26	5.85±9.5	220±128	76±46
100	2	123±95	14±16	12±10	51±36	23.4±22	197±147	66±55
100+CNP	3	222±65	17±3.4	20±3.4	79±5.6	30.5±13	332±99	101±30
70	3	204±59	13±5.5	19±7.3	70±11	19.7±6.4	288±72	102±43
70+CNP	2	171±12	13±3.5	20±1.5	50±4.5	10.8±2.8	223±1.5	99±20
50	3	173±55	13±5.5	18±9.1	62±24	21.3±18	250±78	89±34
50+CNP	3	191±93	12±4.1	17±9.4	51±23	14.6±6.9	288±124	91±52
30	4	177±88	7.9±4.5	14±9.2	58±27	8.08±6.0	274±132	89±49
30+CNP	1	164	3.2	14	87	6.5	359	97

Table S12. Average nutrient leached for *trial 3* experiment with one standard deviation. # of replicates that grew was out of 4 planted.

Treatment	# Replicates Grown	Na kg/ha	K kg/ha	Mg kg/ha	Ca kg/ha	NO_3 kg/ha	Cl kg/ha	SO_4 kg/ha
NT AZ	4	142±38	5.4±0.7	7.7±1.5	59±19	3.6±4.4	181±47	90.8±33
NT 30S	4	148±46	5.1±2.1	9.1±2.4	55±18	4.1±1.4	191±57	83.5±33
NT 70S	4	199±30	7.3±1.3	14±1.5	64±9.1	1.7±0.66	260±32	102±22
CNP AZ	4	181±28	7.7±1.8	11±3.2	69±9.1	3.1±1.5	219±31	115±19
CNP 30S	3	214±34	7.5±0.7	12±2.7	74±9.2	3.6±0.78	265±42	132±20
CNP 70S	4	218±27	7.0±0.9	13±2.4	65±9.5	1.5±0.26	259±35	116±21
30 AZ	4	81±39	2.7±1.4	4.8±2.3	34±21	4.3±7.2	107±51	47.9±25
30+CNP AZ	4	135±60	4.7±2.7	8.1±3.4	56±28	15±9.8	165±76	77.0±34
30 30S	3	111±16	3.6±1.0	7.3±1.3	43±13	6.8±4.3	140±27	62.5±5.4
30+CNP 30S	4	120±56	4.1±2.1	7.6±3.9	42±23	5.3±4.6	147±66	72.6±38
30 70S	4	163±19	4.3±1.4	15±3.9	58±12	14±3.2	205±33	80.3±11
30+CNP 70S	4	126±46	3.4±1.4	10±3.5	43±18	6.4±7.0	171±60	56.7±29

Table S13. Overall average nutrient balance between leachate, plant tissue, and soil for the *trial 1* growing season. Part A is in units of average kg/ha for each treatment, and Parts B and C are percentages. The nitrogen content in the leachate, plant tissue, and post-harvest soil for each treatment totaled to 85, 83, 81, 93, 80% of the initial N available for NT, CNP, 100, 100+CNP, and 70+CNP, respectively (Table 4.12 Part B). The nitrogen mass balance was within 20% of the initial nitrogen available with losses attributed to nitrogen volatilization, microbial activity, and analytical error.

Part A. Average nitrogen content found initially and post-harvest per fertilizer treatment (kg/ha)

	NT	CNP	100	100+CNP	70+CNP
Initial N					
Fertilizer	0.00	0.00	196	196	137
Soil	784	784	784	784	784
Post-Harvest					
Leachate	0.87	0.31	27.0	34.0	11.4
Plant tissue	9.30	4.00	96.0	88.0	70.0
Soil	653	646	673	786	658

Part B. Percentage of nitrogen after harvest between leachate, plant tissue, and post-harvest soil (%)

Post-Harvest	**NT**	**CNP**	**100**	**100+CNP**	**70+CNP**
Leachate	0.11	0.04	2.81	3.45	1.24
Plant tissue	1.19	0.51	9.82	9.02	7.55
Post- Harvest Soil	83.3	82.3	68.6	80.2	71.4
Total	84.6	82.9	81.3	92.7	80.2

Part C. Percentage of added nitrogen in the leachate and plant tissue (%)

Post-Harvest	**100**	**100+CNP**	**70+CNP**
Leachate	13.6	16.9	7.70
Plant tissue	44.4	40.4	44.0

Table S14. Part A is the average *nutrient content (kg/ha)* in harvested plant tissue for *trial 1* experiment. The average is a total of the root and leaf samples for replicates within each treatment with one standard deviation. Part B is the average *concentration (g/kg)* of nutrients in the harvest lettuce leaf. # of replicates that grew was out of 6 planted.

Part A Treatment	# Replicates Grown	**N** kg/ha	**P** kg/ha	**K** kg/ha	**Mg** kg/ha	**Ca** kg/ha	**S** kg/ha	**Zn** kg/ha
NT	6	9.3±6.0	0.96±0.79	27±24	2.5±2.0	8.5±6.8	1.2±1.1	0.018±0.014
CNP	4	4.0±1.7	0.32±0.14	12±4.9	0.70±0.32	2.6±1.1	0.41±0.18	0.005±0.002
100	4	96±29	16±5.6	236±92	18±6.7	82±48	14±4.1	0.169±0.059
100+CNP	3	88±26	11±6.3	252±178	21±13	66±42	12±7.0	0.163±0.100
70+CNP	3	70±1.8	20±8.1	373±165	25±7.2	83±14	20±6.9	0.219±0.046
Part B Treatment		N g/kg	P g/kg	K g/kg	Mg g/kg	Ca g/kg	S g/kg	Zn g/kg
NT	6	17.3	0.77	15.6	2.97	8.93	1.12	0.024
CNP	4	20.4	1.70	70.4	3.10	13.7	2.10	0.020
100	4	24.0	3.08	51.2	2.60	10.8	2.53	0.026
100+CNP	3	21.6	0.80	8.00	3.37	7.60	1.27	0.026
70+CNP	3	16.3	1.83	17.3	3.07	7.30	1.87	0.028

Table S15. Overall average nutrient balance between leachate and plant tissue for the *trial 2* growing season. Part A is in units of average kg/ha for each treatment, and Parts B and C are in percentages.

	Part A Average nitrogen content found initially and post-harvest per fertilizer treatment (kg/ha)									
		NT	**CNP**	**100**	**100+CNP**	**70**	**70+CNP**	**50**	**50+CNP**	**30**
Initial N	Fertilizer	0	0	196	196	137	137	98	98	59
Post-Harvest	Leachate	6.10	5.85	23.4	30.5	19.7	10.8	21.3	14.6	8.08
	Plant tissue	13.5	19.4	70.6	42.4	44.9	47.6	39.7	29.5	28.4
	Part B			Percentage of added nitrogen in the leachate and plant tissue (%)						
				100	**100+CNP**	**70**	**70+CNP**	**50**	**50+CNP**	**30**
Post-Harvest	Leachate			8.8	13	10	3	16	9	3
	Plant tissue			29	15	23	25	27	16	25

Table S16. Part A is the average *nutrient content (kg/ha)* in harvested plant tissue for *trial 2* experiment. The average is a total of the root and leaf samples for replicates within each treatment with one standard deviation. Part B is the average *concentration (g/kg)* of nutrients in the harvest lettuce leaf. # of replicates that grew was out of 4 planted.

