Annual Progress Report, July 1, 1991 - June 30, 1992
NASA Cooperative Agreement # NCC 2-607

IN-51-CR
P.44

A Proposal to Demonstrate Production of Salad Crops in the Space Station Mockup Facility with Particular Attention to Space, Energy, and Labor Constraints

Carolyn Brooks, Principal Investigator

Alabama A&M University

Department of Plant & Soil Science

P.O. Box 1208

Normal , AL 35762

The NASA Technical Officer for this Cooperative Agreement is Dr. Robert D. MacElroy, Life Sciences Division, NASA Ames Research Center, Moffett Field, CA 94035-400

SUMMARY

Several improvements were made to the Salad Machine experimental rack including placement of two new light banks with 33% more light output per bank into the rack. Provision was also made to move plant trays up and down within the rack in 3 inch increments to allow for adjustment with changes in plant height. Plant growth trials were initiated within the rack. Lettuce production was less than desired until nutrient levels were increased to full strength Hoaglands levels. Radish production decrease was correlated to nutrient level increases. Pepper harvests began 12 weeks after planting and remained productive for a 6 week period after which production declined. We recommend a planting of 8 pepper plants every 6 weeks for a total of 24 plants growing at any one time to provide a continuous crop of peppers. Tomato plants experienced disease problems (possibly tobacco mosaic virus) and there was no harvest data.

A Salad Machine Demonstrator rack for placement in the Huntsville Space Station Mockup facility has been designed and is under construction. Completion has been targeted for August 3, 1992 but it appears probable that this targeted date will slip somewhat to a later date. The Salad Machine Demonstrator rack has been patterned after one at NASA Ames Research Center and will feature four plant drawers and a simulated ceramic microporous nutrient delivery system. Although not intended to be an operational rack many operational details have been included in the mockup. This adds a more realistic dimension to the rack and allows for an easy change out if there is a desire to operate a living demonstrator unit in Huntsville in the future.

Plant compatibility studies are starting to yield results after several experiments to allow for graduate student training on hydroponic systems. Radish plants are not affected by sharing of nutrient solutions, whereas lettuce plants grew better on shared nutrient solutions than on nonshared solutions.

Microbial studies suggest that *Pseudomonas* was the predominant species on both lettuce and radish rhizospheres and that radish supports a larger microbial population on it's rhizosphere than does lettuce. There did not appear to be any effect of sharing nutrient solutions on rhizosphere microbial populations.

Comparison of yields between NFT and Micropore systems indicate that yield from micropore systems is 22% less than that of the NFT system. During our studies utilizing the ceramic microporous nutrient delivery system we found it to be an easy and reliable system to work with. Unlike the NFT system, we had little difficulty maintaining an appropriate nutrient status in the nutrient solution by simple maintenance of the electrical conductivity values. There was little variation in plant size and plants always appeared to be healthy and deeply green. Considering the adaptability of the micropore system to microgravity and it's reusability and cleanliness compared to other systems such as rockwool (which could also be used in microgravity) a reduction in yield may be an acceptable tradeoff.

INTRODUCTION

This research has continued along two lines, one at Marshall Space Flight Center with Salad Machine Rack development and the design and construction of a mockup for placement in the Huntsville Space Station Freedom mockup. The second avenue of research has addressed issues of relevance to the operation of the Salad Machine and bioregenerative systems. These issues include plant species compatibility when grown on shared hydroponic systems and

microbial populations of mixed species hydroponic systems. Significant progress is reported below.

SALAD MACHINE RACK DEVELOPMENT

Experimental Model

During the course of growing plants in the Salad Machine standard rack several limits to plant productivity became apparent. The most limiting of these was the amount of light available to the plants with the currently utilized coolwhite T12 fluorescent lamps. The light bank with T12 coolwhite lamps was providing a peak light intensity of 300 $\mu moles/m^2/s$ of photosynthetically active radiation (PAR). Two new light banks which contained 18 T8 Octalume fluorescent lamps and 6 electronic ballasts per bank were constructed and mounted in the Salad Machine standard rack experimental unit. These light banks provided a peak irradiance of 400 $\mu moles/m^2/s$ PAR with considerably less waste heat produced. Two plant growth drawers were mounted side by side under each light bank. Drawer slides were mounted along the sides and middle of the rack to allow for adjustment of the growing height of each tray. This feature would allow for placement of plants close to the lights during the seedling stage and periodic movement of the trays away from the lights as the plants grew, thus increasing plant productivity. After installation of the new light banks plant productivity trials were initiated. The initial planting included 6 lettuce plants, 12 carrot plants, 12 radish plants, 8 sweet pepper plants, and 8 dwarf tomato plants. Lettuce and radish were replanted on a weekly basis and tomatoes and peppers on a monthly schedule. Since the ability of carrot to grow on rockwool was uncertain, further plantings of carrot were postponed until yield data on the initial carrot planting was known. During the first 7 weeks of the productivity trial halfstrength Hoaglands nutrient solution was used. When it became apparent that yield of lettuce was not as high as desired, the nutrient solution was increased to full strength Hoaglands. Lettuce production during the first six weeks of the trial averaged around 50 grams fresh weight (gfw) per plant (Fig. 1). After nutrient solution was increased to full strength Hoaglands solution lettuce yield began to steadily increase and peaked at an average of 98.8 gfw per

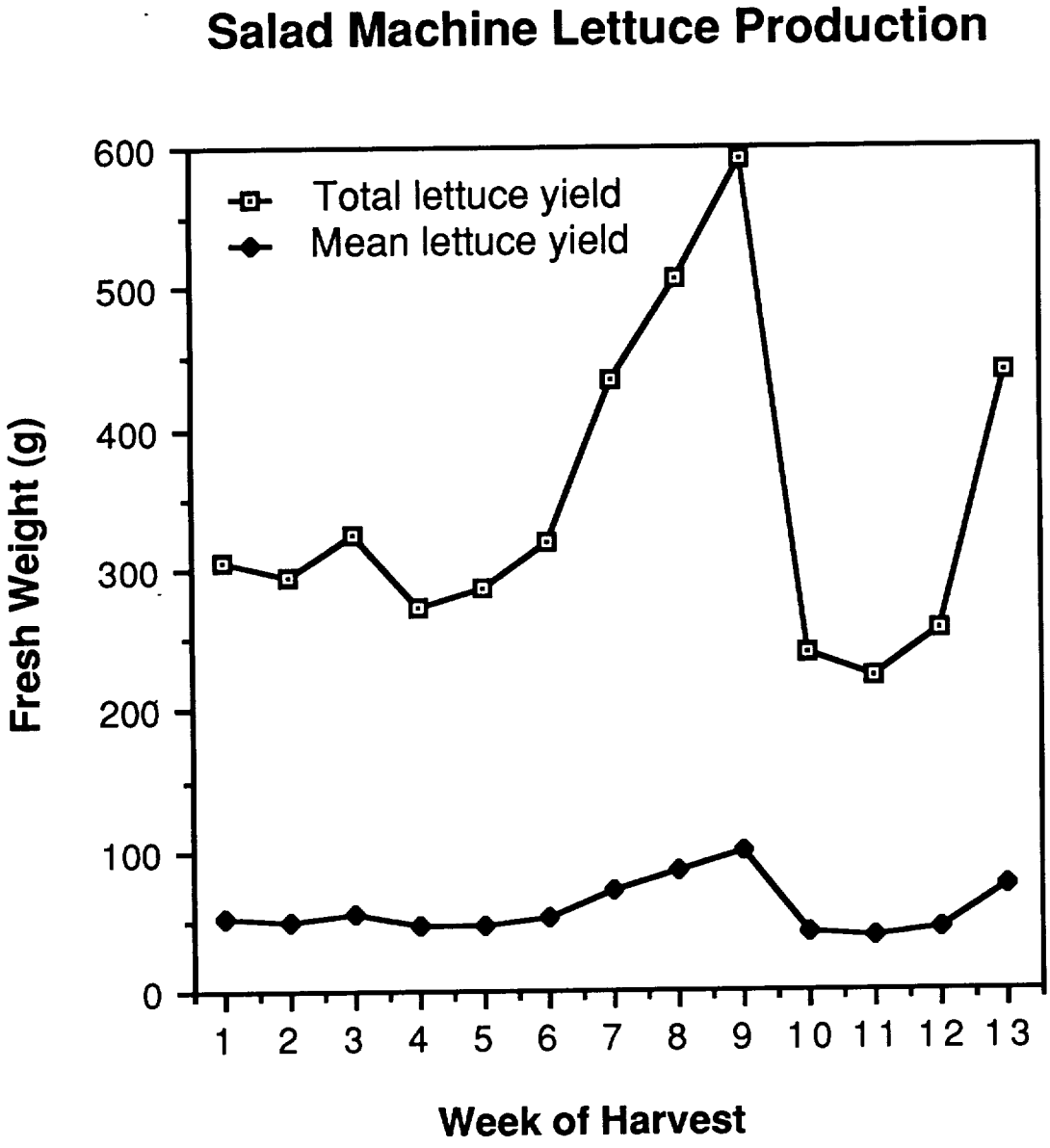

Figure 1. Production of 'Waldmann's Green' lettuce in a Salad Machine rack. Data represents weekly harvests of six plants. Means are the average fresh weight per plant of the six plants harvested.

plant. Radish root yield initially averaged 15 gfw per plant. As the concentration of the nutrient solution was increased, radish production declined (Fig. 2). Sweet pepper harvest began 12 weeks after planting with an initial harvest of 8 mature peppers which had an average fresh weight of 8.4 g (Fig. 3). During subsequent harvests the number of peppers harvested was increased to an average of 18 peppers per week. Total pepper production increased slightly from the first to the sixth week of harvest and declined thereafter.

Salad Machine Mockup Unit

The design and construction of a Salad Machine Mockup rack for placement in the Space Station Freedom Mockup facility in Huntsville Alabama has been proceeding during the last several months. Completion is targeted for August 3, 1992. The rack has been designed to function as a mockup only but will have features to allow easy conversion to an operating unit if desired. The rack will be similar in appearance to the demonstrator unit developed at Ames Research Center. It will feature two light banks and four drawers for growing plants. Lamp connectors for the light banks will be custom machined since current rack design does not leave sufficient space for "off the shelf" lamp ends and the longer T8 lamps. Electronic ballasts will be mounted on a panel at the back of the rack, and will be accessible from behind the rack. The two drawers which would have plants oriented in the normal shoots up:roots down direction will be 16 and 14 inches tall. The two drawers which would have plants in a roots up:shoots down direction will be 8 inches tall. This configuration will allow for different plant heights and, if ever operated, allows more room in the two drawers which would be most likely to be utilized in a living mockup. To further accommodate differences in plant height the drawers are equipped with grooves along the sides to allow for movement of the nutrient delivery trays up and down within the drawers. Similar to the Ames model, each drawer is fronted by a transparent polycarbonate paneled door to allow viewing and access to the plants. Each drawer is equipped with two piccolo style air inlet tubes at the back of the drawer and two piccolo tubes at the front of the drawer for air output. There will be two nutrient delivery trays mounted side by side in each drawer. The nutrient delivery system

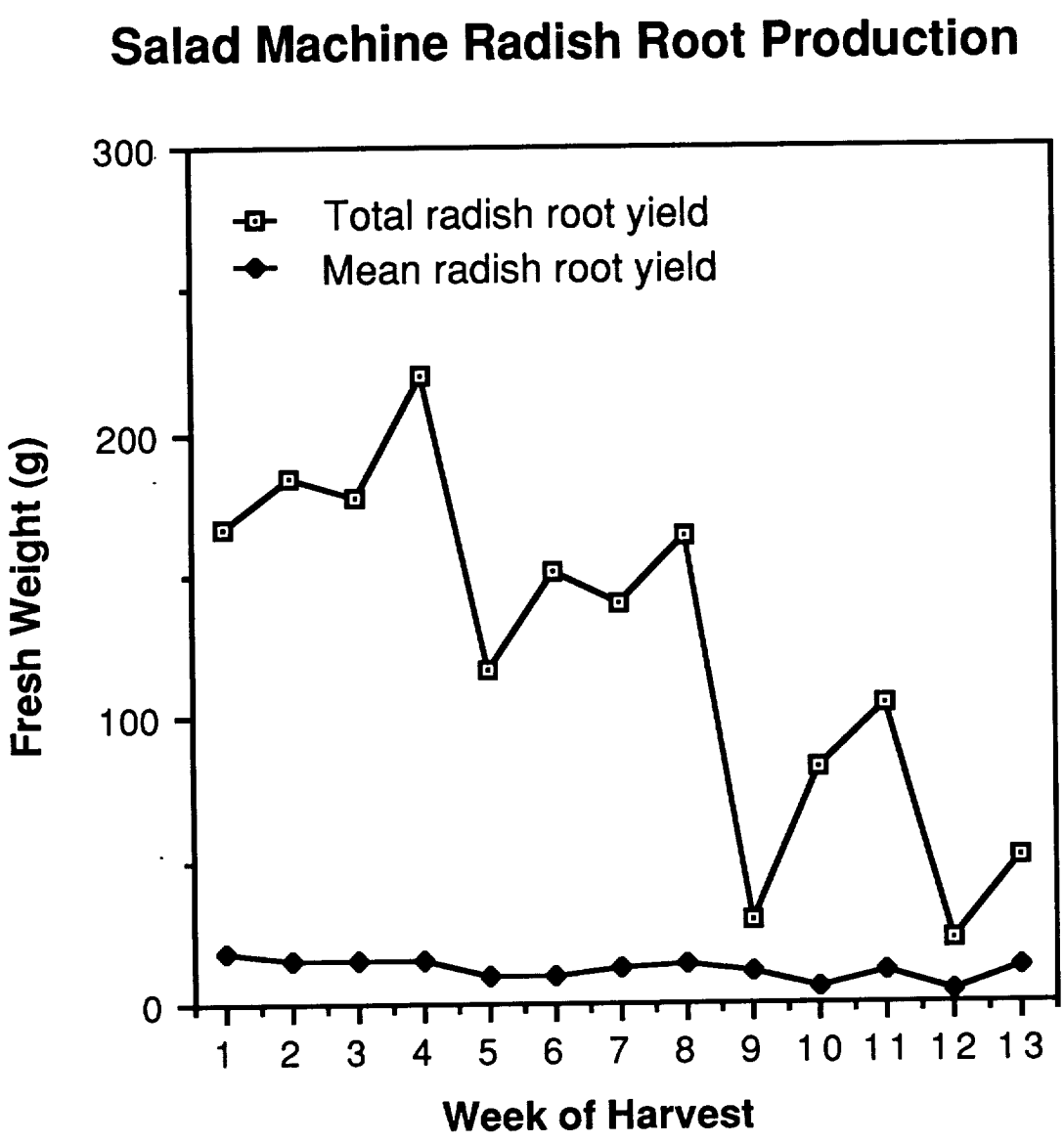

Figure 2. Production of 'Red Prince' radish in a Salad Machine rack. Data represents an average of twelve radishes harvested per week.

