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Phosphorus Recovery from Hydroponics Waste Solutions and its Economic Potential – Supplementary Material

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Supplementary Table S1. Data on hydroponics growers in New South Wales, Australia

FARM NO.	2	3	4	5	1	1 (UPGRADED)
COLLECTION DATE	03/5/2023	03/5/2023	03/5/2023	03/5/2023	07/2/2022	15/12/2022
LOCATION	Wallacia, NSW	Wallacia, NSW	Kemps Creek, NSW	Rossmore, NSW	Brookvale, NSW	Brookvale, NSW
HWNS SAMPLE NUMBER	3, 4, 5 and 6	7 and 8	9	10	1	2
TECHNOLOGY	Dripping / hydroponics	Dripping / hydroponics	Dripping / hydroponics	Greenhouse hydroponics - ebb and flow — controlled environment	Vertical farming (Shipping container)	Vertical farming (racks within a greenhouse)
CROP	Tomato	Cucumber, capsicum and chilli	Tomato, cucumber, zucchini and chilli	flowers, microgreens, and aromatic herbs	Leafy vegetables and microgreens	Leafy vegetables and microgreens
FARM SIZE	Four greenhouses with a total area of 9000 m^2. Tomato plants are grown in lines with 1 meter spacing between the adjacent lines and the plants are 0.8-1.2 meters apart	25 greenhouses with a gross area of over 10000 m^2			5 shipping containers with grown area of almost 1200 m^2	6 racks with a gross area of almost 4000 m^2
SUPPORT MEDIUM	Soil planting mix	Soil planting mix	Soil planting mix	Coco-coir	Coco-coir	Coco-coir
IRRIGATION REPETITION (TIMES PER DAY)	5 – 7 times per day (depending on the amount of sunlight	5 – 7 times per day (energy based)	5 – 7 times per day (energy based)		3 times per day	3 times per day

FARM NO.	2	3	4	5	1	1 (UPGRADED)
	applied on unit area – Jules per m^2. Energy sensors are in use.					
EC IN THE BEGINNING OF THE CYCLE (MS/CM)	1.3 (mS/cm)		2 (for cucumber) 3 (for other crops)		2	2
EC IN THE END OF THE CYCLE (MS/CM)	1.3 (mS/cm)		2 (for cucumber) 3 (for other crops)		2	2
NUTRIENT SOLUTION DISPOSAL FREQUENCY	Daily – portion of the solution is being disposed	Daily – portion of the solution is being disposed	Daily – portion of the solution is being disposed	Daily – all the solution is being disposed	Every month, all the solution is flushed in the sink	Every month, all the solution is flushed in the sink
NUTRIENT SOLUTION CIRCULATION METHOD	40-60% of the nutrient solution is collected from by the end of the cycle then filtered using glass filter media and disinfected using UV and hydrogen peroxide then mixed with fresh water and fertilizer to form fresh nutrient solution.	40-60% of the nutrient solution is collected from by the end of the cycle then filtered using glass filter media and disinfected using UV and hydrogen peroxide then mixed with fresh water and fertilizer to form fresh nutrient solution.	40-60% of the nutrient solution is collected from by the end of the cycle then filtered using glass filter media and disinfected using UV and hydrogen peroxide then mixed with fresh water and fertilizer to form fresh nutrient solution.	None	Closed loop system with constant EC and pH adjustment of the solution. Nutrient solutions from all farms are being collected in one collection tank where water & nutrients are adjusted	Closed loop system with constant EC and pH adjustment of the solution. Nutrient solutions from all farms are being collected in one collection tank where water & nutrients are adjusted

FARM NO.	2	3	4	5	1	1 (UPGRADED)
WATER CONSUMPTION (M^3/DAY)	22-40 m^3/day					
HYDROPONICS WASTE NUTRIENT SOLUTION DISPOSAL VOLUME (M^3/DAY)	10-20 m^3/day					
DISPOSAL METHOD (SINK/THE ENVIRONMENT)	Private dam – natural pond (i.e. native earth in the bottom)	Private dam – natural pond (i.e. native earth in the bottom)	Private dam – natural pond	Private dam – natural pond	Sink	Sink
AVERAGE SPEND ON FERTILIZER ($/DAY)	$312.5/day					
FERTILIZER TYPE (LIQUID/SALTS)	Nutrient salts	Nutrient salts	Nutrient salts	Nutrient salts	Liquid fertilizer	Liquid fertilizer

Supplementary Table S2. Macro & micronutrients, pH, EC and Dissolved Organic Carbon (DOC) analysis for the collected HWNS samples.

