Hydroponics

A Practical Guide for the Soilless Grower

Second Edition

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for the Soilless Grower

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Preface

This is the third edition of this guidebook; the first edition was published in 1983 and its revision was published in 1997. The two previous editions were primarily devoted to describing various techniques for growing plants without soil. These topics have been revised to reflect advances that have been made in understanding how plants grow and the influence that the rooting and atmospheric environments have on plant performance. In this edition, two new chapters have been added, one on the design and function of a hydroponic greenhouse and the other on hydroponic methods for crop production and management. These two new chapters provide the reader with essential information on greenhouse design and function and then give detailed instructions on how to grow various crops hydroponically, both in the greenhouse and outdoors. Although most hydroponic crops are grown commercially in environmentally controlled greenhouses, hydroponic methods and procedures suited for the hobby grower and techniques for outdoor hydroponics are also included. Organic hydroponics is also one of the new topics included.

Accurate statistics on the acreage of greenhouses devoted to vegetable production are not easily obtainable as no official accounting is made by any governmental or private organization(s). Estimates have been made based on information gathered from various sources suggesting that the acreage of greenhouse vegetable production is approximately 100,000 acres. From best estimates at this time, the acreage of hydroponic vegetable greenhouses probably ranges between 50,000 and 70,000 acres. In a recent Hydroponic Merchants Association (HMA) publication[1], they report that there are 3,000 to 4,000 acres of greenhouse vegetable in production in the United States and Canada, 2,000 to 3,000 acres in Mexico, 30,000 acres in Israel, 10,000 acres in Holland, 4,200 acres in England. Australia, New Zealand and other northern European countries have approxiamately 8,000 acres in greenhouse vegetable production. The HMA also reported that in North America, 95 percent of greenhouse vegetables are grown hydroponically and that the monetary value of produced vegetables is over $2.4 billion dollars today which is increasing at an annual rate of 10%. HMA reports that the largest acreages of hydroponic vegetable production in the United States are in four western states, Arizona (240 acres), California (157 acres), Colorado (86 acres), and Nevada (40 acres), with substantial acreages (from 10 to 40 acres at each location) in Pennsylvania, upstate New York, Virginia, Illinois, Nebraska, and Florida. The primary crop grown is tomato, with herbs, lettuce, and peppers being also grown at some of these locations. The hydroponic growing of flowers and other nonvegetable crops utilizing the same techniques and procedures applied to vegetables is also on the increase. Significant advances continue to be made in the application of hydroponic/soilless culture methods of growing and will continue to be made for controlling the environment within the greenhouse as well as the introduction of plant cultivars better

[1] HMA Media Kit, 2004, Hydroponic Merchants Association (HMA), 10210 Leatherleaf Court, Manassas, VA 20111.

adapted to greenhouse conditions. In order to take full advantage of these advances, growers will need to better control the rooting environment and the nutrient element supply to plants, and adopt those cultural practices that will maximize plant performance. Some of the systems initially devised for growing plants hydroponically are either no longer suitable for use in this developing technology or have been modified to adapt to these advances, making them more efficient in water and nutrient element use. Devising hydroponic growing systems for space application, in confined inhospitable environments, and outdoor growing are the new challenges that are changing our concepts of how best to utilize limited water resources, fully utilize both essential and beneficial elements, and provide for an ideal rooting environment. For many of these new applications, hydroponic/soilless systems must function efficiently without the possibility of failure — a challenge that borders on our current concepts of how plants function under varying environmental conditions.

As with the previous editions, this book begins with the concepts of how plants grow and then describes the requirements necessary for success when using various hydroponic and soilless growing methods. The major focus is on the nutritional requirements of plants and how best to prepare and use nutrient solutions to satisfy the nutrient element requirement of plants using various growing systems and under a wide range of environmental conditions. Many nutrient solution formulas are given, and numerous tables and illustrations included. Various hydroponic/soilless systems of growing are described in detail, and their crop adaptation and advantages and disadvantages are discussed. Included are those procedures required to establish and maintain a healthy rooting environment. Past and current sources of information on hydroponics are listed, including reference books, bulletins, magazine articles, and Internet sites as well as a detailed glossary of key terms.

This book provides valuable information for the commercial grower, the researcher, the hobbyist, and the student — all those interested in hydroponics and how this method of plant production works as applied to a wide range of growing conditions. Students interested in experimenting with various hydroponic/soilless growing systems as well as how to produce nutrient element deficiencies in plants are given the needed instructions. This topic has been expanded considerably with new methods and procedures that will arouse the interests of the curious minded.

The hydroponic literature can be confusing to readers due to the variety of words and terms used as well as the mix of British and metric units. In this book, when required to clarify the text, both British and metric units are given. The words "hydroponic" and "soilless" grower are sometimes combined to give "hydroponic/soilless grower," a combined word that is used when the topic being discussed relates to both, but when specific topics are discussed, then either the word hydroponic or soilless is used. The word "hydroponic" is used when growing systems are purely hydroponic, that is the rooting medium does not specifically interact with the plant, while the word "soilless" is used when systems of growing relate to plant production in which the medium can interact with the plant.

The use of trade names and mention of particular products in this book do not imply endorsement of the products named or criticism of similar ones not named, but rather such products are used as examples for illustration purposes.

J. Benton Jones, Jr.

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Chapter 1

Introduction

The word hydroponics has its derivation from the combining of two Greek words, *hydro* meaning water and *ponos* meaning labor, i.e., working water. The word first appeared in a scientific magazine article (*Science*, Feb 178:1) published in 1937 and authored by W.F. Gericke, who had accepted this word as was suggested by Dr. W.A. Setchell at the University of California. Dr. Gericke began experimenting with hydroponic growing techniques in the late 1920s and then published one of the early books on soilless growing (Gericke, 1940). Later he suggested that the ability to produce crops hydroponically would no longer be "chained to the soil but certain commercial crops could be grown in larger quantities without soil in basins containing solutions of plant food." What Dr. Gericke failed to foresee was that hydroponics would in the future be essentially confined to its application in enclosed environments for growing high cash value crops and would not find its way into the production of a wide range of commercial crops in open environments.

Hydroponic Definitions

The author went to three dictionaries and three encyclopedias to find how hydroponics is defined. *Webster's New World College Dictionary,* Fourth Edition, 1999, defines hydroponics as "the science of growing or the production of plants in nutrient-rich solutions or moist inert material, instead of soil"; the *Random House Webster's College Dictionary,* 1999, as "the cultivation of plants by placing the roots in liquid nutrient solutions rather than in soils; soilless growth of plants"; and *The Oxford English Dictionary,* 2nd Edition, 1989, as "the process of growing plants without soil, in beds of sand, gravel, or similar supporting material flooded with nutrient solutions."

In the *Encyclopedia Americana,* International Edition, 2000, hydroponics is defined as "the practice of growing plants in liquid nutrient cultures rather than in soil," in *The New Encyclopaedia Britannica*, 1997 as "the cultivation of plants in nutrient-enriched water with or without the mechanical support of an inert medium, such as sand or gravel," and in *The World Book Encyclopedia,* 1996 as "the science of growing plants without soil."

The most common aspect of all these definitions is that hydroponics means growing plants without soil, with the sources of nutrients either a nutrient solution or nutrient-enriched water, and that an inert mechanical root support (sand or gravel) may or may not be used. It is interesting to note that in only two of the six definitions is hydroponics defined as a "science."

Searching for definitions of hydroponics in various books and articles, the following were found. Devries (2003) defines hydroponic plant culture as "one in which all nutrients are supplied to the plant through the irrigation water, with the growing substrate being soilless (mostly inorganic), and that the plant is grown to produce flowers or fruits that are harvested for sale." In addition, Devries (2003) states, "hydroponics used to be considered a system where there was no growing media at all, such as the nutrient film technique in vegetables. But today it's accepted that a soilless growing medium is often used to support the plant root system physically and provide for a favorable buffer of solution around the root system." Resh (1995) defines hydroponics as "the science of growing plants without the use of soil, but by use of an inert medium, such as gravel, sand, peat, vermiculite, pumice, or sawdust, to which is added a nutrient solution containing all the essential elements needed by the plant for its normal growth and development." Wignarjah (1995) defines hydroponics as "the technique of growing plants without soil, in a liquid culture." In an *American Vegetable Grower* article entitled "Is hydroponics the answer?" (Anonymous, 1978), hydroponics was defined for the purpose of the article as "any method which uses a nutrient solution on vegetable plants, growing with or without artificial soil mediums." Harris (1977) suggested that a modern definition of hydroponics would be "the science of growing plants in a medium, other than soil, using mixtures of the essential plant nutrient elements dissolved in water." Jensen (1997) stated that hydroponics "is a technology for growing plants in nutrient solutions (water containing fertilizers) with or without the use of an artificial medium (sand, gravel, vermiculite, rockwool, perlite, peat moss, coir, or sawdust) to provide mechanical support." Jensen (1997) defined the growing of plants without media as "liquid hydroponics" and with media as "aggregate hydroponics." Another defining aspect of hydroponics is how the nutrient solution system functions, whether as an "open" system in which the nutrient solution is discarded after passing through the root mass or medium, or as a "closed" system in which the nutrient solution, after passing through the root mass or medium, is recovered for reuse.

Similarly related hydroponic terms are "aqua (water) culture," "hydroculture," "nutriculture," "soilless culture," "soilless agriculture," "tank farming," or "chemical culture." A hydroponicist is defined as one who practices hydroponics, and hydroponicum defined as a building or garden in which hydroponics is practiced.

Historical Past

The growing of plants in nutrient-rich water has been practiced for centuries. For example, the ancient Hanging Gardens of Babylon and the floating gardens of the Aztecs in Mexico were hydroponic in nature. In the 1800s, the basic concepts for the hydroponic growing of plants were established by those investigating how plants grow (Steiner, 1985). The soilless culture of plants was then popularized in the 1930s in a series of publications by a California scientist (Gericke, 1929, 1937, 1940).

During the Second World War, the U.S. Army established large hydroponic gardens on several islands in the western Pacific to supply fresh vegetables to troops operating in that area (Eastwood, 1947). Since the 1980s, the hydroponic technique has become of considerable commercial value for vegetable (Elliott, 1989) and flower (Fynn and Endres, 1994) production, and as of 1995 there are over 60,000 acres of greenhouse vegetables being grown hydroponically throughout the world, an acreage that is expected to continue to increase (Jensen, 1995). In a 2004 Hydroponic Merchants Association publication (see page v), they report over 55,000 acres of hydroponic greenhouse vegetable production worldwide, with about 1,000 acres in the United States, 2,100 acres in Canada, and 2,700 acres in Mexico. In these three countries, 68% of the production is in tomato, 15% in cucumber and 17% in pepper.

Hydroponics in Space

Hydroponics for space applications — providing a means of purifying water, maintaining a balance between oxygen (O_2) and carbon dioxide (CO_2) in space compartments, and supplying food for astronauts — is being intensively researched (Knight, 1989; Schwartzkopf, 1990; Tibbitts, 1991; Brooks, 1992). Hydroponic growing in desert areas of the world (Jensen and Tern, 1971) and in areas such as the polar regions (Tapia, 1985; Rogan and Finnemore, 1992; Sadler, 1995; Budenheim et al., 1995) or other inhospitable regions will become important for providing food and/or a mechanism for waste recycling (Budenheim, 1991, 1993).

Hydroponics/Soilless Culture

Actually, hydroponics is only one form of soilless culture. It refers to a technique in which plant roots are suspended in either a static, continuously aerated nutrient solution or a continuous flow or mist of nutrient solution. The growing of plants in an inorganic substance (such as sand, gravel, perlite, rockwool) or in an organic material (such as sphagnum peat moss, pine bark, or coconut fiber) and periodically watered with a nutrient solution should be referred to as soilless culture but not necessarily hydroponic. Some may argue with these definitions, as the common conception of hydroponics is that plants are grown without soil, with 16 of the 19 required essential elements (see pages 29–33) provided by means of a nutrient solution that periodically bathes the roots.

Most of the books on hydroponic/soilless culture (see References) focus on the general culture of plants and the design of the growing system, giving only sketchy details on the rooting bed design and the composition and management of the nutrient solution. Although the methods of solution delivery and plant support media may vary considerably among hydroponic/soilless systems, most have proven to be workable, resulting in reasonably good plant growth. However, there is a significant difference between a "working system" and one that is commercially viable. Unfortunately, many workable soilless culture systems are not commercially sound. Most books on hydroponics would lead one to believe that hydroponic/soilless culture methods for plant growing are relatively free of problems since the rooting media and supply of nutrient elements can be controlled. Jensen (1997), in his overview, stated, "hydroponic culture is an inherently attractive, often oversimplified technology, which is far easier to promote than to sustain. Unfortunately, failures far outnumber the successes, due to management inexperience or lack of scientific and engineering support." Experience has shown that hydroponic/soilless growing requires careful attention to details and good growing skills. Most hydroponic/soilless growing systems are not easy to manage by the inexperienced and unskilled. Soil growing is more forgiving of errors made by the grower than are most hydroponic/soilless growing systems, particularly those that are purely hydroponic.