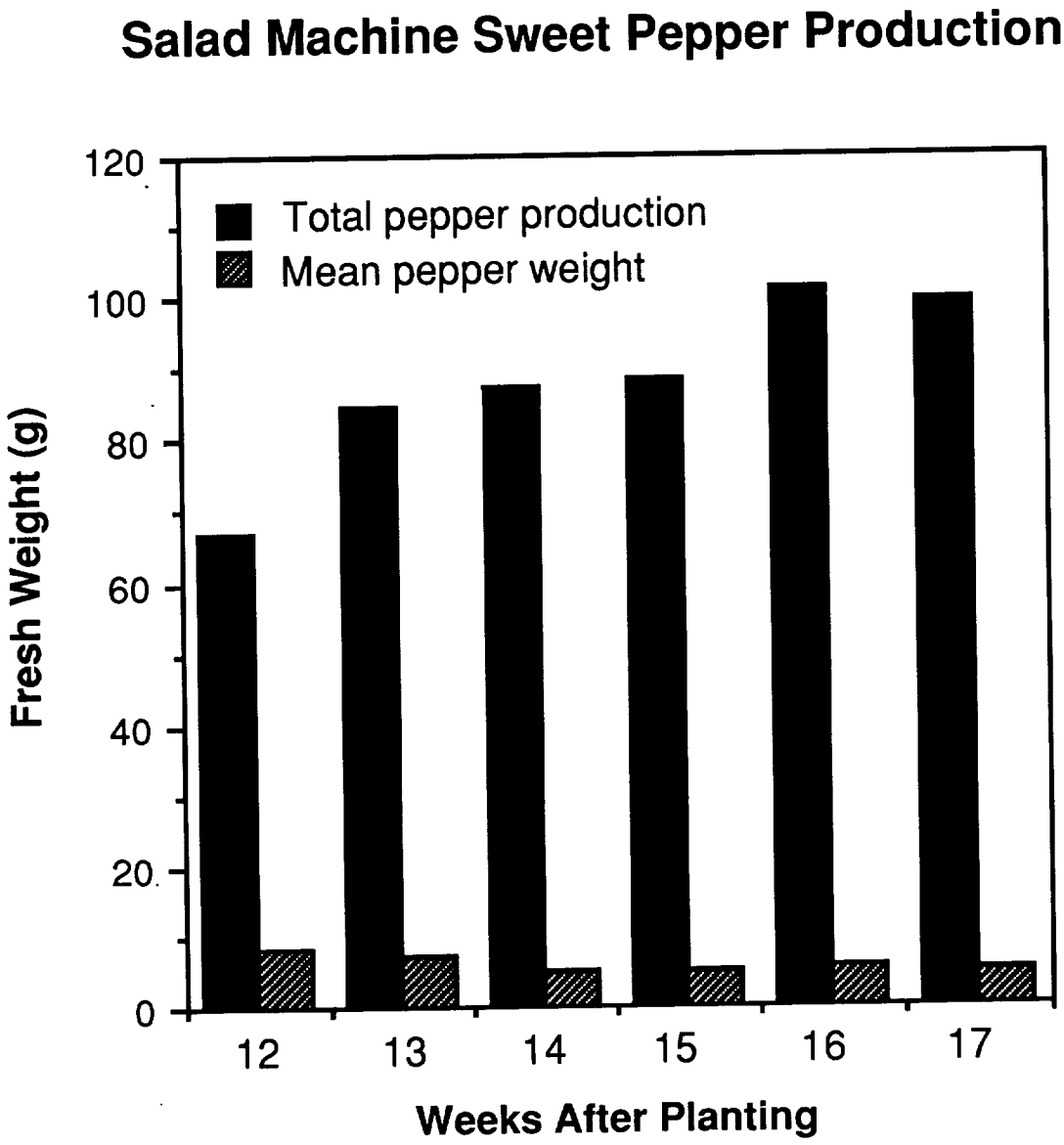

Figure 3. Production of 'Christmas Lights' sweet pepper in a Salad Machine rack. Initial harvest data represents an average of eight peppers harvested per week. Later harvests represent an average harvest of eighteen peppers per week.

will employ a simulated microporous ceramic tube system with eight tubes per nutrient delivery tray. Tubes will be simulated with polyvinylchloride pipe. To minimize space used for hardware, manifolds for nutrient delivery tubes will be custom machined of single piece nylon. Each of the eight nutrient delivery trays will be connected to a single 20 liter bladder type nutrient solution reservoir. Silk plants will be secured to the nutrient tubes to simulate an operating Salad Machine.

SUPPORTING RESEARCH AT ALABAMA A&M UNIVERSITY

During the previous year Salad Machine research at Alabama A&M has focused primarily on the issues of plant compatibility and on surveying microbial populations of mixed-species hydroponic systems to determine how the microbial populations may be affected by different host plants. The progress on these studies is reported on below.

Plant Compatibility Studies

Introduction

The current Salad Machine configuration has four drawers for plant growth and space for one, or possibly two, 20 liter nutrient solution reservoirs. This configuration is designed to maximize productivity within the rack by using the maximum space available for plant growth and as little as possible for supporting hardware. One potential problem with this approach is that all plant species must share the same nutrient solution and yet the plants have the different levels of requirements for each nutrient. If the differences in nutrient requirements are extreme, then it may result in reduced productivity by one or more species within the Salad Machine rack. In addition, there may be allelopathic incompatibilities in which chemicals excreted from the plant roots may build up in the solution over time and inhibit growth of other plant species or even their own growth (3,5,7,8,13). We have begun a series of experiments, on the candidate species for Salad Machine, to evaluate the degree of plant incompatibilities which may exist in a shared nutrient solution system.

Materials and Methods

Several experiments were conducted to determine the compatibility of 'Red Prince' radish (Asgrow Seed, Inc.) with 'Waldmanns Green' lettuce (Asgrow Seed, Inc.). A Nutrient Film Technique (NFT) hydroponic system was set up to conduct these studies. The NFT system consisted of 16 polyvinylchloride (PVC) troughs through which nutrient solution was flowed. The plants were supported by a sheet of opaque plastic which covered the troughs and which had several 19 cm holes drilled in it to allow for plant root access to the nutrient solution. Eight of the troughs were used to grow lettuce and eight were used to grow radish. Four of the eight radish troughs were fed by four individual 20 liter nutrient solution reservoirs. Likewise, four of the lettuce troughs were fed by individual 20 liter reservoirs. The remaining eight troughs were arranged in four lettuce-radish pairs and fed nutrient solution from four 40 liter reservoirs. The troughs were arranged in the growth chamber in four experimental blocks which consisted of one lettuce-radish pair, one individual radish trough, and one individual lettuce trough per block.

Several experiments were conducted to allow the graduate student working on this project to become familiar with growing plants hydroponically and to develop expertise in methods of supplementing the nutrient solution as nutrients are taken up by the plants. Unlike most hydroponics research where a nutrient solution mix is chosen at the start of the experiment and the solution periodically discarded and replaced, the nature of this research in screening for plant incompatibilities including allelopathic responses required that the same solution be used throughout the experiment, and, if possible, for several experiments. Reuse of hydroponic nutrient solutions for long periods of time is also compatible with NASA long term goals of operating bioregenerative systems with a minimum of water use and waste water to be processed. Minimal use of water for Salad Machine on Space Station Freedom will also make Salad

Machine a more attractive prospect. The environmental and experimental parameters for the experiments were as follows:

Experiment 1

Temperature- aerial 22°C; root zone 27°C.

Lighting- Continuous lighting from coolwhite VHO fluorescent lamps; light intensity ranged from 400 to 500 µmoles/m^2/s.

Relative humidity- set at 75%.

Growth period- 30 days

Flow rate- 1l/min/trough.

Nutrient solution- a modified half strength Hoaglands (See Table 1) During the course of the experiment either distilled water or Half Strength Hoaglands Nutrient solution were added to keep solutions up to a volume of 20 or 40 liters and Electrical Conductivity levels at 1.1 mS.

Experiment 2

Temperature- aerial 25°C; root zone 27°C.

Lighting- Continuous lighting from coolwhite VHO fluorescent lamps; light intensity ranged from 400 to 500 µmoles/m2/s.

Relative humidity- set at 75%.

Growth period- 30 days

Flow rate- 1l/min./trough.

Nutrient solution- a modified half strength Hoaglands (see Table 1). Nutrient solution or water added as needed to maintain volume and E.C. of 1.5 mS

Table 1. Macronutrient concentrations in several plant compatibility studies.

	Nutrient Concentration (mM)			
Nutrient	Exp1	Exp2	Exp3	Exp4
NO_3-N	6.4	10.5	11.25	7.5
NH_4-N	0.0	3.0	0.0	0.0
K	1.1	3.0	4.5	2.9
P	0.8	0.5	0.75	0.8
Ca	5.29	2.5	3.75	2.5
Mg	2.02	1.0	1.5	1.0
S	2.02	1.0	1.5	1.0

Experiment 3

Temperature- aerial 25^{o}C; root zone 26^{o}C

Lighting- Continuous lighting from coolwhite VHO fluorescent lamps; light intensity ranged from 250-350 μmoles/m^{2}/s

Relative humidity- set at 75%

Growth period- 30 days

Flow rate- 1 l/min/trough; Dissolved oxygen 9.4-10.5%

Nutrient solution- Three quarter strength Hoaglands solution (see Table 1); Nutrient solutions were discarded and replaced weekly for two blocks of the experiment. Nutrient solutions were supplemented with stock solutions for the remaining 8 troughs.

Experiment 4

Temperature- aerial 25^{o}C; root zone 26^{o}C

Lighting- Continuous lighting from coolwhite VHO fluorescent lamps; light intensity ranged from 400-500 μmoles/m^{2}/s

Relative humidity- set at 75%

Growth period- 30 days

Flow rate- 1 l/min/trough; Dissolved oxygen 9.4-10.5%

Nutrient solution- a modified half strength Hoaglands solution (see Table 1); Nutrient solutions were supplemented with stock solutions according to Wheeler et. al. (12).

Results and Discussion- Experiment 1-2

There was a great deal of unexplained variation between blocks in both experiment 1 and 2. In the first experiment radish root fresh weight was greater when radishes were grown on nonshared reservoirs in three of the 4 blocks (Fig. 4). However an opposite trend was seen in one of the four blocks. Mean radish root fresh weight of plants grown on shared nutrient solution was nearly double the mean fresh weight of radishes grown on nonshared solutions of the other three blocks (Fig. 4). During the second experiment radish root fresh weight was greater for radishes grown on shared nutrient solution in two blocks and greater for radishes grown on non shared reservoirs in the other two blocks (Fig. 5). Lettuce shoot fresh weight production did not appear to be related to sharing of nutrient solutions. In experiment 1, lettuce shoot fresh weight was greater in troughs grown on shared nutrient solution for two of the blocks and in two of the blocks lettuce production was greater in troughs grown on nonshared solutions (Fig. 6). Lettuce production during the second experiment was greatly varied. In two of the blocks with shared nutrient solutions lettuce production was vigorous, with an average fresh shoot weight of 61.61 and 74.97 g per plant (Fig 7). In block two, lettuce shoot fresh weight of plants grown on shared solution was somewhat less than that of plants grown on nonshared solution and only one third that of the lettuce grown on shared solution in block three. Block four showed low yields in both shared and nonshared troughs. Because there was no consistent trend among blocks results are viewed with great caution.

