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Nutrient Management for Recirculating Hydroponics

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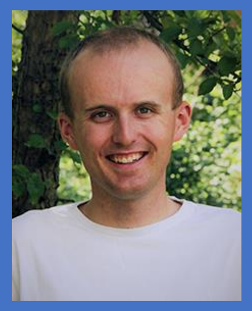

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Introduction

Discarding nutrient solutions is wasteful and unnecessary. The optimal composition and concentration of a refill solution can be calculated from the desired elemental concentration in leaf tissue and the water use efficiency. Here we review the use of this approach for long term nutrient management in recirculating hydroponics.

Principles

Hydroponic culture means nutrients are either in the solution or the plants (Fig. 1). Water and nutrients are added to the solution; water is transpired, and the nutrients stay behind in the plant tissue. Covered tanks minimize evaporative losses and allow direct measurement of plant water use.

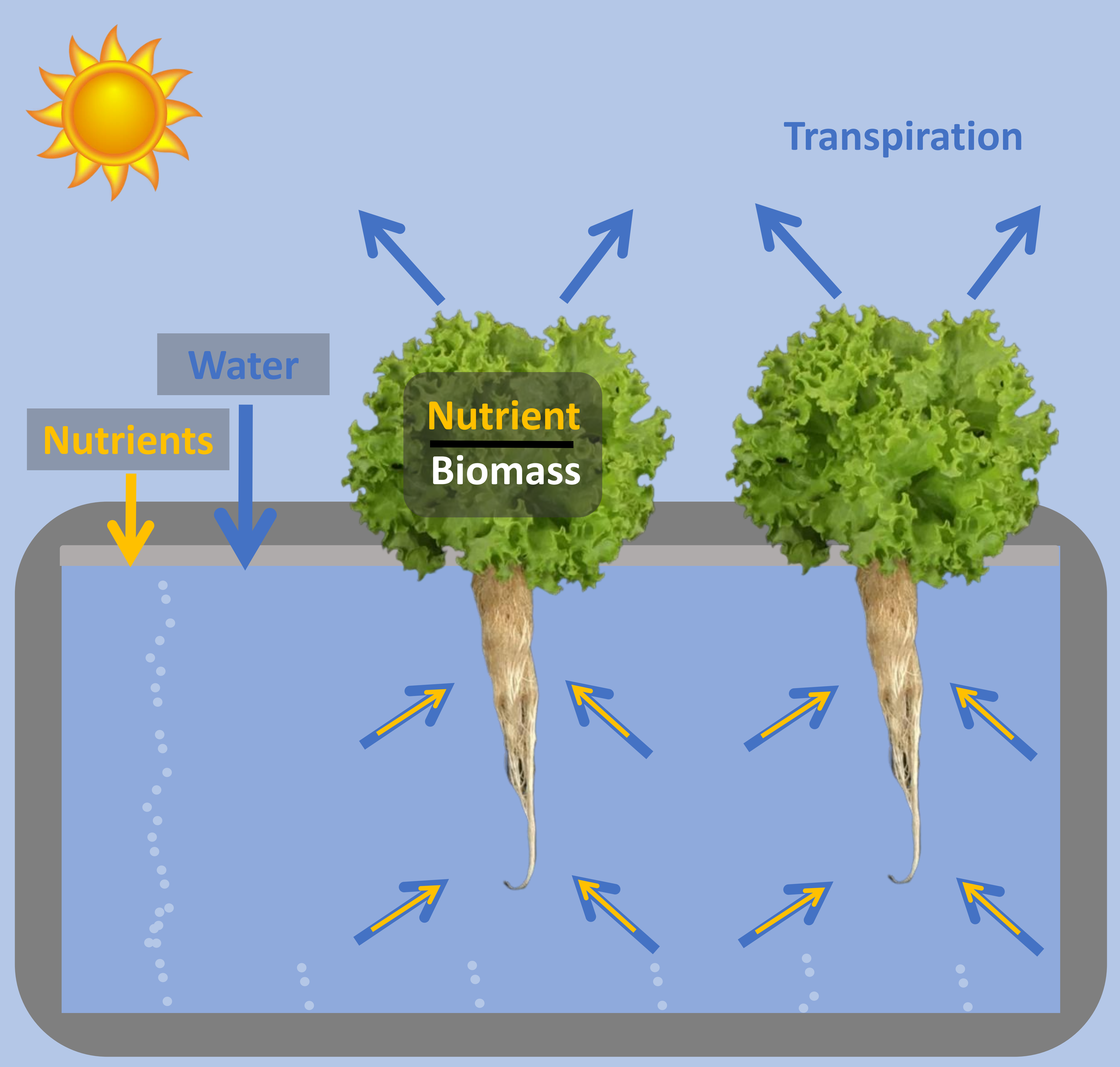

Fig. 1: Constant solution volume is achieved through small, frequent refills of water and nutrients. Roots take in nutrients with water. The water is transpired through the leaves and the nutrients stay behind.

Water Use Efficiency (WUE)

WUE is defined as the dry biomass produced per the water transpired. WUE can be estimated from environmental conditions (Fig. 2). Elevated CO_2 and humidity can double the WUE (Table 1).

Fig. 2: Deep flow hydroponic systems for determining WUE.