Advantages and Disadvantages

In 1981, Jensen listed the advantages and disadvantages of the hydroponic technique for crop production, many of which are still applicable today:

Advantages

a. Crops can be grown where no suitable soil exists or where the soil is contaminated with disease.
b. Labor for tilling, cultivating, fumigating, watering, and other traditional practices is largely eliminated.
c. Maximum yields are possible, making the system economically feasible in high-density and expensive land areas.
d. Conservation of water and nutrients is a feature of all systems. This can lead to a reduction in pollution of land and streams because valuable chemicals need not be lost.
e. Soilborne plant diseases are more readily eradicated in closed systems, which can be totally flooded with an eradicant.
f. More complete control of the environment is generally a feature of the system (i.e., root environment, timely nutrient feeding or irrigation),

and in greenhouse-type operations, the light, temperature, humidity, and composition of the air can be manipulated.

g. Water carrying high soluble salts may be used if done with extreme care. If the soluble salt concentrations in the water supply are over 500 ppm, an open system of hydroponics may be used if care is given to frequent leaching of the growing medium to reduce the salt accumulations.
h. The amateur horticulturist can adapt a hydroponic system to home and patio-type gardens, even in high-rise buildings. A hydroponic system can be clean, lightweight, and mechanized.

Disadvantages

a. The original construction cost per acre is great.
b. Trained personnel must direct the growing operation. Knowledge of how plants grow and of the principles of nutrition is important.
c. Introduced soilborne diseases and nematodes may be spread quickly to all beds on the same nutrient tank of a closed system.
d. Most available plant varieties adapted to controlled growing conditions will require research and development.
e. The reaction of the plant to good or poor nutrition is unbelievably fast. The grower must observe the plants every day.

Wignarajah (1995) gave the following advantages of hydroponics over soil growing:

1. All of the nutrients supplied are readily available to the plant.
2. Lower concentrations of the nutrient can be used.
3. The pH of the nutrient solution can be controlled to ensure optimal nutrient uptake.
4. There are no losses of nutrients due to leaching.

Wignarajah (1995) gave only one disadvantage of hydroponic systems, "that any decline in the O_2 tension of the nutrient solution can create an anoxic condition which inhibits ion uptake." His recommendation is that only aeroponics solves this problem since it provides a "ready supply of O_2 to the roots, hence never becomes anoxic."

The Hydroponic Techniques

In 1983, Collins and Jensen prepared an overview of the hydroponic technique of plant production, and more recently, Jensen (1995) discussed probable future hydroponic developments, stating that "the future growth of controlled environment agriculture will depend on the development of production systems that are competitive in terms of costs and returns with open field agriculture" and that "the future of hydroponics appears more positive today than any time over the last 30 years." In a brief review of hydroponic growing activities in Australia, Canada, England, France, and Holland, Brooke (l995a) stated that “today’s hydroponic farmer can grow crops safely and in places that were formerly considered too barren to cultivate, such as deserts, the Arctic, and even in space.” He concluded, “hydroponic technology spans the globe.” Those looking for a brief overview of the common systems of hydroponic growing in use today will find the article by Rorabaugh (1995) helpful.

Proper instruction in the design and workings of a hydroponic/soilless culture system is absolutely essential. Those not familiar with the potential hazards associated with these systems or who fail to understand the chemistry of the nutrient solution required for their proper management and plant nutrition will normally fail to achieve commercial success with most hydroponic/soilless culture systems.

The technology associated with plant production, hydroponic or otherwise, is rapidly changing, as can be evaluated by reviewing the various bibliographies on hydroponics (Anon., 1984; Gilbert, 1979, 1983, 1984, 1985, 1987, 1992). Those interested in hydroponics must keep abreast of the rapid developments that are occurring by subscribing to and reading periodicals, such as the magazines *The Growing Edge*;[1] and *Maximum Yield Hydrogardening*[2] by membership and participation in groups devoted to the hydroponic/soilless growing of plants; and by becoming acquainted with the books, bulletins, and developing computer, video, and Internet (i.e., e-mail: hydrosoccam@aol.com) sources of hydroponics information. It could be that the problem today is not the lack of information on hydroponics (there are over 400,000 Web sites about hydroponics, for example), but the flood of information, much lacking a scientific basis, that leads to confusion and poor decision-making on the part of users.

“Is Hydroponics the Answer?” was the title of an article that appeared in 1978 (Anon., 1978) that contained remarks by those prominent at that time in discussions of hydroponic topics. In the article was the following quote: “Hydroponics is curiously slow to receive the mass grower endorsement that some envisioned at one time.” Carruthers (1998) provided a possible answer for what has been occurring in the United States, stating, “the reasons for this slow growth can be attributed to many factors, including an abundance of rich, fertile soil and plenty of clean water.” At the 1985 Hydroponics Worldwide: State of the Art in Soilless Crop Production conference, Savage (1985a) in his review stated, “many extravagant claims have been made for hydroponics/soilless systems, and many promises have been made too soon, but the reality is that a skilled grower can achieve wondrous results.” In addition, he sees “soilless culture technology as having reached ‘adulthood’ and rapid maturing to follow.” In addition, Savage (1985a) stated that “soilless and controlled environment crop production take special skills and training; however, most failures were not the result of the growing method, but can be attributed to

[1] *The Growing Edge*, P.O. Box 1027, Portland, OR 97339; tel: (503) 757-0027; Web site: www.growingedge.com.

[2] Maximum Yield Hydro Gardening, 11–1925 Bowden Rd., Nanaimo, B.C. Canada V95 1H1; tel: (250) 729-2677; fax: (205) 729-2687; Website: www.maximumyield.com.

poor financial planning, management, and marketing." More recently, at the 2003 South Pacific Soilless Culture Conference, Alexander (2003b) reported on current developments, stating "hydroponics is growing rapidly everywhere and within the next 5 to 10 years will be established as a major part of our agricultural and horticultural production industries."

Wilcox (1980) wrote about the "High Hopes of Hydroponics," stating that the "future success in the greenhouse industry will demand least-cost, multiple-cropping production strategies nearer to the major population centers." More recently, Naegely (1997) stated that the "greenhouse vegetable business is booming." She concluded, "the next several years promise to be a dynamic time in the greenhouse vegetable industry." Growth in the hydroponic-greenhouse industry was considerable in the 1990s, and its continued future expansion will depend on developments that will keep "controlled environmental agriculture" (CEA) systems financially profitable (see pages 305–307). Jensen (1997) remarked, "while hydroponics and CEA are not synonymous, CEA usually accompanies hydroponics — their potentials and problems are inextricable."

"Hydroponics for the New Millennium: A Special Section on the Future of the Hydroponic Industry" is the title of a series of articles by six contributors who addressed this topic from their own perspectives; the final comment was, "it really is an exciting time to be in the worldwide hydroponic industry, whether it's for commercial production or a hobby" [*Growing Edge* 11(3):6–13, 2000]. Jones and Gibson (2002) stated that "the future of the continued expansion of hydroponics for the commercial production of plants is not encouraging unless a major breakthrough occurs in the way the technique is designed and used." Those factors limiting wide application are cost, the requirement for reliable electrical power, inefficiencies in the use of water and nutrient elements, and environmental requirements for disposal of spent nutrient solution and growing media. Just recently, Schmitz (2004) remarked that "hydroponics is also seen as too technical, too expensive, too everything."

The Future of Hydroponics

What is not encouraging for the future is the lack of input from scientists in public agricultural colleges and experiment stations that at one time made significant contributions to crop production procedures, including hydroponics. The early hydroponic researchers, Dr. W.F. Gericke and D.R. Hoagland for example, were faculty members at the University of California. Today, there are only a few in universities who are still active in hydroponic investigations and research. The current status of Agricultural Cooperative Extension programs varies considerably from state to state. In the past, state specialists and county agents played major roles as sources for reliable information, but today these services are being cut back. Also, few of these specialists and agents have any expertise in hydroponics or extensive experience in dealing with greenhouse management questions. Edwards (1999), however, sees a positive role that county extension offices play, providing assistance to those seeking information, stating that "the Extension office is often the first place these people contact."

The science of hydroponics is currently little investigated, and much of the current focus is on the application of existing hydroponic techniques. Hydroponics, as a method of growing, is being primarily supported by those in the private sector who have a vested interest in its economic development. An example is the Hydroponic Merchants Association (HMA),[1] an association of those who manufacture, distribute, and market hydroponic growing systems that "exists to serve the interests of those who have made hydroponics, aquaponics, greenhouse growing, and other associated trades their livelihood" (Peckenpaugh, 2002f). Most of the hydroponic scientific advancements made today are by those who are investigating how this technique can be made to work for plant production in outer space (Hankinson, 2000a).

Another disturbing factor is that the Hydroponic Society of America[2] has not been active since 1997 when it published its last Proceedings. The Society was founded in 1979 and had been holding annual meetings and publishing proceedings from 1981 through 1997. Also, the International Society of Soilless Culture,[3] an organization that had held meetings and published proceedings in the past, has not been active for several years.

The role that commercial and scientific advancements have on society cannot be ignored when considering what is occurring in hydroponics today. The ease of movement of produce by surface and air transport, for example, allows for the growing of food products at great distances from their point of consumption. The advent of plastics has had a enormous impact on hydroponics because growing vessels, liquid storage tanks, drip irrigation tubing and fittings, greenhouse glazing materials, and sheeting materials, essential components in all hydroponic/greenhouse operations, are derived from a wide range of plastic materials that vary in their physical and chemical characteristics (Garnaud, 1985; Wittwer, 1993). The use of computers and computer control of practically every aspect of a hydroponic/greenhouse operation have revolutionized decision-making and managerial control procedures. Although one might conclude that hydroponic crop production is becoming more and more a science, there is still much art required that makes this method of plant production a challenge as well as an adventure.

The role of the Internet, the superhighway of information technology and communication, has changed and will continue to change how we educate ourselves and obtain the information and devices needed to establish and manage hydroponic/greenhouse systems. The ability to instantly send word and picture messages opens to the most isolated the world of information and resources added to the Internet daily. A grower with a plant problem,

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[1] Hydroponic Merchants Association, 10210 Leatherland Court, Manassas, VA 20111; tel: (703) 392-5890; fax: (503) 257-0213; www.hydromerchants.org.

[2] Hydroponic Society of America, P.O. Box 1183, El Centro, CA 94530; tel: (510) 232-2323; fax: (510) 232-2384; Web site: www.hsa.hydroponics.org.

[3] International Society of Soilless Culture. (There is no current address for the Society and the Web site is not currently being supported.)

whether cultural or nutritional, the result of a disease or insect, can send photographs to an expert for identification and solution. The Internet is "awash" with innumerable Web sites on practically any subject. What might prove to be the challenge is how to separate the reliable from the unreliable while wading through the mass of material that exists.

This book describes various systems of hydroponic/soilless growing and the requirements essential for success. The common procedures for both inorganic and organic media as well as purely hydroponic culture are included, with emphasis on the essential requirements for each technique. Although the importance of these factors is discussed in some detail in this text, the reader is advised to seek other resources for general information on plant production, greenhouse design and construction, environmental control, cultivar selection, general plant cultural practices, and pest management.

Elemental Compound and Ion Symbol Designation

In this text, all elements are designated by their symbols, whereas reagents and compounds are named and their symbol compositions shown when first mentioned in that portion of the text. The symbols for those elements, compounds, and ions found in this text are as follows:

Element	*Symbol*	*Element*	*Symbol*
Aluminum	Al	Nickel	Ni
Antimony	Sb	Nitrogen	N
Arsenic	As	Oxygen	O
Boron	B	Phosphorus	P
Bromine	Br	Platinum	Pt
Cadmium	Cd	Potassium	K
Chlorine	Cl	Rubidium	Rb
Chromium	Cr	Selenium	5e
Cobalt	Co	Silicon	Si
Copper	Cu	Silver	Ag
Fluoride	F	Sodium	Na
Indium	In	Strontium	Sr
Iodine	I	Sulfur	S
Iron	Fe	Titanium	Ti
Lead	Pb	Uranium	U
Lithium	Li	Vanadium	V
Magnesium	Mg	Yttrium	Y
Manganese	Mn	Zinc	Zn
Molybdenum	Mo		

Compound/Ion	*Symbol*
Acetate	$C_2H_3O_2^-$
Ammonium	NH_4^+
Arsenate	AsO_4^{2-}
Bicarbonate	HCO_3^-
Borate	BO_3^{3-}
Carbon dioxide	CO_2
Carbonate	CO_3^{2-}
Cyanide	CN^-
Dihydrogen phosphate	$H_2PO_4^-$
Monohydrogen phosphate	HPO_4^{2-}
Nitrate	NO_3^-
Nitrite	NO_2^-
Phosphate (ortho)	PO_4^{3-}
Silicate	SiO_4^-
Sulfate	SO_4^{2-}
Water	H_2O

In those situations where there may be confusion if only the symbol is used, both the element, compound, or ion and its symbol will be used.

References

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Adi Limited, 1982, Aeroponics in Israel, HortSci. 17(2):137.