Possible reasons for the inconsistencies include : leaching of inhibitory substances from the troughs or other parts of the NFT system, non uniform plant populations at the start of the experiment, and difficulty maintaining adequate nutrient status in solutions due to utilizing electrical conductivity (E.C.) as a measure of nutrient status. Eliminating or ruling out the factors which may

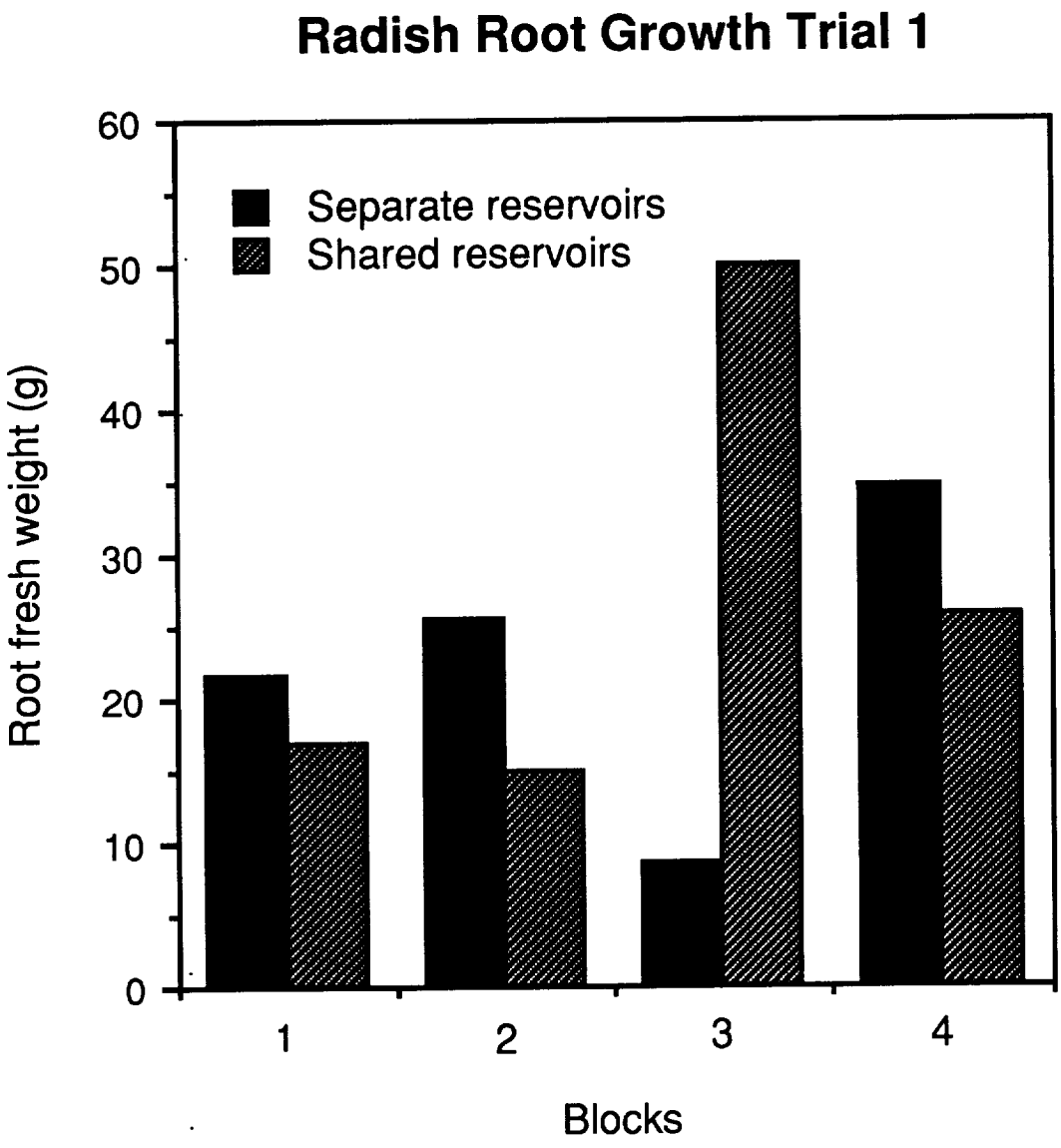

Figure 4. Comparison of 'Red Prince' radish root growth grown on shared and nonshared nutrient solutions. Data is presented as the average root fresh weight per plant. Means represent the average of seven observations.

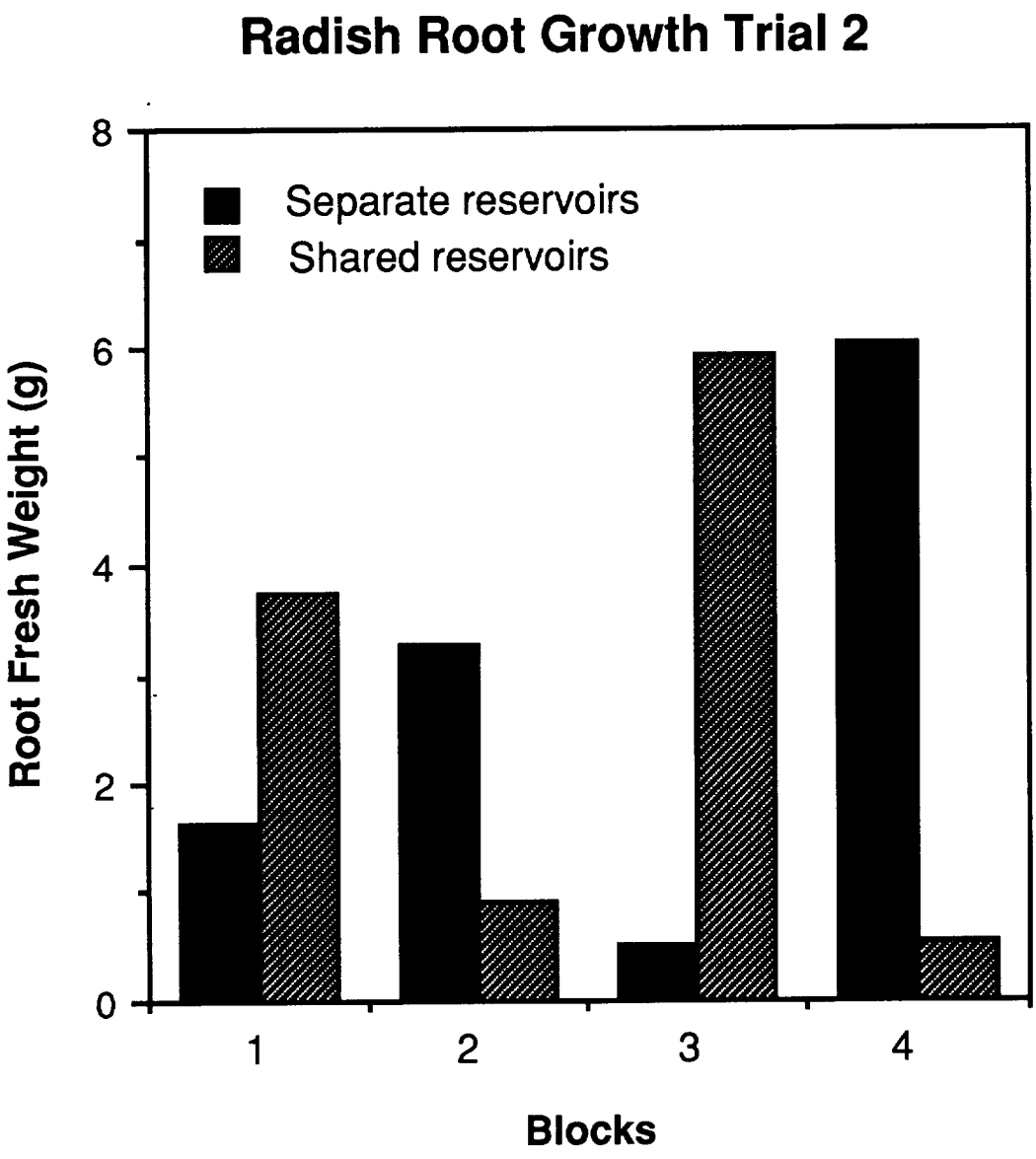

Figure 5. Comparison of 'Red Prince' radish root growth grown on shared and nonshared nutrient solutions. Data is presented as the average root fresh weight per plant. Means represent the average of seven observations.

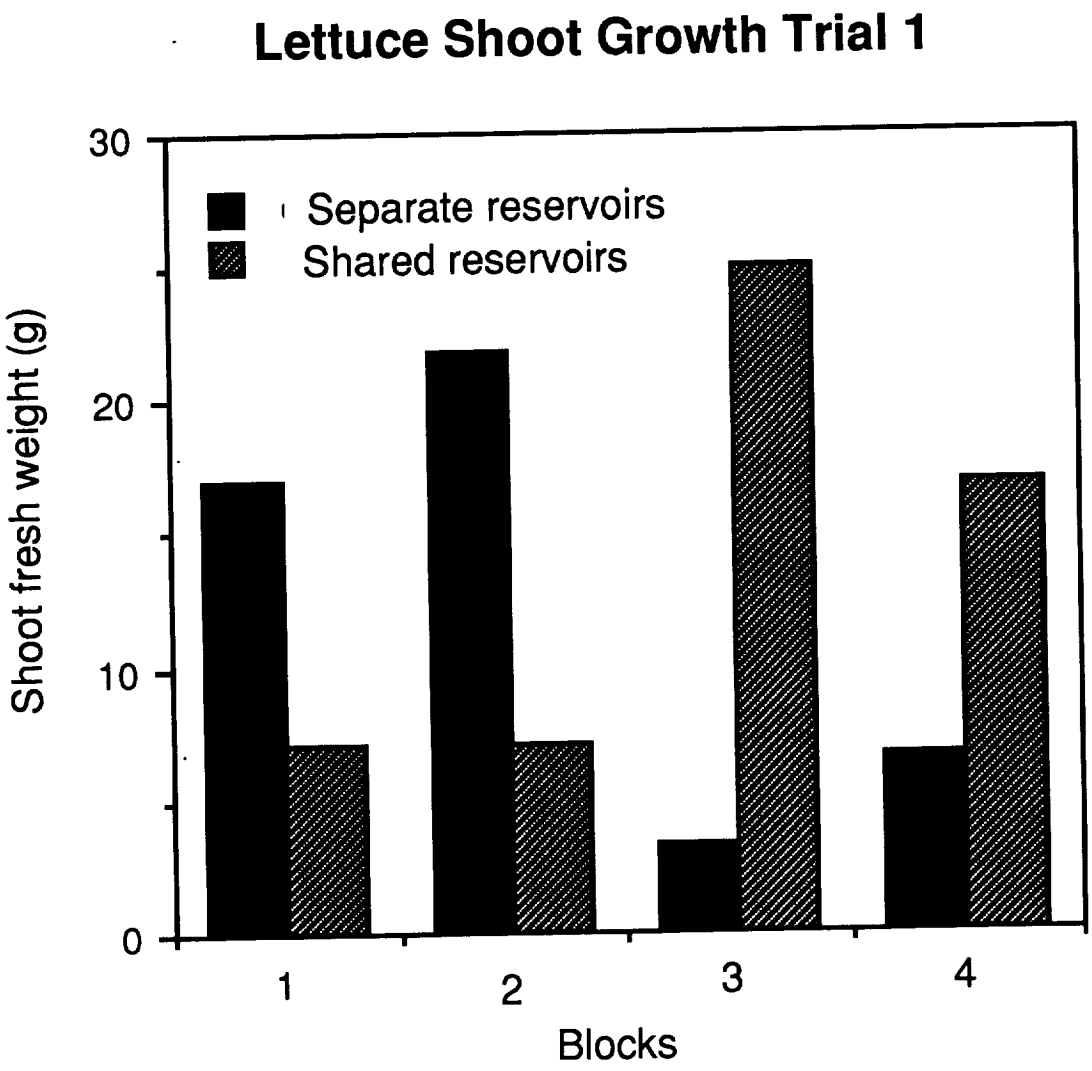

Figure 6. Comparison of 'Waldmanns Green' lettuce shoot growth grown on shared and nonshared nutrient solutions. Data is presented as the average shoot fresh weight per plant. Means represent the average of seven observations.