Parameter	Unit	Concentrations of HWNS samples in mg/L									
		1	2	3	4	5	6	7	8	9	10
Phosphorus	mg/L	20.8	53.2	8.3	14.0	12.2	19.5	37.5	37.6	12.4	69.6
Calcium	mg/L	84.9	228.0	121.8	396.0	391.1	377.9	196.6	271.4	218.5	147.9
Potassium	mg/L	162.2	290.4	149.0	379.5	320.6	404.9	307.7	343.1	171.5	199.5
Magnesium	mg/L	24.9	37.2	60.8	164.9	127.3	153.3	63.6	81.9	61.1	27.9
Sodium	mg/L	21.7	24.6	75.9	161.7	139.6	147.6	38.8	46.1	28.6	19.2
Copper	mg/L	0.8	0.7	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.4
Iron	mg/L	0.4	0.4	0.3	2.0	3.0	1.9	0.9	1.4	0.6	1.6
Boron	mg/L	3.6	1.1	0.5	0.9	0.7	0.8	0.6	0.6	0.2	0.2
Zinc	mg/L	0.7	0.5	0.2	0.1	0.3	0.2	0.2	0.1	0.3	0.6
Ammonia	mg/L	4.2	6.5	0.6	0.3	0.3	0.4	3.7	2.5	0.5	3.3
Nitrate	mg/L	90.2	227.7	75.5	247.1	147.9	241.5	217.3	273.3	150.6	111.1
Nitrite	mg/L	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.5	0.0	0.0
DOC	mg/L	9.0	16.3	0.1	13.3	1.7	16.5	8.9	16.1	16.4	17.3
pH	-	6.9	5.9	6.9	7.4	7.6	7.6	6.7	6.8	7.1	5.3
EC	mS/cm	1.2	2.4	1.7	3.4	2.8	3.3	2.5	2.9	1.9	1.6

Supplementary Table S3. Assumptions for Economic Analysis of Calcium Phosphate Recovery from HWNS.

Assumption Category	Detail
Market Price Basis	Rock phosphate used as a benchmark for estimating the market price of recovered calcium phosphate.
Cost Determinant	The cost of sodium hydroxide (NaOH) for pH adjustment of HWNS to 9.5 is the primary cost factor, excluding other operational expenses.
Processing Loss	A 25% beneficiation loss for rock phosphate is considered (Koppelaar & Weikard, 2013).
Calcium Phosphate Grade	The grade of calcium phosphate in rock phosphate is denoted as BPL, with a specific conversion equation of $BPL\% = 2.185 \times P_2O_5\%$ (Hammache et al., 2020; Lassis et al., 2015).
Chemical Form Assumption	The recovered calcium phosphate is assumed to be in the form of Ca3(PO4)2, matching the BPL content.
NaOH Purity	The purity of commercial NaOH solid pellets is assumed to be 97%.
Initial pH Assumption	The median initial pH of HWNS samples is approximately 7. As observed in the results of this research, most samples possess a neutral pH.
NaOH Requirement for pH Adjustment	From batch studies with 30 samples, it was estimated that nearly 30 g of NaOH is required to increase the pH of 1m³ of HWNS by one unit. This figure is crucial for driving the cost estimates across all samples.

Phosphorus Recovery Efficiency	The phosphorus removal/recovery efficiency at a pH of 9.5 is projected to be 98% based on the chemical precipitation batch study results.