Part A Treatment	**# replicates grown**	**N** kg/ha	**P** kg/ha	**K** kg/ha	**Mg** kg/ha	**Ca** kg/ha	**S** kg/ha	**Zn** kg/ha
NT	3	13±3.9	2.3±1.7	31±11	2.6±2.0	8.1±5.3	1.7±1.0	0.023±0.020
CNP	4	19±6.5	3.3±0.86	45±16	3.7±1.6	13±4.2	2.3±0.72	0.037±0.014
100	2	71±17	7.4±0.74	161±13	9.0±1.5	30±2.7	7.5±1.0	0.105±0.012
100+CNP	3	42±5.2	4.4±0.97	91±20	5.7±1.5	18±3.9	4.2±1.0	0.061±0.004
70	3	45±6.7	5.1±0.94	105±12	6.5±0.08	26±9.7	4.4±0.56	0.068±0.003
70+CNP	2	48±6.1	5.5±0.52	114±17	6.5±0.08	20±1.6	5.3±0.73	0.070±0.005
50	3	40±11	4.0±1.1	84±20	4.5±1.5	18±7.3	3.3±0.96	0.048±0.017
50+CNP	3	30±21	3.7±2.7	70±50	5.0±4.0	17±12	3.4±2.3	0.049±0.037
30	4	28±15	5.4±5.1	111±106	5.4±4.8	21±21	4.3±3.7	0.050±0.044
30+CNP	1	40	6.8	124	9.1	30	6.4	0.081
Part B Treatment		N g/kg	P g/kg	K g/kg	Mg g/kg	Ca g/kg	S g/kg	Zn g/kg
NT	3	26.3	3.23	55.9	2.90	11.3	2.47	0.026
CNP	4	18.5	2.98	42.8	2.28	9.03	1.73	0.026
100	2	34.3	3.45	78.1	3.35	12.8	3.15	0.042
100+CNP	3	36.6	3.43	74.7	3.30	12.9	3.20	0.039
70	3	32.1	3.63	80.0	3.23	16.7	2.97	0.036
70+CNP	2	36.6	3.95	88.3	3.65	12.5	3.65	0.042
50	3	36.4	3.63	81.8	3.43	12.7	3.23	0.036
50+CNP	3	26.9	2.87	60.1	2.63	11.1	2.27	0.028
30	4	27.0	3.23	68.9	2.80	11.5	2.45	0.028
30+CNP	1	13.6	2.20	40.8	2.40	9.7	1.70	0.023

Table S17. The average leaf yield, nitrate leached, and nitrogen in the plant tissue in kg/ha for the *trials 1 and 2* experiments.

Treatments	**Trial 1 Leaf Yield**	**Trial 1 Nitrate Leached**	**Trial 1 Nitrogen in Leaf Tissue**	**Trial 2 Leaf Yield**	**Trial 2 Nitrate Leached**	**Trial 2 Nitrogen in Leaf Tissue**	**Average Trial 1+2 Leaf Yield**	**Average Trial 1+2 Nitrate Leached**	**Average Trial 1+2 Nitrogen in Leaf Tissue**
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
NT	4,710	0.87	9.33	6,335	6.09	13.5	5,252	2.61	10.7
CNP	1,949	0.31	4.00	9,989	5.85	19.4	5,969	3.08	11.7
100	39,471	27.5	96.2	38,740	23.4	70.6	39,227	26.1	87.7
100+CNP	40,283	33.8	88.4	22,090	30.5	42.4	31,187	32.2	65.4
70				25,989	19.7	44.9	25,989	19.7	44.9
70+CNP	38,171	11.4	69.6	30,456	10.8	47.6	35,085	11.2	60.8
50				20,141	21.3	39.7	20,141	21.3	39.7
50+CNP				12,507	14.6	29.5	12,507	14.6	29.5
30				15,350	8.08	28.4	15,350	8.08	28.4

Table S18. Average nutrient balance between leachate and plant tissue for the *trial 3* growing season. Part A is in units of average kg/ha for each treatment and Part B is in percentages.

	Part A Average nitrogen content initially & post-harvest per fertilizer treatment (kg/ha)											
		NT AZ	**NT 30S**	**NT 70S**	**CNP AZ**	**CNP 30S**	**CNP 70S**	**30 AZ**	**30+CNP AZ**	**30 30S**	**30+CNP 30S**	**30 70S**	**30+CNP 70S**
Initial N	Fertilizer	0	0	0	0	0	0	59	59	59	59	59	59
Post-Harvest	Leachate	3.6	4.1	1.4	3.1	3.6	1.5	4.3	15	6.8	5.3	14	6.4
	Plant tissue	7.6	6.2	1.2	12	7.3	1.7	34	37	30	38	28	30
Post-Harvest	**Part B Percentage of added nitrogen in the leachate and plant tissue (%)**												
	Leachate							1.2	19	4.7	2.2	22	8.5
	Plant tissue							44	50	40	54	45	50

Table S19. Part A is the average nutrient content in harvested plant tissue for *trial 3* experiment. The average is a total of the root and leaf samples for replicates within each treatment with one standard deviation. Part B is the average concentration of nutrients in the harvest lettuce leaf. # of replicates that grew was out of 4 planted.

Part A Treatment	**# Replicates Grown**	**N** kg/ha	**P** kg/ha	**K** kg/ha	**Mg** kg/ha	**Ca** kg/ha	**S** kg/ha	**Zn** kg/ha
NT AZ	4	7.6±1.3	0.70±0.11	15±2.80	0.99±0.18	2.8±0.58	0.79±0.13	0.007±0.001
NT 30S	4	6.2±1.3	0.60±0.18	13±3.39	0.98±0.24	2.8±0.77	0.69±0.15	0.006±0.002
NT 70S	4	1.2±0.61	0.13±0.07	2.6±1.38	0.22±0.12	0.53±0.28	0.12±0.06	0.001±0.001
CNP AZ	4	12±1.3	0.86±0.17	21±2.44	1.3±0.25	4.1±0.74	0.98±0.16	0.01±0.001
CNP 30S	3	7.3±0.81	0.72±0.08	15±2.37	1.1±0.15	3.3±0.33	0.78±0.09	0.007±0.001
CNP 70S	4	1.7±0.51	0.22±0.07	3.9±1.09	0.32±0.09	0.82±0.25	0.20±0.06	0.002±0.001
30 AZ	4	34±9.4	2.2±0.47	59±13.9	4.1±1.3	13±4.6	3.1±1.0	0.03±0.01
30+CNP AZ	4	37±11	2.3±0.76	63±21.8	4.5±2.1	14±8.1	3.2±1.1	0.03±0.01
30 30S	3	30±11	2.2±0.85	58±22.0	4.7±2.2	13±6.1	2.7±1.1	0.03±0.02
30+CNP 30S	4	38±3.6	3.0±0.23	71±4.43	5.2±0.92	16±2.9	3.4±0.48	0.04±0.01
30 70S	4	28±6.4	1.5±0.62	39±17.4	3.4±1.3	8.5±3.5	2.0±0.78	0.02±0.01
30+CNP 70S	4	30±7.8	1.7±0.43	47±8.40	4.1±1.3	10±2.9	2.2±0.57	0.02±0.01
Part B Treatment		N g/kg	P g/kg	K g/kg	Mg g/kg	Ca g/kg	S g/kg	Zn g/kg
NT AZ	4	20.8	1.60	35.7	1.65	7.15	1.60	0.013
NT 30S	4	14.4	1.20	25.3	1.38	5.93	1.23	0.009
NT 70S	4	13.9	1.50	26.0	1.90	6.40	1.20	0.010
CNP AZ	4	22.3	1.38	34.6	1.58	7.18	1.50	0.012
CNP 30S	3	16.0	1.43	29.4	1.63	6.97	1.30	0.009
CNP 70S	4	11.5	1.50	22.1	1.60	5.80	1.10	0.009
30 AZ	4	21.3	1.28	37.2	1.53	7.30	1.53	0.012
30+CNP AZ	4	25.5	1.28	38.8	1.83	7.90	1.68	0.014
30 30S	3	18.8	1.23	35.6	1.73	7.00	1.40	0.011
30+CNP 30S	4	19.3	1.30	34.1	1.68	7.13	1.28	0.013
30 70S	4	15.6	0.85	22.2	1.50	5.38	1.05	0.007
30+CNP 70S	4	17.9	0.95	26.5	1.65	6.00	1.18	0.010

Table S20. The average leaf yield, nitrate leached, and nitrogen in the plant tissue in kg/ha for the *trial 3* experiment.