Aldrich, R.A., and Bartok, J.W., Jr., 1994, Greenhouse Engineering, NRAES, Natural Resource, Agriculture and Engineering Services (NRAES), Ithaca, NY.

Antkowiak, R.I., 1993, More oxygen for your NFT, The Growing Edge 4(3):59–63. Argo, W.R. and Fisher, P.R., 2003, Understanding pH Management for Container-Grown Crops, Meister Publishing, Columbus, OH. Arnon, D.I. and Stout, R.R., 1939, The essentiality of certain elements in minute quantity for plants with special reference to copper, Plant Physiol.14:371–375. Asher, C.J., 1991, Beneficial elements, functional nutrients, and possible new essential elements, pp. 703–723 in J.J. Mortvedt (Ed.), Micronutrients in Agriculture, SSSA Book Series Number 4, Soil Science Society of America, Madison, WI. Asher, C.J. and Edwards, D.G., l978a, Critical external concentrations for nutrient deficiency and excess, pp. 13–28 in A.R. Ferguson, B.L. Bialaski, and J.B. Ferguson (Eds.), Proceedings 8th International Colloquium, Plant Analysis and Fertilizer Problems. Information Series No. 134. New Zealand Department of Scientific and Industrial Research, Wellington, New Zealand. Asher, C.J. and Edwards, D.G., 1978b, Relevance of dilute solution culture studies to problems of low fertility tropical soils, pp. 131–152 in C.S. Andrew and E.J. Kamprath (Eds.), Mineral Nutrition of Legumes in Tropical and Subtropical Soils. Commonwealth Scientific & Industrial Research Organization, Melbourne, Australia. Ashton, J.H., 2003, Cool crops in hot weather. Organic Gardening 50(4):36–38. Ashworth, W., 1991, The Encyclopedia of Environmental Studies. Facts on File, New York. Baisden, G., 1994, Frankenfood: bioengineered bonanza of the future, or your worst nightmare come true. The Growing Edge 5(4):34–37, 42. Baker, K.F. (Ed.), 1957, The U.C. System for Producing Healthy Container-Grown Plants. California Agricultural Experiment Station Manual 23. Berkeley, CA. Ball, V. (Ed.), 1985, Ball Redbook: Greenhouse Growing, 14th edition, Reston Publishing, Reston, VA. Ball, V., 2003, Greenhouse cooling, pp. 120–123, in C. Beytes (Ed.), Ball Redbook, Vol. 1, 17th Ed., Ball Publishing, Batavia, IL. Bar-Akiva, A., 1984, Substitutes for benzidine as H-donors in the peroxidase assay for rapid diagnosis of iron in plants. Commun. Soil Sci. Plant Anal. 15:929–934. Bar-Akiva, A., Maynard, D.N., and English, J.E., 1978, A rapid tissue test for diagnosis of iron deficiencies in vegetable crops, HortSci. 13:284–285. Barber, S.A., 1995, Soil Nutrient

Bioavailability: A Mechanistic Approach, 2nd ed. John Wiley & Sons, New York. Barber, S.A. and Bouldin, D.R. (Eds.), 1984, Roots, Nutrient and Water Influx, and Plant Growth. ASA Special Publication 136. American Society ofAgronomy, Madison, WI. Barry, C., 1996, Nutrients: The Handbook of Hydroponic Nutrient Solutions, Casper Publications Pty Ltd, New South Wales, Australia. Bartels, P.L., 2000, Washington Middle School, The Growing Edge 12(1):65–67. Bartok, J.W., Jr., 2000, Greenhouses for Homeowners and Gardeners, Cooperative Extension NRAES-137, Natural Resource, Agriculture, and Engineering Service (NRAES), Ithaca, NY. Bauerle, W.L., 1984, Bag culture production of greenhouse tomatoes. Ohio State University, OARDC Special Publication 108, Wooster, OH. Bauerle, W., 1990, A window into the future in precision nutrient control, pp. 25–27 in S. Korney (Ed.), Proceedings of the 11th Annual Conference on Hydroponics. Hydroponic Society of America, San Ramon, CA. Bauerle, W., Short, T.H., Mora, E., Hoffman, S., and Nantais, T., 1988, Computerized individual nutrient fertilizer injector: The System. HortSci. 23(5):910. Becker, K., 2003, Pesticide application equipment, pp. 197–200, in C. Beytes (Ed.), Ball Redbook: Greenhouse and Equipment, Vol. 1, 17th ed., Ball Publishing, Batavia, IL. Belanger, R.R., Bowen, P.A., Ehret, D.L., and Menzies, J.G., 1995, Soluble silicon: its role in crop and disease management of greenhouse crops. Plant Dis. 79(4):329–335. Bennet, J., 1997, The Tomato Handbook: Tips & Tricks for Growing the Best Tomatoes, Firefly Books, Buffalo, NY. Berry, W.L., 1985, Nutrient solutions and hydroponics, in Proceedings of the 6th Annual Conference of Hydroponics, Hydroponic Society of America, Concord, CA. Berry, W.L., 1989, Nutrient control and maintenance in solution culture, pp. 1–6 in S. Korney (Ed.), Proceedings of the 10th Annual Conference on Hydroponics. Hydroponic Society of America, Concord, CA. Berry, W.L. and Wallace, A., 1981, Toxicity: the concept and relationship to the dose response curve, J. Plant Nutr. 3:13–19. Beytes, C. (Ed.), 2003a, Ball Redbook: Greenhouse and Equipment, Vol. 1, 17th Ed., Ball Publishing, Batavia, IL. Beytes, C., 2003b, Four levels of climatic control, pp. 132–137, in C. Beytes (Ed.), Ball Redbook: Greenhouse and Equipment, Vol. 1, 17th ed., Ball Publishing, Batavia, IL. Bezdicek, D.F. (Ed.), 1984, Organic Farming: Current Technology and Its Role in a Sustainable Agriculture. ASA Special Publication Number 26. American Society of Agronomy, Madison, WI. Bij, J., 1990, Growing commercial vegetables in rockwool, pp. 18–24 in S. Korney (Ed.), Proceedings of the 11th Annual Conference of Hydroponics. Hydroponic Society of America, Concord, CA. Bloom, A., 1987, Nutrient requirement changes during plant development, pp. 10–12 in Proceedings 8th Annual

Conference: Hydroponic Effective Growing Techniques, Hydroponic Society of America, Concord, CA. Bottomley, J.A., 1999, Spriggs hydroponic flower farm: Consistency, quality, and commitment, The Growing Edge 10(6):20–27. Bottomley, J.A, 2000, Growing cucumbers in the Darling range, The Growing Edge 11(4):34–41. Bottomley, J.A., 2001a, Australian hydroponic roses, The Growing Edge 12(3):58–63. Bottomley, J.A., 2001b, Pest control light, The Growing Edge 12(3):66–73. Boodley, J.W. and Sheldrake, R., Jr., 1972, Cornell Peat-Lite Mixes for Commercial Plant Growing, Information Bulletin No. 43, New York College of Agriculture, Cornell University, Ithaca, NY. Bould, C., Hewitt, E.J., Needham, P., and Robinson, J.B.D., 1984, Diagnosis of Mineral Disorders in Plants, Vol. 1: Principles, Chemical Publishing, New York. Bradley, P., 2003, Spreading the soilless word down south: The Mexican Institute for Simplified Hydroponics, The Growing Edge 14(4):14–19. Bradley, P. and Tabares, C.H.M., 2000a, Building by design: hydroponics in developing countries, Part 1, The Growing Edge 11(5):40–51. Bradley, P. and Tabares, C.H.M., 2000b, Building by design: hydroponics in developing countries, Part 2, The Growing Edge 11(6):46–57. Bradley, P. and Tabares, C.H.M., 2000c, Building by design: hydroponics in developing countries, Part 3, The Growing Edge 12(1):47–57. Bradley, P. and Tabares, C.H.M., 2000d, Spreading Simplified Hydroponics: Home Hydroponic Gardens, Global Hydroponics Network, Corvallis, OR. Brentlinger, D., 2001, Making science come alive, The Growing Edge 12(6):15–17. Bridgewood, L., 2001, Winter challenge: growing delicious tomatoes in cold seasons, Practical Hydroponics & Greenhouses, Issue 60:88–91. Brooke, L.L., 1990a, Hydroponics: a growing technology for the 1990s, The Growing Edge 1(1):21–23. Brooke, L.L., 1990b, The chemical dynamics of hydroponic nutrient solutions, The Growing Edge 1(2):47–50. Brooke, L.L., 1991, Aero-hydroponics: the hydroponic method of the future, The Growing Edge 2(1):25–26, 65–66. Brooke, L.L., 1992, Hydroponics: a global perspective, The Growing Edge 4(1):20–22, 52. Brooke, L.L., 1993, The lives of plants, Part 1: Seedlings, cuttings and transplants, The Growing Edge 4(3):18–21, 55–57. Brooke, L.L., 1994, Advanced nutrient management for hydroponic growers: check your nutrient IQ, The Growing Edge 5(3):45–49. Brooke, L.L., 1995a, A world ahead: the leaders in hydroponic technology, The Growing Edge 6(4):34–39, 70–71. Brooke, L.L., 1995b, Oxygen: for the health of your hydroponic crops, The Growing Edge 7(1):21–22, 79. Brooke, L.L., 1996, The Organic-hydroponic debate: opening Pandora’s box, The Growing Edge 7(3):59–63, 76. Brooke, L.L. and Siberstein, O., 1993, Hydroponics in schools: an educational tool, The Growing Edge 5(1):20–22,

66. Brooks, C., 1992, Development of a semi-automated system for production of salad vegetables for use on space station Freedom, pp. 72–76 in D. Schact (Ed.), Proceedings of the 13th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA. Brown, P.M., Welsh, R.M., and Cary, E.E., 1987, Nickel: a micronutrient essential for higher plants, Plant Physiol. 85:801–803. Bruce, R.R., Palls, J.E., Jr., Harper, L.A. and Jones, J.B., Jr., 1980, Water and nutrient element regulation prescription in nonsoil media for greenhouse crop production, Commun. Soil Sci. Plant Anal. 11(7):677–698. Budenheim, D.L. 1991, Plants for water recycling, oxygen regeneration and food production, Waste Manage. Res. 9:435–443. Budenheim, D.L, 1993, Regenerative growing systems, pp. 17–31, in P. Bates and S. Korney (Eds.), Proceedings of the 15th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA. Budenheim, D.L., Straight, C.L., Flynn, M.T. and Bates, M., 1995, Controlled environment agriculture at the Amudsen–Scott South Pole Station, Antarctic and CELSS Antarctic Analog Project, pp. 108–124 in M. Bates (Ed.), Proceedings of the 6th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA. Bugbee, B., 1995, Nutrient management in recirculating hydroponics culture, pp. 15–30, in M. Bates (Ed.), Proceedings of the 16th Annual Conference of Hydroponics, Hydroponic Society of America, San Ramon, CA. Bunt, A.C., 1988, Media and Mixes for Container-Grown Plants, 2nd ed., Unwin Hyman, London. Buyanovsky, G., Gale, J., and Degani, N., 1981, Ultraviolet radiation for the inactivation of microorganisms in hydroponics, Plant and Soil 60:131–136. Bunlyn-Maples, N.J., 1994–1995, Greenhouse growing southern style, The Growing Edge 6(2):48–53, 77. Burnham, K., 1990, Biological pest control: the new bottom line — Sparing the sprayer, The Growing Edge 1(2):36–40. Carlile, W.R. and Sweetland, E., 1983, The use of composted peat sludge mixtures in horticultural growth media. Acta Hort. 150:511–517 Carson, E.W. (Ed.), 1974, The Plant Root and Its Environment, University Press of Virginia, Charlottesville, VA. Carruthers, S., 1991–1992, Carbon dioxide enrichment — mass through gas, The Growing Edge 3(2):23–26, 60–61. Carruthers, S., 1998, The future of hydroponics: a global perspective, The Growing Edge 19(2):5–6. Chandler, A.R., 2003, Preventing tomato diseases, Organic Gardening 50(3):28–30. Chaney, R.L., 1983, Plant uptake of inorganic waste constituents, pp. 50–76 in J.F. Patt, P.B. Marsh, and J.M. Kla (Eds.), Land Treatment of Hazardous Wastes. Noyes Data Corporation, Park Ridge, NJ. Childers, N.F., 2003, The Strawberry. Modern Technology, Dr. Norman F. Childers' Publications, Gainesville, FL. Christensen, H.D., 1994, A