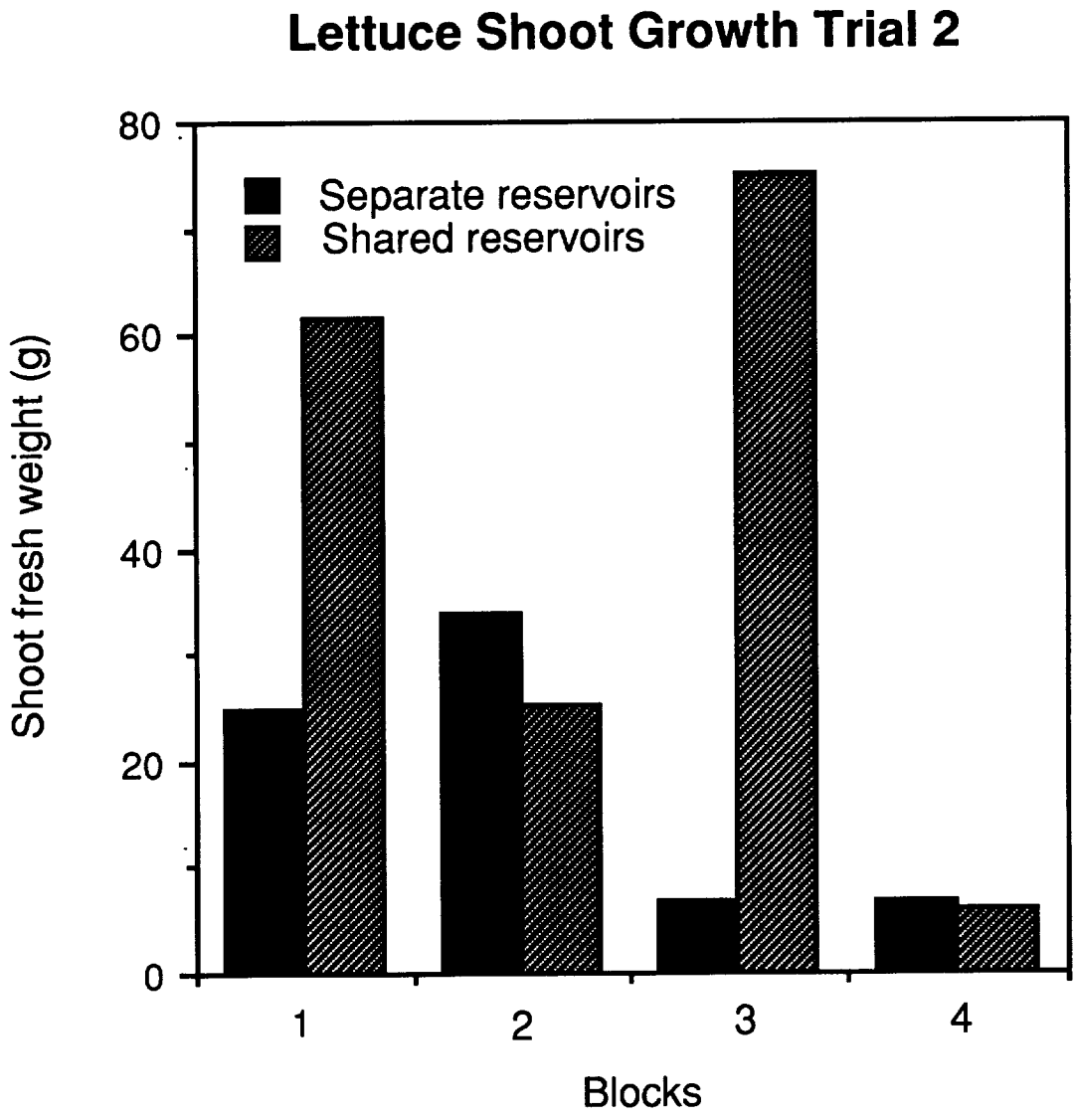

Figure 7. Comparison of 'Waldmanns Green' lettuce shoot growth grown on shared and nonshared nutrient solutions. Data is presented as the average shoot fresh weight per plant. Means represent the average of seven observations.

be causing the inconsistent results has required a multifaceted approach.

Non uniform plant population at start of the experiment may have been to due to a number of factors including sensitivity of young seedlings to salt concentrations and buildup of salt solutions on wicks surrounding seedlings during first week of experiment. Both lettuce and radish seedlings were susceptible to high salt concentrations, although radish seedlings were not as sensitive as lettuce seedlings. The sensitivity of seedlings to the salt concentrations present in the nutrient solution along with the natural variation in growth potential in any population of seeds resulted in a varied population at the start of the experiment. To overcome these problems we have developed a strategy of planting seedlings in deionized water for the first 4 days for lettuce and 2 days for radish. In addition, many extra seeds are planted in each plug and numerous extra plugs are planted to ensure survival of a uniform population of plants. Seedlings are thinned periodically, with a final thinning one week after placing seedlings in nutrient solution to ensure that all seedlings are equally capable of tolerating the concentrated salts in the nutrient solution.

Experiment 3

Since the NFT system had been newly constructed for this series of plant incompatibility experiments and thus had not been demonstrated to reliably support plant growth it was decided to attempt to grow plants on the NFT system utilizing the more usual and less challenging technique of replacing the used nutrient solution with new solution on a weekly basis. If healthy vigorous plants could be grown in this manner then it would tend rule out something being wrong with the system itself and give the graduate student performing the studies more confidence in his system. A study was conducted in which half the troughs had nutrient solution replaced weekly and half had solution E.C. maintained. Yields of radish and lettuce grown on replaced solutions were double those of

plants grown on supplemented solutions (Fig. 8) thus suggesting that at least some of the problems were related to maintaining appropriate nutritional content of the nutrient solution.

Experiment 4

Once a uniform population is established it is important to be able to meet the nutritional needs of the plants while not poisoning the plants with toxic levels of nutrients. Initial experiments utilized electrical conductivity as a measure of nutrient status. Electrical conductivity values were maintained by the addition of Hoaglands solution to the nutrient solutions when E.C. values decreased below the initial values of the nutrient solution. This method assumes that plants will take up nutrients in the proportion in which they are provided. Unfortunately this is hardly ever the case and nutrient deficiencies or toxicities often result (1,6,10). In addition, electrical conductivity readings are not equally sensitive to different ions. For example, nitrate concentration does not have as close a correlation with E.C. readings as does potassium (6). We observed a number of symptoms including interveinal chlorosis of the leaves as well as a general paleness of leaves which suggested nutritional deficiencies were occurring (4). To remedy this situation we began a series of experiments in which we collected samples of nutrient solution on a weekly basis and analyzed for various nutrients either by atomic absorption spectroscopy or by use of nitrate or potassium specific electrodes. We have also adopted the approach of Wheeler et. al. (12) in adding certain concentrations of nutrient concentrates to the nutrient solutions based on solution uptake rather than E.C. values. Results of these experiments will be reported below.

Results Experiment 4

Implementation of the above mentioned changes resulted in an experiment in which consistent results were obtained for all four experimental blocks (Fig. 9). Shared or separate nutrient solutions

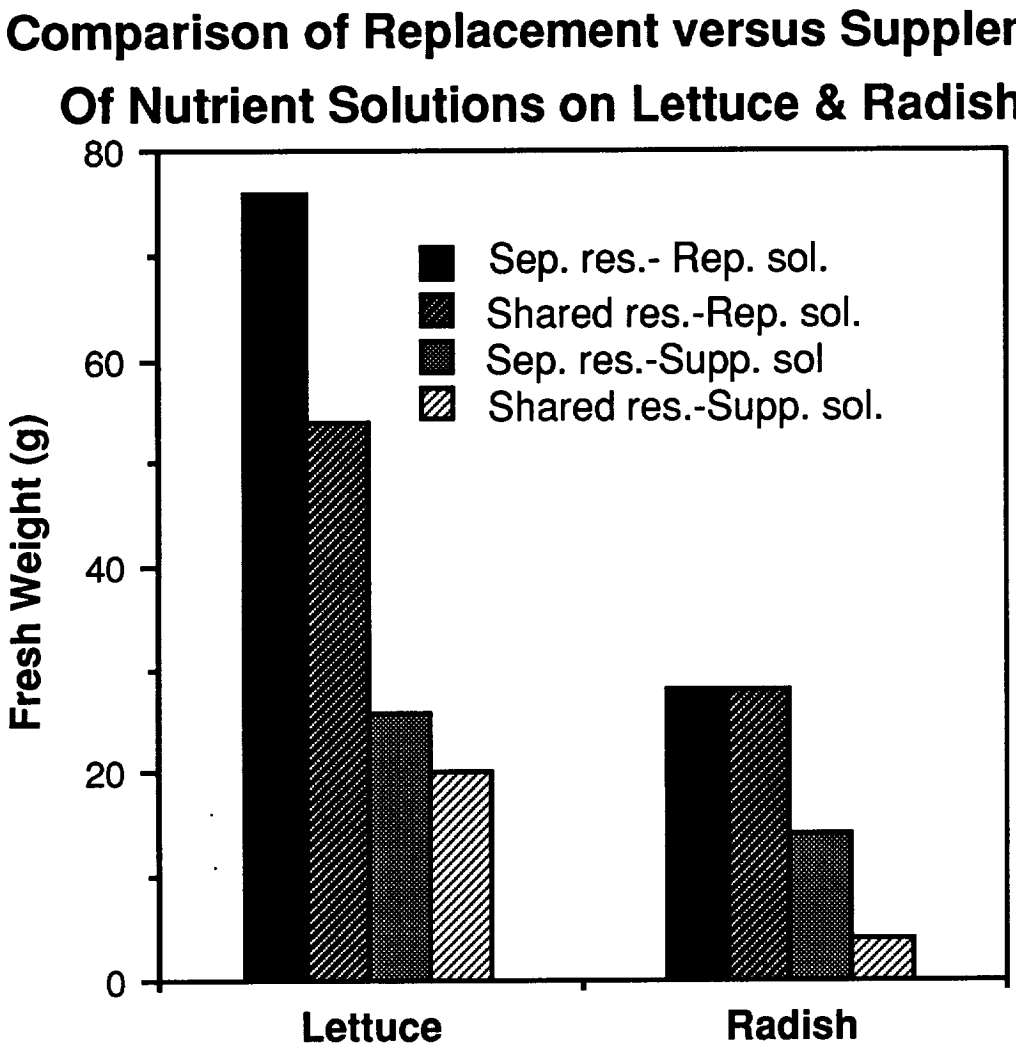

Figure 8. Comparison of replacing versus supplementation of nutrient solutions on growth of 'Waldmanns Green' lettuce and 'Red Prince' radish. Data is presented as the mean root (radish) or shoot (lettuce) fresh weight per plant. Means represent the average of fourteen observations.

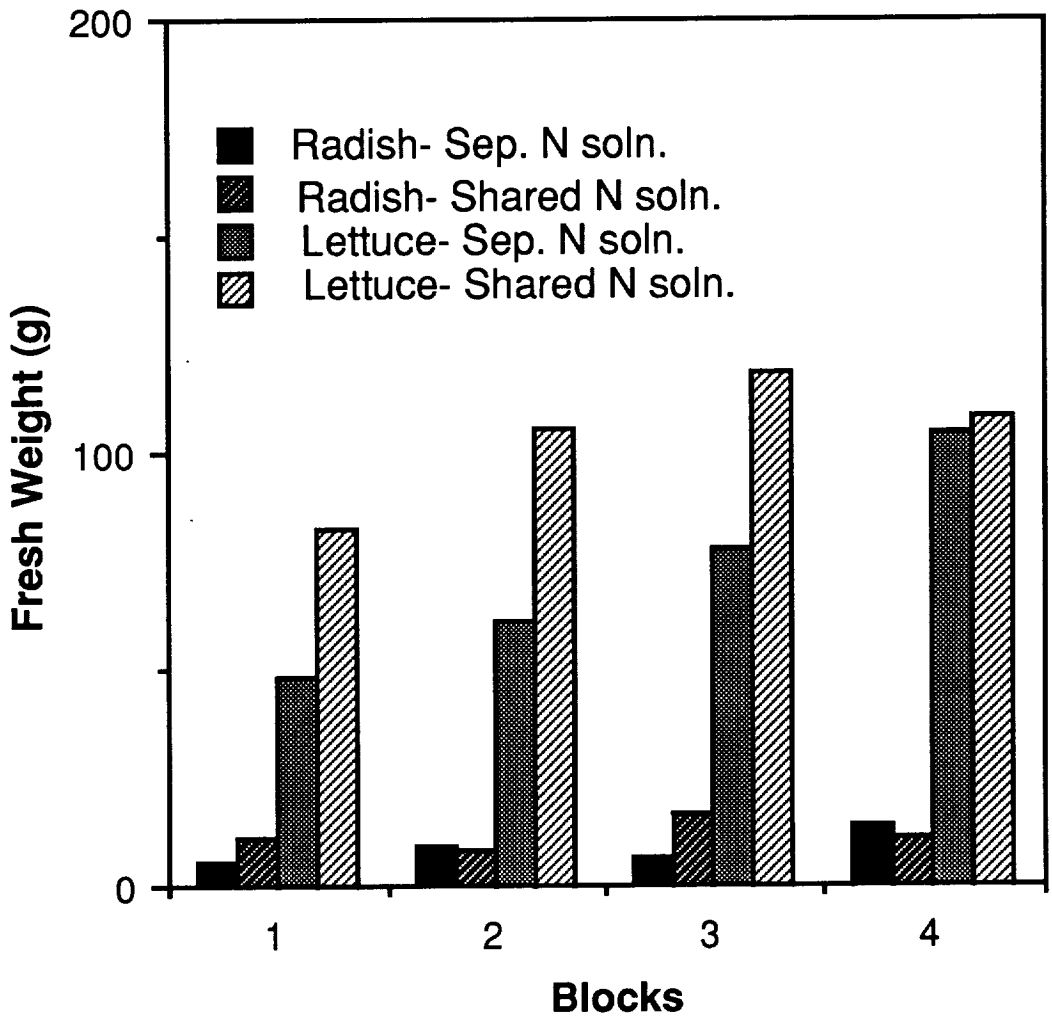

Figure 9. Effect of sharing nutrient solution on growth of 'Red Prince' radish and 'Waldmanns Green' lettuce. Data is presented as mean root (radish) or shoot (lettuce) fresh weight per plant. Means represent the average of seven observations.

did not appear to have a significant impact on radish growth, however lettuce plants grew better in shared nutrient solutions than in separate reservoirs (Fig. 10). One possible explanation for this could be that radish is less demanding of the nutrient pool than lettuce and therefore, in a shared reservoir, there are more nutrients available to the lettuce plants; in effect the lettuce plants get a share of a portion of the radish nutrients as well as their own.