Treatment	**Leaf Yield** (kg/ha)	**Nitrate Leached** (kg/ha)	**Nitrogen in Leaf Tissue** (kg/ha)
NT AZ	2,680	3.60	7.60
NT 30S	2,558	4.10	6.20
NT 70S	393	1.40	1.20
CNP AZ	4,142	3.10	12.0
CNP 30S	2,924	3.60	7.30
CNP 70S	454	1.50	1.70
30 AZ	11,573	4.30	34.0
30+CNP AZ	11,695	15.5	37.0
30 30S	11,533	6.80	30.0
30+CNP 30S	14,253	5.30	38.0
30 70S	8,771	14.0	28.0
30+CNP 70S	9,502	6.40	30.0

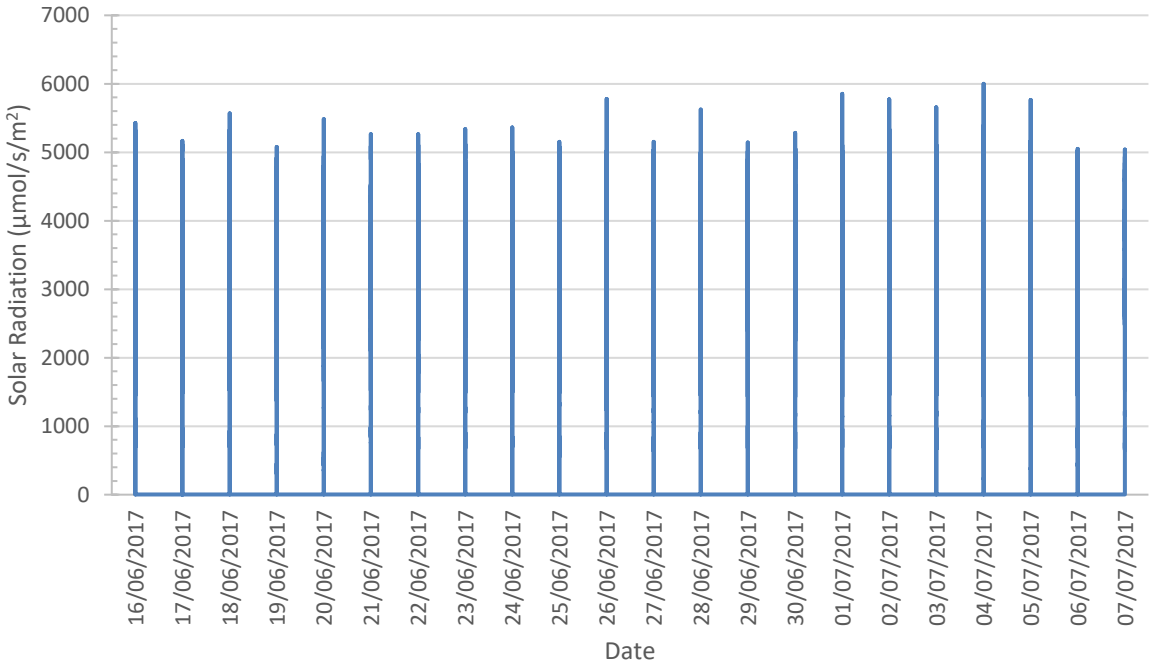

Figure S1. Photosynthetically active radiation (PAR) data for the *trial 1* experiment from sensor in greenhouse.

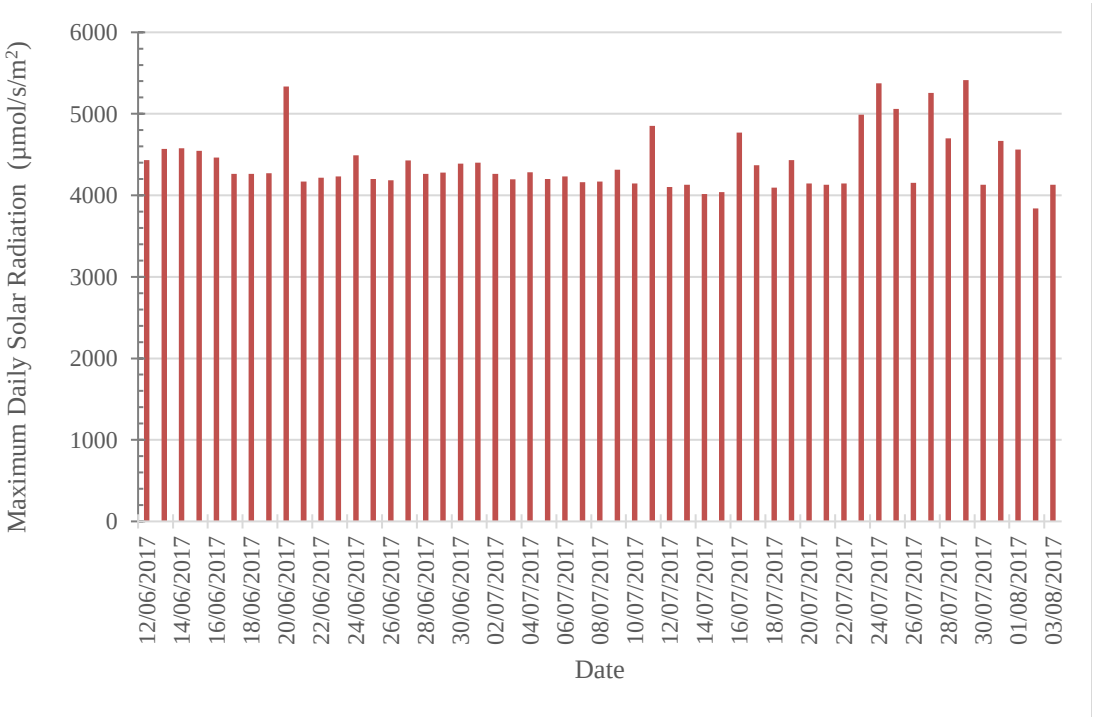

Figure S2. Solar radiation data for the *trial 1* experiment from Tempe Town Lake weather station to supplement missing PAR data in Figure S1.