non-circulating hydroponic system: keep it simple, The Growing Edge 5(3):41–43, 71. Christensen, M., 1994b, The Christensen model: a passive hydroponic system fit for a tabletop, The Growing Edge 6(l):14. Christian, M., 1990a, Commercial basil production for the small-time operator, The Growing Edge 1(2):20–23. Christian, M., 1990b, Basil production for the small-time operator — An update, The Growing Edge 1(4):48–50. Christian, M., 1996, Fancy lettuce … from the land down under, The Growing Edge 8(1):55–59, 86. Christian, M., 1997, Guerrilla NFT California style, The Growing Edge 8(3):47–53. Christian, M., 1999, New Zealand hydroponics: simplicity in design, The Growing Edge 11(1):17–2l. Christian, M., 2001, Nutrient solution dosers: automation for recirculation, The Growing Edge 12(1):68–74. Christian, M., 2002, Sun Aqua farms, The Growing Edge 13(4):20–25. Clark, R.B., 1982, Nutrient solution: growth of sorghum and corn in mineral nutrition studies, J. Plant Nutr., 5(8):1003–1030. Cloyd, R.A., 2003a, The basics of greenhouse pest control, pp. 195–200, in C. Beytes (Ed.), Ball Redbook: Greenhouse and Equipment, Vol. 1, 17th ed., Ball Publishing, Batavia, IL. Cloyd, R.A., 2003b, Worker protection standards, pp. 209–211, in C. Beytes (Ed.), Ball Redbook: Greenhouse and Equipment, Vol. 1, 17th ed., Ball Publishing, Batavia, IL. Cloyd, R.A., 2003c, Managing insects and mites, pp. 113–125, in Hamrick, D. (Ed.), Ball Redbook, Crop Production, Vol. 2, 17th ed., Ball Publishing, Batavia, IL. Coene, T., 1995, Greenhouse coverings uncovered, The Growing Edge 6(3):66–72. Coene, T., 1995–1996, Plant plane hydroponics: moves out of the greenhouse, The Growing Edge 7(2):35–39. Coene, T., 1996–97, The sulfur lamp in horticulture, The Growing Edge 8(2):30–34, 80. Coene, T., 1997, The ins and outs of soilless gardening, The Growing Edge 8(4):34–40. Colla, G. and Saccardo, F., 2003, Application of systematic variation method for optimizing mineral nutrition of soilless-grown zucchini squash, J. Plant Nutr. 26(9):1859–1872. Collins, W.L. and Jensen, M.N., 1983, Hydroponics, A 1983 Technology Overview. Environment Research Laboratory, University of Arizona, Tucson, AZ. Cooper, A., 1976, Nutrient Film Technique for Growing Crops, Grower Books, London, England. Cooper, A., 1979a, Commercial Applications of NFT, Grower Books, London. Cooper, A., 1979b, The ABC of NFT, Grower Books, London. Cooper, A., 1985, New ABC's of NET, pp. 180–185 in A.J. Savage (Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop Production. International Center for Special Studies, Honolulu, HI. Cooper, A., 1988, The ABC of NFT, Grower Books, London, England. Cooper, A., 1996, The ABC of NFT Nutrient Film Technique, Casper Publications, Narrabeen, Australia. Cosgove, D.C., Jones, J.B., Jr., and Mills, H.A., 1985, Influence of NO 3 and NH

4 on Kjeldahl N, NO 3 -N, and snap bean pod yield, HortSci. 20(3):427-429.

Cottrell, C.T., 1996, Hydroponics for independence, The Growing Edge 7(3):32–36, 74. Creaser, G., 1995, Hydroponic paradise: Part 1: the float system, The Growing Edge 7(1):30–34. Creaser, G., 1995–1996, Hydroponic paradise: Part 2: a visit to Anguilla, The Growing Edge 7(2):18–21. Creaser, G., 1996a, Hurricane hydro, The Growing Edge 7(4):25–28. Creaser, G., 1996b, Valley Fresh Produce: it's hydro-organic, The Growing Edge 8(l):60–64. Creaser, G., 1996–1997, The hydroponic home(made) unit, The Growing Edge 8(2):43–47, 79. Creaser, G., 1997, Cultivate herbs and savor the returns, The Growing Edge 8(3):68–73. Cunningham, D., 1997, Everything old is new again: the return of the Gericke system, Practical Hydroponics & Greenhouses, May/June 1997:69–72. Dalton, L. and Smith, R., 1999, Hydroponic Crop Production, NZ Hydroponic International, Ltd.,Tanranga, New Zealand. Daughtrey, M.L., 2003, Managing diseases, pp. 127–137, in Hamrick, D. (Ed.), Ball Redbook, Crop Production, Vol. 2, 17th ed., Ball Publishing, Batavia, IL. Day, D., 1991, Growing in Perlite, Grower Digest 12, Growing Publications Ltd, London. DeKorne, J.B., 1992–93, An orchard of lettuce trees: vertical NET system, The Growing Edge 4(2):52–55. Devries, J., 2003, Hydroponics, pp. 103–114, in C. Beytes (Ed.), Ball Redbook: Greenhouses and Equipment, Vol. 1, 17th ed., Ball Publishing, Batava, IL. Docauer, J.M., 2004, Growing the Verti-Gro way, The Growing Edge 15(5):50–54. Donnan, R., 1997, Hydroponic strawberries, Practical Hydroponics & Greenhouse Issue 34 54–64. Douglas, J.S., 1976, Advanced Guide to Hydroponics, Drake Publishers, New York. Duke, J.A., 2002, Handbook of Medicinal Herbs, 2nd ed., CRC Press, Boca Raton, FL. Eastwood, T., 1947, Soilless Growth of Plants, 2nd ed., Reinhold Publishing, New York. Edey, A., 1994, Solviva greenhouse, The Growing Edge 5(3):20–25, 70. Edwards, J., 1999, Partners in successful farming: county extension offices help growers market their products, The Growing Edge 10(5):52–61. Edwards, K., 1985, New NET breakthroughs and future directions, pp. 186–192 in A.J. Savage (Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop Production. International Center for Special Studies, Honolulu, HI. Edwards, R., 1994, Computer control systems wired to grow, The Growing Edge 5(3):34–38. Elber, G., 1997, Carbon dioxide enrichment lets your plants breathe easier, The Growing Edge 9(2):81–85. Elliott, B., 1989, Commercial trends in hydroponics, pp. 59–66 in S. Korney (Ed.), Proceedings of the 10th Annual Conference on Hydroponics. Hydroponic Society of America, Concord, CA. Emamuel, T.M., 2003, Digging into Gerbera media, The

Growing Edge 14(4):58–64. Epstein, E. 1972. Mineral Nutrition of Plants: Principles and Perspectives, John Wiley & Sons, New York. Epstein, E., 1994, The anomaly of silicon in plant biology, Proc. Natl. Acad. Sci. 91:11–17. Erickson, C., 1990, Hydroponic Nutrient Management, The Growing Edge 1(1):53–56. Eskew, D.L., Welsh, R.M., and Norvell, W.A, 1984, Nickel in higher plants: further evidence for an essential role, Plant Physiol. 76:691–693. Essington, M.E., 2004, Soil and Chemistry: An Integrated Approach, CRC Press, Boca Raton, FL. Evans, R.D., 1995, Control of microorganism in flowing nutrient solutions, pp. 31–43 in M. Bates (Ed.), Proceedings of the 16th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA. Farnhand, D.S., Hasek, R.F., and Paul, J.L., 1985, Water Quality, Leaflet 2995. Division of Agriculture Science, University of California, Davis, CA. Farquhar, L., 2003, Scottish highland hydroponics, The Growing Edge 14(3):20–25. Faulkner, S.P., 1993, Leaf analysis: measuring nutritional status of plants, The Growing Edge 4(1):24–28, 67–68.

Glass, D.M., 1989, Plant Nutrition: An Introduction to Current Concepts, Jones and Bartlett Publishers, Boston, MA.

Goldberry, K.L., 1985, Greenhouse structures and systems, pp. 12–20, in A.J. Savage (Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop Production, International Center for Special Studies, Honolulu, HI.

Gough, R.E., 1993, Glossary of Vital Terms for the Home Gardener, Food Products Press, New York.

Goulant, F.S., 1994, A windowsill herb garden, The Growing Edge 6(21):18–20. Green, J.L., 1990, Root death: causes and treatments in recirculating systems, The Growing Edge 1(3):60–63. Grosser, S, 2003, Gutter-connected greenhouses, pp. 7–12, in C. Beytes (Ed.), Ball Redbook, Vol. 1, 17th ed., Ball Publishing, Batavia, IL. Grossman, J., 1999, Finding the path of most resistance — Stimulating plant immunity, The Growing Edge 11(1):83–87. Gunstone, G.W., 1994, Biological systems for glasshouse horticulture, The Growing Edge 5(4):43–47, 50–51. Halbrooks, M.C. and Wilcox, G.E., 1980, Tomato plant development and elemental accumulation, J. Amer. Soc. Hort. Sci. 105(6):826–828. Hamrick, D. (Ed.), 2003, Ball Redbook: Crop Production, Vol. 2, 17th ed., Ball Publishing, Batavia, IL. Hanan, J.J., 1998, Greenhouse: Advanced Technology for Protected Horticulture, CRC Press, Boca Raton, FL. Hancock, J.F., 1999, Strawberries, Crop Production Science in Horticulture

11. CABI Publishing, Wallingford, Oxon, UK. Handreck, H.A. and Black, N.D., 1994, Growing Media for Ornamental Plants and Turf, 4th ed., University of New South Wales Press, Sydney, Australia. Handrick, K.A., 1993, Properties of coir dust and its use in the formulation of soilless media, Commun. Soil Sci. Plant Anal. 24:349–363. Hankinson, J., 2000a, Hydroponics on Mars: designing for long-term space flight, The Growing Edge 11(3):32–39. Hankinson, J., 2000b, A hydroponic lesson plan, The Growing Edge 11(5):28–37. Harper, L.A., Pallas, J.E., Jr., Bruce, R.R., and Jones, J.B., Jr., 1979, Greenhouse microclimate for tomatoes in the southeast, J. Amer. Soc. Hort. Sci. 104(5):659–663. Harrington, M., 2001a, The growing web, The Growing Edge 12(1):87. Harrington, M., 2001b, The growing web, The Growing Edge 13(2):85–87. Harris, D., 1977, Hydroponics: The Gardening without Soil, Pumell & Sons, Cape Town, South Africa. Harssema, H., 1977, Root Temperature and Growth of Young Tomato Plants, H. Veenman & Zonen, B.V., Wageningen, The Netherlands. Hartman, P.L., Mills, H.A., and Jones, J.B., Jr., 1986, The influence of nitrate/ammonium ratios on growth, fruit development, and element concentration in “Floradel” tomato plants, J. Am. Soc. Hort. Sci. 111(4):487–490. Hayden, A.L., 2003, The good, the bad, and the ugly: inorganic fertilizers, toxic metals, and proposed regulations, The Growing Edge 15(2):42–50. Henrickson, R., 1977, The Great American Tomato Book. Doubleday & Company, Inc., Garden City, NY.

Herrmann, C.C. and Brooke, L.L., 1990, Water should taste good to plants, The Growing Edge 1(4):39–42. Hershey, D.R., 1990, Pardon me, but your roots are showing, The Science Teacher 57:42–45. Hershey, D.R., 1992a, Plant nutrient solution pH changes, J. Biol. Educ. 26(2):107–111. Hershey, D.R. 1992b, Inexpensive hydroponic teaching methods, pp. 27–34 in D. Schact (Ed.), Proceedings of the 13th Annual Conference on Hydroponics. Hydroponic Society of America, San Ramon, CA. Hershey, D.R. 1995. Plant Biology Science Projects, John Wiley & Sons, New York. Hershey, D.R. and G.W. Stutte, 1991, A laboratory exercise on semiquantitative analysis of ions in nutrient solution, J. Agron. Educ. 20:7–10. Hershey, D.R., 1994, Hydroponics for teaching: history and inexpensive equipment, Amer. Biol. Teacher 56:111–118. Hewitt, E.J., 1966, Sand and Water Culture Method Used in Study of Plant Nutrition. Technical Communication No. 22 (revised). Commonwealth Bureau of Horticulture and Plantation Crops, East Malling, Maidstone, Kent, England. Hoagland, D.R. and Arnon, D.I., 1950, The Water Culture Method for Growing Plants without Soil, Circular 347, California Agricultural Experiment Station, University of California, Berkeley, CA. Hochmuth, G., 1991a, Florida Greenhouse Vegetable Handbook, Vol. 3, Circular SP 48, Florida Cooperative Extension Service, University of Florida, Gainesville, FL. Hochmuth, G., 1991b, Production of greenhouse tomatoes in Florida, in G. Hochmuth (Ed.), Florida Greenhouse Vegetables Production Handbook, Vol. 5, University of Florida, Gainesville, FL. Hochmuth, G., 1996, Greenhouse tomato nutrition and fertilization for southern latitudes, pp. 37–49 in Greenhouse Tomato Seminar. ASHS Press, American Society for Horticultural Science, Alexandria, VA. Hochmuth, G., 2001, Nutrient Solution Formulation for Hydroponic (Perlite, Rockwool, and NFT) Tomatoes in Florida, Nutrient Solutions, North Florida Reseach and Education Center, Suwannee Valley, Live Oak, FL. Hochmuth, G. and Hochmuth, B., 1996, Challenges for growing tomatoes in warm climates, pp. 34–36, in Greenhouse Tomato Seminar, ASHS Press, American Society for Horticultural Science, Alexandria, VA. Horst, D.M., 1997, Roses, hydroponics and computers: an innovative mix, The Growing Edge 8(3):18–22. Hurd, R.G., 1985, United Kingdom: current research and developments in soilless culture with particular reference to NFT, pp. 164–171 in A.J. Savage (Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop Production. International Center for Special Studies, Honolulu, HI. Hurd, R.G., Adams, P., Massey, D.M., and Price, D. (Eds.), 1980, Symposium on Research on Recirculating Water Culture, Acta Horticulture No. 98. The Hague, The Netherlands. Ibsen, G. and Nielsen, J., 1999, The Great Tomato Book, Ten Speed Press, Berkeley, CA. Ikeda, H. and Osawa, T., 1981, Nitrate- and ammonium-N absorption by vegetables from nutrient solution containing ammonium nitrate and the resultant change of solution pH, Japan. Soc. Hort. Sci. 50(2):225–230. Ingratta, F.J., Blom, T.J., and Strave, W.A., 1985, Canada: current research and developments, pp. 95–102, in A.J. Savage (Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop Production, International Center for Special Studies, Honolulu, HI. Jackson, D., 1996, Insect predators: treat them right, The Growing Edge 7(4):30–31. Jacobsen, P., 2003, Insect screens, pp. 201–205, in C. Beytes (Ed.), Ball Redbook: Greenhouse and Equipment, Vol. 1, 17th ed., Ball Publishing, Batavia, IL.