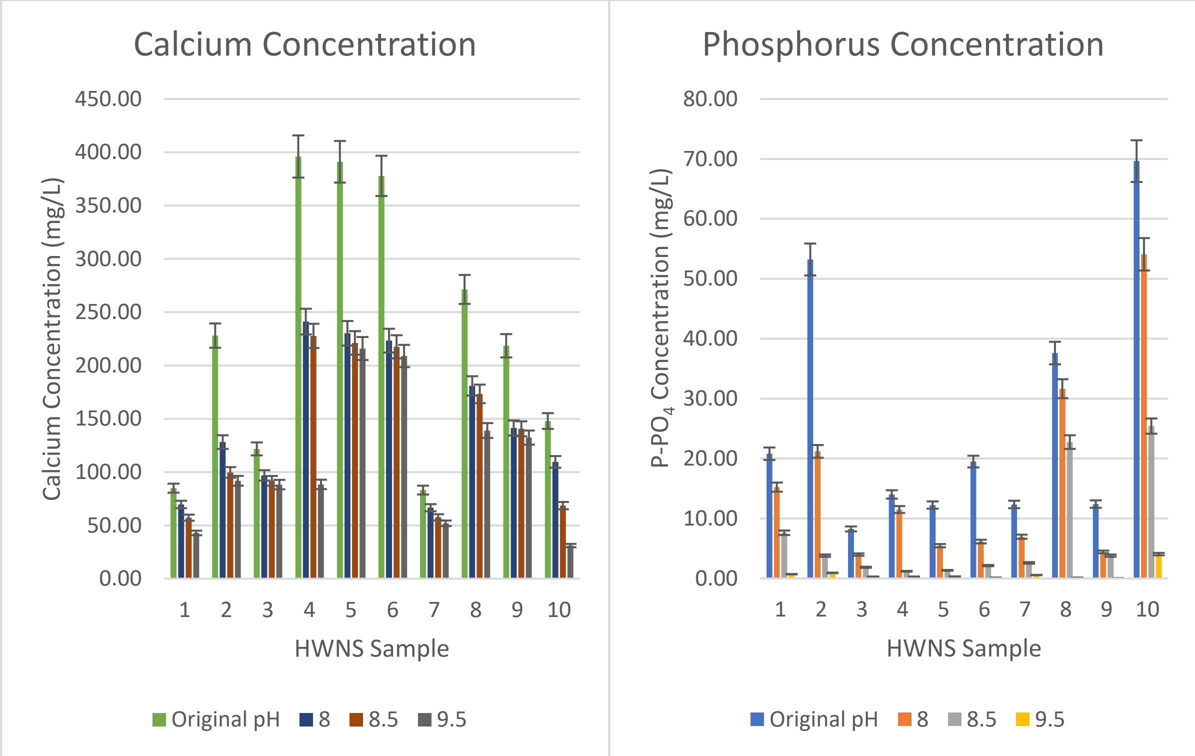
Supplementary Table S4 Volume of 3N NaOH Solution Required to Adjust pH to 8, 8.5, and 9.5

HWNS Sample No.	Farm No.	pH initial	Volume of 3N NaOH added to increase the pH to:		
			pH – 8 (µL 3N NaOH)	pH – 8.5 (µL 3N NaOH)	pH – 9.5 (µL 3N NaOH)
1	Farm 1	6.94	9	12	30
2	Farm 1	5.88	30	41	63
3	Farm 2	6.88	12	25*	47*
4	Farm 2 (greenhouse 1)	7.44	8.5	17*	34
5	Farm 2 (greenhouse 2)	7.58	7.5	16	38
6	Farm 2 (greenhouse 3)	7.55	6	14	35
7	Farm 3	7.25	6	12	25
8	Farm 3	6.80	7	15	40
9	Farm 4	7.08	7	18*	35
10	Farm 5	5.31	20	40	65

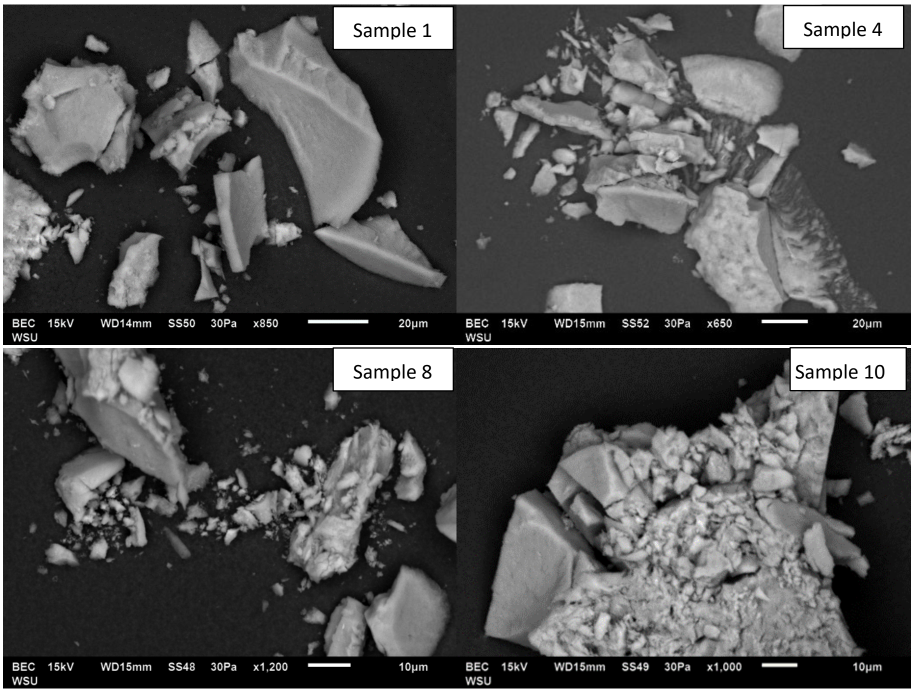
**Samples that required 0.5 HCl addition (±3 µL)*

