

PLANT NUTRIENT DELIVERY

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INTRODUCTION

Unique growing procedures are needed to effectively cultivate plants in space. Fluids behave differently in microgravity, and therefore, many plant nutrient delivery systems used on earth will not function effectively in space. In a microgravity climate, a plant nutrient delivery system (NDS) must provide adequate amounts and uniform distribution of water, nutrient, and oxygen levels in the root zone, while at the same time, prevent release of free nutrient solution to the atmosphere. Solid media such as, vermiculite mixtures and various gelling agents that contain predetermined amounts of water and nutrients have been successfully used in passive plant nutrient delivery systems for brief stays in orbit. However, for extended plant cultivation in space, root-zone media will require more than just an initial loading of water and nutrients due to losses from plant evapo-transpiration and nutrient uptake. The ultimate goal is to design a nutrient delivery system that is capable of sustaining plants for long periods under hypogravity, yet require minimal system maintenance and limited demands on crew time. Testing in our laboratory has evaluated several types of nutrient delivery system (NDS) hardware and procedures designed for growing plants in gravitational research as well as for planetary bioregenerative life support for humans during long-term space missions. Concepts currently being tested at Kennedy Space Center (KSC) include microporous tubes with and without various types of solid media, and gravity-dependent systems such as the hydroponic nutrient film technique (NFT).

CURRENT STATUS OF RESEARCH

Methods

At KSC, the performance of each nutrient delivery concept has been based largely upon the yield response of Advance Life Support staple crops such as wheat (*Triticum aestivum* L.) and sweetpotato (*Ipomoea batatas* L.). In a series of ground-based investigations with wheat, our primary focus was to characterize the microporous tube system with and without zeoponic substrate in terms of overall plant growth, nutrient uptake patterns, and water use. Nutrient solution was constantly circulated under a slightly negative hydrostatic pressure (or suction) through the central cavities of hydrophilic, microporous, ceramic filter tubes (0.45 μm nominal pore diameter, OD 2.3 cm, ID 2.1 cm, 2 mm flow channel diameter). Nutrient solution moved through the porous wall of the tube into the rooting environment by capillary attraction. In sub-irrigated microporous tube systems we used stainless-steel tubes (nominal pore size 30 μm , OD 0.953 mm, ID 0.635 mm), covered with zeoponic substrate from Johnson Space Center. The sub-irrigated solid growing matrix provides root anchorage and a buffered source of nutrients. Zeoponic substrates are being developed to supply all essential macro- and micronutrients (e.g. slow-release fertilization) to plants over several growth cycles.

In gravity-dependent hydroponic systems at KSC, a general NFT nutrient management approach is applied to all ALS crops. The KSC approach calls for daily replenishment of minerals to maintain a nutrient solution formula essentially equivalent to modified 0.5-X strength Hoagland's solution (i.e., electrical conductivity $\sim 1200 \mu\text{S}/\text{cm}$). In addition nitrate is the sole source of nitrogen, and nitric acid and potassium hydroxide are used to constantly maintain pH at approximately 5.8. Past tests at KSC with a generalized NFT protocol has generally produced excellent yields with most ALS crops. However, the standard KSC nutrient management approach tends to promote disproportionate foliage growth relative to storage organs (i.e, potato and sweetpotato). A major difference between the KSC and Tuskegee University nutrient solution formulations is with nitrogen nutrition. The generalized KSC modified 0.5-X strength Hoagland's contains approximately twice the amount of nitrogen found Tuskegee University's nutrient solution. In addition, the KSC protocol uses nitrate as the sole source of N, whereas the Tuskegee protocol uses a mixed source of N in the form of a 6:1 ratio of $\text{KNO}_3:\text{NH}_4\text{PO}_4$.

Results

In terms of aboveground biomass production, seed yield, and harvest index, the drip-irrigated peat vermiculite system was the most successful among the compared nutrient delivery systems (Table 1). The systems using zeoponic substrate produced wheat with excessive seedless tiller formation as compared to wheat produced with the microporous tubes only or drip-irrigated peat-vermiculite. Plants in the sub- and drip-irrigated zeoponics systems

displayed as many as 8 tillers, which failed to produce seed. The plants grown in zeoponic substrate were exposed to a mixed-nitrogen source (NH₄ and NO₃), that may have promoted greater tiller formation in those plants.