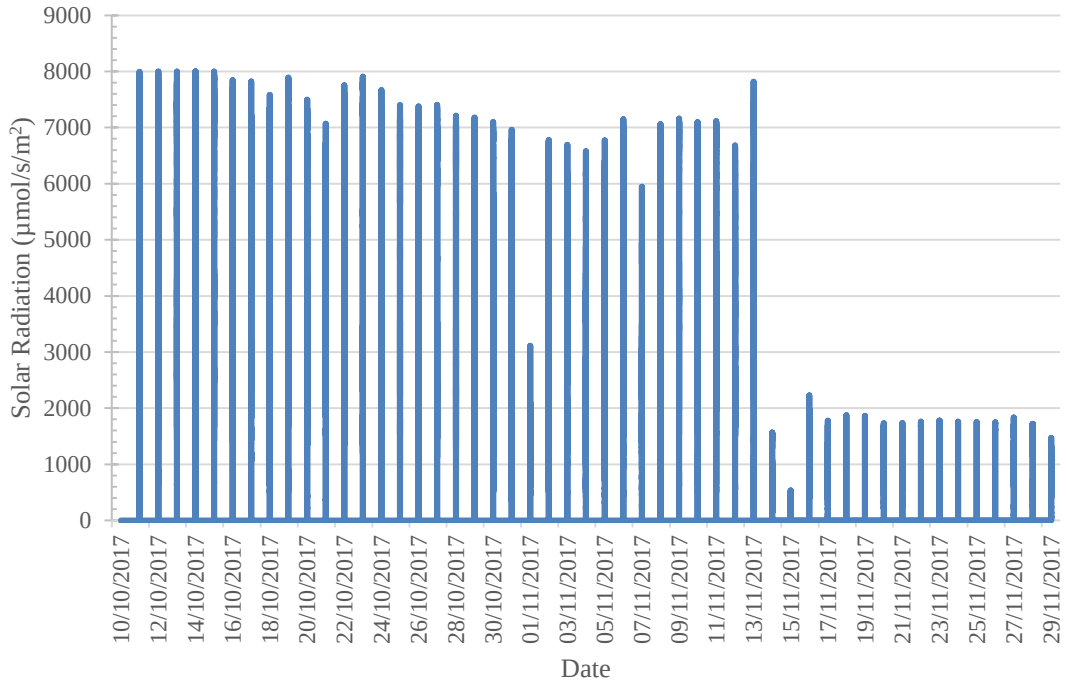

Figure S3. PAR data for the *trial 2* experiment from sensor in greenhouse.

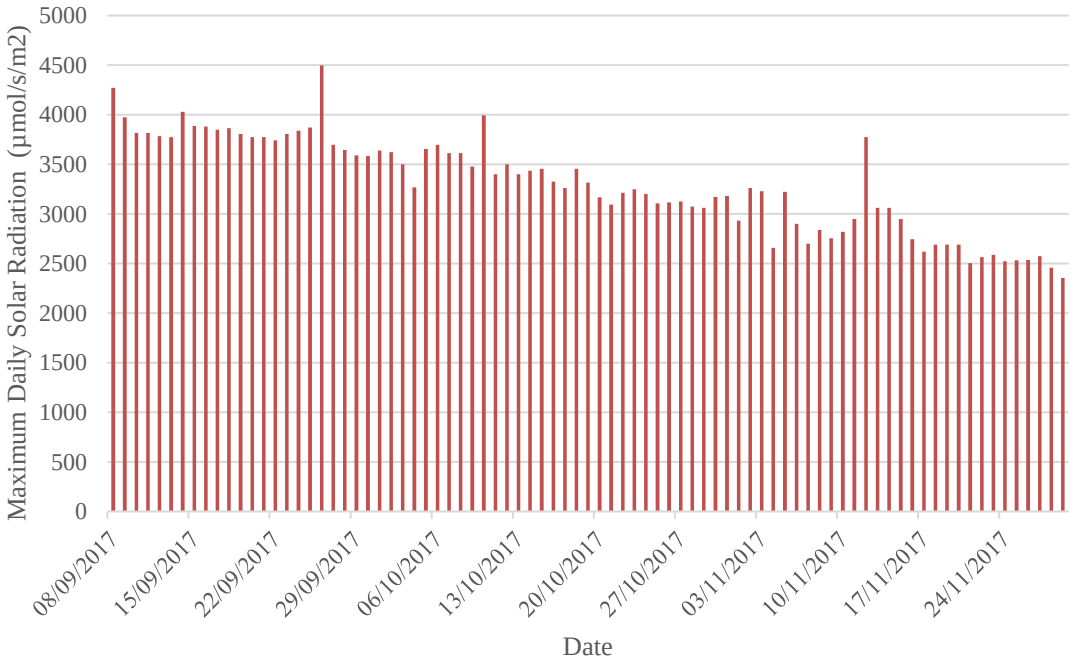

Figure S4. Solar radiation data for the *trial 2* experiment from Tempe Town Lake weather station to supplement missing PAR data in Figure S3.

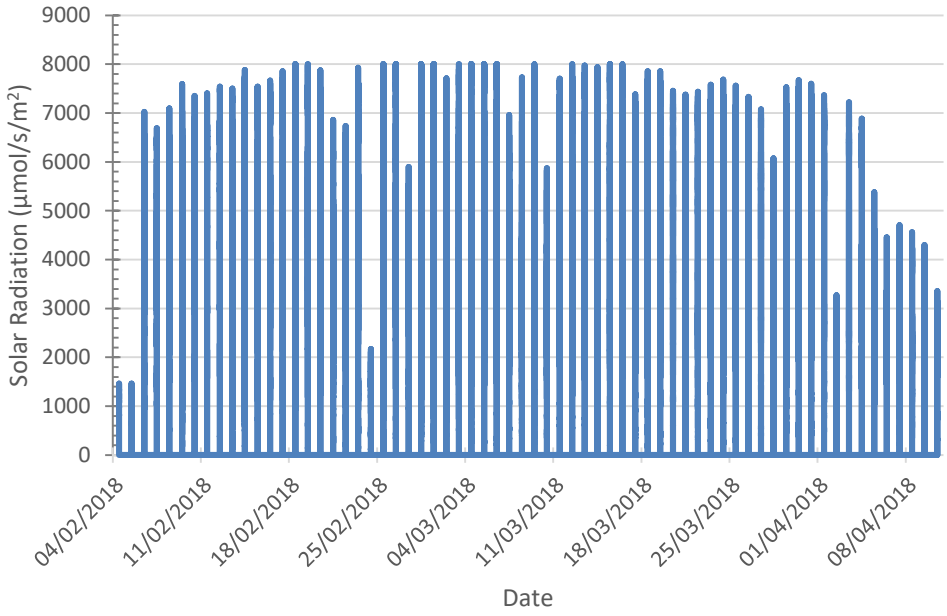

Figure S5. PAR data for the *trial 3* experiment from sensor in greenhouse.

Randomized complete block design
Microsoft Excel was used to randomize the treatments within each block by assigning each treatment a letter and random number (using the random number function) and then sorting the numbers and assigning each treatment to a row within the block (Grant, 2010).