Jacoby, B., 1995, Nutrient uptake by plants, pp. 1–22, in M. Pessarakli (Ed.), Handbook of Plant and Crop Physiology, Marcel Dekker, Inc., New York.

Jefferson, E., 1999, The Shona people use hydroponics to fight hunger, The Growing Edge 10(4):43–51

Jensen, D., 2000, Hybrid hydro: aeroponics in Texas, The

Growing Edge 11(6):22-27.

Jensen, M.N., 1981, New developments in hydroponic systems: descriptions, operating characteristics, evaluation, pp. 1-25, in Proceedings: Hydroponics: Where Is it Growing? Hydroponic Society of America, Brentwood, CA.

Jensen, M.N., 1995, Hydroponics of the future, pp. 125-132 in M. Bates (Ed.), Proceedings of the 16th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA.

Jensen, M.N, 1997, Hydroponics, HortSci. 32(6):1018-1021.

Jensen, M.N. and Malter, A.J., 1995, Protected Agriculture: A Global Review, World Bank Technical Paper #253, The World Bank, Washington, D.C.

Jensen, M.N. and Silberstein, O., 2000, Controlled academic expansion, The Growing Edge 12(2):27-29.

Jensen, M.N. and Tern, M.A., 1971, Use of controlled environments for vegetable production in desert regions of the world, HortSci. 6:33-34.

Jesiolowski, J. and Hager, L. (Eds.), 1999, 300 Super Tomato Tips, Rodale Press, Inc., Emmaus, PA.

Johnson, B., 1998a, Hydroponics revolutionizes the cut-rose industry, The Growing Edge 9(5):40-47.

Johnson, B., 1998b, Organic control of the codling moth, The Growing Edge 10(1):81-86.

Johnson, B., 1998c, Hydroponic veggies: a bull market for U.S. growers, The Growing Edge 10(2):21-24.

Johnson, B., 1999, Heirloom vegetables — resurrecting the past while insuring the future, The Growing Edge 11(2):52-64.

Johnson, B., 2000a, Controlling forces in greenhouses, The Growing Edge 11(5):64-71.

Johnson, B., 2000b, Solar greenhouse realism, The Growing Edge 12(2):60-65.

Johnson, B., 2001a, Rockwool uses revealed, The Growing Edge 12(6):67-71.

Johnson, B., 2001b, Rockwool vs. cocopeat: a head-to-head media event!, The Growing Edge 13(2):40-45

Johnson, B., 2002a, Attached passive solar greenhouses, The Growing Edge 13(3):68-75.

Johnson, B., 2002b, Determining plant diseases: affordable testing tools and a blueprint for the future, The Growing Edge 13(5):52-59.

Johnson, B., 2002c, Greenhouse nutrient management: regulations and treatment options, The Growing Edge 13(6):38-43.

Johnson, B., 2002d, Hydroponic Gerber: worldly transvall wonders, The Growing Edge 14(2):24-30.

Johnson, B., 2003, Hot water storage heating: keeping the CO 2 where you can use it, The Growing Edge 14(3):41-45. Jones, J.B., Jr., 1980, Construct your own automatic growing machine, Popular Science 216(3):87. Jones, J.B., Jr., 1983, A Guide for the Hydroponic and Soilless Grower, Timber Press, Portland, OR. Jones, J.B., Jr., 1985, Growing plants hydroponically, Amer. Biol. Teacher 47(6):356-358. Jones, J.B., Jr., 1993a, Grower application of media and tissue analysis, pp. 7-14 in T. Alexander (Ed.), Proceedings of the 14th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA. Jones, J.B., Jr., 1993b, Plant Nutrition Basics, The Major Elements, Micronutrients, Plant Analysis, and Tissue Testing (VHS Video Series). GroSystems, Anderson, SC. Jones, J.B., Jr., 1993c, Nutrient Element Deficiencies in Tomato (VHS Video Series), GroSystems, Anderson, SC.

Jones, J.B., Jr., 1997, Hydroponics: A Practical Guide for the Soilless Grower, St. Lucie Press, Boca Raton, FL.

Jones, J.B., Jr., 1998a, Plant Nutrition Manual, CRC Press, Boca Raton, FL.

Jones, J.B., Jr., 1998b, Phosphorus toxicity in plants: when and how does it occur?, Commun. Soil Sci. Plant Anal. 29(11-12):1779-1784. Jones, J.B., Jr., 1999, Tomato Plant Culture: In the Field, Greenhouse and Home Garden, CRC Press, Boca Raton, FL. Jones, J.B., Jr., 2000, Building a better hydroponic tomato, The Growing Edge 12(1):36-46. Jones, J.B., Jr., 2001, Laboratory Guide for Conducting Soil Tests and Plant Analysis, CRC Press, Boca Raton, FL. Jones, J.B., Jr., 2003, Agronomic Handbook: Management of Crops, Soils, and their Fertility, CRC Press, Boca Raton, FL.

Jones, J.B., Jr., and V.W. Case, 1990, Sampling, handling, and analyzing plant tissue samples, pp. 389–427, in R.L. Westerman (Ed.), Soil Testing and Plant Analysis, 3rd ed., SSSA Book Series Number 3, Soil Science Society of America, Madison, WI.

Jones, J.B., Jr., and Gibson, P.A., 2001, Excessive solar radiation and tomatoes, The Growing Edge 12(6):60–65.

Jones, J.B., Jr., and Gibson, P.A., 2002. A Growing perspective: hydroponics, yesterday, today, and tomorrow, The Growing Edge 13(3):50–56. Jones, J.B., Jr., and Gibson, P.A., 2003, A new look at nutrient solutions, The Growing Edge 14(5):57–63. Jones, J.B., Jr., Wolf, B., and Mills, H.A., 1991, Plant Analysis Handbook: A Practical Sampling, Preparation, Analysis, and Interpretation Guide, MicroMacro Publishing, Athens, GA.

Jones, J.P., Stall, R.E, and Sitter, T.A. (Eds.), 1991, Compendium of Tomato Diseases, APS Press, American Phytopathological Society, St. Paul, MN. Jones, S., 1990, Deep water NFT, The Growing Edge 2(1):45–46. Jutras, M.W., 1979, Nutrient Solutions for Plants, Circular 182, South Carolina Agriculture Experiment Station, Clemson, SC.

Kabata-Pendias, H., 2000, Trace Elements in Soils and Plants, 3rd ed., CRC Press, Boca Raton, FL.

Kalra, Y.P. (Ed.), 1998, Handbook of Reference Methods for Plant Analysis, CRC Press, Boca Raton, FL.

Kano, A. (Ed.), 1995, Greenhouse Environment Control and Automation, ISHS Acta Horticulturae 399.

Kapuler, A.M., 2000, Perennial Capsium peppers in the greenhouse, The Growing Edge 11(5):59–63.

Karpeles, K., 1996, It’s catching on … The hydroponic cirriculum, The Growing Edge 8(1):28–34.

Kellither, J.M., 1990, Integrated pest management for the home gardener, The Growing Edge 1(3):30–34. Kelliher, J.M., 1992, Pest control for greenhouse growers, The Growing Edge 4(1):39–42, 53. Kelliher, J.M., 1994, Biological control for specialty collections, Part II, The Growing Edge 5(4):59–64. Khudheir, G.A. and Newton, P., 1983, Water and nutrient uptake by tomato plants grown with the nutrient film technique in relation to fruit production, Acta Hort.

44:133. Kiliebrew, F., 1996, Greenhouse tomato disease identification and management, pp. 21–25 in Greenhouse Tomato Seminar, ASHS Press, American Society for Horticultural Science, Alexandria, VA. Kinro, G.Y., 1999a, Pesticides: a primer on regulations and safe use, The Growing Edge 10(6):82–83. Kinro, G.Y., 1999b, Choices for safe pesticide use, The Growing Edge 11(1):70–75. Kinro, G.Y., 2000, Naturally hydroponic, The Growing Edge 11(6):38–45. Kinro, G.Y., 2002, Green growers 2002, The Growing Edge 14(3):60–63. Kinro, G.Y., 2003, Going pro — how to turn a hobby into a career, The Growing Edge 14(5):44–49. Kleemann, S., 1996, Alternative power generation for greenhouse growers, The Growing Edge 8(1):18–26 Knight, S.L., 1989, Maximizing productivity for CELSS using hydroponics, pp. 27–33, in S. Korney (Ed.), Proceedings of the 10th Annual Conference on Hydroponics, Hydroponic Society of America, Concord, CA. Knutson, A., 1997a, Sage of distinction, The Growing Edge 8(4):61–68. Knutson, A., 1997b, Expand your options with a hobby greenhouse, The Growing Edge 8(4):70–71. Knutson, A., 1997c, On thyme, The Growing Edge 9(2):64–69. Kratky, B.A., 1996, Noncirculating Hydroponic Methods, DPL Hawaii, Hilo, HI. Kubiac, J., 1999a, A legacy of hydroponic growing, The Growing Edge 10(3):35–38. Kubiac, J., 1999b, Saving energy in a solar greenhouse, The Growing Edge 11(1):38–45. Kubiac, J., 1999c, Year-round gardening at herb web farm, The Growing Edge 11(1):46–53. Kubiac, J., 2000, Glorious greens, The Growing Edge 12(2):58–59. Landers, M., 2001, Organic hydroponics, The Growing Edge 12(5):32–37. Larsen, J.E., 1979, Soilless culture at Texas A&M, pp. 46–61, in Proceedings First Annual Conference on Hydroponics: The Soilless Alternative, Hydroponic Society of America, Brentwood, CA. Leskovar, D.J. and Cantliffe, D.F., 1990, Does the initial condition of the transplants affect tomato growth and development? Proc. Fla. State Hort Soc. 103:148–153. Lindsay, W.L., 1979, Chemical Equilibria in Soil, John Wiley & Sons, New York. Linguist, R.K., 1985, Insect and mite pest control for crops grown under protected cultivation, pp. 51–57 in A.J. Savage (Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop Production, International Center for Special Studies, Honolulu, HI. Lopez, L.M., 1981, Hydroponic studies in plant culture with historical roots, Sci. Teacher 48(6):47–49. Lorenz, O.A. and Maynard, D.N., 1988, Knott's Handbook for Vegetable Growers, 3rd ed., John Wiley & Sons, New York. Lubkeman, D., 1998, Basic atmospheric greenhouse control, The Growing Edge 9(6):57–65. Lubkeman, D., 1999, Computer controls in the greenhouse, The Growing Edge 10(3):63–70. Ma, Y.B. and Nichols, D.G., 2004, Phytotoxicity and detoxification of fresh coir dust and coconut shell, Commun. Soil Sci. Plant Anal. 35(1):205–218. Male, C.J., 1999, 100 Heirloom Tomatoes for the American Garden, Workman Publishing, New York. Manrique, L.A., 1993, Greenhouse crops: a review, J. Plant Nutr. 16:2411–2477. Markert, B., 1994, Trace element content of “Reference Plant,” in D.C. Adriano, Z.S. Chen, and S.S. Yang (Eds.), Biochemistry of Trace Elements, Science and Technology Letters, Northwood, NY. Marschner, H., 1995, Mineral Nutrition of Higher Plants, Academic Press, New York. Mason, S.C. and Wilcox, G.E., 1964, Nitrogen status evaluation of tomato plants, J. Amer. Soc. Hort. Sci. 107(3):483–486. Martin-Prevel, P, Gagnard, J. and Gautier, P. (Eds.), 1987, Plant Analysis as a Guide to the Nutrient Requirements of Temperate and Tropical Crops. Lavosier Publishing, New York. Mass, J.L. (Ed.), 1998, Compendium of Strawberry Diseases, The American Phytopathological Society, APS Press, St. Paul, MN.