A comparison of leaf sap nitrate concentration in radish and lettuce showed very little difference in nitrate content of radish grown on separate or shared nutrient solutions twelve days after planting (Fig. 11). However, lettuce plants grown on shared reservoirs had nearly double the nitrate content as those from separate reservoirs (Fig. 12). As with nitrate, comparison of potassium concentration in radish leaf sap twelve days after planting revealed very little difference between shared or nonshared nutrient solutions (Fig. 13). Lettuce leaf sap potassium levels were somewhat higher in plants grown on shared nutrient solutions relative to those grown on nonshared solutions (Fig. 14). Analysis of leaf sap nitrate and potassium content during the fourth week of the experiment showed an opposite trend. The leaf sap nitrate and potassium concentrations in both radish and lettuce plants which were grown on separate reservoirs was now at least double that of plants grown on shared reservoirs (Figs. 11-14). Reports in the literature indicate that normal potassium content for radish and lettuce on a fresh weight basis is 3220 ppm and 2640 ppm respectively (11). Normal lettuce nitrate content on a fresh weight basis ranges from 2500 ppm to 4650 ppm (2). It appears that potassium and nitrate levels in the leaf sap of radish and lettuce are near normal levels until the end of the growth period when levels in leaf sap of plants grown on shared reservoirs declines to below normal levels. We are not sure how to interpret this data. Is there an inhibition of nutrient uptake in the later stages of growth in the shared solution troughs? Is there greater nutrient uptake by lettuce in shared troughs due to greater pool size and less use by radish plants? Before these questions can be answered we must verify the accuracy

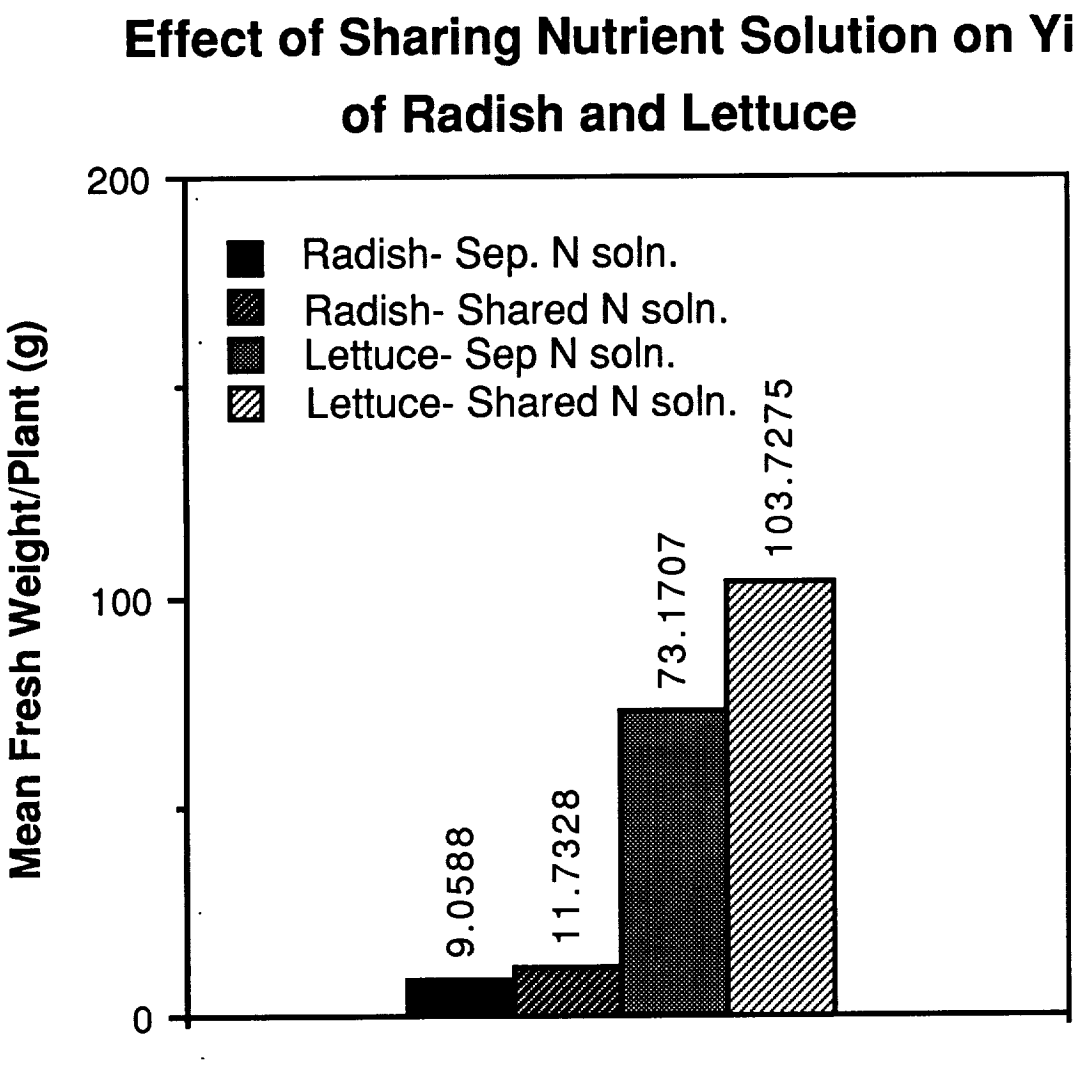

Figure 10. Effect of sharing nutrient solution on growth of 'Red Prince' radish and 'Waldmanns Green' lettuce. Data is presented as mean root (radish) or shoot (lettuce) fresh weight per plant. Means represent the average of twenty-eight observations.

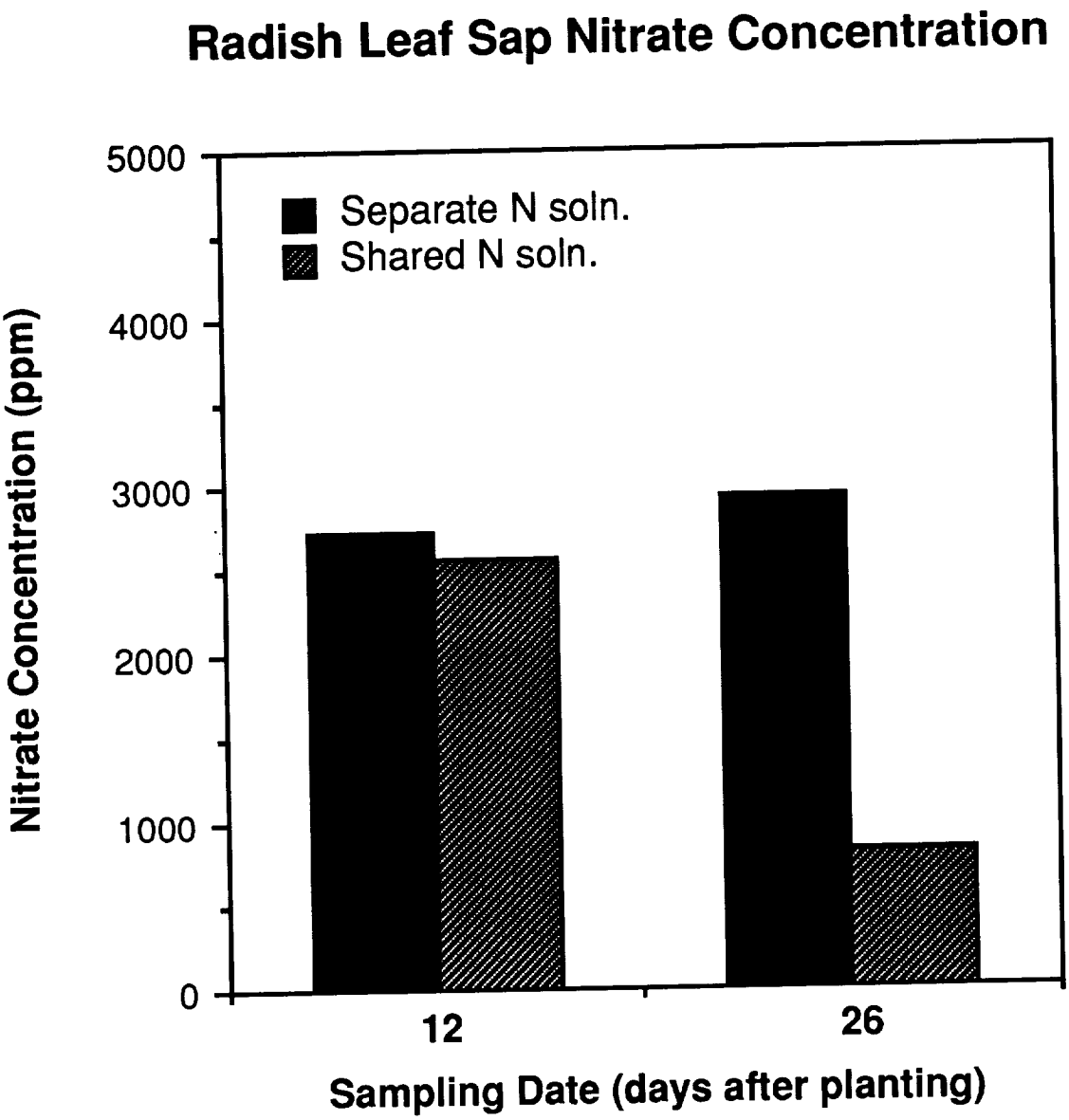

Figure 11. Effect of sharing nutrient solution on 'Red Prince' radish leaf sap nitrate concentration. Means represent the average of four (first sampling date) and eight (second sampling date) observations.

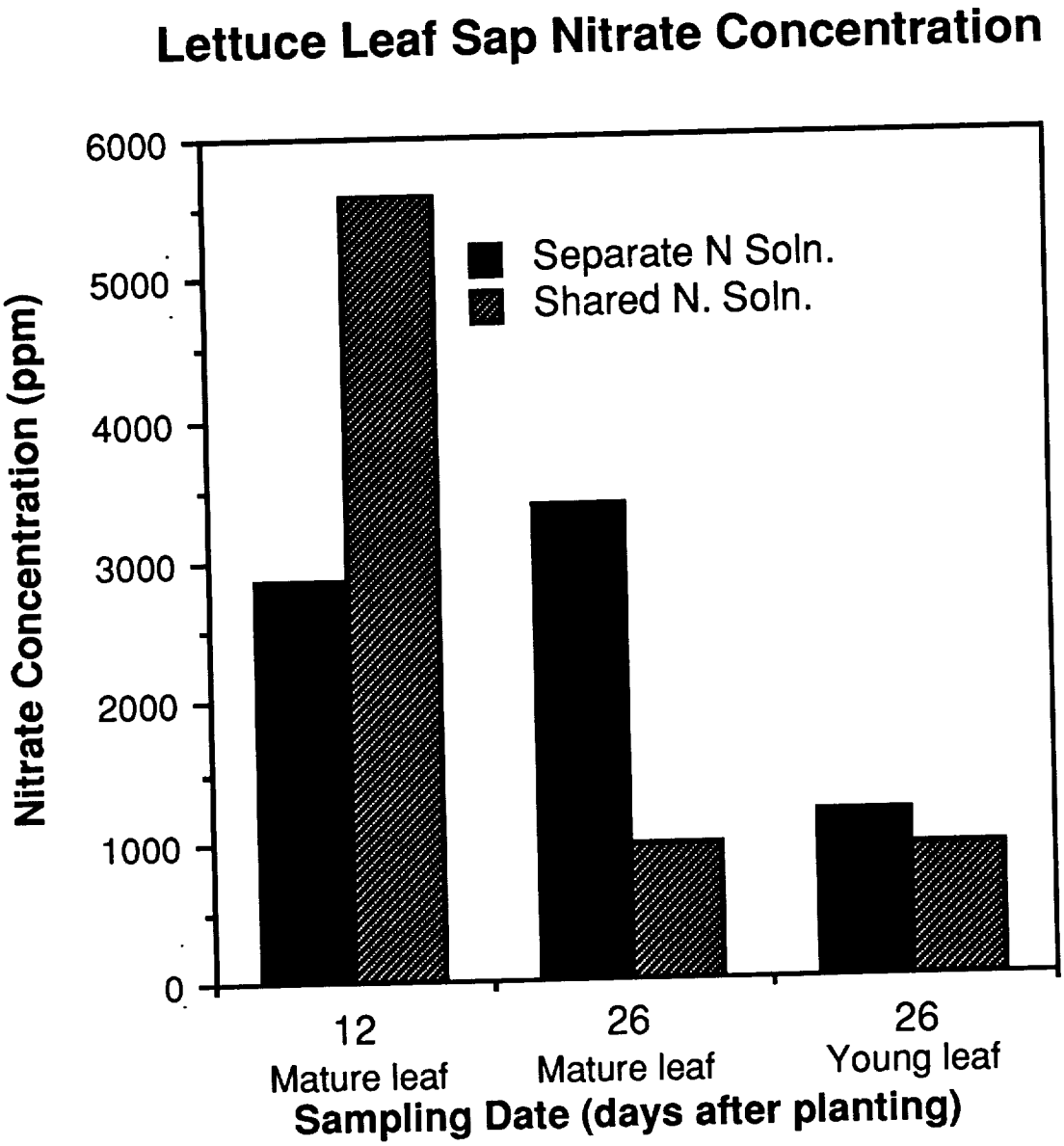

Figure 12. Effect of sharing nutrient solution on 'Waldmanns Green' lettuce leaf sap nitrate concentration. Means represent the average of four (first sampling date) and eight (second sampling date) observations.