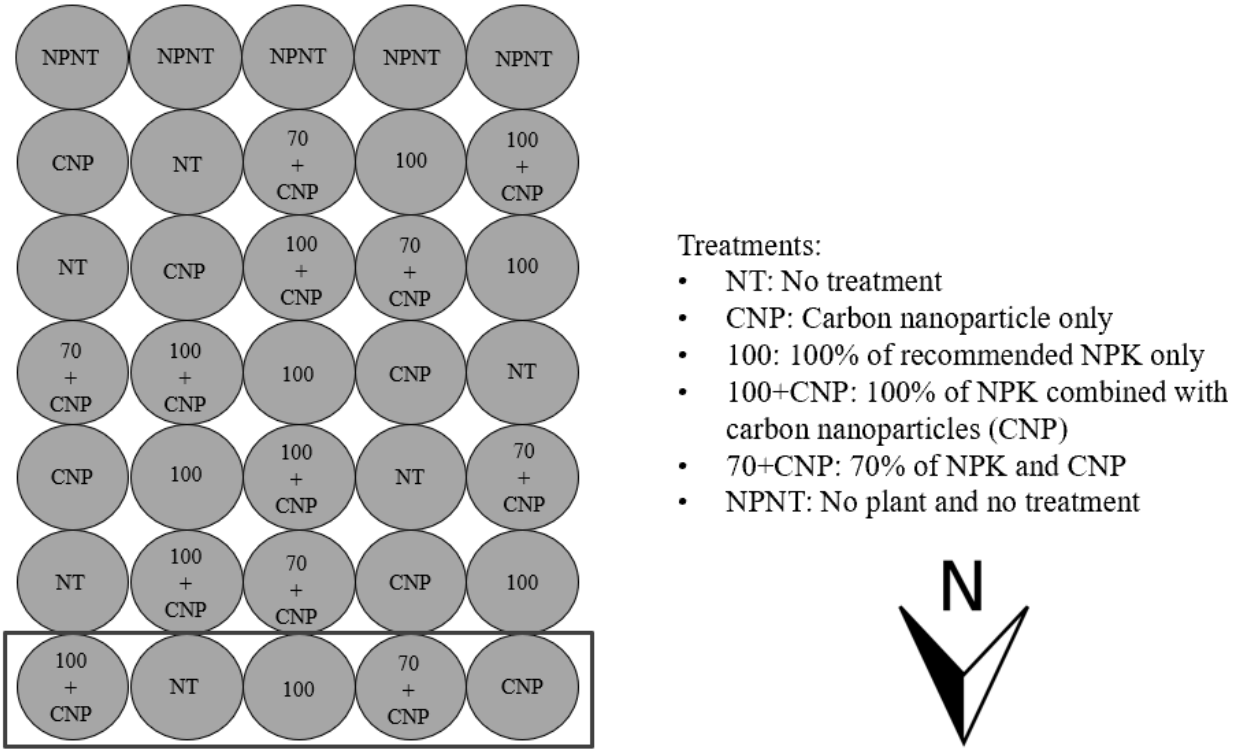

Figure S6. Trial 1 treatment pot configuration. The Randomized Complete Block Design is oriented as rows from left to right, meaning that each row contains one replicate of each treatment. The NPNT pots contained soil that was only irrigated to ensure irrigation standards were met.

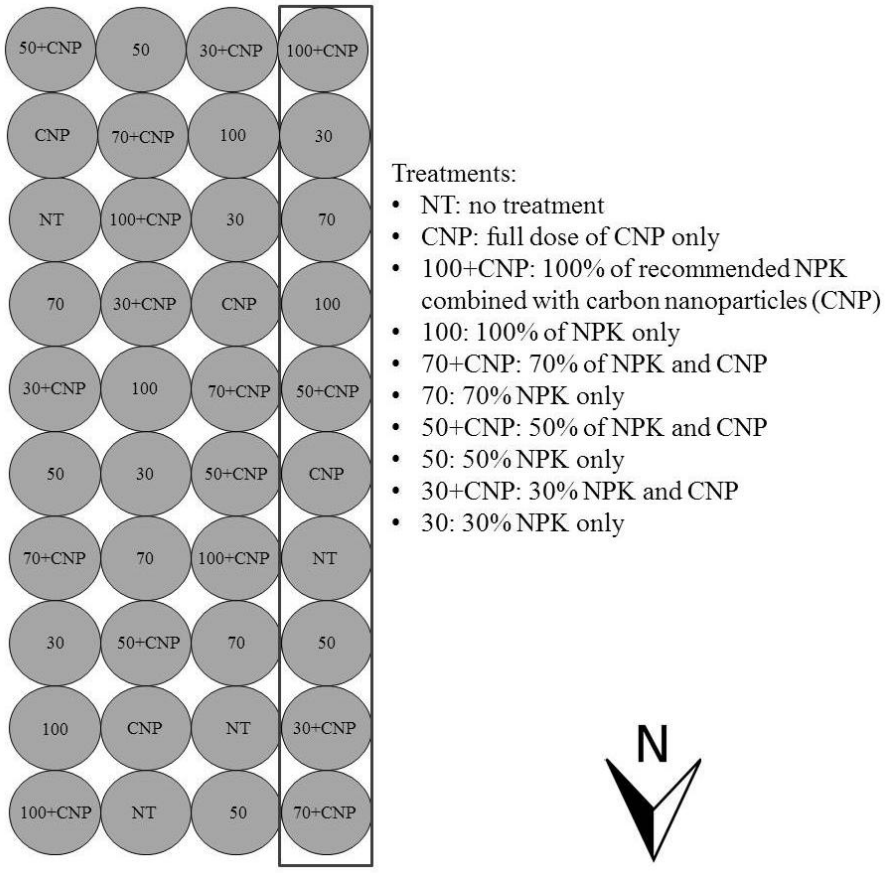

Figure S7. Trial 2 treatment pot configuration. The Randomized Complete Block Design is oriented as vertical columns, meaning that each column contains one replicate of each treatment.

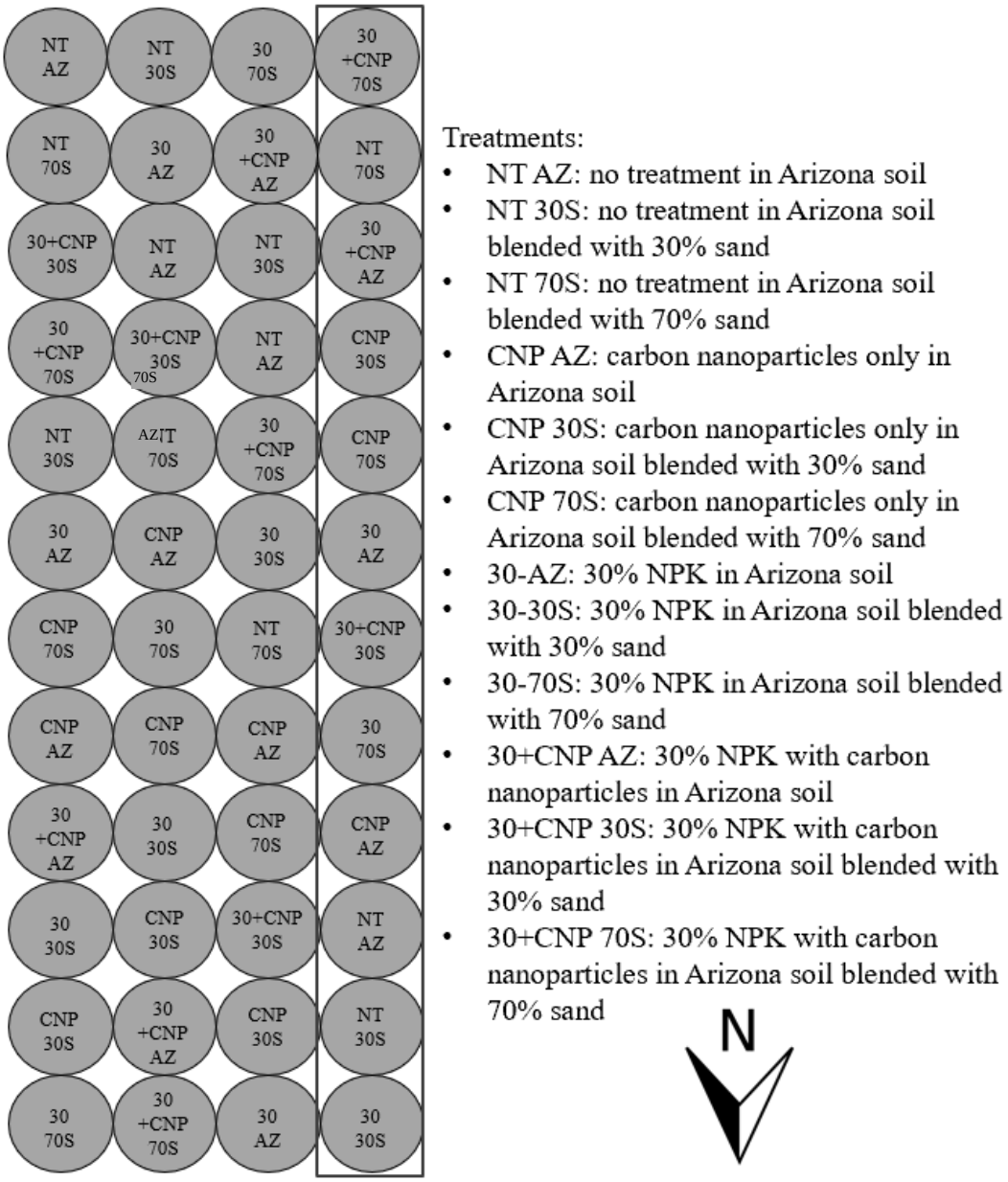

Figure S8. Trial 3 treatment pot configuration. The Randomized Complete Block Design is oriented as vertical columns, meaning that each column contains one replicate of each treatment.