Conversely, wheat grown in microporous tube only and drip-irrigated peat vermiculite systems were supplied with NO₃-N alone, and these plants produced a maximum of 2-3 tillers per plant. However, it is important to note that the particular wheat growth cycle reported here was accomplished with the first generation of zeoponic substrate.

In recent tests with sweetpotato, we observed significantly less foliage growth and more storage root production when nutrient solution N concentration was reduced (Table 2). Previous research by others has shown that although nitrogen stimulates both sweetpotato foliage yields and storage root production, high available nitrogen (e.g. KSC treatments) results in vegetative growth that occurs at the expense of storage root production. Overall, the method of pH control did not appear to have a significant role in total biomass production or partitioning within either the KSC or Tuskegee University protocols. Total biomass production was greatest in the KSC treatments, which can be attributed to the daily replenishment of nutrients, especially the constant supply of N. However, in these same treatments storage root production was extremely low. The Tuskegee treatments had significantly less foliage growth and more storage root production.

Table 1. Wheat harvest data summary \pm SE (per tray)¹

	Porous Tubes	Porous Tubes +Zeoponics	Drip-Irrig. Zeoponics	Drip-Irrig. P. Vermiculite
Aboveground DM (g) ²	96.9 \pm 3.5	90.9 \pm 0.6	126.8 \pm 5.0	148.9 \pm 0.6
Straw DM (g)	33.7 \pm 2.0	48.1 \pm 0.1	78.8 \pm 2.0	61.0 \pm 0.3
Spike DM (g)	63.2 \pm 1.7	44.7 \pm 0.5	59.2 \pm 3.2	98.9 \pm 0.6
Chaff DM (g) ³	23.0 \pm 1.2	35.3 \pm 1.1	46.2 \pm 1.3	31.6 \pm 0.3
Seed DM (g)	40.3 \pm 0.9	8.5 \pm 1.5	13.1 \pm 1.9	67.2 \pm 0.7
Spike No.	104 \pm 6	218 \pm 6	247 \pm 6	155 \pm 1
Harvest Index (%) ⁴	41.5	9.4	10.3	45.1

¹Means from 45 plants per tray which was equivalent to approximately 900 plants per m².

²Aboveground dry matter (DM) = Spike DM + Straw DM; ³Chaff DM = Spike DM - Seed DM; ⁴Harvest index does not include roots

Table 2. Biomass yield comparison from sweetpotato plants grown under different nutrient and pH control management regimes.

Treatment	Total Biomass			Edible Biomass		
	(kg/m ²)	(g/m ² d)	(g/mol PAR)	(kg/m ²)	(g/m ² d)	(g/mol PAR)
KSC HNO ₃ /KOH	3.07	25.59	0.68	0.13	1.11	0.03
KSC HCl/NaOH	3.22	26.87	0.72	0.14	1.16	0.03
TU HCl/NaOH	2.38	19.84	0.53	0.90	7.46	0.20
TU HNO ₃ /KOH	2.48	20.67	0.55	0.72	5.97	0.16

CONCLUSION

In ground-based studies, each NDS sufficiently supported wheat biomass production to varying degrees and showed distinct patterns for plant nutrient uptake, water use, and partitioning between vegetative and edible tissues. Tests to date confirm that reduced nitrogen availability in the nutrient solution would appear as a plausible solution to limit the potential for large shoot growth by sweetpotato in NFT culture.

FUTURE PLANS

Nutrient delivery system tests at KSC are continuing using refinements of each system and improved generations of solid substrates in preparation for future microgravity missions on shuttle (WONDER) and space station (PESTO). In ground-based experiments, a study is planned to outline the baseline N-supply requirements for potato production in our NFT systems. Perhaps potato (analogous to sweetpotato) would exhibit significantly less foliage growth and more tuber production with a nutrient management regime that limits N-supply in NFT systems.

INDEX TERMS

Microporous tube, microgravity, hydroponic, zeolite, NFT, nutrient thin film, sweetpotato, Hoagland's solution, nutrient solution culture, growth media, soil, potting media, N-nutrition, zeoponics, peat-vermiculite