Table 1: Environmental influence on water use efficiency. The first location represents a greenhouse in Utah while the second location is representative of indoor growing with high relative humidity and added CO_2.

Location	Environment	WUE (g L^{-1})
Open greenhouse	40% humidity, 400 ppm CO_2	3
Closed greenhouse	60% humidity, 1200 ppm CO_2	6

Calculating Nutrient Concentrations

$$\text{Desired Tissue Concentration} \times \text{WUE} = \text{Solution Concentration}$$

$$\frac{30 \text{ mg N}}{\text{g biomass}} \times \frac{3 \text{ g biomass}}{\text{Liter solution}} = \begin{matrix}\text{90 mg/L N} \\ \text{(90 ppm N)}\end{matrix}$$

This approach is applied to all nutrients (Table 2). Desired tissue concentration can be determined from literature for individual species.

Table 2: An optimal initial and refill nutrient solution derived using the equation above. Micronutrient concentrations omitted for simplicity.

Element	Tissue concentration		WUE (g L^{-1})	Optimal concentration	
	(%)	(mg g^{-1})		(ppm)	(mM)
N	3	30	3	90	6.4
P	0.4	4	3	12	0.4
K	4	40	3	120	3
Ca	1.5	15	3	45	1.1
Mg	0.5	5	3	15	0.6
S	0.5	5	3	15	0.5
Si	0.5	5	3	15	0.5

Automated pH Control

Hydroponic solutions are poorly buffered. Automated pH control maintains pH near 5.8 for optimal nutrient uptake. Ammonium typically improves plant growth. Nitrogen form dictates pH changes: nitrate uptake increases pH and ammonium uptake decreases pH (Fig. 3). Small, frequent additions of ammonium are necessary to minimize large pH decreases. This can be accomplished with pH control using nitric acid and ammonium sulfate.