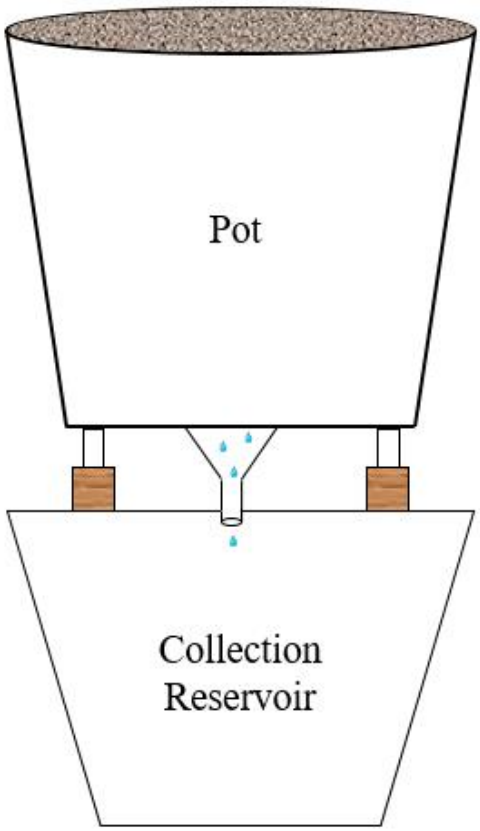

Figure S9. Leachate Collection Setup. The water flows from the pot through the funnel into the collection reservoir. The pot is elevated on wooden blocks to provide enough room for the funnel.

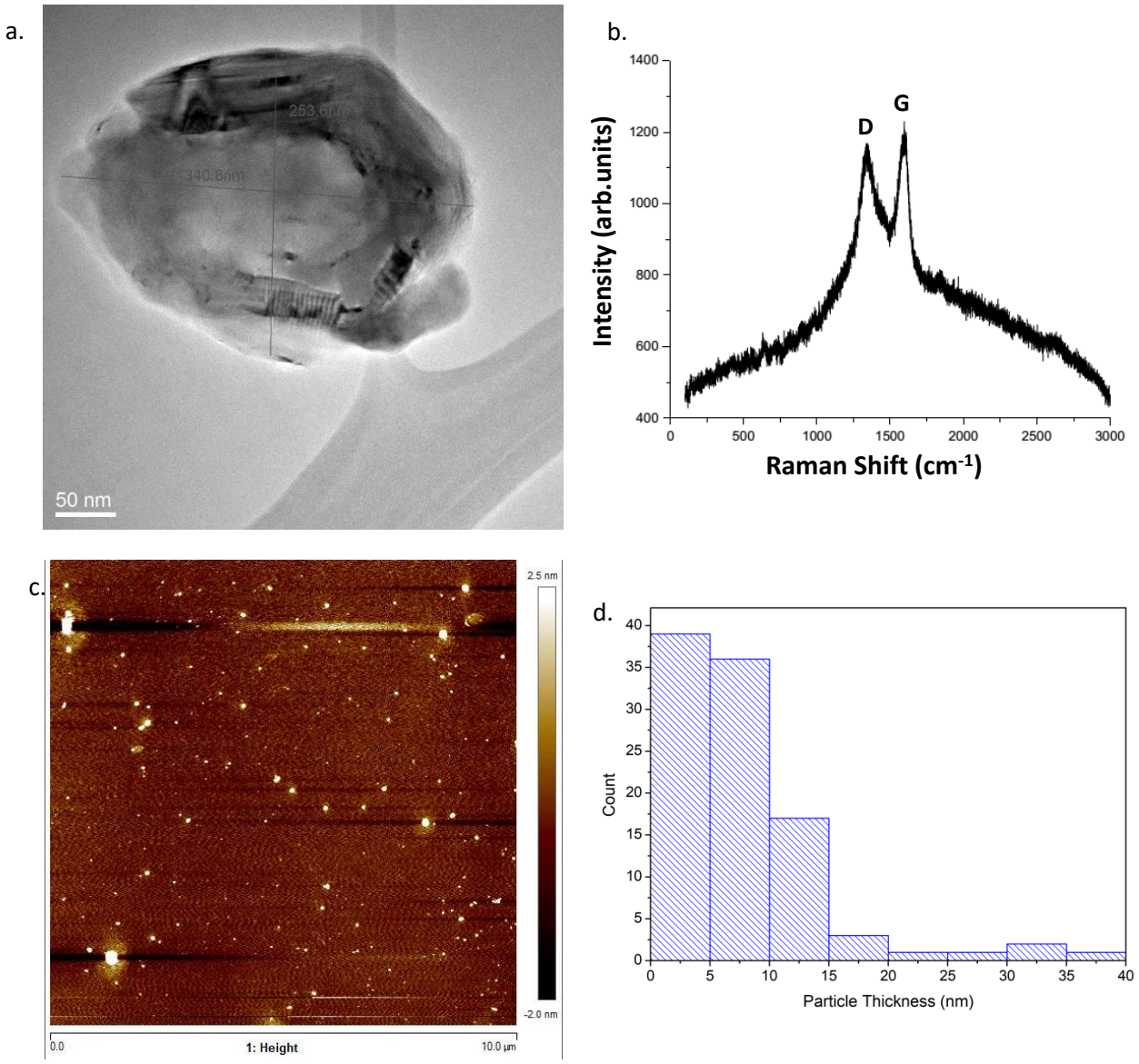

Figure S10. Graphite nanoparticle characterization: a) TEM for size and structure, b) Raman for types of carbon, and c,d) AFM for particle thickness.