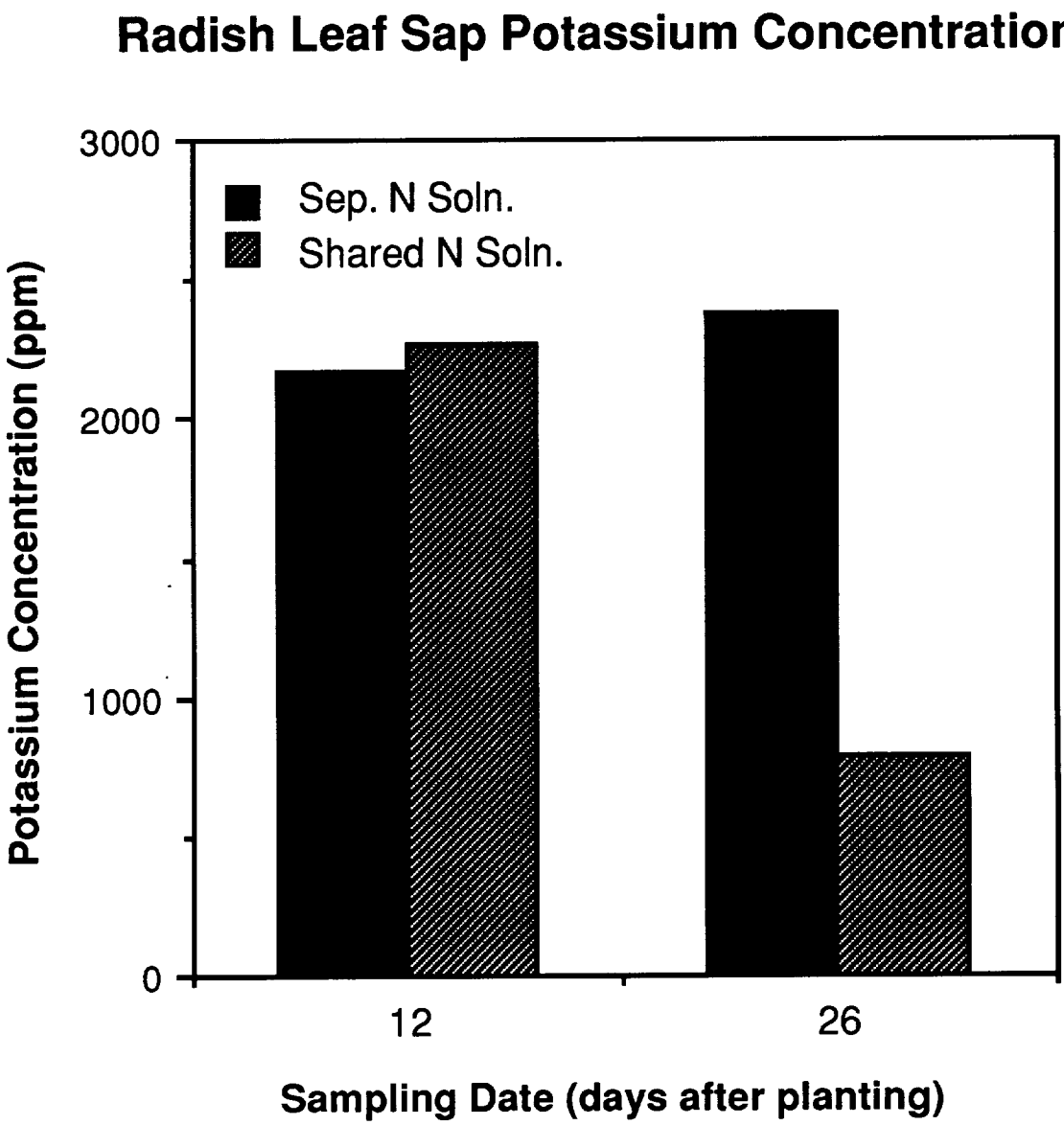

Figure 13. Effect of sharing nutrient solution on 'Red Prince' radish leaf sap potassium concentration. Means represent the average of four (first sampling date) and eight (second sampling date) observations.

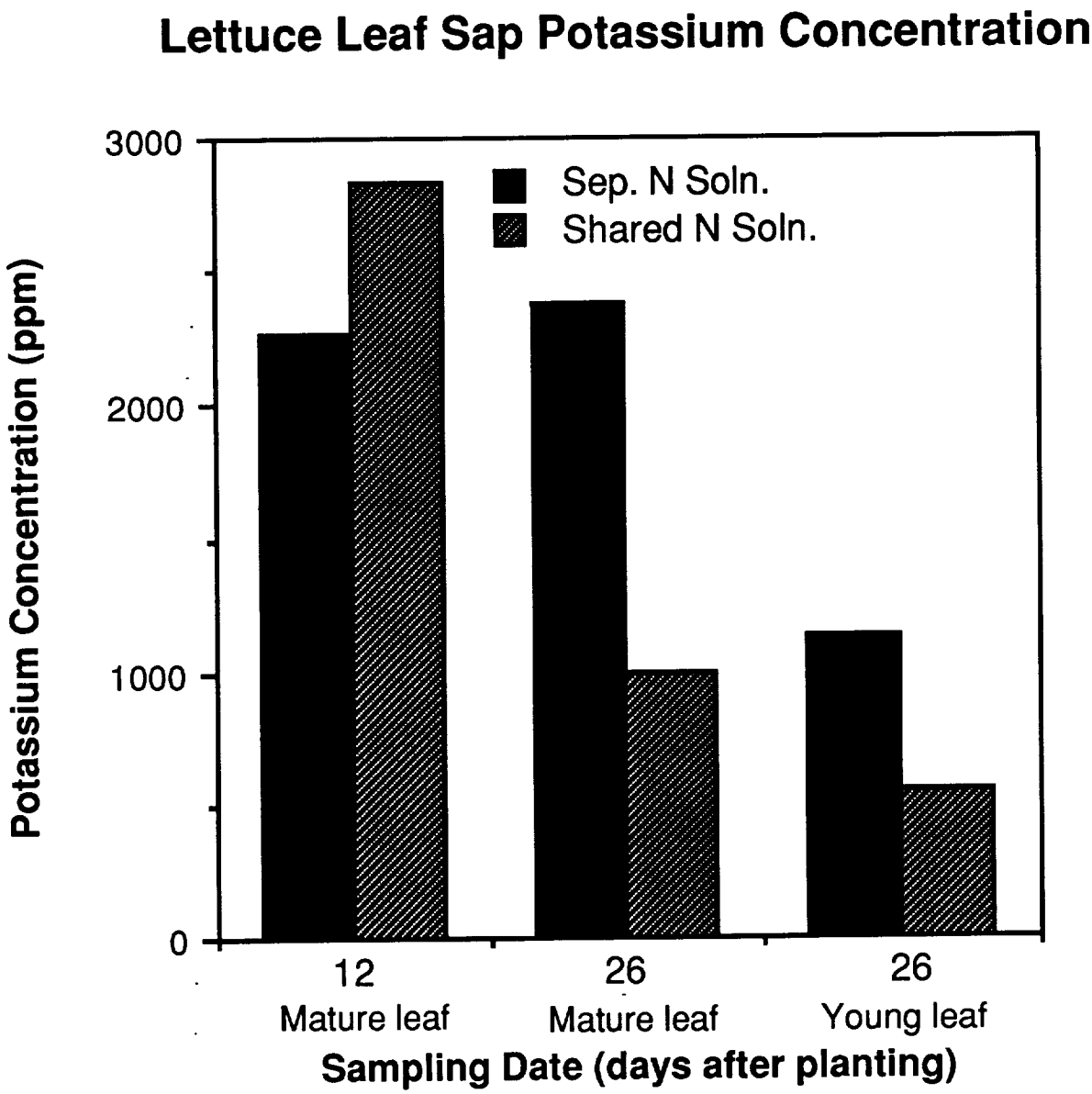

Figure 14. Effect of sharing nutrient solution on 'Waldmanns Green' lettuce leaf sap potassium concentration. Means represent the average of four (first sampling date) and eight (second sampling date) observations.

of the data. Although we have seen a consistent trend in both leaf sap nitrate and potassium content for both young and mature leaves of lettuce and mature leaves of radish, rapid elemental analysis of fresh tissues is relatively new and consistent results are highly dependant on consistent sampling methods. Since this is the first time we have utilized this equipment and method we will verify the reliability of this technique by comparison of the leaf sap data collected at the end of the growing period with atomic absorption analysis of dried tissues collected at the end of the growing period.

Weekly sampling of nutrient solution for analysis of several of the macroelements and one of the minor elements was conducted. Nitrate and potassium levels stayed roughly the same as the initial concentrations (Figs. 15,16), while calcium levels increased to roughly 150% of the initial concentrations during the second half of the experiment (Fig. 17). Magnesium concentrations increased to more than double the initial levels during the second half of the experiment (Fig. 18) while manganese levels steadily increased throughout the experiment to reach levels that were double the initial concentrations (Fig. 19). These results indicate the need for some modification in the amounts of stock solutions that are added to the nutrient solutions throughout the experiment.

Microbial populations in NFT systems.

Research initially focused on familiarizing the NASA Space Grant Fellowship student researcher with aseptic and microbiological methodology. Since initial experiments were focusing on technique development, only a limited number of samples were taken. The goals of these initial experiments were 1) to develop and evaluate methodology for identifying the microbial population of the rhizosphere of plants grown on an NFT Hydroponic system and 2) to familiarize the student researcher with the equipment at Alabama A&M University and Marshall Space Flight Center which would be necessary for microbiology research.

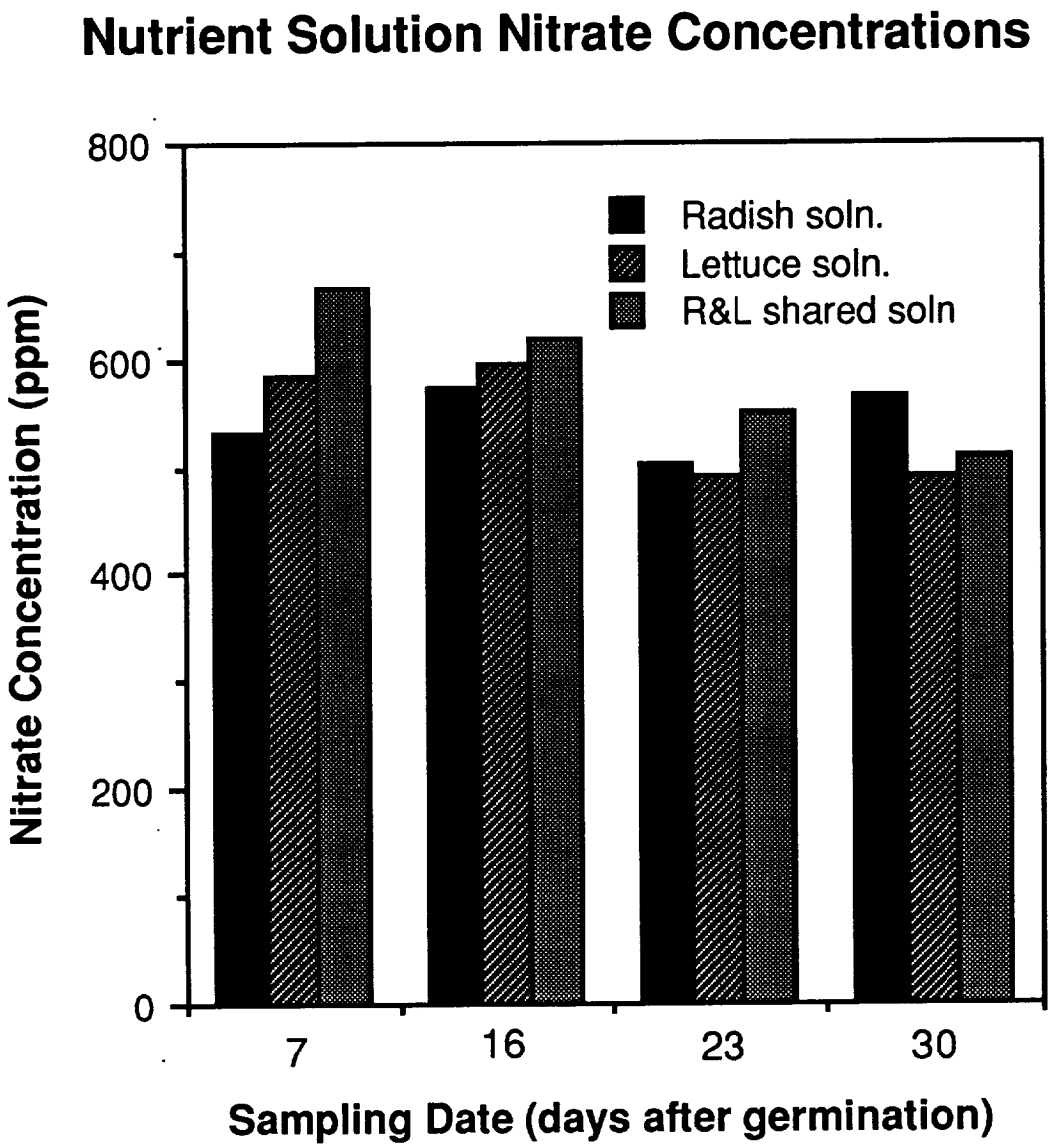

Figure 15. Suitability of Wheeler et. al. supplement concentrations in maintaining nitrate solution concentrations in shared and nonshared reservoirs. Nitrate concentrations were measured with an Orion nitrate specific electrode.