Maynard, D.N. and Hochmuth, G.J., 1997, Knott’s Handbook for Vegetable Growers, 4 th ed., John Wiley & Sons, New York. McEno, J., 1990, Hydroponic IPM, The Growing Edge 1(3):35–39. McGrath, M., 2002a, You Bet Your Tomatoes. Rodale, Emmaus, PA. McGrath, M., 2002b, The whitefly wars: solutions for serious growers, The Growing Edge 14(1):56–62. McGrath, M., 2003, Sicilian hydroponic tomatoes: Cooperative San Paolo di Caltagirone, The Growing Edge 14(5):38–42. Meade, A., 2001, Antarctic hydroponics: an update from McMurdo Station, The Growing Edge 12(3):40–43. Meade, A., 2002a, Soilless lettuce in the South Pacific, The Growing Edge 13(4):40–43. Meade, A., 2002b, Cornell’s CEA Center: sophisticated soilless models, The Growing Edge 14(2):40–44. Meade, A., 2003, SUNY Oswego: teaching technology through hydroponics, The Growing Edge 15(2):68–72. Mengel, K. and Kirkby, E.A., 1987, Principles of Plant Nutrition, 4th ed., International Potash Institute, Worblaufen-Bern, Switzerland. Mengel, K., Kirkby, E.A, Kosegarten, H., and Appel, T., 2001, Principles of Plant Nutrition, 5th ed., Kluwer Academic Publishers, Dordrecht, The Netherlands. Mertz, W., 1981, The essential trace elements, Science 213:1332–1338. Meyer, S., 1998, Starting tomatoes from seed, Organic Gardening 45(2):46–49. Mills, H.A. and Jones, J.B., Jr., 1996, Plant Nutrition Handbook II, MicroMacro Publishing, Athens, GA. Mizra, M. and Younus, M., 1997, An overview of the greenhouse vegetable industry in Alberta, Canada, pp. 187–189, in K. Wignarajah (ed.), Proceedings 18th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA. Mohyuddin, M., 1985, Crop cultivars and disease control, pp. 42–50, in A.J. Savage (Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop

Production, International Center for Special Studies, Honolulu, HI. Molyneux, C.J., 1988, A Practical Guide to NFT, T. Snap & Co. Ltd., Preston, Lancashire, England. Montgomery, L., 2002, Austin High hydroponics, The Growing Edge 13(3):77–80. Moreno, D.A., Ahammad, L., Villora, G.V. and Romero, L.M., 2003, Relationship of leaf macronutrient concentrations in new tomato varieties to fruit yield, J. Plant Nutr. 26(5):1035–1054. Morgan, L., 1997a, Solutions for that home-grown flavor, The Growing Edge 8(4):24–31. Morgan, L., 1997b, Grow your own hydroponic stawberries, The Growing Edge 9(l):l8–23. Morgan, L., 1997c, Organic fertilizers for hydroponics, The Growing Edge 9(2):32–39. Morgan, L., 1998a, The pH factor in hydroponics, The Growing Edge 9(4):25–33. Morgan, L., 1998b, Electrical conductivity in hydroponics, The Growing Edge 9(5):25–33. Morgan, L., 1998c, Hydroponic water chestnuts & other aquatic crops, The Growing Edge 9(6):43–55. Morgan, L., 1998d, Organic disease control, The Growing Edge 10(1):41–50. Morgan, L., 1998e, Organic pest control, The Growing Edge 10(2):35–42. Morgan, L., 1999a, Neem: revolutionizing pest and disease control, The Growing Edge 10(3):51–61. Morgan, L., 1999b, Coconut fiber: the environmentally friendly medium, The Growing Edge 10(5):24–30. Morgan, L., 1999c, Introduction to hydroponic gullies and channels, The Growing Edge 10(6):67–75. Morgan, L., 1999d, Hydroponic sweet peppers and aubergines, The Growing Edge 11(1):25–37. Morgan, L., 1999e, Hydroponic seed raising and plant propagation, The Growing Edge 11(2):25–37. Morgan, L., 1999f, Hydroponic Lettuce Production: A Comprehensive, Practical and Scientific Guide to Commercial Hydroponic Lettuce Production, Casper Publications Pty Ltd, Narrabeen, Australia.

Morgan, L., 2000a, Beneficial elements for hydroponics: a new look at plant nutrition, The Growing Edge 11(3):40–51. Morgan, L., 2000b, From sprouts to salads, The Growing Edge 11(5):12–27. Morgan, L., 2000c, Water, water everywhere, The Growing Edge 11(6):28–37. Morgan, L., 2000d, Miniature marvels, The Growing Edge 12(1):20–31. Morgan, L., 2001a, Greenhouse extremes, Part One: minimizing the effects of high temperatures, The Growing Edge 12(3):24–39. Morgan, L., 2001b, Greenhouse extremes, Part Two: minimizing the effects of low temperatures, The Growing Edge 12(4):65–73. Morgan, L., 2001c, Growing hydroponic raspberries, The Growing Edge 12(5):58–69. Morgan, L., 2001d, Root zone control, The Growing Edge 12(6):38–49. Morgan, L., 2001e, Rots and spots and drop … Oh my: preventing and treating problems during flowering and fruiting, The Growing Edge 13(1):18–31. Morgan, L., 2001f, Corlander and basil: continuous crops for profit, The Growing Edge 13(2):26–35.

Morgan, L., 2002a, Cultivating hydroponic cucumbers, The Growing Edge 13(3):32–43. Morgan, L., 2002b, Hydroponic crops from the tropics: babaco and passionfruit, The Growing Edge 13(4):56–68. Morgan, L., 2002c, Hydroponic crop preparation procedures, The Growing Edge 13(5):42–51 Morgan, L., 2002d, Hydroponic classroom experiments, The Growing Edge 13(6):56–70. Morgan, L., 2002e, Hydroponic Q&A, The Growing Edge 14(1):11. Morgan, L., 2002f, Raft system specifics, The Growing Edge 14(2):46–60. Morgan, L., 2003a, Inside greenhouse design, The Growing Edge 14(3):26–38. Morgan, L., 2003b, Hydroponic strawberries: year round perfection through superior technology, The Growing Edge 14(4):46–60. Morgan, L., 2003c, Carbon dioxide enrichment, The Growing Edge 14(5):64–74. Morgan, L., 2003d, Hydroponic tomatoes: the complete guide to soilless success — Part 1: tomato plant physiology, The Growing Edge 14(6):56–57. Morgan, L., 2003e, Hydroponic tomatoes: the complete guide to soilless success — Part 2: production systems and crop management, The Growing Edge 15(1):60–73. Morgan, L., 2003f, Hydroponic substrates, The Growing Edge 15(2):54–66. Morgan, L., 2004a, Hydroponic herbs: how to set up a successful commercial operation, The Growing Edge 15(4):30–47. Morgan, L., 2004b, Exotic familiar herbs: more commercial opportunities, The Growing Edge 15(5):30–46. Morgan, L., 2004c, Getting started: seeds and seedlings, The Growing Edge 15(5):70–73. Morgan, L. and Lennard, S., 2000, Hydroponic Capsicum Production: A Comprehensive, Practical and Scientific Guide to Commercial Hydroponic Capsicum Production, Casper Publications Pty Ltd, Narrabeen, Australia. Mpelkas, C.C., 1989, Electric light energy: a key environmental factor in horticultural technology, pp. 53–78, in Electrical Energy in Agriculture, McFate, K.L. (ed.), Energy in World Agriculture 3, Elsevier, New York. Muckle, E.M., 1993, Hydroponic Nutrients: Easy Ways to Make Your Own, Growers Press, Inc., Princeton, British Columbia, Canada. Munson, R.D. and Nelson, W.L., 1990, Principles and practices in plant analysis, pp. 359–387, in R.L. Westerman (Ed.), Soil Testing and Plant Analysis, 3rd ed., SSSA Book Series Number 3, Soil Science Society of America, Madison, WI. Musgrave, C.E., 2001, Creating your own nutrient solution, The Growing Edge 13(1):60–66. Naegely, S.K., 1997, Greenhouse vegetables business is booming, Greenhouse Grower 15:14–18. Nakazawa, L., 1990, Bananas grown in Oregon, The Growing Edge 1(3):21–22. Nederhoff, E., 2001, Commercial greenhouse growing in the Netherlands, The Growing Edge 12(4):31–43.

Nelson, P.V., 2002, Greenhouse Operations and Management, 6th ed., Pearson Education, Upper Saddle Run, NJ.

Nickols, M., 2002, Aeroponics: production systems and research tools, The Growing Edge 13(5):30–35.

Nicol, E., 1990, Hydroponics and aquaculture in the high school classroom, Am. Biol. Teacher 52:182–184.

Nielson, K.F., 1974, Roots and root temperature, pp. 253–333, in E.W. Carson (Ed.), The Plant Root and Its Environment, University Press of Virginia, Charlottesville, VA.

Nyun, J.S., 1997, Hot climate gardening, The Growing Edge 9(2):74–79.

Ogden, R.J., Pokorny, F.A., Mills, H.A., and Dunavent, M.G., 1987. Elemental status of pinebark-based potting media, Hort. Rev. 9:103–131. Olliver, K., 2000, Lunar hydroponics, The Growing Edge 12(2):68–75. Pais, I., 1992, Criteria of essentiality, beneficiality, and toxicity of chemical elements, Acta Alimentaria 21(2):145–152. Pais, I. and Jones, J.B., Jr., 1997, The Handbook of Trace Elements, St. Lucie Press, Boca Raton, FL.

Pallas, J.E., Jr. and Jones, J.B., Jr., 1978, Platinum uptake by horticultural crops, Plant and Soil 50:207–212.

Papadopoulos, A.P., 1991, Growing Greenhouse Tomatoes in Soil and in Soilless Media, Agricultural Canada Publication 1865/E, Communications Branch, Agricultural Canada, Ottawa, Canada.

Papadopoulos, A.P., 1994, Growing Greenhouse Seedless Cucumbers in Soil and in Soilless Media, Agricultural Canada Publication 1902/E, Communications Branch, Agricultural and Agri-Food Canada, Ottawa, Canada.

Papadopoulos, A.P. and Pararajasingham, S., 1996, The influence of plant spacing on light interception and use in greenhouse tomato (Lycopersicon esculentum Mill): a review, Scienta Hortic. 68:1–29.

Parker, D., 1989, Back to the future? Organic hydroponics for the gardener, The Growing Edge 1(1):25–28, 51–52.

Parker, D., 1991, Hydroponic herbs at home, The Growing Edge 2(3):34–37. Parker, D., 1992–1993a, Systems for beginners: Hydro 101, The Growing Edge 4(1):61–66. Parker, D., 1992–1993b, Hydroponic solutions for beginners, The Growing Edge 4(2):60–62. Parker, D., 1993, Bioponic greenhouse: the best of both worlds, The Growing Edge 4(4):22–27. Parker, D., 1993, Site selection for beginners: hydroponics 101, The Growing Edge 4(4):50–56. Parker, D., 1994a, Lighting for beginners: Part 1, The meaning of light, The Growing Edge 5(4):53–57, 66–67. Parker, D., 1994b, Lighting for beginners: Part 2, Let there be light, The Growing Edge 6(1):46–50, 68. Paterson, J.A. and Hall, D.A., 1981, A method for studying the influence of nutrition on tomato plant vigour in hydroponic culture, Hort. Res. 21:103–106. Paterson, J.C., 1981, Modify your pH perspective, Florists' Review 169(4386):34–35, 92, 94. Peckenpaugh, D.J., 2001a, The Growing Web, The Growing Edge 11(6):87. Peckenpaugh, D.J., 2001b, The Growing Web, The Growing Edge 12(3):81–87. Peckenpaugh, D.J., 2001c, The Growing Web, The Growing Edge 12(5):80–86. Peckenpaugh, D.J., 2001b, Soilless growing at Arcadia School, The Growing Edge 13(1):42–45