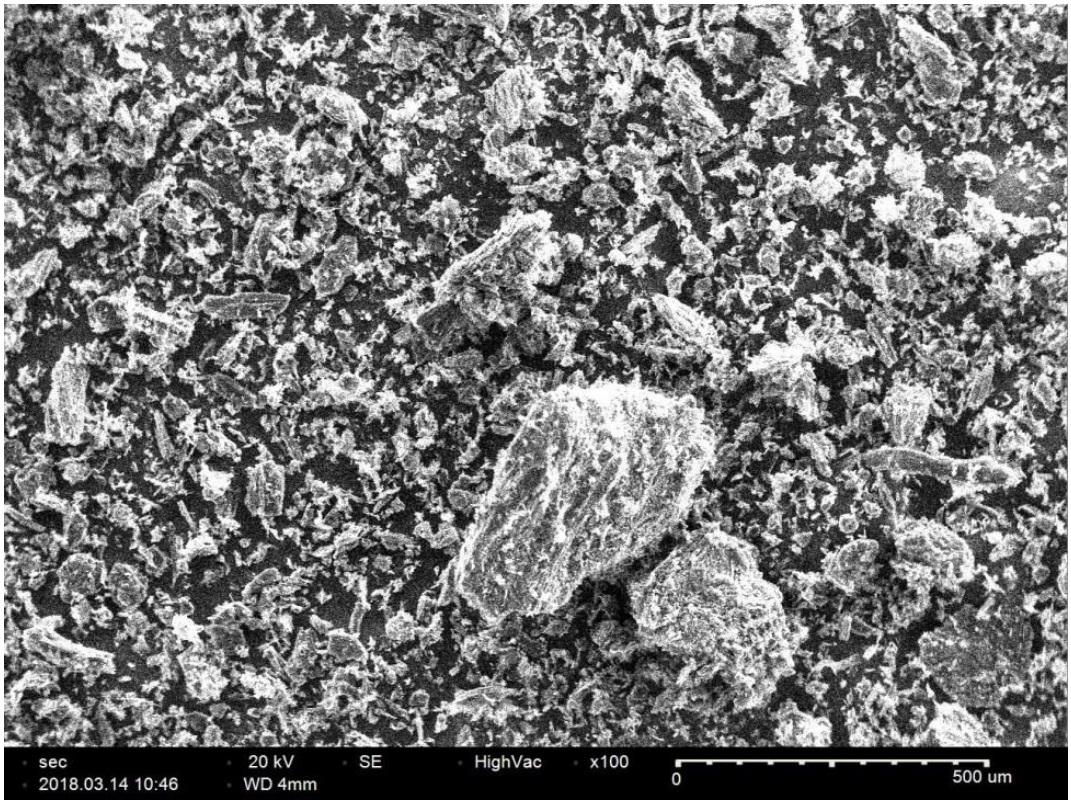

Figure S11. SEM image showing size distribution of carbon nanoparticles (CNPs). The image contains over 100 particles ranging in size from <100 nm to >300 μm

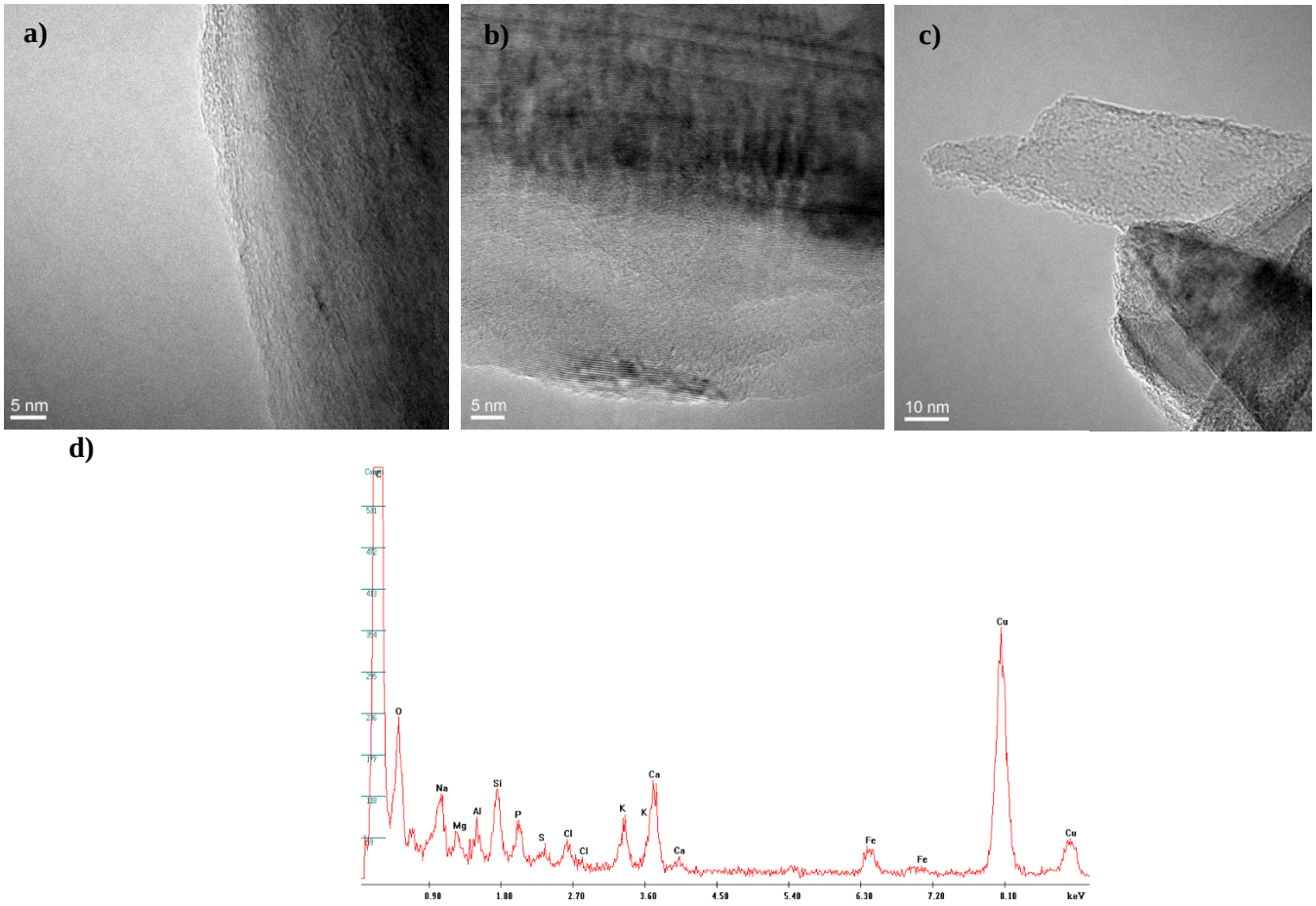

Figure S12. a-c) TEM images demonstrating graphite and amorphous carbon structures. d) elemental mapping of the CNP surface.

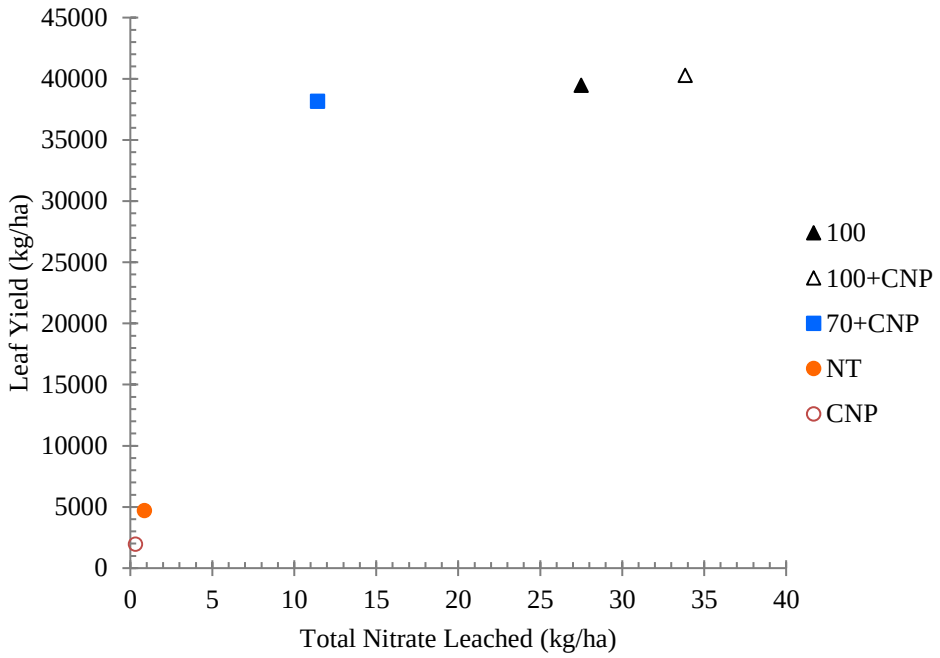

Figure S13. *Trial 1* leaf yield (kg/ha) versus total nitrate leached (kg/ha). NPK fertilizer treatments are grouped by color, and an open symbol represents a treatment with CNP added.