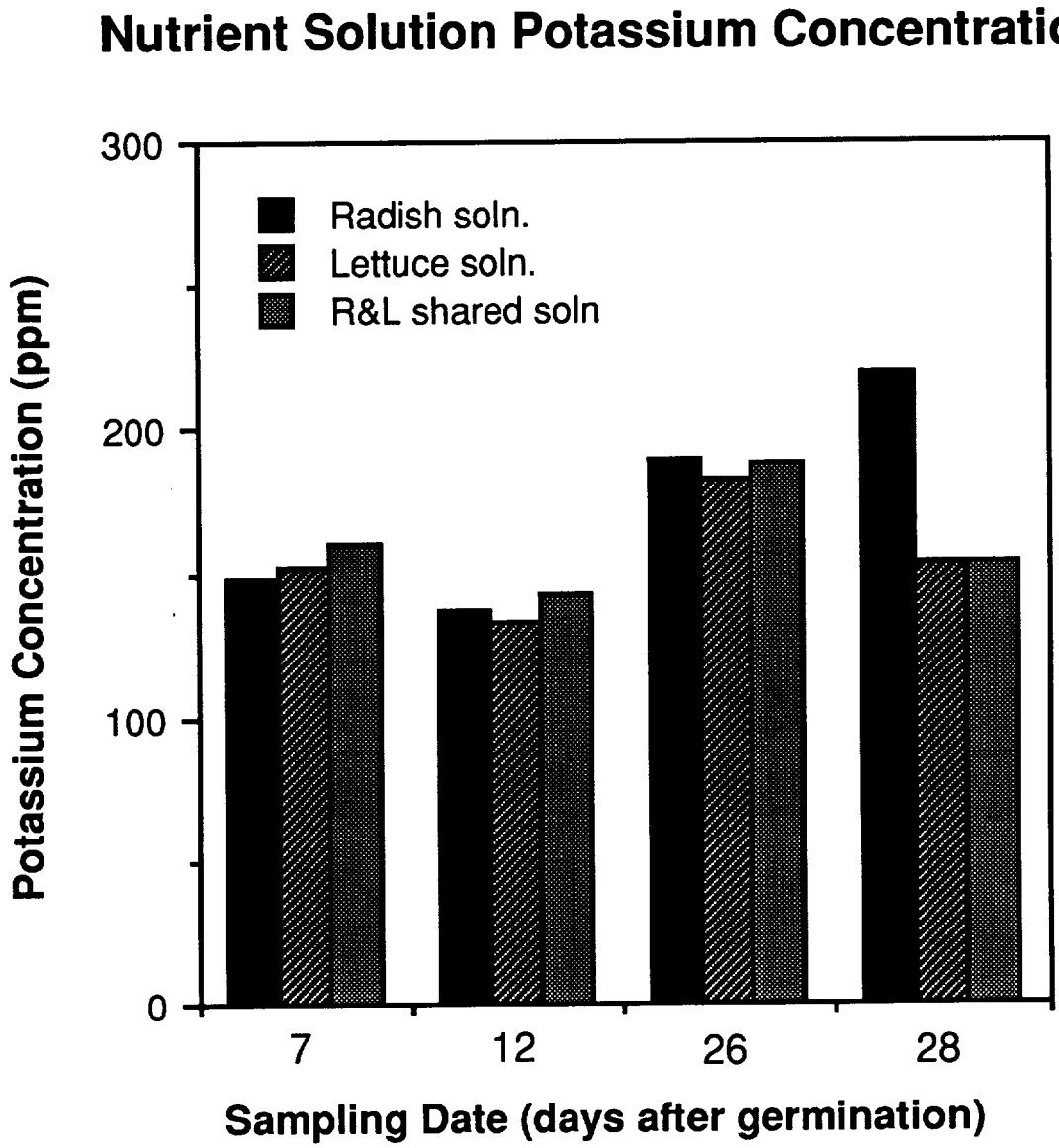

Figure 16. Suitability of Wheeler et. al. supplement concentrations in maintaining potassium solution concentrations in shared and nonshared reservoirs. Potassium concentrations were measured with either a Cardy potassium specific sensor or by atomic absorption spectroscopy.

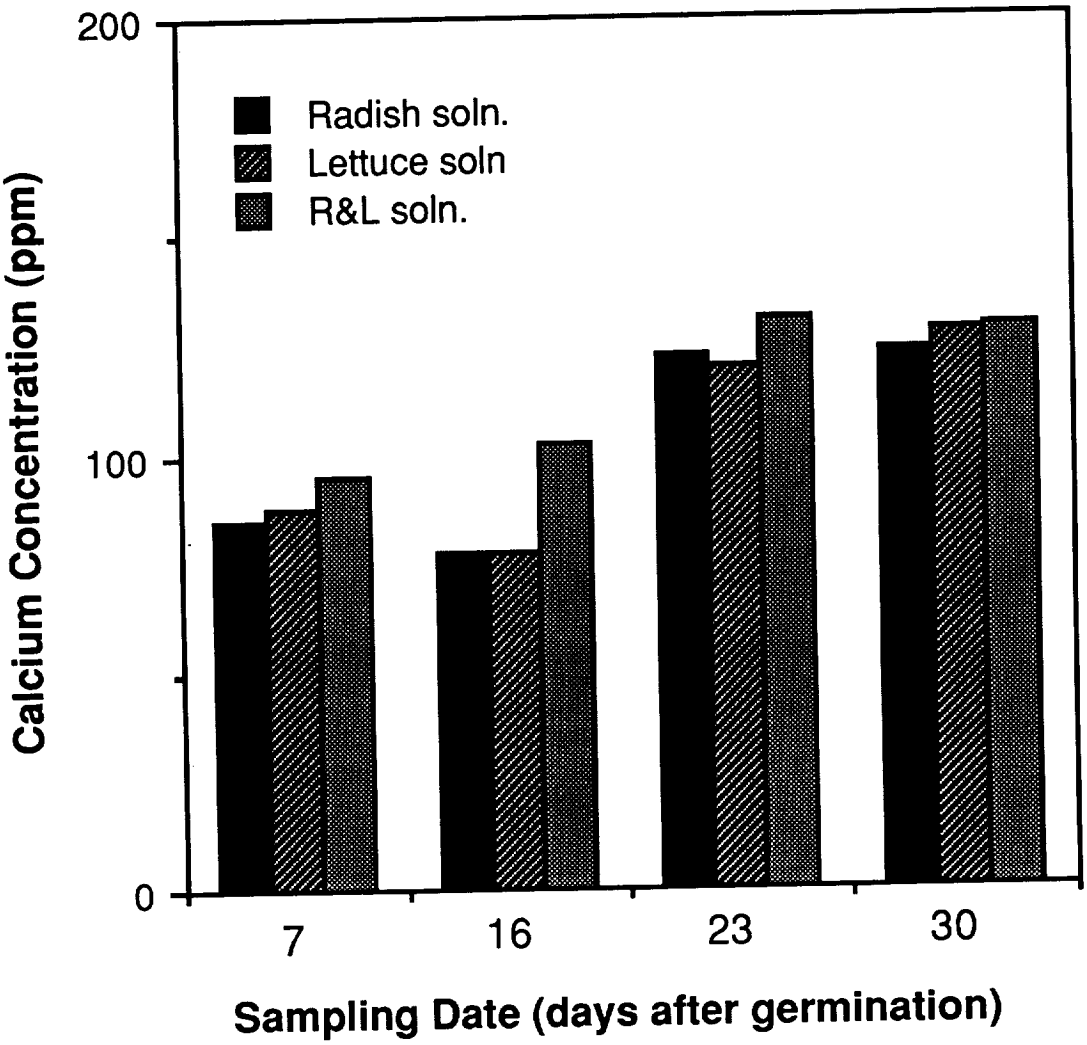

Figure 17. Suitability of Wheeler et. al. supplement concentrations in maintaining calcium solution concentrations in shared and nonshared reservoirs. Calcium concentrations were measured by atomic absorption spectroscopy.

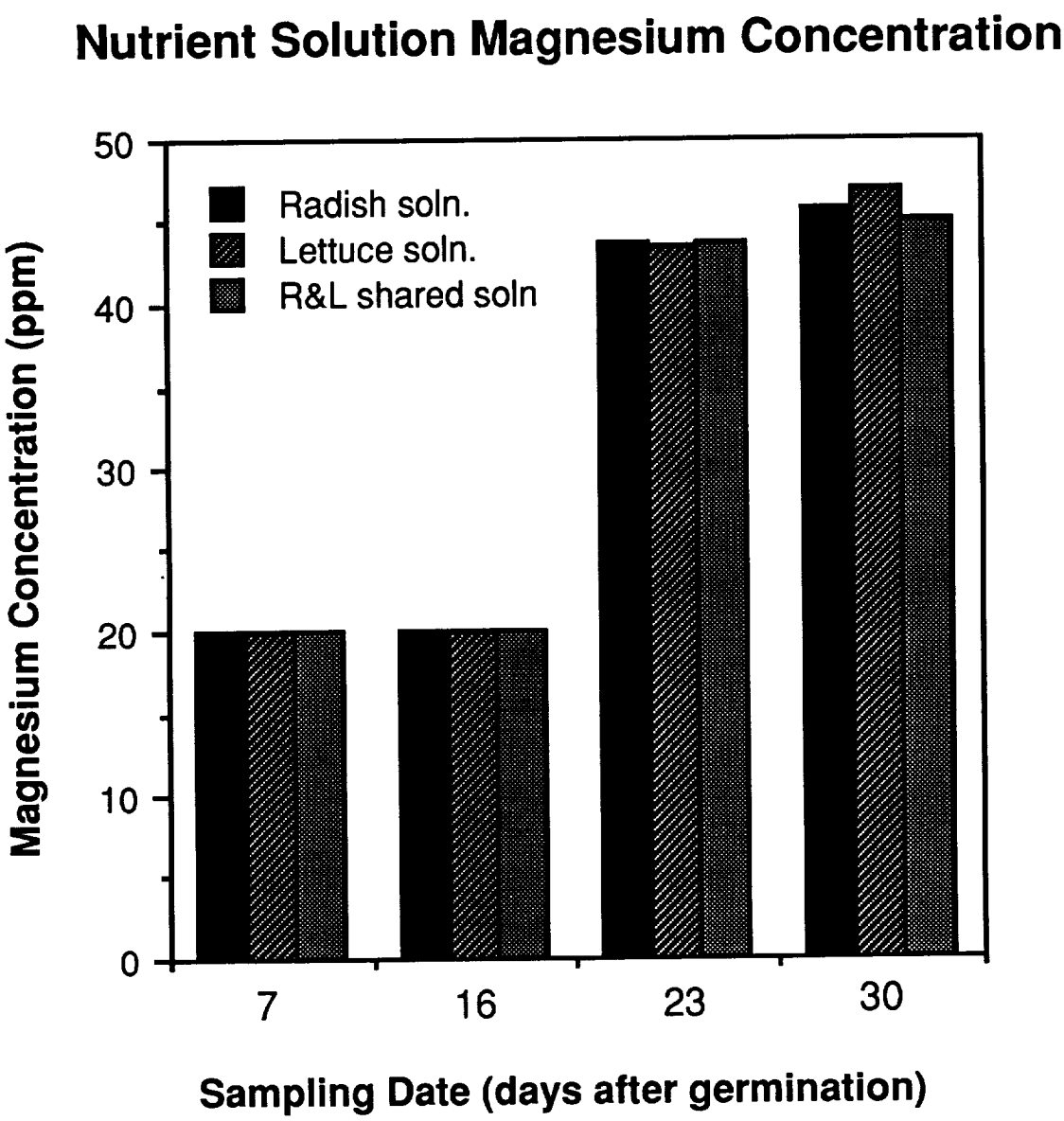

Figure 18. Suitability of Wheeler et. al. supplement concentrations in maintaining magnesium solution concentrations in shared and nonshared reservoirs. Magnesium concentrations were measured by atomic absorption spectroscopy.