Supplementary Table S5 The main components of "Optimum Hydro 2- Part – Grow" nutrient solution (Manufacturer's data sheet)

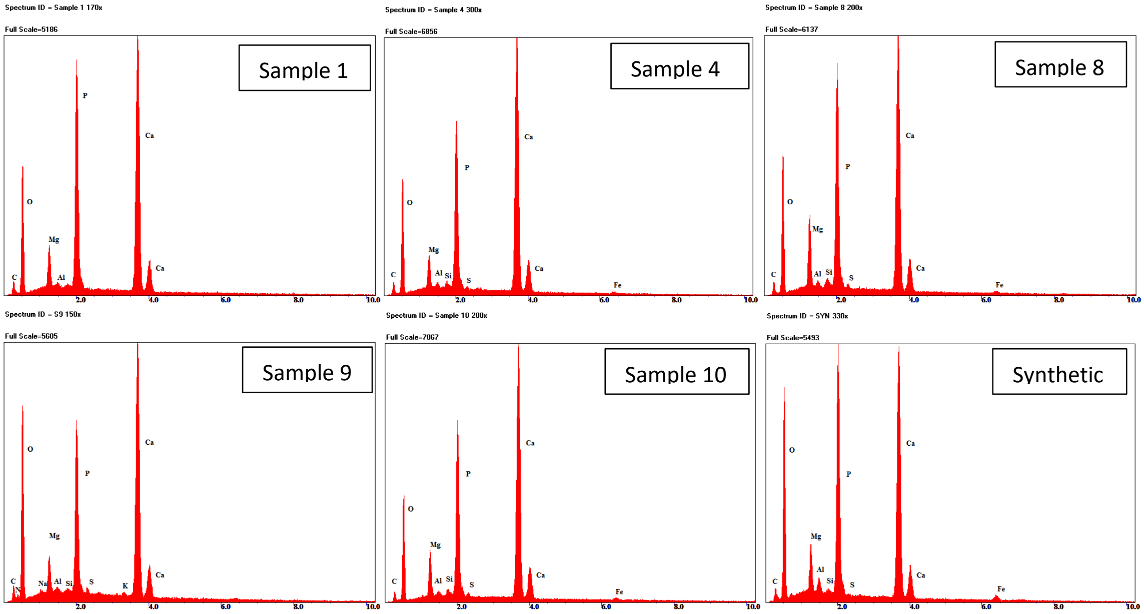
Parameter	Part A	Part BError! Bookmark not defined.
Nitrate-nitrogen (mg/L)	40400	16600
Ammonium-Nitrogen (mg/L)	3100	0
Total Nitrogen (mg/L)	43500	16600
Phosphorus (mg/L)	0	10000
Potassium (mg/L)	16300	58900
Calcium (mg/L)	45000	0
Magnesium (mg/L)	0	12500
Sulfur (mg/L)	0	16500
Iron (mg/L)	750	0
Manganese (mg/L)	0	220
Boron (mg/L)	0	50
Zinc (mg/L)	0	37.5
Molybdenum (mg/L)	0	12.5