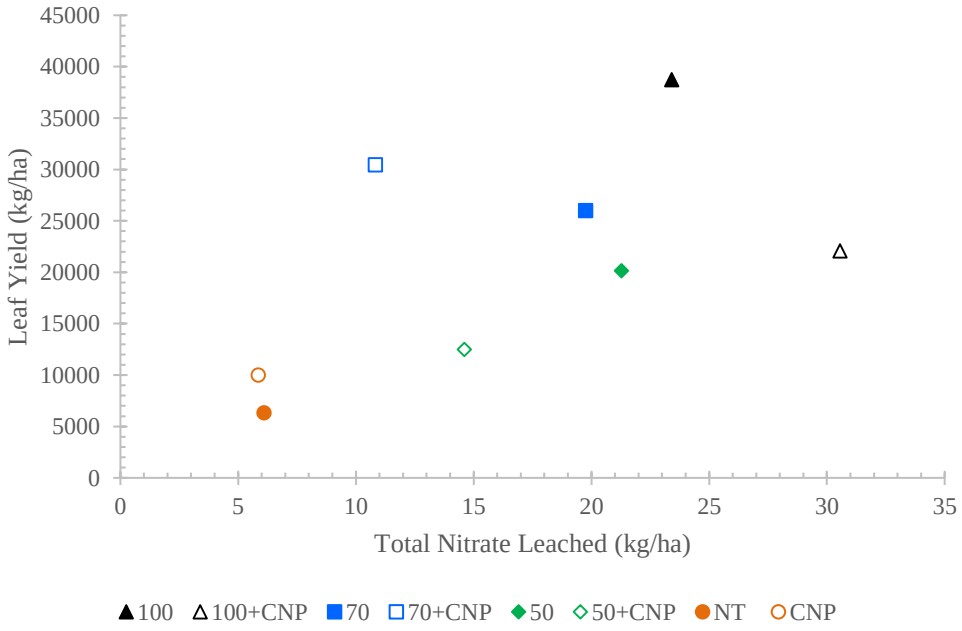

Figure S14. *Trial 2* leaf yield (kg/ha) versus total nitrate leached (kg/ha). NPK fertilizer treatments are grouped by color and symbol, and an open symbol represents a treatment with CNP added.

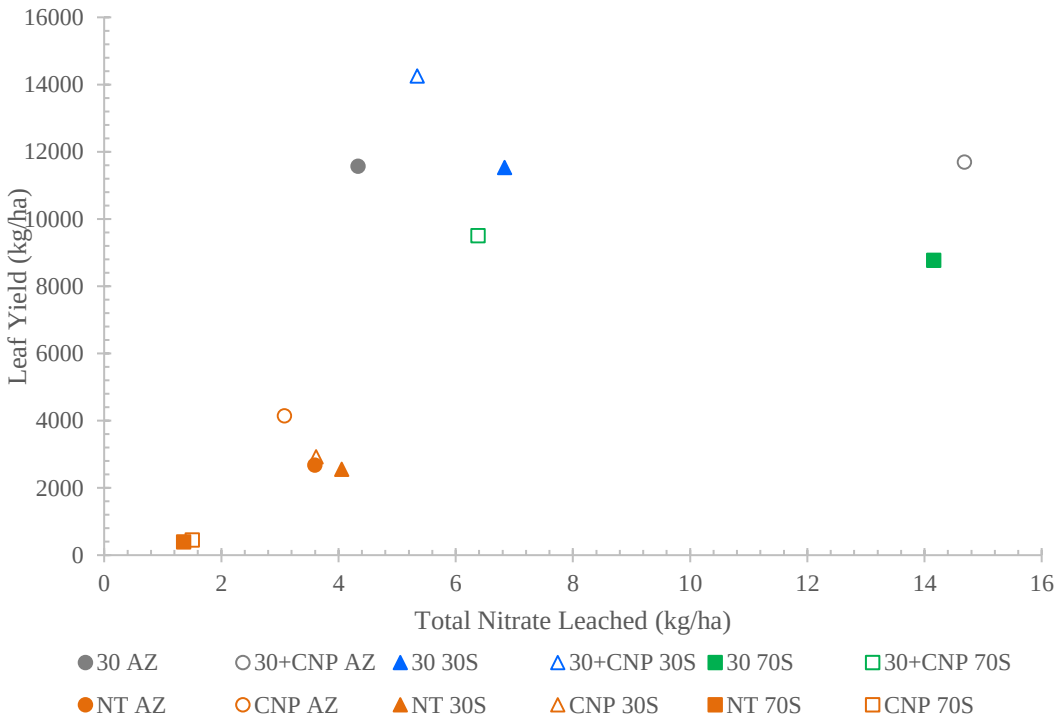

Figure S15. *Trial 3* leaf yield (kg/ha) versus total nitrate leached (kg/ha). NPK fertilizer treatments are grouped by color and soil types are grouped by symbol. An open symbol represents a treatment with CNP added.

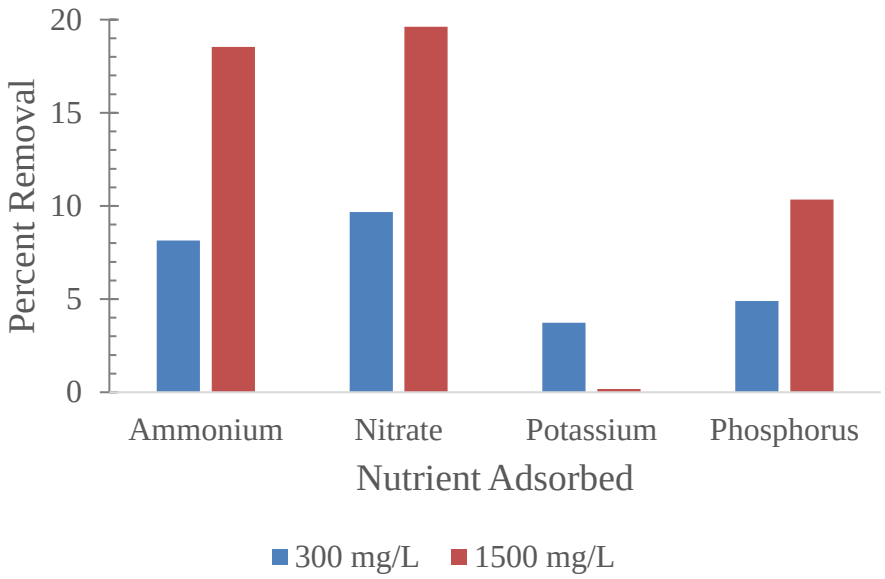

Figure S16. Adsorption study using CNPs at 300 and 1,500 mg/L mixing in a nutrient solution (ammonium, nitrate, potassium, and phosphate) for three days on an end-over-end shaker.

References

1. T. Grant, The Randomized Complete Block Design (RCBD), http://pbgworks.org/sites/pbgworks.org/files/RandomizedCompleteBlockDesignTutorial.pdf, 2018).