Peckenpaugh, D.J., 2001e, Frontier Middle School, The Growing Edge 13(1):49–53. Peckenpaugh, D.J., 2001f, Hydroponic resources for teachers, The Growing Edge 13(2).48–57. Peckenpaugh, D.J., 2002a, Hobbyist hydroponics: some general resources for every grower, The Growing Edge 13(4):31–39. Peckenpaugh, D.J., 2002b, The growing web, The Growing Edge 13(4):81–83. Peckenpaugh, D.J., 2002c, Hydroponic chiles: cultivation tips for Capsaicin, The Growing Edge 13(5):61–73. Peckenpaugh, D.J., 2002d, The growing web, The Growing Edge 13(5):83–86. Peckenpaugh, D.J., 2002e, Thinking large but starting small, The Growing Edge 13(6):48–55. Peckenpaugh, D.J., 2002f, HMA 2002: Betting on the future, The Growing Edge 14(1):12–21. Peckenpaugh, D.J., 2002g, Salmon Creek hydroponics, The Growing Edge 14(1):50–56. Peckenpaugh, D.J., 2002h, Basil Bob and the greenhouse that couldn't stop growing, The Growing Edge 14(2):14–22. Peckenpaugh, D.J., 2003a, Pest and disease control for the hydroponic grower, The Growing Edge 14(3):64–74. Peckenpaugh, D.J., 2003b, Homemade recirculating drip hydroponics: Part 1: System construction, The Growing Edge 14(6):75–78. Peckenpaugh, D.J., 2003c, Homemade recirculating drip hydroponics: Part 2: System operation and maintenance, The Growing Edge 15(2):74–77. Peckenpaugh, D.J., 2004a, Industry perspectives: future visions from Otmar Silberstein, The Growing Edge 15(3):58–61. Peckenpaugh, D.J. 2004b, The best little greenhouse tomato industry in the south, The Growing Edge 15(4):50–62. Peet, M.M., 1992, Fruit cracking in tomato, HortTechnology 2(2):216–223. Peverill, K.I, Sparrow, L.A., and Reuter, D.J. (Eds.), 1999, Soil Analysis: An Interpretation Manual, CSIRO Publishing, Collingwood, Australia. Pitts, M., Handley, D., and Walker, C., 1998, Strawberry Production Guide for the Northeast, Midwest, and Eastern Canada, Cooperative Extension, NRAES-85, Northeast Regional Agricultural Engineering Service, Ithaca, NY. Pokorny, F.A., 1979, Pine bark container media — an overview, Combined Proc. Int. Plant Propagators Soc. 29:484–495. Raper, C.D., Jr., 1987, Measurement and control of ionic composition using automated ion chromatography: design and maintenance of recirculating hydroponic systems, HortSci. 22:1000. Rearden, J., 2003, Greenhouse heating, pp. 123–132, in C. Beytes (Ed.), Ball Redbook, Greenhouses and Equipment, Vol. 1, 17th ed., Ball Publishing, Batavia, IL. Reisenauer, N.M. (Ed.), 1983, Soil and Plant Testing in California, University of California Division of Agricultural Science Bulletin 1879, University of California, Berkeley, CA. Rengel, Z., 1998, Nutrient Use in Crop Production, Food Products Press, The Haworth Press, Inc., New York. Rengel, Z., 2002, Chelator EDTA in nutrient solution decreases growth of wheat, J. Plant Nutr. 25(8):1709–1725. Resh, H.M., 1990, A world of soilless culture, pp. 33–55, in S. Korney (Ed.), Proceedings of the 11th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA. Resh, H.M., 1995, Hydroponic Food Production, 5 th ed., Woodbridge Press Publishing, Santa Barbara, CA. Resh, H.M., 1998, Hydroponics: Questions & Answers for Successful Growing, Woodbridge Press, Santa Barbara, CA. Resh, H.M., 2001, Hydroponic Food Production, 6th ed., Woodbridge Press Publishing, Santa Barbara, CA. Resh, H.M., 2002, Cuisinart Resort & Spa: growing and learning in Anguilla, The Growing Edge 14(1):28–36. Resh, H.M., 2003, Hobby Hydroponics, Newconcept Press, Mahwah, NJ.

Reuter, D.J. and Robinson, J.B. (Eds.), 1986, Plant Analysis: An Interpretation Manual, Inkata Press Pty Ltd., Victoria, Australia.

Richerson, S.A., 2002, Preparing the greenhouse for winter, The Growing Edge 14(2):62–67.

Ricks, D., 1996, The land: a touch of reality in a world of fantasy, The Growing Edge 8(1):38–44.

Roberto, K., 2001, How-To Hydroponics, 3rd ed., Futuregarden, Inc., Farmingdale, NY.

Roberts, W.J., 1985, Energy conservation and environmental control, pp. 21–30, in A.J. Savage (Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop Production, International Center for Special Studies, Honolulu, HI.

Robinson, L., 2002, Village Farms: big time hydroponic tomatoes, The Growing Edge 13(6):22–28.

Rodriguez de Cianzio, S.R., 1991, Recent advances in breeding for improving iron utilization by plants, pp. 83–88, in Y. Chen and Y. Hadar (Eds.), Iron Nutrition and Interactions in Plants, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Rogan, M. and Finnemore, M., 1992, The last place on earth: greenhouse gardening at the South Pole, The Growing Edge 3(4):36–38.

Rogers, T., 2000, Hydroponic blueprints: a quality run-to-waste system for the masses, The Growing Edge 11(5):77–81.

Rombough, L.J., 1997, From backyard to big business: new natural controls, The Growing Edge 8(4):68–69.

Roorda van Eysinga, J.P.N.L. and Smith, K.W., 1981, Nutritional Disorders in Glasshouse Tomatoes, Cucumbers, and Lettuce, Centre for Agricultural Publishing and Documentation, Wageningen, The Netherlands.

Rorabaugh, PA., 1995, A brief and practical trek through the world of hydroponics, pp. 7–14, in M. Bates (Ed.), Proceedings of the 16th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA.

Russell, E.J., 1950, Soil Conditions and Plant Growth, Longmans, Green and Company, London.

Ryall, D., 1993, Growing greenhouse vegetables in a recirculating rockwool system, pp. 35–39, in T. Alexander (Ed.), Proceedings of the 14th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA.

Ryder, E.J., 1999, Lettuce, Endive, and Chicory, Crop Production Science in Horticulture Series 7, CABI Publishing, Wallingford, Oxon, UK.

Rudder-Nasenohr, K., 2000, Grimm’s gardens, The Growing Edge 11(6):59–65.

Sadler, P., 1993–1994, Gardening on ice: South Pole and McMurdo Station, The Growing Edge 5(2):36–39, 68.

Sadler, P., 1995, The Antarctic hydroponic project, pp. 97–107, in M. Bates (Ed.), Proceedings of the 16th Annual

Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA.

Savage, A.J., (ed.), 1985a, Hydroponics Worldwide: State of the Art in Soilless Crop Production, International Center for Special Studies, Honolulu, HI.

Savage, A.J., 1985b, Master Guide to Planning Profitable Hydroponic Greenhouse Operations, International Center for Special Studies, Honolulu, HI.

Savage, A.J., 1989, Master Guide to Planning Profitable Hydroponic Greenhouse Operations, revised edition, International Center for Special Studies, Honolulu, HI.

Savage, A.J., 1995, Garden of the future, The Growing Edge 6(3):40–47.

Scaife, A. and Stevens, K.L., 1983, Monitoring sap nitrate in vegetable crops: comparison of test strips with electrode methods and effects of time of day and leaf composition, Commun. Soil Sci. Plant Anal. 14:761–771.

Scaife, A. and Turner, M., 1984, Diagnosis of Mineral Disorders in Plants: Volume 2, Vegetables, Chemical Publishing Co., New York. Schippers, P.A., 1979, The Nutrient Flow Technique, V.C. Mimeo 212. Department of Vegetable Crops, Cornell University, Ithaca, NY.

Schippers, P.A., 1991, Practical aspects to fertilization and irrigation systems, pp. 14–24, in S. Knight (Ed.), Proceedings of the 12th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA.

Schmitz, J., 2004, Couple spreads hydroponics gospel in the Northwest, The Fruit Growers News 43(4):40.

Schneider, R., 1998, Winter tomatoes at the office, The Growing Edge 9(6):17–19.

Schneider, R., 1999a, “Lettuce” bring you quality: from Honey Port Farms, The Growing Edge 19(3):20–23. Schneider, R., 1999a, Growing in Virginia — hydroponics makes a difference for inmates, The Growing Edge 10(4):35–40. Schneider, R., 1999a, Computerizing the variables in your hydroponic system, The Growing Edge 10(6):35–41. Schneider, R., 2000, The hydroponic adventure continues — creative chaos and catastrophe, The Growing Edge 11(3):17–23. Schneider, R., 2001, The cucumber that ate summer system 6!, The Growing Edge 12(3):20–27. Schneider, R., 2002, Summer salad system success, The Growing Edge 13(3):44–49. Schneider, R., 2003, Summer system VI: The birth of Star Hydro, The Growing Edge 14(3):75–80. Schneider, R., 2004, Summer's harvest interrupted, The Growing Edge 15(3):69–76. Schneider, R. and Ericson, L., 2001, Backyard buckeye hydr o, The Growing Edge 12(4):75–79. Schoenstein, G.P., 1993, Hydro-organics: organic hydroponic solution, The Growing Edge 4(4):18–20, 66. Schoenstein, G.P., 2001, Hope through hydroponics, The Growing Edge 13(2):69–79. Schon, M., 1992, Tailoring nutrient solution to meet the demands of your plants, pp. 1–7, in D. Schact (Ed.), Proceedings of the 13th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA. Schroder, F.G., 1992, Plant plane hydroponics, The Growing Edge 3(1):52–55. Schwartzkopf, S., 1990, Design of an experimental hydroponic system for space flight, pp. 46–56, in S. Korney (Ed.), Proceedings of the 11th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA. Schwarz, M., 2003, Industry perspectives: Israeli pioneers of hydroculture, The Growing Edge 15(1):52–58. Sheldrake, R., Jr. and Boodley, J.W., 1965, Commercial Production of Vegetable and Flower Plants, Cornell Extension Bulletin 1065, Cornell University, Ithaca, NY. Sherrard, T., 2003, Supplemental lighting, pp. 137–140, in C. Beytes (Ed.), Ball Redbook: Greenhouse and Equipment, Vol. 1, 17th ed., Ball Publishing, Batavia, IL. Short, T., 2003, Greenhouse ventilation, pp. 115–123, in C. Beytes (Ed.), Ball Redbook: Greenhouse and Equipment, Vol. 1, 17th ed., Ball Publishing, Batavia, IL. Silberstein, O., 1995, Hydroponics: making waves in the classroom, The Growing Edge 6(4):16. Silberstein, O. and Spoelstra-Pepper, C., 1999, Hydroponic workshops for teacher — A traveling roadshow, The Growing Edge 11(2):10–11. Simon, D., 2003, Innovation abounds in Burlington County, The Growing Edge 15(1):28–35. Simon, D., 2004a, Grow it in a greenhouse, The Growing Edge 15(4):18–20. Simon, D., 2004b, Hydro machine goes round and round, The Growing Edge 15(5):10–11. Slake, G., 1983, CO 2 enrichment of tomato crops, pp. 152–163, in Physiology, Yield, and Economics, CRC Press, Boca Raton, FL. Smith, A.F., 1994, The Tomato in America: Early History, Culture, and Cookery. University of South Carolina Press, Columbia, SC. Smith, B., 2000, The growing world of hydroponics, The Growing Edge 12(1):82–85. Smith, B., 2001a, Designing and building your own home hydroponic system: Part one: let's kick around some possibilities! The Growing Edge 12(3):78–80. Smith, B., 2001b, Designing and building your own home hydroponic system: Part two: let's keep it simple ….at the start! The Growing Edge 12(4):80–83. Smith, B., 2001c, Designing and building your own home hydroponic system: Part three: setting up the system, The Growing Edge 12(5):74–79. Smith, B., 2001d, Designing and building your own home hydroponic system: Part four: let's get growing! The Growing Edge 12(6):78–83. Smith, B., 2001e, The growing world of hydroponics, Part five: managing the crop, The Growing Edge 13(1):81–85. Smith, B., 2001f, The growing world of hydroponics, Part six: automated nutrient dosing, The Growing Edge 13(2):81–84. Smith, B., 2002a, The growing world of hydroponics, Part seven: enjoying the fruits of your labor, The Growing Edge 13(3):81–83. Smith, B., 2002b, The growing world of hydroponics, Part eight: growing into the winter, The Growing Edge 13(4):75–79. Smith, B., 2002c, The growing world of hydroponics, Part nine: lettuce and yet more lettuce, The Growing Edge 13(5):79–82. Smith, B., 2002d, The growing world of hydroponics, Part ten: a sea of lettuce, The Growing Edge 13(6):79—84. Smith, B., 2002e, The growing world of hydroponics: soilless rose, The Growing Edge 14(2):79–84. Smith, B., 2003a, What would you grow in water? … Watercress, The Growing Edge 14(3):81–87. Smith, B., 2003b, The growing world of hydroponics: keeping it simple, The Growing Edge 14(5):79–84. Smith, B., 2003c, From seed to corporation — PTO growers: Part 1, The Growing Edge 14(6):79–83. Smith, B., 2003d, From seed to corporation — PTO growers: Part 2, The Growing Edge 15(1):79–83. Smith, B., 2003e, From seed to corporation — PTO growers: Part 3, The Growing Edge 15(2):79–83. Smith, B., 2004, A short history of NFT gully design, The Growing Edge 15(3):79–82. Smith, D.L., 1987, Rock Wool in Horticulture, Grower Publications Ltd, London. Smith, J.E., 1985, South Africa: current research and developments, pp. 150–163, in A.J. Savage (Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop Production, International Center for Special Studies, Honolulu, HI. Smith, K.C., 1998, R.S. Goins greenhouse: North Carolina tomato growers, The Growing Edge 9(6):21–25. Smith, R., 1999, The growing world of hydroponics, The Growing Edge 11(1):14–16. Smith, R., 2001, Growing hydroponic potatoes, The Growing Edge 12(4):58–63. Snyder, R.C., 1995, Starting Vegetable Transplants, Extension Service, Mississippi State University Publication 1995, Crystal Springs, MS. Snyder, R.C., 1997, Greenhouse Tomato Handbook, Mississippi State University Extension Service Publication 1828, Crystal Springs, MS. Soffer, H., 1985, Israel: current research and developments, pp. 123–130, in A.J. Savage (Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop Production, International Center for Special Studies, Honolulu, HI. Soffer, H., 1988, Research on aero-hydroponics, pp. 69–74, in Proceedings of the 9th Annual Conference on Hydroponics, Hydroponic Society of America, Concord, CA. Sonneveld, C., 1989, Rockwool as a substance in protected cultivation, Chronic. Hort. 29(3):33–38. Spillane, M., 1992, Nature's pharmacy — medicinal plants for the home garden, The Growing Edge 3(3):44–47. Spillane, M., 1999, Never too hot to handle, The Growing Edge 10(3):41–46. Spillane, M., 2000, Getting schooled in hydroponics, The Growing Edge 11(6):74–80. Spillane, M., 2001, Fresh greens from Quebec, The Growing Edge 12(6):52–59. Spillane, M., 2002a, Reusing rockwool: economical and environmental solutions for commercial growers, The Growing Edge 13(6):30–37. Spillane, M., 2002b, Sustainable solutions from new technologies, The Growing Edge 14(2):32–39. Spillane, M., 2003a, Biological pest and disease control: a natural approach to problem solving and prevention, The Growing Edge 15(1):36–45. Spillane M., 2003b, Thiessen greenhouses: cut roses in cyberspace, The Growing Edge 15(2):36–11. Spillane, M., 2004, Hydroponic cucumbers flow from Canada, The Growing Edge 15(3):30–37. Srivastava, J.P., and Kumar, A., 1995, Current perspectives in water loss from plants and stomal action, pp. 45–59, in M. Pessarakli (Ed.), Handbook on Plant and Crop Physiology, Marcel Dekker, Inc., New York. Steiner, A.A., 1961, A universal method for preparing nutrient solutions of certain desired composition, Plant and Soil 15:134–154. Steiner, A.A., 1980, The selective capacity of plants for ions and its importance for the composition of the nutrient solution, pp. 37–97, in R.G. Hurd, P. Adams, D.M. Massey, and D. Price (Eds.), Symposium on Research on Recirculating Water Culture, Acta Horticulture No. 98, The Hague, The Netherlands. Steiner, A.A., 1984, The universal nutrient solution, pp. 633–650, in Proceedings Sixth International Congress of Soilless Culture, The Hague, The Netherlands. Steiner, A.A., 1985, The history of mineral plant nutrition til about 1860 as source of the origin of soilless culture methods, Soilless Culture 1(1):7–24. Straver, W.A., 1996a, Inert growing media for greenhouse tomatoes, pp. 13–15, in Greenhouse Tomato Seminar, ASHS Press, American Society for Horticultural Science, Alexandria, VA. Straver, W.A., 1996b, Nutrition of greenhouse tomatoes on inert substrates in northern latitudes, pp. 31–33, in Greenhouse Tomato Seminar, ASHS Press, American Society for Horticultural Science, Alexandria, VA. Taggart, B. and Randolph, G., 1996, A taste of the tropics … hydroponic bananas, The Growing Edge 7(4):56–61. Takahashi, E., Ma, J.F., and Miyake, Y., 1990, The possibility of silicon as an essential element for higher plants, pp. 99–122, in Comments on Agricultural and Food Chemistry, Gordon and Breach Scientific Publications, London. Tan, K.H., 1993, Principles of Soil Chemistry, 2nd ed., Marcel Dekker, New York. Tapia, M.L., 1985, Chile and the Antarctic: current research and developments, pp. 103–155, in A.J. Savage