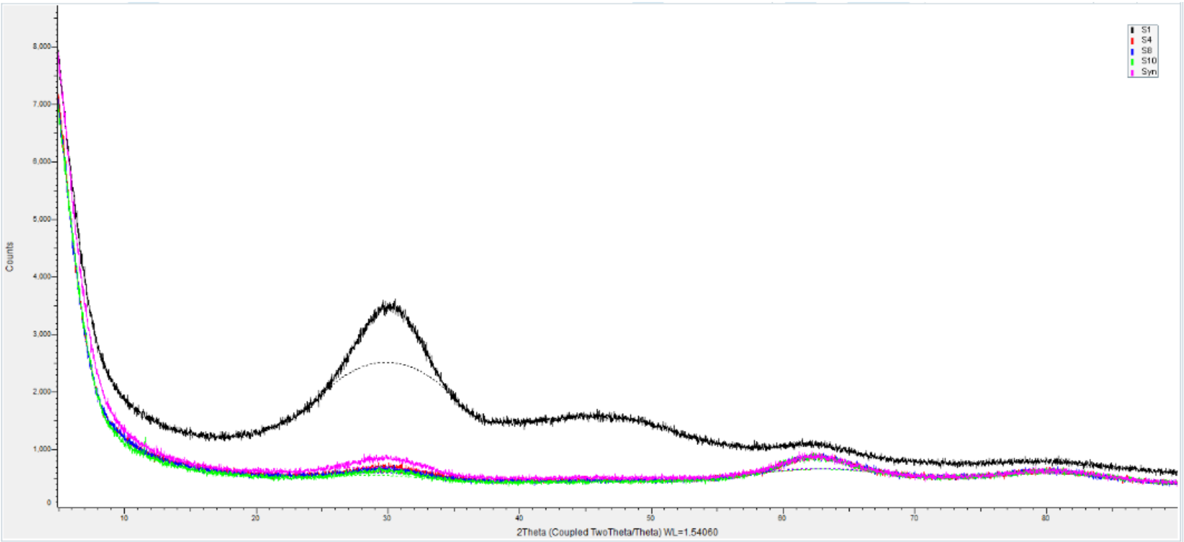
Supplementary Figure S1. Variations of calcium and phosphorus concentrations in the supernatant samples at different pH



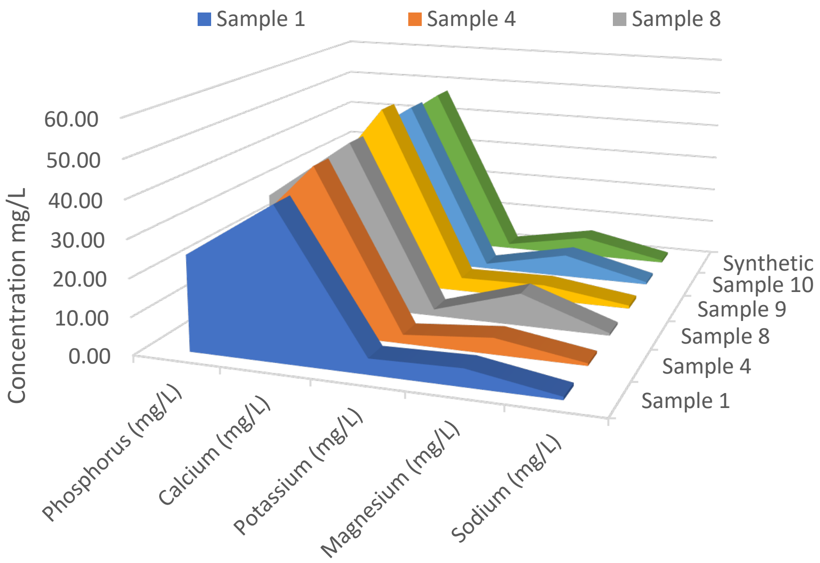
Supplementary Figure S2 SEM Images of Precipitates Recovered from Samples 1, 4, 8 and 10



Supplementary Figure S2. EDS Analysis of Precipitates Recovered from Samples 1, 4, 8, 9, 10, and the Synthetic Precipitate Derived from Commercial Nutrient Solution



Supplementary Figure S3. XRD Analysis of Precipitates Recovered from Samples 1, 4, 8, 10, and the Synthetic Precipitate Derived from Commercial Nutrient Solution



	Phosphorus (mg/L)	Calcium (mg/L)	Potassium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)
Sample 1	25.29	40.16	4.18	4.72	0.84
Sample 4	20.97	44.53	2.37	4.40	0.68
Sample 8	29.36	45.86	1.77	8.82	0.64
Sample 9	21.54	50.73	3.78	4.13	0.86
Sample 10	32.24	47.24	1.41	6.31	0.63
Synthetic	31.47	47.00	1.25	5.47	0.62

Supplementary Figure S4. Main Cation Concentrations in the Digested Precipitates - Samples 1, 4, 8, 9, 10, and the Synthetic Precipitate

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