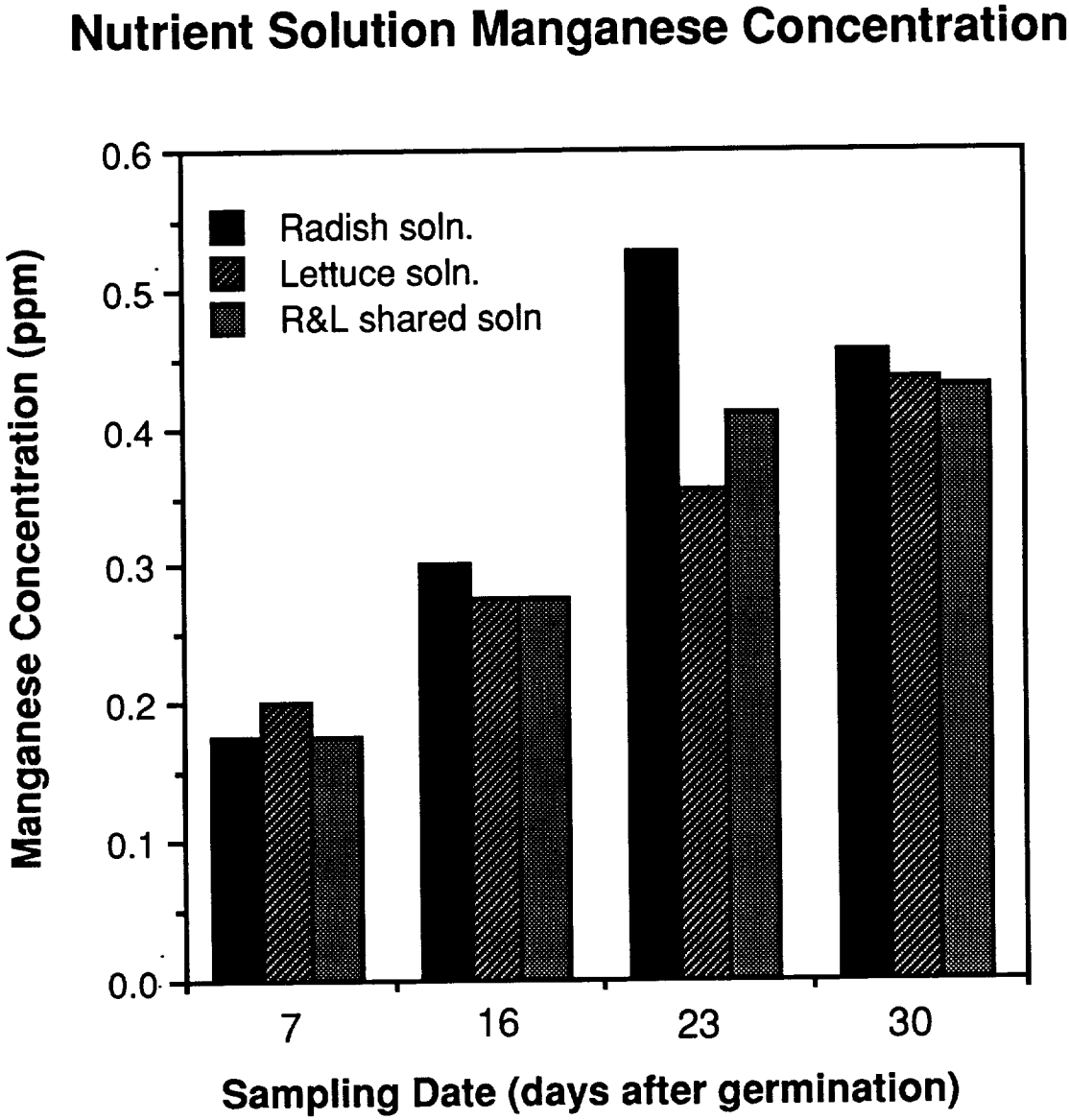

Figure 19. Suitability of Wheeler et. al. supplement concentrations in maintaining manganese solution concentrations in shared and nonshared reservoirs. Manganese concentrations were measured by atomic absorption spectroscopy.

For the first experiment root samples from 'Red Prince' radish were collected and placed in 100 ml of sterile 0.8 % saline solution to which two drops of Tween 20 was added. Roots were blended for three minutes with a Waring blender and then dilutions of 10^{-3}, 10^{-4}, and 10^{-5} were made. The dilution series was made to find the dilution which would result in spread plates with between 30 to 300 colony forming units (cfu's) per plate. This range of cfu's would ensure the presence of adequate numbers of colonies to provide a representative sampling of the microbes in the rhizosphere and yet allow a manageable number of colonies to work with. Six spread plates were made from each dilution onto R_2A agar. R_2A agar is routinely utilized in culturing of microbes which are commonly found in water. The spread plates were evenly distributed between two temperature treatments of 28°C and 22°C. Plates were incubated at 22°C because it was the temperature at which the plants were grown and 28°C was chosen because it is a more normal temperature for the incubation of microbes. Plates were examined and counted every 24 hours until 96 hours when 14 colonies were selected from the spread plates for use in developing competence in making streak plates. Streak plates are used for isolating single colonies from spread plates to allow for identification of the colonies. Fourteen 4-quadrant streak plates were made and incubated for another 48 hours. The specimens were then taken to a microbiology laboratory at Marshall Space Flight Center which specializes in microbial analysis of water systems and six selected plates analyzed using the BIOLOG Microbial Identification System. Three of the plates were identified as *Pseudomonas* species. The BIOLOG system was unable to identify the samples from the other three plates. There was no consistent pattern in colony numbers relative to dilution. The next several experiments focused on this problem. It was thought that clumping of microbes due to inadequate homogenizing of the root tissue may be resulting in variation in the number of colonies per plate. To determine optimum blending time in the next experiment, root tissues were blended for either 3, 5, or 7 minutes with a Waring blender and then dilutions of 10^{-3}, 10^{-4}, and 10^{-5} made and plated. Since we were now able to operate our plant growth chamber at 25°C plates were incubated at 25°C. Plates were checked every 24 hours and counted at 64 hours. There was still no clear cut pattern of counts relative to dilution regardless of blending time. Two further experiments were conducted to

obtain a consistent range of plates counts relative to dilution. With increasing refining of techniques, accuracy in measuring, etc. more consistent results were obtained. It was curious to note that occasionally there would be more colonies in plates of greater dilution than in plates which had less diluted samples. For example, in one experiment, the colony morphology was clearly different in 10^{-5} dilution plates versus 10^{-4} plates. Could the greater dilution of the samples have diluted out a more competitive and therefore predominant organism and allowed a less representative organism to come to the forefront? If this is the case, then it would be more representative of the true microbial populations to use higher dilutions provided they fell into the desired range of colony numbers. After several experiments it was determined that a dilution of 10^{-3} would yield the necessary number of cfu's on the spread plates and this dilution was used in subsequent experiments.

After several experiments to develop methodology were undertaken, a study comparing growth of microbes on R_2A media versus Flo agar (a BBL product for the identification of (*Pseudomonas*) was conducted. By using a media which had been developed to support a great variety of microbes which are commonly found in water (R_2A) and a media which had been developed for Pseudomonads (Flo agar) we hoped to get an estimate of the percentage of microbes in our samples which were Pseudomonads and determine if the relative percentage of microbes in general, and Pseudomonads in particular, was affected by its host plant or its presence in a monospecies versus dual-species nutrient solution. We took this rather broad-brush approach because it became clear that to do a survey by individual identification of microbial colonies for the 16 separate NFT troughs and have sufficient samples to have meaningful data would require more financial and manpower resources than we have available. Since preliminary identifications had picked up *Pseudomonas* on radish roots and also since Dr. Richard Strayer had found *Psuedomonas* species to be a predominant species on rhizospheres of some hydroponically grown plant species it was decided to focus on Pseudomonads in our investigations.

Microbial growth on Flo agar was essentially equivalent to that on R_2A for all treatments except that of radish grown on a shared nutrient solution

(Table 2). Microbial growth of samples taken from radish roots and grown on Flo agar was 64% of that grown on R_2A (Table 2). Microbial growth from samples taken from radish roots was more than double that of microbes taken from lettuce roots (Table 2). There was no effect of sharing nutrient solution on growth of microbes from either radish or lettuce roots. It was interesting to note that radish had roughly twice the microbial growth as lettuce. This information adds to the findings of R. Strayer who has reported on microbial populations of hydroponically grown soybeans and wheat (9). These preliminary results represent the first data on microbial populations of mixed plant species hydroponic systems that we are aware of. It is interesting that although there are differences in microbial population numbers between lettuce and radish there was no effect of shared nutrient solution on the populations of microbes on the rhizosphere of either species. It may be that the predominant influence of the host plant overrides any influence from the other plant species which shares the nutrient solution. These studies are preliminary in nature and further studies need to be conducted at different times during the growing period and the microbial content of the nutrient solution itself evaluated to get a better picture of the microbial interactions which may take place in mixed systems.

Comparison of NFT and Micropore Hydroponic Systems on Lettuce Production

The ceramic microporous tube nutrient delivery system shows promise as a system for use in microgravity environments. One potential drawback of this system is that it is reported to have a lower productivity rate than other nutrient delivery systems such as NFT hydroponics. A ceramic tube microporous nutrient delivery system was borrowed from Kennedy Space Center to evaluate productivity of the micropore system versus an NFT system and to gain experience to allow incorporation of the micropore system into a Salad Machine Demonstrator rack. A five tube micropore system was assembled and set up in the same walk-in environmental growth chamber as the 16 trough NFT system. Experimental conditions were the same as those described for experiment 1 and 2 of the NFT systems. Seven plants were planted per tube for the first experiment and

Table 2. Comparison of two culture media on the growth of microorganisms from a two-species NFT system.

TRT	R2A	Flo agar
Radish	29.5 + 4.9	24.9 + 3.8
Radish (shared soln.)	29.2 + 3.7	18.8 + 1.9
Lettuce	11.0 +2.7	11.5 +2.5
Lettuce (shared soln.)	14.8 + 2.0	11.4 + 1.6

* Standard error of the mean. Means represent averages of 12 samples per treatment-media combination.

three plants per tube for the second experiment. The NFT system had 7 plants per trough for both experiments.

Mean gfw of lettuce plants grown on the micropore system was virtually identical to that of plants grown on the NFT system (Table 3). There was however, as mentioned above, considerable variation in results from the NFT system. Lettuce plants grew poorly on both systems during the first experiment. During the second experiment lettuce production was increased. Mean gfw per lettuce plant grown on the micropore system was 83.22 g versus 30.99 gfw for the NFT system (Table 4). When this data was normalized for the area each system occupied then the micropore system produced 22% less lettuce than the NFT system did (Table 4). Again, there was considerable variation in growth on the NFT system but very little variation in growth from tube to tube on the micropore system. The micropore system is very easy to work with and at all times the plants appeared to be very healthy and a deep green in color. Plants grown on the NFT system in these two experiments appeared to be under nutrient stress in at least some of the troughs and this is reflected in the low yields in some of the troughs.

Table 3. Shoot fresh and dry weight of 'Waldmanns Green' lettuce plants grown on either an NFT or Micropore hydroponics system. **Exp. 1.**

System	Trough/tube	Shoot fw (g)	Shoot dw (g)
Micro	1	12.35	2.56
Micro	2	14.51	2.26
Micro	3	13.27	2.60
Micro	4	13.51	2.48
Micro	5	12.36	1.89
Overall mean-micro system		**13.28**	**2.37**
Shoot prod./m2-micro sys.		**623.21**	**111.38**
NFT	1	16.98	1.42
NFT	2	7.15	0.99
NFT	3	21.87	1.96
NFT	4	7.10	0.89
NFT	5	3.34	0.41
NFT	6	25.07	2.02
NFT	7	6.61	0.77
NFT	8	16.85	1.57
Overall mean- NFT System		**13.29**	**1.26**
Shoot prod./m2-NFT system		**1184.19**	**112.71**

Table 4. Shoot fresh and dry weight of 'Waldmanns Green' lettuce plants grown on either an NFT or Micropore hydroponics system. **Exp. 2.**

System	Trough/tube	Shoot fw (g)	Shoot dw (g)
Micro	1	64.34	9.15
Micro	2	82.35	10.12
Micro	3	63.72	7.27
Micro	4	85.88	10.63
Micro	5	119.81	13.32
Overall mean- micro system		**83.22**	**10.10**
Shoot prod/m2-micro sys		**1889.63**	**229.34**
NFT	1	27.76	3.33
NFT	2	61.61	7.65
NFT	3	33.70	3.41
NFT	4	25.09	2.72
NFT	5	5.98	1.15
NFT	6	74.98	9.87
NFT	7	6.84	1.14
NFT	8	6.03	0.95
Overall mean-NFT system		**30.99**	**3.92**
Shoot prod./m^2-NFT system		**2405.19**	**299.39**

LITERATURE CITED

1) Bailey, B.J., B.G.D. Haggett, A. Hunter, W.J. Albery, and L.R. Svanberg. 1988. Monitoring nutrient film solutions using ion-selective electrodes. J. of Agric. Eng. Res. 40: 129-142.

2) Gerber, J.W. 1988. Hydroponics worldwide: State of the art in soilless crop culture. ed. A.J. Savage, Wageningen, The Netherlands.

3) Hazebroek, J.P., S.A. Garrison, and T. Gianfagna. 1989. Allelopathic substances in asparagus roots: Extraction, characterization, and biological activity. J. Amer. Soc. Hort. Sci 114: 152-158.

4) Maynard,D.N. 1979. Nutritional disorders of vegetable crops: a review. J. of Plant Nut. 1:1-23.

5) Putman, A.R. and C.H Tang. 1986. The Science of Allelopathy. A Wiley Interscience Publication. John Wiley & Son, New York.

6) Resh, H.M. 1978. Hydroponic food production: A definitive guidebook of soilless food growing methods. Woodbridge Press Publishing Co., Santa Barbara, CA 93111.

7) Shafer, W.E. and S.A. Garrison. 1980. Effects of decomposing root tissues on lettuce, tomato, and asparagus seed emergence. HortScience 15(3): 74.

8) Shafer, W.E. and S.A. Garrison. 1980. Effects of asparagus root extracts on lettuce and asparagus seed germination and growth. HortScience 15(3): 74.

9) Strayer, R.F. 1991. Microbiological characterization of the biomass production chamber during hydroponic growth of crops at the controlled ecological life support system (CELSS) breadboard facility.

Proceedings of the 21st International Conference on Environmental Systems. Society of American Engineers. San Francisco, CA.

10) Takano, T. 1988. Effects of conductivity and temperature of nutrient solution on the mineral nutrition of horticultural crops in water culture. Acta Hort. 130:299-305.

11) Thomas, L. 1991. Bioponics, part 4. The Growing Edge 2(4): 35.

12) Wheeler, R.M., C.L. Mackowiak, J.C. Sager, W.M. Knott, and C.R. Hinckle. 1990. Potato growth and yield using NFT. Am. Potato J. 67:177-187.

13) Yang, Hsu-Jen. 1982. Autotoxic and allelopathic potential of asparagus officinalis. HortScience 17(3): 83.