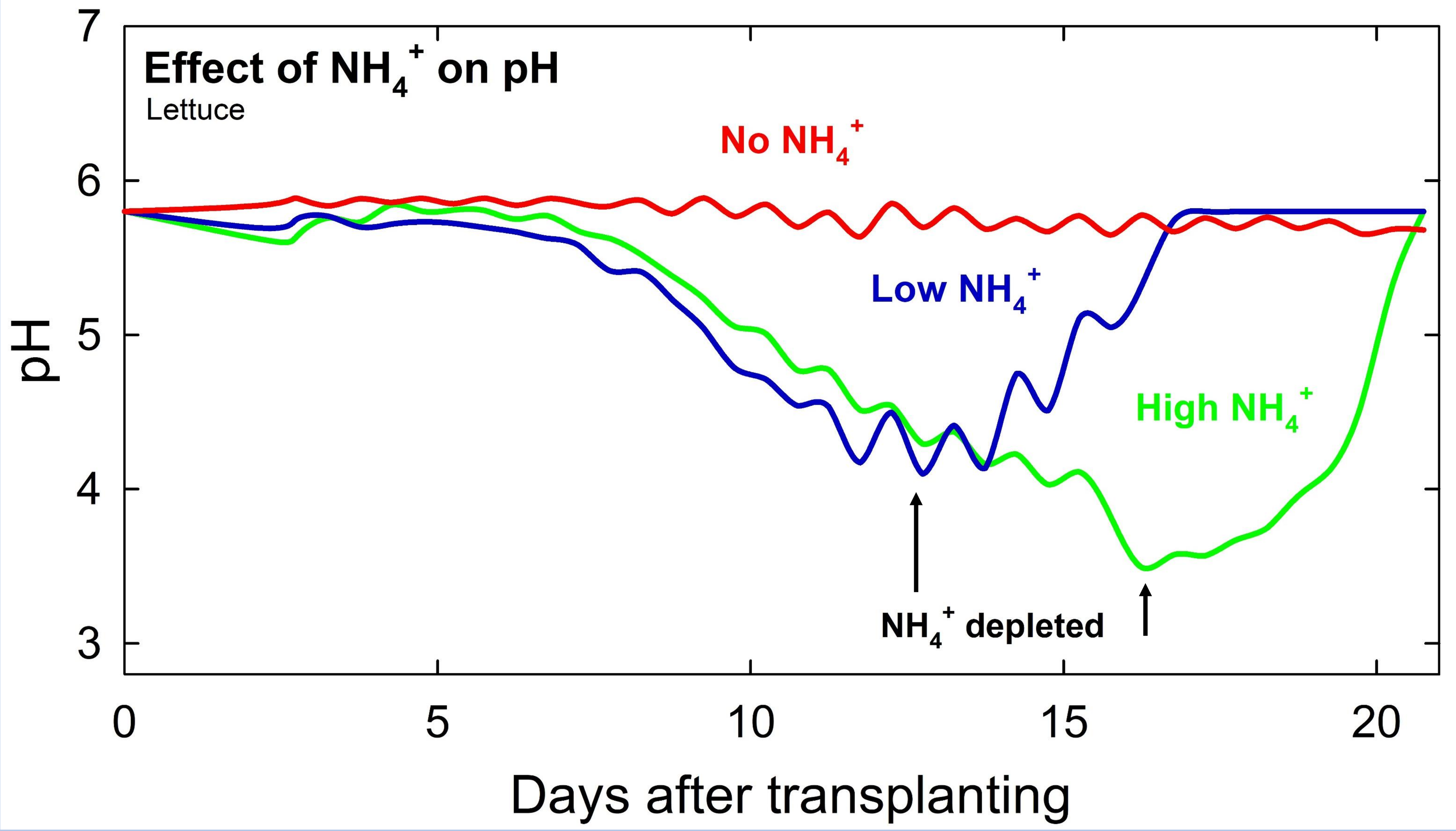

Fig. 3: Effect of increasing ammonium on pH of lettuce nutrient solution.

Mass Balance Recovery

Table 3: Average mass balance recovery of essential nutrients in lettuce, n=3.

Element	Leaf		Root		Solution		Total (%)
N	70	+	11	+	18	=	98
P	66		12		18		96
K	69		10		19		98
Ca	22		2		78		102
Mg	22		3		73		98
S	7		3		100		110
Fe	12		9		50		71
B	8		2		85		94
Mn	41		5		3		49
Zn	31		12		76		119
Cu	4		3		91		99
Mo	12		19		78		109
Ni	3		15		112		130

This approach assumes good mass balance recovery (Table 3). Nutrients are recovered in leaves, roots, and solution. High recovery in leaves indicates active uptake (N, P, and K). Recoveries above 100% indicate contamination. Iron precipitates and typically has a low recovery. It is unclear why Mn recovery was low in this study.

Conclusion

This mass balance approach minimizes water and fertilizer waste. Solutions can be recirculated for months and this increases sustainability of hydroponic food production.

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