(Ed.), Hydroponics Worldwide: State of the Art in Soilless Crop Production, International Center for Special Studies, Honolulu, HI. Taylor, T.M., 2003, Secrets to a Successful Greenhouse and Business, GreenEarth Publishing Co., Melbourne, FL. Taylor, M.D. and Locascio, S.J., 2004, Blossom-end rot: A calcium deficiency, J. Plant Nutr. 27(l):123–139. Texier, W., 1994–1995, Hydroponics: beyond the basics, The Growing Edge 6(2):42–47, 73–74. Thayer, R.H., 1991, Hydroponic or organic: what's the difference?, The Growing Edge 2(1):41–43. Thomas, L., 1990, Bioponics: the application of organic gardening to hydroponics, The Growing Edge 1(3):40–43. Thomas, L., 1991a, Bioponics: Part two, The Growing Edge 2(2):37–43, 65. Thomas, L., 1991b, Bioponics Part III: solution pH and temperature as limiting factors, The Growing Edge 2(3):40–43, 61. Thomas, L., 1991c, Bioponics Part IV, The Growing Edge 2(4):35–40. Thomas, L., 1992–1993, Bioponics Part V: Enzymes for hereditary potential, The Growing Edge 4(2):36–41. Thomas, L., 1995–1996, Hydroponic tomatoes: the flavor factor, The Growing Edge 7(2):23–26. Thomas, L., 1996, Extending the life of your nutrient solution, The Growing Edge 7(4):21–23, 78. Thomas, W. and Thomas, B., 1996–97, Orchards and perlite: a perfect match, The Growing Edge 8(2):18–23,77. Thompson, G., 2002, North American Strawberry Growers Association Newsletter 27(4):1–2. State College, PA. Tibbitts, T.W., 1991, Hydroponic culture of plants in space, pp. 54–60, in S. Knight (Ed.), Proceedings of the 12th Annual Conference on Hydroponics, Hydroponic Society of America, San Ramon, CA. Tindall, J.A., Mills, H.A., and Radcliffe, D.E., 1990, The effect of root zone temperature on nutrient solution uptake of tomato, J. Plant Nutr. 13:939–956. Tite, R.L., 1983, Growing Tomatoes: A Greenhouse Guide, ADAS Primer 2, Ministry of Agriculture, Fisheries, and Food, Grower Books, London. Trelease, S.F. and Trelease, H.M., 1935, Physiologically balanced culture solutions with stable hydrogen ion concentration, Science 78:438–439. Ulrich, A., Mostafa, M.A.E., and Allen, W.W., 1980, Strawberry Deficiency Symptoms: A Visual and Plant Guide to Fertilization, Priced Publication 4098, Agricultural Sciences Publications, University of California, Berkeley, CA. Van Patten, G.F., 1989, Hard rock gardening: keeping up with the rockwool revolution, The Growing Edge 1(1):37–41. Van Patten, G.F., 1991a. Gardening: The Rockwool Book, Van Patten Publishing, Portland, OR. Van Patten, G.F., 1991b, Rockwool — cube garden, slab garden, The Growing Edge 2(3):25–29. Van Patten, G.F., 1992, Hydroponics for the rest of us, The Growing Edge 3(3):24–33, 48–51. Van Patten, G.F., 1998, Indoor lighting demystified, The Growing Edge 10(1):25–33. van Zinderen Bakker, E.M., 1986, Development of hydroponic systems and a look into the future, Section III, in Proceedings 7th Annual Conference on Hydroponics: The Evolving Art, the Evolving Science, Hydroponic Society of America, Concord, CA. Vasilerko, V., 2002, Hydroponics and humates: ancient acids for modern agriculture, The Growing Edge 14(1):64–69. Vavrina, C.S. and Orzolek, M.D., 1993, Tomato transplant age: a review, HortTechnology 3(3):313–316. Verwer, F.L. and Wellman, J.J.C., 1980, The possibilities of Grodan rockwool in horticulture, pp. 263–278 in Fifth International Congress on Soilless Culture, International Society for Soilless Culture, Wageningen, The Netherlands. Volkmar, K.M. and Woodbury, W., 1995, Plant-water relationships, pp. 23–43, in M. Pessarakli (Ed.), Handbook of Plant and Crop Physiology, Marcel Dekker, Inc., New York. Vollebrecht, R., 2003, Open-roof greenhouses, pp. 13–17, in C. Beytes (Ed.), Ball Redbook, Vol. 1, 17th ed., Ball Publishing, Batavia, IL. Vyn, K., 2000, Designing a medicinal garden, The Growing Edge 11(3):83–84. Wallace, A., 1971, Regulation of the Micronutrient Status of Plants by Chelating Agents and Other Factors, UCLA 34P5 1–33, Arthur Wallace, Los Angeles, CA. Wallace, A., 1989, Regulation of micronutrients and uses of chelating agents in solution culture, pp. 50–53 in S. Korney (Ed.), Proceedings of the 10 th Annual Conference on Hydroponics, Hydroponic Society of America, Concord, CA.

Ward, G.M., 1964, Greenhouse tomato nutrition: a growth analysis study, Plant and Soil 21:125–133.

Warnke, D.D., 1986, Analyzing greenhouse growth media by the saturation extraction method, HortSci. 21:223–225.

Warnke, D.D., 1988, Recommended test procedure for greenhouse growth media, pp. 34–37, in W.C. Wahnke (Ed.), Recommended Chemical Soil Test Procedures, North Central Regional Publication No. 221 (revised), North Dakota Agricultural Experiment Station, Fargo, ND.

Waterman, M.P., 1993–1994, Building a better tomato, The Growing Edge 5(2):20–25, 69.

Waterman, M.P., 1994, An introduction to herb mint, The Growing Edge 5(4):29–33, 70.

Waterman, M.P., 1995, Sweet or fiery: peppers are hot! The Growing Edge 6(3):48–54, 76–77.

Waterman, M.P., 1996a, The good, the bad and the ugly: insect research doesn’t discriminate, The Growing Edge

7(3):22-28, 75.

Waterman, M.P., 1996b, Tomato research presses on, The Growing Edge 7(4):34-40, 79.

Waterman, M.P., 1996-1997, Lettuce rejoice, The Growing Edge 8(2):62-69.

Waterman, M.P., 1997, Re-inventing our food supply, The Growing Edge 9(2):22-31.

Waterman, M.P., 1998a, New veggies for our garden, The Growing Edge 9(4):34-41.

Waterman, M.P., 1998b, What's new in tomato research, The Growing Edge 9(6):27-35.

Waterman, M.P., 1999, Growing for growth: medicinal Chinese herbs and vegetables are gaining in popularity, The Growing Edge 10(5):62-70.

Waters, W.E., Geraldson, C.M., and Woltz, S.S., 1972, The Interpretation of Soluble Salt Tests and Soil Analysis by Different Procedures, AREC Mimeo Report GC-1972, Bradenton, FL.

Wells, O.S., 1996, Row cover and high tunnel growing systems in the United States, HortTechnology 6(3):172-176.

Whipker, B.E., Dole, J.M., Cavins, T.J., and Gobson, J.L., 2003, Water quality, pp. 9-18, in D. Hamrick (Ed.), Ball Redbook: Crop Production, Vol. 2, 17th ed., Ball Publishing, Batavia, IL.

White, J.W., 1974, Dillon Research Fund, Progress Report on Research at Penn State, Pennsylvania Flower Growers Bull. 89:3-4.

Wigriarajah, K., 1995, Mineral nutrition in plants, pp. 193-222, in M. Pessarakli (Ed.), Handbook of Plant and Crop Physiology, Marcel Dekker, New York.

Wilcox, G.E., 1980, High hopes for hydroponics, Am. Veg. Grower 28:11-14.

Wilcox, G.E., 1983, Hydroponic systems around the world, their characteristics and why they are used, pp. 1-14, in Proceedings Fourth Annual Conference, Theme: Hydroponics How Does It Work, Hydroponic Society of America, Concord, CA.

Wilcox, G.E., 1991, Nutrient control in hydroponic systems, pp. 50–53, in S. Knight (Ed.), Proceedings of the 12th Annual Conference on Hydroponics, Hydroponic Society of America, Concord, CA.

Wilcox, G.E., Hoft, J.E., and Jones, C.M., 1973, Ammonium reduction of calcium and magnesium content of tomato and seed corn leaf tissue and its influence on the incidence of blossom-end rot of tomato fruit, J. Am. Soc. Hort. Sci. 98(1):86–89.

Wilson, G, 2002a, Soilless systems in the sky: to boldly grow where none have grown before, The Growing Edge 13(3):24–29.

Wilson, G., 2002b, Expanding into aeroponics, The Growing Edge 13(5):36–39.

Wittwer, S.H., 1993, Worldwide use of plastics in horticultural crops, HortTechnology 3:6–19. Wittwer, S.H. and Honma, S., 1969, Greenhouse Tomatoes: Guidelines for Successful Production, Michigan State University Press, East Lansing, MI. Wittwer, S.H. and Honma, S., 1979, Greenhouse Tomatoes, Lettuce & Cucumbers, Michigan State University Press, East Lansing, MI. Wood, C.W., Reeves, D.W., and Himelrick, D.G., 1993, Relationships between chlorophyll meter readings and leaf chlorophyll concentration, N status, and crop yield: a review, Proc. Agron. Soc. N.Z. 23:1–9. Yanda, B. and Fisher, R., 1980, Solar Greenhouse: Design, Construction and Operation, John Muir Publications, Santa Fe, NM. Yoemans, K., 1996, Allelophy: bio-weapons of the future, The Growing Edge 2(2):33–36. Yoemans, K., 1991, Photomorphogenesis: the struggle for sunlight, The Growing Edge 3(1):56–60. Yuste, M.-P. and Gostincar, J. (Eds.), Handbook of Agriculture, Marcel Dekker, New York.